# EDSN REPORT 151

# Team Transport


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Revised May 3, 2023

Class Section: 101

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Spring 2023

# 1.3) Introduction

## 1.3.1) Background

As a team, the purpose of the completion of this assignment was to identify problems within the issue of water transportation and identify why water transportation is an important topic in need of design improvement. After the research we have conducted through experimentation, scholarly reading, and in person, as well as Zoom and phone interviews with different stakeholders having to do with the issue of water transportation, we have found many reasons why water transportation matters, has many problems, could be improved through design processes.

Firstly, according to the Institute of Altitude Medicine in Telluride Colorado [1], one “need[s] an additional liter to a liter and a half of water at [high] altitudes”. This becomes even more of an issue during extreme conditions, such as in extreme heat, extreme cold, and extreme elevations like that of Golden, Colorado. Secondly, according to the United States Centers for Disease Control and Prevention [2], “2 billion people lack access to safely managed drinking water at home”. With this knowledge, in addition to the knowledge that the Unites States pays only $0.0023 per gallon of water according to Steve Maxwell’s [3] *Water is Cheap—Ridiculously Cheap!*, we can come to the conclusion that the world would have much more access to clean and safe drinking water if we had more cheap and efficient ways to transport water from areas with water abundance to areas without.

Additionally, even to those privileged enough to live in areas with abundant access to clean and safe drinking water, water transportation still becomes an issue on the individual scale, as carrying water around can be difficult, cumbersome, and unsanitary if not done properly. Even in areas of water abundance, keeping that water from freezing or evaporating outdoors can be problematic in areas that frequently endure extreme temperatures and weather conditions.

Finally, all modern solutions to the issue of water transportation have issues and disadvantages. For example, pipes that transport water can break, leak, and fail, while all vessels for holding water are only able to hold so much before reaching their capacity. With all of this information being uncovered, it becomes apparent that there can be better ways to design systems of water transportation.

### 1.3.2) Problem Definition

How might we transport water in extreme and difficult conditions?

### 1.3.3) Context of the Problem

The problem of access to clean drinking water is a global one. The most affected environments tend to be rural communities and those in extreme environments where regular infrastructure cannot meet requirements. Water access is inhibited in these cases because rural communities cannot benefit from the same costly but effective water infrastructure that those in denser cities can. Extreme environments inhibit the transportation of clean drinking water because water is difficult to transport, and extreme environments introduce new and sometimes difficult to predict challenges. In addition to these challenges, water scarcity and stress are growing, and more people are being threatened with restricted access to clean water [4].

Key stakeholders in the clean water transportation challenge are those in rural communities and extreme environments. These people are affected most by a lack of clean drinking water. However, all people are stakeholders in that all people need clean drinking water and benefit from convenient access to it. Other key stakeholders include administrators of clean drinking water and its distribution. Those who are responsible for providing clean drinking water are key stakeholders in the development of solutions to water transportation challenges.

Geographically, rural and extreme environments span the globe. Polar and equatorial extremes introduce their own unique environmental challenges to the transport of clean drinking water due to their temperature and terrain extremes. All countries benefit from convenient clean water transport but developing countries in particular benefit from access to clean water.

### 1.3.4) Existing Solutions

There are countless solutions to transporting water in extreme and difficult conditions as there are countless distinct types of extreme conditions. Focusing on extreme conditions, the main two ways to transport water are as follows: through pipes and above ground via vehicles. With pipes you must insulate or heat the pipes to keep water from freezing in them. On larger scale pipes and transportation as long as the water stays moving the pipes are much less likely to freeze. The city of boulder has set procedures for their citizens before winter such as: draining sprinklers, removing hoses, insulating lines, and installing insulated water pipes [5]. The ways pipes are insulated are from pipe sleeves, an insulating device that keeps the temperature of the pipes higher than if the pipes were there themselves. In places where pipe sleeves do not work manual heating from heat tapes or heat cables that require energy and produce heat are required to keep pipes from freezing [5]. Additionally, in towns with cold temperatures the city has devoted teams to repairing busted pipes in a timely fashion to not cause further water damage.

In extreme warm temperatures, the problem lies less in water transportation and more in water and water reservoirs. Cities allocate more of their resources towards preventing water usage and creating useful reservoirs. Existing solutions include sealed water transport systems to stop water from evaporation, as opposed to open water transportation such as streams or rivers in areas with copious amounts of water [6]. Legislation to help lower water usage from companies and households. Drought response plans to accommodate if a year has a significantly lower rain rate than expected a city has plans to ensure that each citizen has enough water to live comfortably.

In extreme conditions where a water system is not in place to deliver clean water to households' water movement is normally split into two sections. Moving the water first, then cleaning the water once it has reached its destination, the opposite of how water systems work in America and other developed nations. Cleaning water includes those such as membrane separation technology. This technology uses pressure to push water through a porous barrier that is only wide enough to leave space for clean water [7]. Chlorination is one of the older chemical water solutions, it is cheap and effective but comes with other health risks and is unable to remove man-made chemicals [7]. BSF (Biosand Water Filtration) is a filtered system for household water use that uses layers of sieved and washed sand and gravel to create a filtration system that can remove more than 90% of bacteria and 100% of parasites [7].

### 1.3.5) Ancillary Issues

In the case of water transport, the main issues are leaks and cracks in water transport systems under extreme weather, freeze ups for people manually transporting water in colder environments, and no access to water transportation systems for people in hard-to-reach communities, and villages. Furthermore, because of the low population concentration in villages, capital investments appear uneconomic. In addition, inadequate planning, insufficient budget, incomplete execution of plans, and lack of understanding and emphasis by donor countries and agencies have often not helped the cause of water supply in rural areas [1]. Water transport for people in third world countries is highly political, and centered around the urban portions of the city, leaving those in more remote locations with no access to water transport systems. On another note, both of my stakeholders, Cecelia, and Kimberly had issues with water pipes bursting in the winter. The conveyed water is aggressive towards AC pipes during winter period and approaches neutral values during summer, with sporadic scaling formation at the peak water temperatures over 21 °C [4]. As temperatures decrease in the winter, the conveyed waters aggressiveness contributes to the corrosion of pipes and water systems, making incidents like leaks and cracks more common. While there are many ways to transport water, defects can be found in all systems.

## 1.4) Stakeholder Outreach

| Team Member | Stakeholder Outreach |
|---|---|
| Ian Keeffe | • Zoom Interview with Tyler Odell (4)<br>• Zoom Interview with Eamon Odell (4)<br>• In person direct on site participation and interview with Andrew Mitchell on Quandary Peak (5)<br>• Two Scholarly Articles on Importance of Hydrating In extreme Environments (2) |
| Ryan Reiser | • Zoom interview with Tyler Reiser (4)<br>• Zoom Interview with Daniel Scarpitta (4)<br>• Zoom interview with Joshua Enders (4)<br>• Three Scholarly Articles on Various Subjects Related to Water Transportation (3) |
| Sebastian Accetta | • Zoom interview with Bethiah Crane (4)<br>• Re-creation of small-scale water transport in freezing conditions (3)<br>• Scholarly article: "Water Consumption and sustainability in Arizona: A Tale of Two Desert Cities" (1)<br>• Scholarly article: "Made in the Shade" (1)<br>• Scholarly article: "Procter & Gamble's PUR Purifier of Water" (1) |
| Hunter Hartley | • Scholarly articles x5 (1 each, 5 total)<br>• Simulation of key stakeholder experiences – Frozen pipes (3)<br>• Simulation of key stakeholder experiences – Inconvenient drinking water access (3)<br>• Email correspondence with the intent to interview – Redirected from Colorado Division of Water Resources -> Denver Department of Public Health and Environment -> Denver Water (in progress) |
| Jade Davis | • Phone interview with Kimberly Constanopolis (9)<br>• Phone interview with Cecelia Murphy (8)<br>• Email correspondence with McDonald Farms Enterprises Company (10)<br>• Scholarly Articles x5 on issues with water transport (1)(2)(3)(5)(6)<br>• 47 min documentary about water access (7) |

## 1.5) Individual Team Member Sections

### Ryan Reiser

The first and most informative piece of stakeholder engagement I received was from Mr. Tyler Reiser, an engineering bachelor's and master's graduate from the Worcester Polytechnic Institute of Technology. During his studies, Mr. Reiser took up an internship with the Philadelphia Water Department, during which he worked hands-on solving problems related to water treatment and water transportation. When talking with Mr. Reiser, he brought to my attention that quality and efficient water transportation is so difficult to achieve because liquids need to be kept extremely isolated to ensure that it remains clean; "after all, nobody feels safe drinking potentially contaminated water" (Tyler Reiser). Additionally, individual water transportation must also be kept at near room-temperatures for the water to remain drinkable whenever and wherever it is taken. The differing was that water can easily be contaminated during the water transportation process are illustrated in the below field sketch:

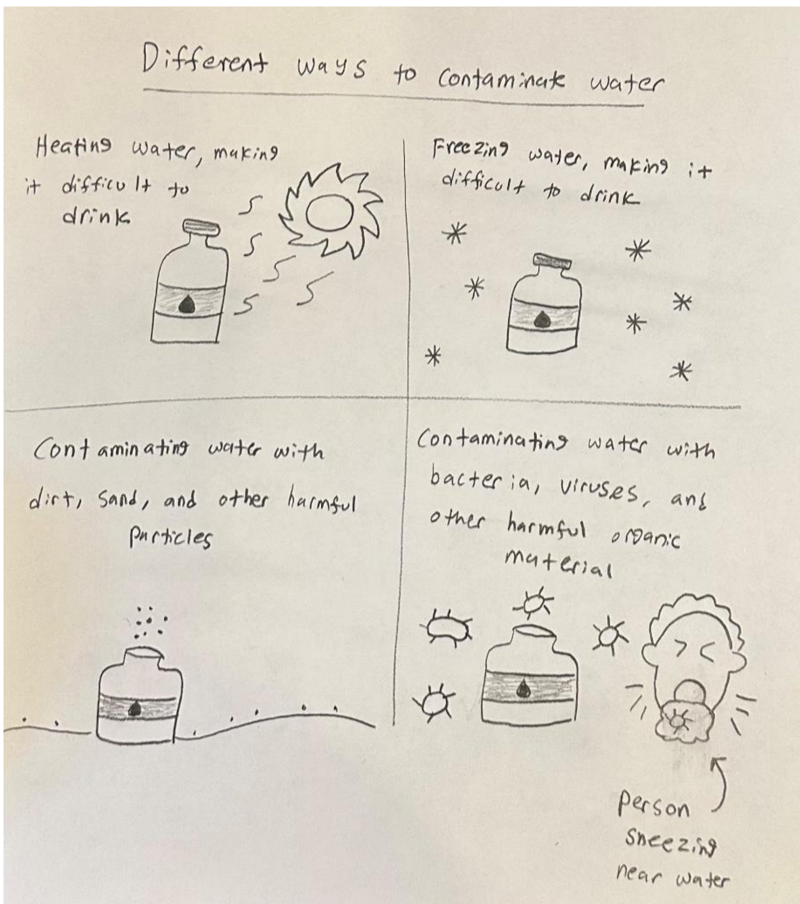



*Figure 1.1: Different Ways to Contaminate Water*

This interview was useful to me because it shifted my perspective of water transportation as simply a means of moving liquid to a way of keeping liquids isolated from the outside world.

For my second piece of stakeholder engagement, I interviewed a friend of mine, Mr. Daniel Scarpitta, a computer engineering major from The Pennsylvania State University and frequent outdoor recreationalist. During my interview with Mr. Scarpitta, he stressed the importance of water transportation when mentioning “Water a substance that literally all organisms require to survive, so finding a new and more effective way to transport it across long distance would be revolutionary and, of course, has the potential to save lives”. Similarly to how Daimler’s trip to San Francisco in *Innovation Starts with Empathy* left the Mercedes Benz team with “personal memories of why it was important to pursue this business opportunity in the first place” (Dav Patnaik), my interview with Mr. Skarpitta reminded me of why designing around water transport is an important field to pursue and innovate.

For my third piece of stakeholder engagement, I interviewed another friend of mine, Mr. Josh Enders, a Music Education major at West Chester University. Mr. Enders plays a wide variety of instruments, though he is most proficient at the trumpet, which he refers to playing when he mentioned “I’m playing it all the time, so I drink a ton of water almost every single day”. This reliance on water was even more important to Mr. Enders during high school, when he would be playing trumpet for hours in line of the hot sun during Marching Band. Mr. Enders brought up that when transporting water, the most important thing for him is to find a vessel that can contain large quantities of water, as he goes through so much on a typical day.

My fourth piece of stakeholder engagement, I wanted to further investigate the problems of plastic water bottles as modern forms of water transportation. My first scholarly article for this section is *Chemical compounds and toxicological assessments of drinking water stored in polyethylene terephthalate (PET) bottles: A source of controversy reviewed* by Christina Bach, Xavier Dauchy, Marie-Christine Chagnon, and Serge Etienne [8]. This article outlines the study of how different water bottle types leech unwanted elements into the water that they are storing. The study comes to the conclusion that “It is now assumed, and all scientific reports agree, that formaldehyde, acetaldehyde and antimony are replayed to PET and can migrate into the bottled water depending on certain storage parameters and types of drinking water”. However, it is important to note that, according to this article, these compounds usually do not pose any human health risk. A similar scholarly article, *Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water* by Peter Schmid, Martin Kohler, Regula Meierhofer, Samuel Luzi, and Martin Wegelin [9], brings up solar water disinfection as a simple and inexpensive water treatment procedure commonly used in developing countries. This technique works by using solar radiation to elevate water temperatures high enough to destroy pathogenic germs, however the study initially questions whether such a technique could release harmful PET bottle materials into the water, which could be dangerous to human health. The process of the solar water disinfection process is illustrated in the below field sketch:

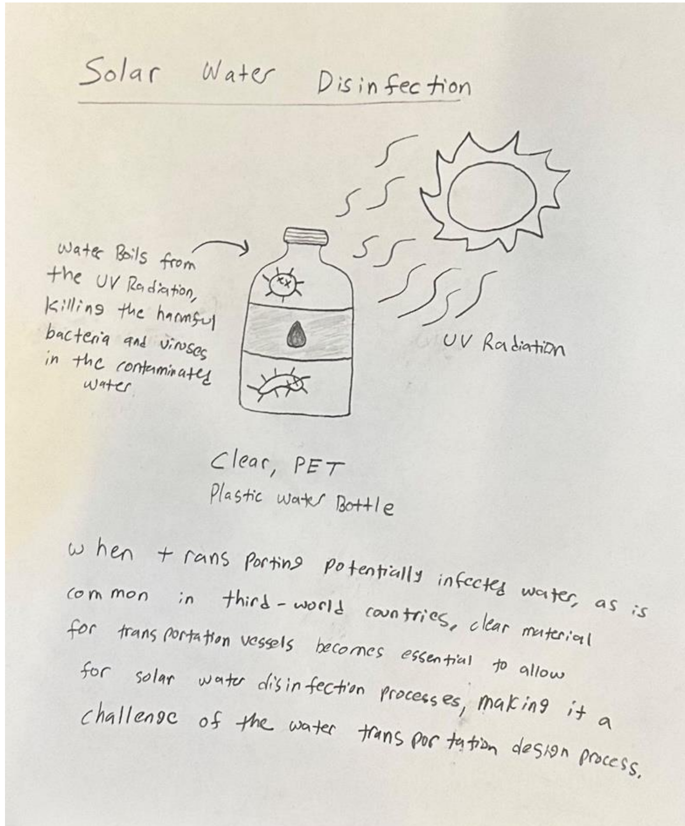



*Figure 1.2: Solar Water Disinfection*

The article comes to the final conclusion that “the present survey and literature data on chemicals migrating from PET bottles to drinking water confirm that the SODIS treatment process is safe and does not trigger the migration of hazardous contaminants at critical levels”. These articles taught me that plastic water bottles safely transport water without danger of ingesting hazardous material, and that they even work well to clean water using the SODIS treatment process. Because of the lack of risk associated with using plastic water bottles, along with the benefits that it provides to those that frequently rely on Solar Water Disinfection to decontaminate their water, we now know that incorporating plastic water-bottles into our design will be beneficial to stakeholders and increase the sales of our product.

My final piece of stakeholder engagement comes from the scholarly article *Water is Cheap—Ridiculously Cheap!* by Steve Maxwell [3]. This article reminds readers that, contrary to the water shortages and water pollution frequently highlighted in modern news, water is still an abundant and cheap resource in certain geographical locations. The United States pays a lot less for water than most other areas of the world, paying only $0.0023 per gallon of water. The article mentions “The United States is blessed with a wealth of water resources in most regions of the country, and we clearly have the innovative spirit and the technological wherewithal to figure out how to treat and transport water to those regions of the country with less water”. This article taught me that the world has enough water to sustain our entire population, however the problem is transporting water to the areas that need it most. Lack of water generally is not an issue in the United States because North America geographically has a lot of access to water. However, to sustain those in less water-fortunate areas, we need to find more efficient ways to transport clean water across vast distances.

Summary:

In conclusion, my research into the issues of water transportation has brought to my attention several factors that I can use to my advantage during the design process. In the three personal interviews I had with different stakeholders, I first learned from my interview with Mr. Tyler Reiser that the most critical aspect of designing around water transportation is to isolate the water, as to not corrupt it with the temperatures and contamination of the outside world. Additionally, in my interview with Mr. Daniel Scarpitta, I learned that designing around sustainability is another large problem of water transportation, as most modern solutions typically require burning and processing large quantities of fossil fuels, creating waste and pollution. Finally, in my interview with Mr. Joshua Enders, I was reminded how important the issue of water transportation can be to the everyday person. The scholarly articles I read and analyzed during my fourth piece of stakeholder engagement informed me of solar water disinfection as a commonly used technology to disinfect water in warm areas, which is important because quality water transportation measures should use ultra-violet resistant and clear material to allow for this technique to be used. Because of this, it is now useful information to know that incorporation of plastic water bottles into our design would be a beneficial feature to stakeholders. In my final piece of stakeholder engagement, Steve Maxwell's article *Water is Cheap—Ridiculously Cheap!* [3] showed me how cheap clean water could be, if not for the high costs of transporting that water over large distances.

Remaining Unknowns:

After my research, I am still left wondering what other problems exist with modern water transportation that I may have overlooked. After researching into problems with plastic PET water bottles as current modern ways of transporting water, I have concluded that using that they have advantages and disadvantages as a material for storing and transporting liquids. I wonder what other advantages and disadvantages this type of material has for storage and transportation, as well as what other materials would be a good fit for our group's project and prototype. Finally, I wonder what other problems exist with modern day solutions to water transportation that my group would be able to fix and benefit from when creating our project and prototype.

## Jade Davis

Summary and Perspective Gathering

Water can be transported in many ways, by pipeline, by a water bottle, by filling up a hydro flask, tanker trucks, rural aqueducts, camelbaks, etc. Out of all these ways of transporting water all of them have issues when it comes to extreme weather conditions. When transporting water, we either think of pipes, or man-made water carrying designs like camelbaks. The fault in these systems stems from the lack of consideration for extreme conditions.

Steel pipes serve as the main source for transporting water, gas, and other petrochemical substances for longer distances [10]. Since the installation of steel pipes, the design has not been changed very much. We are now going into a new wave of climate change and global warming, with these old pipe designs, water transport can majorly be affected. Our results show that asbestos fibers are emitted from degraded AC pipes because of wall softening due to calcium leaching from hydrated cementitious materials, resulting in the loss of mechanical stability [11]. With current pipe designs, although they were made to withstand extreme conditions, over time the pipes start to wear out. As weather conditions become more unpredictable, all pipelines should be remodeled to withstand modern day extreme conditions. Pipes in such environments may lead to the initiation of defects in their inner surface such as leak holes, cracks, corrosion, etc [10]. I had a personal interview with stakeholder Kimberly Constanopolis, and she said, “about every other week the city of Harvey is having water leakage, or water main breaks in the winter”. This problem left Kimberly without a source of water for almost a week, she had to leave her neighborhood to wash clothes, cook, take a shower, use the bathroom. The fact that she could not do basic everyday chores and necessities without leaving her home is all due to an issue with water transport. Another stakeholder, Cecelia, commented on how her basement was damaged due to a water transport pipe bursting around her house. She said, “There was a really bad storm the night before and the dropping temperatures didn’t help, when I woke up the next morning to grab my work uniform from the basement, there was a light coating of water all over the floor”. This once again was due to the unreliable design of the pipes which can be seen in (figure 1.3) below.

*Figure 1.3: Cracks and Leaks with Pipes in Extreme Conditions*

Water transport is not just an issue with mainline pipes and in industrial applications but with personal applications as well. People who like to be outdoors and do activities such as hiking, or winter sports through the desert, or through the mountain, experience issues with water transport. Hikers tend to have a camel back or some source of water that they brought with them. The issues with bring a Camelbak or a refillable water bottle is the fact that you cannot see the amount of water that you drank and if these sources are not cleaned well it can start to develop mold and a plastic taste during use which can be seen below in (figure 1.4).

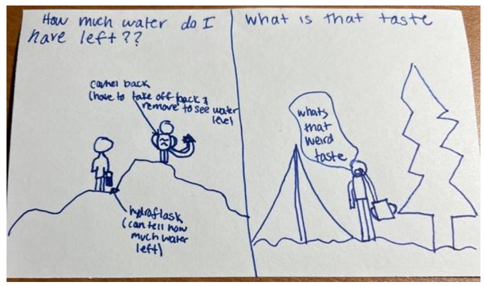



*Figure 1.4: Issues with Camelbak Water Transportation Systems*

When doing hiking trips under extreme weather conditions it’s important to know how much water you have left so that you know if you can continue or if you need to return. People who hike in cold places or do winter sports in places with extremely cold weather have issues with their water sources freezing. People who do extreme hikes in the desert, or the Grand Canyon, must have water throughout their journey due to the high temperatures. The Grand Canyon and the desert both can reach temperatures over 100°F during the days in the summer. When hiking an exerting energy, it is important to stay hydrated because heat causes loss of fluids. Add a backpack, take a typical day in July or August, begin climbing 500 feet in elevation per mile over the course of nine or so miles, and you have a Grand Canyon desert heat experience. Even with ample water and food it can challenge the most positive of mental attitudes and seem to suck the life right out of you. If you plan poorly and end up a bit short on water, it can very quickly become a no-kidding life or death situation [12]. The table below (figure 1.5) will show how loss of fluids contributes to certain side effects.

| Loss of body weight in fluids | Affects |
|---|---|
| 1% | 10% loss in a person's mental faculties. |
| 2% | Sensation of thirst begins |
| 5% | Illness (exhaustion/heatstroke) |
| 10% | Extreme heat related danger (emergency services required) |

*Figure 1.5: Loss of Body Weight in Fluids*

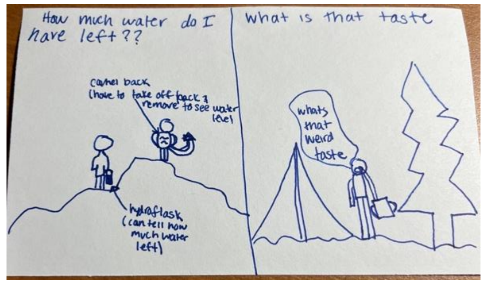



*Figure 1.6: Extreme Environments*

As you can see from the data above water transport is very important. One of the final aspects of water transport that I observed is water transport in underdeveloped countries and small villages. People in countries like Zambia, Uganda, and Zimbabwe, suffer from a lack of clean water. Often the women and children that are retrieving this water must walk several miles with buckets on top of their heads. The rural communities of developing countries, which commonly have no service of any kind, either for potable water or for excreta disposal. The design of rural water supply projects and programs to reach this this third group of households has a long history of failure [13]. Their sources of water could be a well, pond, lake, river, or rainwater or some combination thereof [14]. (Figure 1.7) below shows the extensive process of water transport for people in third world countries.

*Figure 1.7: Ways of Water Transport for Those Without A Water Transport System*

In the United States we have many ways of transporting water. In Colorado, even though water resources are becoming scarce we have companies that handle water treatment and distribution. One of the companies that I reached out to was McDonald Farms Enterprises, their company offers potable and non-potable water pick-up, transport, and delivery services throughout Colorado and surrounding states [15]. I asked them how they can transport water to all these different places, short distance, and long distance. Through email correspondence he referred me to the company website that talks about the special equipment they use for transport. The equipment consists of stainless steel insulated or non-insulated trailers (up to 6,000-gallon capacity), Specialized food grade pumps and fittings for loading and unloading portable water, temporary emergency service equipment for water transfer or bypass situations [15].  Developing countries do not have access to water transport services like these.

## Remaining unknowns & Summary

Water transport issues happen everywhere, some cases are more extreme than others but nevertheless, the issue should be addressed. Some of the remaining unknowns about is how to modify water transport. For hikers and people who do outdoor activities, the unknown is how to allow them to carry a substantial amount of water that is lightweight, easy to clean/refill, and has visible markings for water levels. The unknown for pipes is how to prevent corrosion of the pipe over time, and how to provide an extra layer of protection in the case of extreme weather or leaks. For those without a water transport system available to them, the unknown is how to carry large amounts of water manually, and easily. With the resources and information gathered we should be able to address one of the issues that falls under the water transport umbrella.

## Ian Keeffe

Staying hydrated is extremely important, especially in extreme conditions. According to the Institute of Altitude Medicine in Telluride Colorado [16], one “need[s] an additional liter to a liter and a half of water at [high] altitudes”. This high altitude applies to us Golden residents and becomes even more important when we travel into the mountains. Hydration in cold environments such as ours is also important. According to the Massachusetts General Hospital [17]“As temperatures drop[s] it can become harder to keep hydration up. It’s not uncommon to feel less thirsty in cold weather and many people are unaware that cold-weather dehydration exists… Regardless of the temps outside, staying hydrated is important all year round.” Keeping oneself hydrated in these extreme environments is very important and without an efficient and reliable system of transporting water, this necessary hydration would prove impossible.

When transporting water in extreme environments, one of the first considerations one must make is prevention against freezing. No matter the transportation system, if the surrounding air is below freezing, the water freezing is a serious concern.

The first stakeholders I talked to were Tyler and Eamon Odell. They are twins that grew up mountaineering on Mount Washington, the location of the record for coldest wind chill ever recorded in the US was just set again on the 4th of February at a blistering -108 degrees. Neither of the twins have used a Camelback system because of the higher cost of this system.

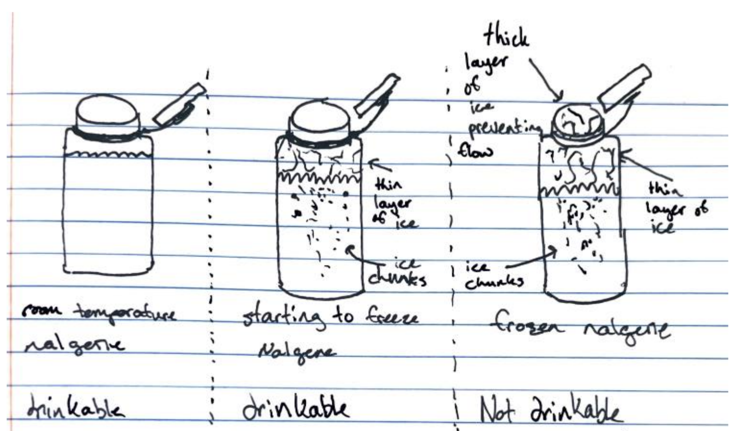



*Figure 1.8: Nalgene with Water in Different Phases*

They both prefer to use Nalgene brand wide mouth water bottles. They find that these are the best cheap bottles to use in the winter. They find that when they are first starting to freeze the water begins to turn slushy (See Figure 1.8). At this state the water is still drinkable and refreshingly cold. This is ideal. They often freeze worse than this though. They will begin to freeze in a thin layer on the walls of the water bottle above the water line. They then freeze directly under the cap across the mouth of the water bottle (See Figure 1.8). This prevents water from being able to be drank from the Nalgene and is surprisingly hard to remove without special tools. However, the Odells often bring ice axes with them in these extreme environments to tackle the terrain. They use this ice axe to chip away that ice and open back up the mouth. Other prevention techniques they have come up with is putting warm water in the bottle in the morning of their expedition and then putting a Smartwool mountaineering sock over the bottle to insulate it. They also stuff the water bottles inside their coats in the most extreme conditions.

I also interviewed Andrew Mitchell after a failed attempt at skiing Quandary Peak, a classic ski mountaineering route. He is an experienced outdoors man, with 37 fourteeners under his belt, with 13 of these being during winter, and is the manager of the Mines Climbing Wall. He also prefers wide mouth Nalgene's for winter. He prefers the narrow mouth Nalgene's for ease of use, because the narrow mouth is easier to drink from, but in the cold, they freeze under the cap even faster. He also typically brings an ice axe and uses it to remove ice from the mouth. He has another strategy for freezing prevention that the Odell's do not use, which is storing the water bottle upside down. By storing it upside down you store the water at the typical freezing point, which causes it to freeze less because it has a greater mass and therefore thermal capacity.

He has also had a Camelback freeze while using it. This was on Quandary peak about a mile and a half up (it is a 3.4 mile route). The tube that goes from the nozzle to the reservoir froze, preventing water flow. It appeared to him that there still would have been flow through the nozzle and that that hadn't fully frozen. To hydrate on the rest of the route, he drank out of the reservoir.

Some remaining unknowns I would like to figure out is what actual temperatures these systems fail at. Having a good baseline and tests of systems such as having your water bottle in a sock and more would greatly help our tests and streamline the testing process. It would have been nice to ask stakeholders what they would pay for a system that does the job properly instead of just using the systems people have created of their own.

With all this data, I have found that many people are able to come up with systems for managing their water bottles temperature with little to no additional cost. A solution to this problem would have to be cheap and have great added benefit over these other systems to sell well. This challenge area would be good to investigate if we are certain we can come up with a cheap enough solution.

## Hunter Hartley

The World Health Organization's "Guidance on Water Supply and Sanitation in Extreme Weather Events" [18] outlines some causes for concern regarding access to drinking water, specifically extreme weather events. The report states that globally, droughts and floods affect more people than other natural disaster types. Some of the implications of these events for drinking water are somewhat obvious – for example, increased demand creating shortages and damaged infrastructure failing to provide access. However, some less obvious but no less important challenges arise as well. For example, under severe weather conditions, the services that distribute and dispose of clean water and wastewater can become sources of chemical and biological contamination. Overflow of wastewater into surface water sources can contaminate and prohibit the use of these sources, and prolonged drought can lead to malfunctioning of water treatment systems. This source emphasized an aspect of the drinking water transportation problem – sanitation – that could otherwise have been neglected. It is important that we provide a means of maintaining the cleanliness of the water we transport.

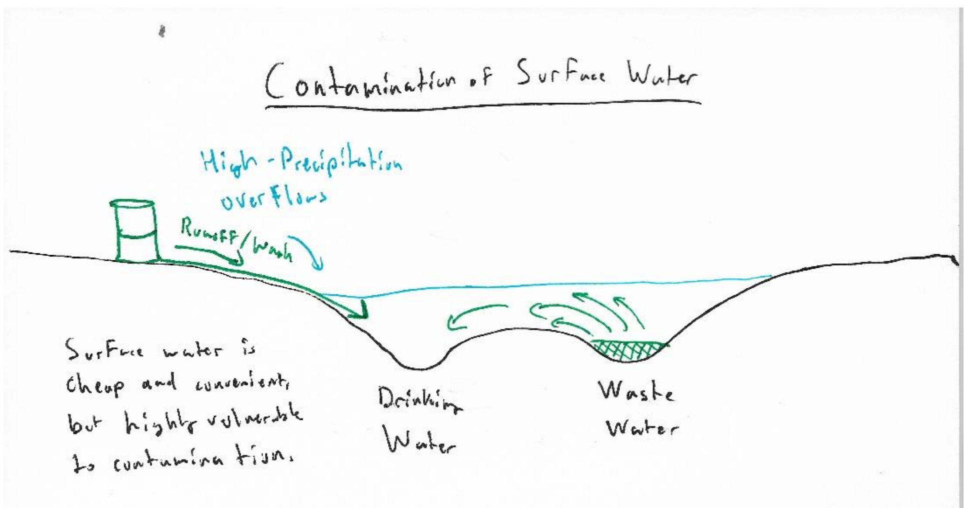



*Figure 1.9: Contamination of Surface Water*

PM Engineer's article on CPVC and PEX protection [19] provides some insight into the challenges associated with choosing a material to transport water. PEX and CPVC are the two most used pressure piping materials in new residential construction in the US. They provide many useful characteristics for transporting drinking water—corrosion resistance, reliability, ease of use, and low cost to name a few—but are sensitive to certain environments and use cases. PEX is sensitive to ultraviolet light exposure, meaning that it can only be exposed to sunlight for a specified length of time before it degrades and loses its strength. CPVC is sensitive to chemical damage due to material incompatibilities. Contact with some rubbers and flexible plastics can cause the CVPC to soften or crack over time. The duration of our prototyping phase will be too short for us to notice these characteristics first-hand. Therefore, knowing these material characteristics beforehand is important in order for us to develop a prototype that can maintain its performance in the long-term and in unusual applications.

*Environmental Geology* volume 44 [21] sheds some light on the shortcomings of existing water transportation solutions in rural areas. The researchers investigated a set of rural communities in South Africa to determine the causes for their drinking water quality and supply issues. The researchers found that most of the communities were being supplied substandard quality drinking water, and that water quality management procedures were insufficient. Furthermore, the researchers found that groundwater supply schemes failed more frequently than surface water schemes. The causes of these failures tended to be pump failures, infrastructure deterioration, and insufficient oversight of the quality and distribution. This article provides some examples of existing solutions to the problem we're investigating, and how these solutions fall short of their goals. These shortcomings provide a possible area for exploration and development for our group.

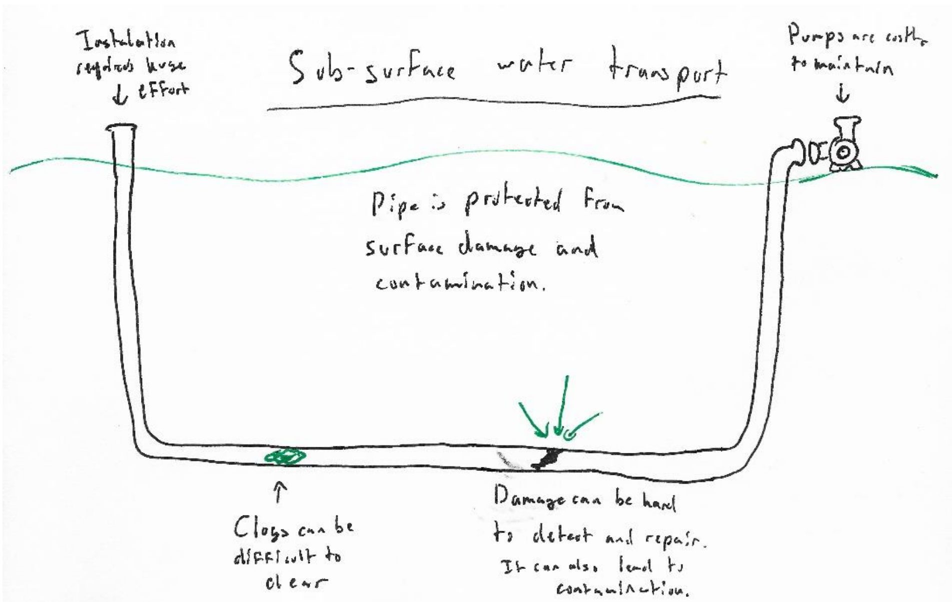



*Figure 1.10: Subsurface Water Transport*

*Water Encyclopedia*'s first volume [21] provides a great deal of information about the challenges surrounding drinking water access. One piece of useful information regards water-related diseases. The source states that a lack of access to clean drinking water results in nearly 250 million cases of water-related diseases yearly, and roughly five to ten million result in death. The source also relates infant mortality to clean drinking water access. In addition to the suffering associated with these diseases, estimates from the late 70s have shown that these water-related diseases cost the world $125 billion annually in lost productivity and treatment. This text can motivate our team to emphasize cleanliness and safety of the water we transport, and can provide justification for the cost of our solution.

The Center for Disease Control and Prevention's Healthy Housing Reference Manual [22] lays out some of the difficulties associated with sourcing clean water in rural areas. For instance, the process of constructing a safe well is more involved and sensitive than many realize. The process of creating a new well also creates a new path through which contaminants can enter a water source, and therefore the construction must be done with these contaminants in mind. Dug wells are far more vulnerable to contamination than drilled wells because of how shallow and wide they are. This manual also states that chlorination is the most common water disinfectant, with ozonation, ultraviolet radiation, heat, and iodination also being possible methods of disinfection. This manual provides our group with two resources—it shows the shortcomings of another solution to the problem of drinking water access, and it outlines some steps that can be taken to increase the safety of drinking water.

In order to simulate the experiences of a key stakeholder, I experimented with different material types and how they handle freezing water. To do so, I filled one PEX tube and one steel tube with water, and then froze them in a freezer. The ends of the PEX tube were sealed with clamps, and the steel pipe was terminated with threaded caps. The PEX was able to handle the expansion of the water without visible damage or deterioration. However, the steel pipe failed catastrophically at the threads.

*Figure 1.11: PEX and Steel Tubes with Frozen Water*

The results of this simulation can influence how we regard freezing-damage risks in our design process, and the material choices that will result. If we decide to use hard materials, they should be designed with pressure relief mechanisms while keeping possible contamination in mind. Even if we choose a material that can handle the expansion, unexpected high pressures can result from the freezing, which can damage seals and joints.

To further simulate key stakeholder experiences, I decided to partially restrict my drinking water access for a day. I kept my drinking water on the opposite side of the house to add inconvenience to the process of accessing it. While I was able to drink at any time, I found that I chose to drink far less frequently than I normally do when my drinking water is conveniently accessible. While this level of inconvenience could not result in dangerous dehydration, I found that I did not meet healthy drinking levels throughout the day. The results of this simulation can provide another area of the problem to investigate and address—where drinking water is obtainable, but inconvenient enough to discourage regular drinking. It may be that general health could be improved if the convenience with which water is accessed is maximized.

In order to interview sources with knowledge on the water transportation process, I reached out to the Colorado Division of Water Resources. Corey DeAngelis responded to my email and informed me that the Division of Water Resources dealt with the administration of water in the state and that I should contact the Denver Department of Public Health and Environment. Candy Romero from the

Denver Department of Public Health and Environment informed me that I should reach out to Denver Water instead. I am now working to contact Denver Water to set up an interview. Nonetheless, it is apparent just from getting bounced around the Colorado administrative bodies that the transportaion of drinking water is more than just a technical challenge—the water rights and management require organization beyond a technical feat.

Remaining Unknowns:

After my research, there are still many factors to consider as we develop our solution. Though it is too early to know what materials we will use in our prototype, we will have to investigate the long-term sensitivities and compatibilities of these materials. We will also have to attempt to anticipate currently unforeseen use cases and long-term influences. We do not yet know all of the locations and applications our prototype may see use in.

Summary:

The issue of clean water transportation affects enough people worldwide to justify the pursuit of solutions. The challenges associated with a solution to this problem include long-term resiliency, cleanliness, and resistance to extreme environmental events. There are many possible improvements and developments to be made on or in addition to existing solutions.

## Sebastian Accetta

The first stakeholder engagement that I had was with a Durango Colorado local countryside resident named Bethiah Crane. The city of Durango only has a population of nineteen thousand with a large countryside population. These residents range far from the downtown area though, resulting in piping not being economically viable for the city as they would have to manufacture and build miles of water piping just for a few houses. The resulting consequence leads to houses in the countryside needing to get water though one of two sources: trucked water or water wells.

Trucked water is the least efficient of the two methods as it requires a large amount of energy to move water through trucks. Moving 5,000 gallons of water can range from $525 to $2,000 depending on the distance from town and the conditions of the roads. An average person in America uses 3,000 gallons of water per month. So not being water efficient can be very expensive in the countryside. Bethiah and her family would often not shower at the house in order to conserve water and would rather only show at the local recenter when they went into town.

A second major problem with trucked water is the danger of not being able to receive water during months of the year. Durango is a mountain town that often receives a large amount of snowfall during the year. This can lead to roads being blocked, dangerous or even fully closed. If a resident was about to get a water delivery but a snowstorm landed a day or so before they could simply not have their water delivered for that week. There is no danger of terminal dehydration as snow outside can always be brought inside to melt. But it is a common occurrence for countryside residents to be a water free household at least once a year. Places with warmer conditions such as Texas, Alabama and other states do not have the same concern for getting their water as the roads do not close, and the wells do not freeze.

The second way for Durango countryside residents to get water is from a well that they own. A working well is cheaper, more efficient, and has a higher-water volume than trucking in water. The problem arises that wells in cold conditions often freeze due to extreme cold conditions. This was the problem with Bethiah's household as she did own a well, but it was constantly freezing. A well needs a thermal blanket or another type of insulation in order to keep the water from freezing. The process of installing an insulator to wells is not an extraordinarily difficult task. However, it requires trained personnel to do so and in a small population town not many individuals are trained to perform such a skilled action. This results in well improvements being overpriced and very overbooked, needing to schedule an appointment multiple weeks in advance.

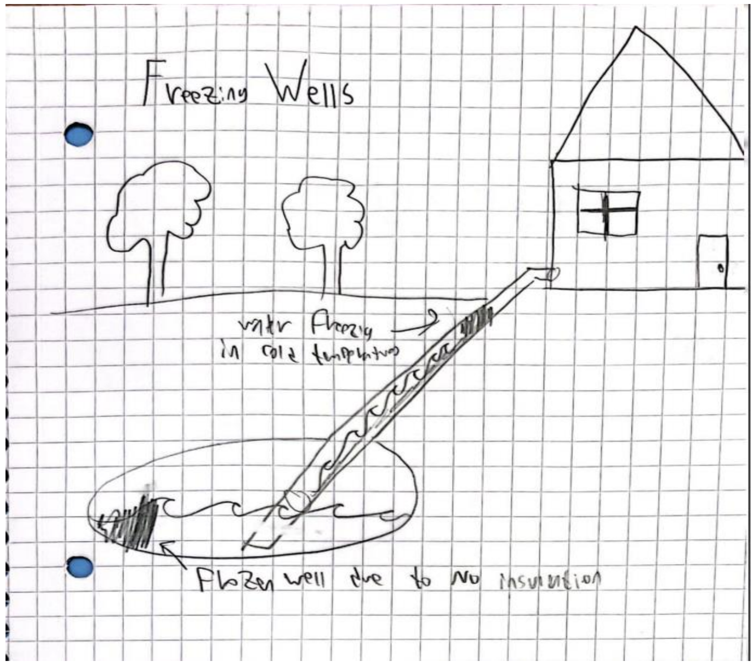



*Figure 1.12: Example Household With A Well For Their Water Supply*

The second problem with wells is the piping from the well to the household. The pipes can freeze from lower temperature, not have enough pressure to move the water, or fully burst from very cold conditions. These fixes are much more difficult as they require access to the pipes which are consistently underground requiring digging to find the pipes. Newer built wells are less probable to have pipe bursts as the technology for both pipes and piping pathing has improved to lower the chance of bursting pipes. But older wells have older pipes and often suffer pipe failures which can render a well useless until an entire new piping system is in place.

Bethiah was lucky enough to never have her pipes burst as her well was over fifty years old but she had consistent problems with the reservoir freezing. She had three different contractors come in and try to fix the problem, but all three fixes only lasted a short term and within a month during the winter seasons the well was back frozen and useless. The lack of running water in combination with a few other factors led Bethiah to sell her house and move closer to downtown where the local piping system reached.

The second stakeholder engagement that I had was on the small scale of moving water in extreme conditions. This was moving water from a bladder, a small reservoir of water contained in a back, to a drinkable location on the person wearing the backpack. I simulated an extreme cold environment by using a freezer and putting the camel back into the freezer. The freezer was set to negative thirteen degrees Celsius. The water in the hose (the connecting part of the bladder to the mouthpiece) froze within ten minutes. The water in the bladder took a much longer time to freeze as it took around 45 minutes to an hour to freeze. This points out the most important part of microscale water transportation. Water in a smaller contained area will freeze before water in a larger contained area. Another interesting fact from experience is that if the water is moving it will not freeze. These two facts are a good place to improve microscale water transportation now.

The third stakeholder engagement I investigated the other side of extreme water conditions: extreme heat. I read a scholarly article called “Water Consumption and sustainability in Arizona: A Tale of Two Desert Cities” [23]. This article contained two main points, a social societal point of reducing overall water. And an engineering standpoint of maintaining the most water and transporting water in the most efficient way possible.

The most noticeable part of the societal side was that campaigns, slogans, and education did little to no effect on the overall societal usage of water. The highest decline of water usage was from policy incentives. An example is the update of the Universal Plumbing Code in 1982 where all new construction required reduced flow plumbing fixtures. A policy change that lowered the water usage to population growth curve. Tucson and Phoenix move and store their water underground to lower the rate of evaporation by keeping the water colder. Additionally in applicable spots, such as the bottom of hills or valleys, water collection sites can be places to not only prevent flooding but also retain water from the sky that would normally be absorbed by the landscape.

Tucson was once known as the green desert as all the lawns would have sprinklers to keep the grass outside their homes green in order to conform to the rest of society. The invention of “desert yard-scaping” drastically changed this. The norm went from green grasses to fancy cacti and other native desert plants. The invention and societal preference lead to a massive decrease of water usage requiring no advanced technical solutions. Small scale solutions that can be spread across large audiences is an easy way to create large impacts.

The fourth stakeholder I engaged in was the American Water Works Association and a journal article they wrote about the “shade balls” that are used to cool reservoirs in large conditions [24]. Half of the work for moving water in extreme conditions is moving it, the other half is storing it in a nearby place. The flux of water that a city uses is not a constant rate, it changes hour by hour, day by day, month by month and so on. This means that there must be a way to store water nearby for easy access. In Los Angeles California this is done by an above ground reservoir called Ivanhoe reservoir storing over 795 million gallons of water. This worked efficiently until eventually they realized that around two million cubic meters were being absorbed by the sun. Their solution? 96 million plastic balls were put onto the reservoir's surface to lower sun contact to the water's surface. The city of Los Angeles claims that 1.7 million cubic meters of water will be saved by this implementation. As the balls were placed into the water in 2008, the data suggests they are working on saving water. Other reservoirs across the world have also implemented a similar strategy covering their reservoirs with sun absorbing materials.

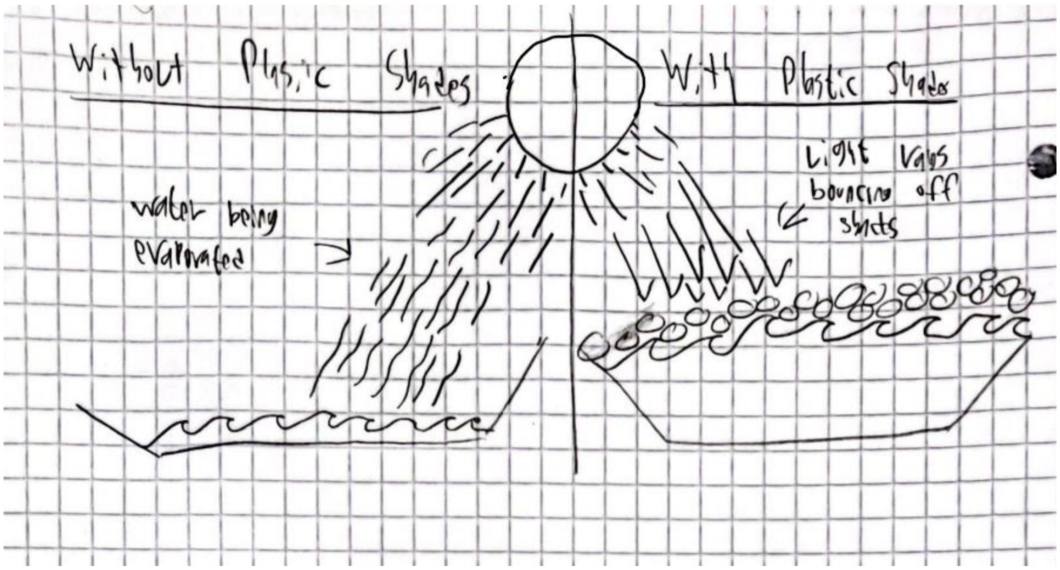



*Figure 1.13: Reservoir Without Shades Versus a Reservoir With Shades.*

The fifth stakeholder I engaged was a scholarlily article written by the University of South Carolina which reviewed proctor and gamble water purifier or water [25]. In extreme conditions such as a hurricane or difficult situations where clean water is not a common commodity, P&G packets were invented to create pure water from nonpure sources. Power follows a three-step process to separate harmful bacteria and chemicals from pure water. The first step of coagulation releases a negatively charged chemical which will attract the positively charged chemicals such as dirt. The second step of flocculation packs those small clumps into large groups that are denser than water itself to allow them to sink to the bottom of the container. The last step of adding chlorine removes the positively charged parasites and bacteria's that remain in the liquid, leaving behind only clean drinkable water. A packet, the same size as a salt packet, can create ten liters of clean water within thirty minutes. The packets sell for below manufacturing price resulting in a net return loss in investment but save millions of lives throughout the world.

From this research I have learned that both big and small-scale improvements can create large differences in water transportation. Also, the act of transporting water is not only limited to physical transportation, reservoirs and spigots are just as important for the transportation as the physical act of transporting water. Additionally, there are simple solutions such as desert landscaping which reduces the number of locations where water is transported. There are also technical solutions to solving transportation such as shade balls or new chemical technologies to keep well reservoirs from freezing. These solutions have a connecting link though: thinking outside the box. Putting 96 million plastic balls on top of a reservoir is not the first idea that came to mind when trying to prevent evaporation, a major problem when transporting water in extreme heat, but the mere idea itself allowed millions of gallons of water to be saved.

After my research, I wish there was easy access to see solutions in person. I would love to visit freezing wells and compare them to the newest model well being implemented now. It would be amazing to visit the Ivanhoe reservoir and talk to the creators, seeing what process they followed to find the solution as I doubt plastic balls was the first idea that came to their mind.

# 2.0) Existing Solutions / Alternatives Reviewed, and Options Selected

## 2.1) Stakeholders Summary and Existing Solutions:

Our project aims to find a solution to the natural difficulties that come with transporting water across large distances and in extreme climates and weather. Therefore, stakeholders in our design include those that live in extreme conditions, those that need to transport water over large distances, and those that do not have the income to afford high quality water-transportation solutions. However, more than just those stakeholders, out solution to the issues of water transportation would be applicable to the lives of anybody who must transport water on a regular basis, such as those who currently carry plastic water-bottles from home to their work, school, recreational centers, and anywhere else that people would go on a regular basis.

There are currently existing technologies that similarly solve the issues of water transportation, such as the HydroFlask, a metal-insulated water bottled that similarly keeps water temperature stagnant to prevent it from getting too hot or too cold, shown in Figure 2.1 below. However, unlike the HydroFlask, which would normally cost its customers $45 per bottle, our solution to the issue of water transportation would be cheaper, making it more accessible to the general public. Additionally, unlike the metal and opaque HydroFlask, our solution incorporates regular plastic PET water bottles into the design, allowing for the process of Solar Water Disinfection to be used, which is a sanitization technique commonly used in third-world countries during which ultraviolet radiation from the sun kills the harmful and bacteria that could get people sick when drinking potentially contaminated water. These are important features to include in our design because people who live in the most extreme climates are often those in financially impoverished communities who cannot afford luxury water-transportation solutions, rely on solar water disinfection processes to clean their water, and need to transport water over large distances without the internal water temperature drastically changing.


*Figure 2.1*

## 2.2) Requirements, Customer Needs, and Technical Specifications

### Customer Needs:

The final prototype is being designed to meet a set of customer needs:

- **Affordable access to product:** The product must be affordable for our customers in a variety of financial circumstances.
- **Must not add excessive weight to bottle:** The product will often be carried by a person, and therefore must not add too much weight that one has to carry.
- **Must function in extreme environments:** The product must continue to function as expected in a variety of extreme environments, such as extreme temperatures.
- **Water must stay drinkable:** The water must not become undrinkable during the use of the product.

### General Requirements:

To meet these costumer needs, a set of general requirements can be derived:

- **Low cost:** The product must meet a maximum cost.
- **Low weight:** The product must meet a maximum weight.
- **Must survive extreme temperature:** The product must maintain its performance in extreme temperatures.
- **Must be well-insulated:** The product must provide adequate thermal insulation for the water.
- **System must be water-tight:** To prevent contamination or loss, the system (comprised of our sleeve and the enclosed water bottle) must be water-tight. I.e., the bottle and/or the sleeve must be watertight.

## Technical Specifications:

To define adequate performance, a set of technical specifications can be created from the general requirements:

| General Requirement | Technical Specification | |
|---|---|---|
| **Low cost** | Maximum material cost ($):<br>Maximum estimated production cost ($): | $35<br>$15 |
| **Low weight** | Maximum weight (g): | 200g |
| **Survive extreme temperature** | Maximum temperature (°C):<br>Minimum temperature (°C): | -40°C<br>70°C |
| **Must be water-tight** | Water loss (system): | <1mL/yr. |

*Figure 2.2: Technical Specifications*

## 2.3) Individual Looks-Like Prototype and Concept

### Ryan Reiser

The looks-like prototype I created is of hydration jacket that is intended to make water transportation easier by allowing carried water-weight to be distributed across the entire body, while simultaneously using the water to regulate the body-temperature of the wearer. This would remove the need to use water bottles to transport water, which would also reduce the waste that comes with using plastic water bottles in addition to making the transportation of water easier and more convenient to the user. Because of the insulation provided by the outside of the jacket in addition to the high specific heat of the water caused by the hydrogen bonding within the water molecules, the water inside the jacket would stay at its desired temperature for a long period of time, allowing users to wear and transport the water easily across long distances. A figure of a field-sketch and looks-like prototype of the hydration jacket from the outside can be seen below in figure 2.1, while a figure of the field-sketch and looks-like prototype of the hydration jacket from the inside can be seen below in figure 2.2.


*Figure 2.3: Field-Sketch and Looks Like Prototype of Hydration Jacket Concept Viewed from the Outside*

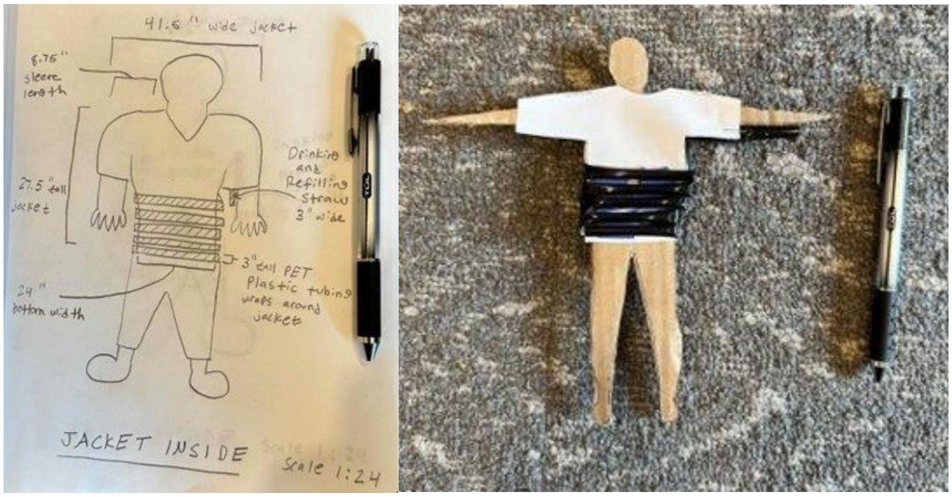



*Figure 2.4: Field Sketch and Looks Like Prototype of Hydration Jacket Concept Viewed from the Inside*

## Jade Davis

The solution I prototyped allows people in areas without a water transport system to easily transport water from their nearest source. The prototype itself is called the water barrel, which is what it is essentially. The barrel itself is made of plastic and was designed to roll easily on rough terrains or grassy areas. The functionality of the barrel and what makes it special is the metal reversable handlebar, that would allow the user to push or pull the water uphill or downhill. The rotational handlebars allow the user to not be constrained in how they move the barrel. There was also a grip on the metal handle bars that helps the user keep a strong hold on the water transport system when travelling. The final aspect of the water barrel that was designed for those in colder conditions is a rotational blade that cuts through the water as the barrel moves to prevent the water from freezing as easily.

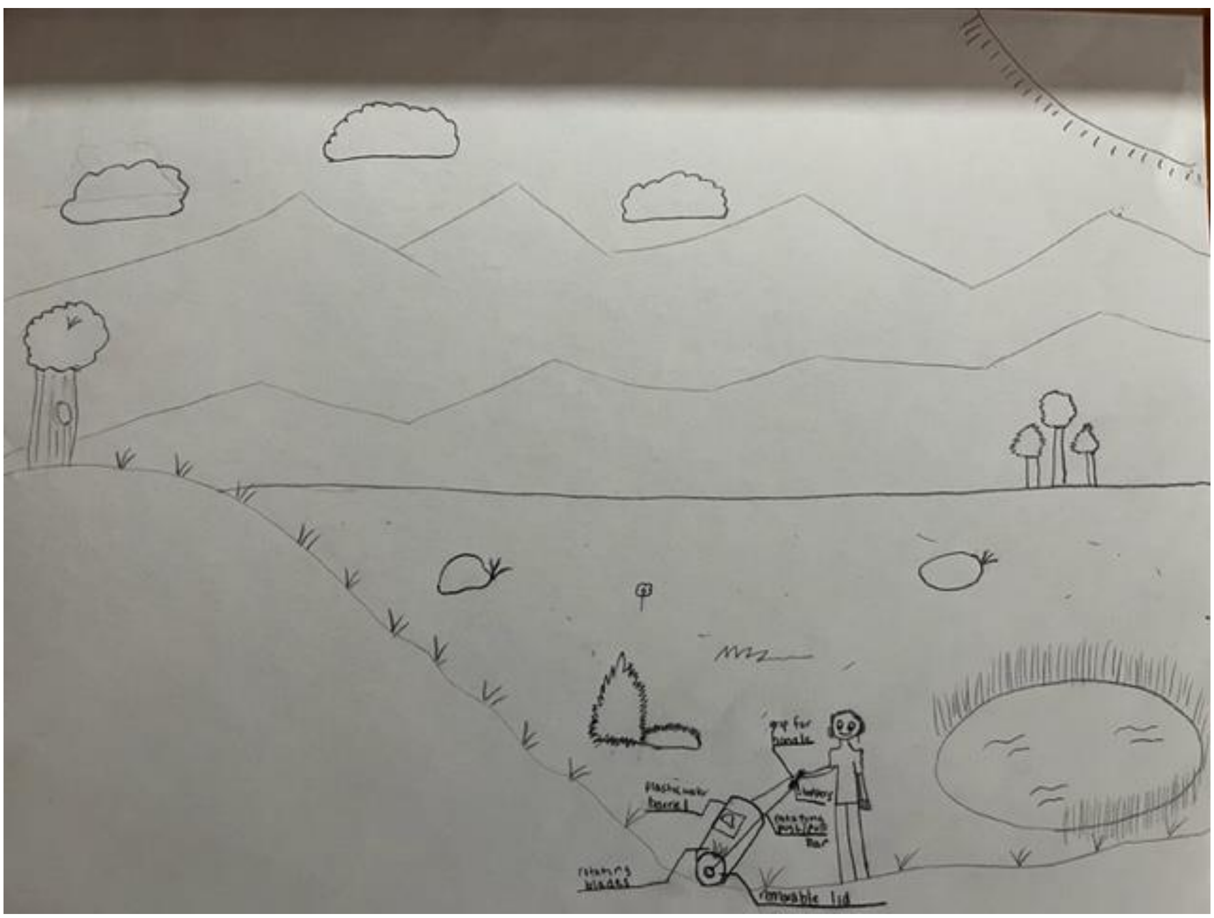



*Figure 2.5: Field Sketch of Water Barrel Transport System*


*Figure 2.6 Orthographic Views and Dimensions*

This solution addresses water transport under extreme conditions by providing easily transport on rough terrains, and it helps prevent water from freezing, when a user is in colder conditions. The stakeholders had issues with freezing systems, or systems that broke or cracked in the colder temperatures. With this prototype you wouldn't have to worry about the water freezing or the barrel cracking and leaking when transporting water.

## Ian Keeffe

The prototype I created is the Insulated water bottle sleeve. This water bottle sleeve provides insulation to a disposable plastic water bottle. The user can then reuse a disposable plastic water bottle in extreme environments that would typically require a more expensive, metal insulated water bottle. Instead of this high expense, users can buy the insulated sleeve and use a cheap disposable water bottle and have a lest costly setup. This would also be significantly lighter than a metal water bottle, which would provide a great advantage as well. The main use for this would be outdoor recreation.

It would be particularly useful in activities like ice climbing, skiing, and other long duration low exertion sports. This would also have a use in multi day activities such as backpacking where the user has a bigger water storage back at camp or deep in their bag and uses our product as a smaller more accessible bottle for easy access.

*Figure 2.7: Insulated Water Bottle Sleeve Looks Like Prototype*

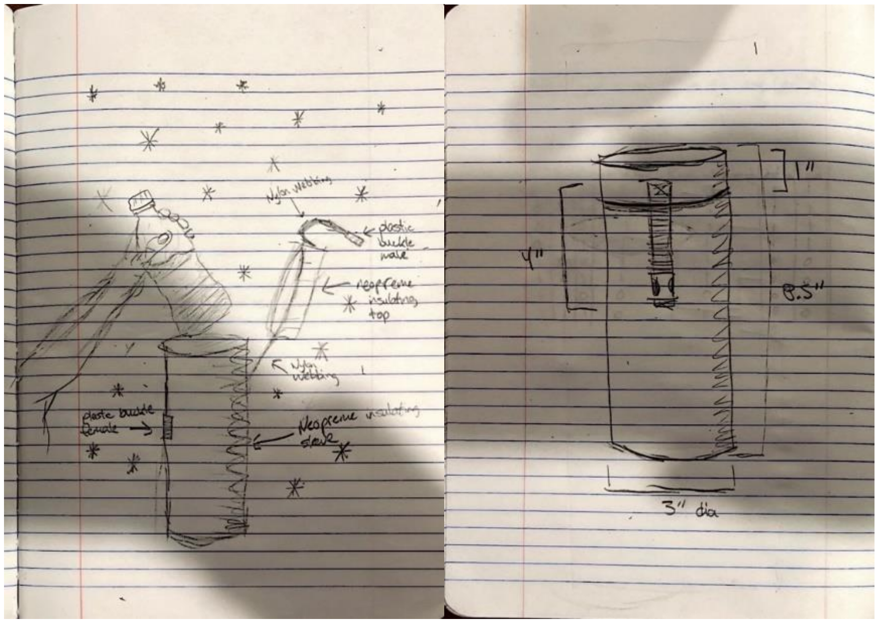



*Figure 2.8: Insulated Water Bottle Sleeve Field Sketch*

This solution addresses our problem because it allows users to transport water in extreme environments. It creates a cheap, efficient, and appealing solution that users will enjoy. It prevents freezing of water and uses cheap materials. Because it gives a new use to disposable water bottles, it will lessen the user's environmental impact.

## Hunter Hartley

The off-road water cart features off-road capable wheels, a rugged frame, and a versatile strap-mounting solution to transport water on difficult terrain. Unlike existing water cart solutions, the proposed off-road water cart would feature a safety-brake that locks the wheels when the user's hands are removed from the device (figure 2.10).. The strap-mounting design allows a variety of water containers to fit the cart, and for auxiliary hardware (e.g. water purification systems) to be installed alongside the container (figure 2.10).

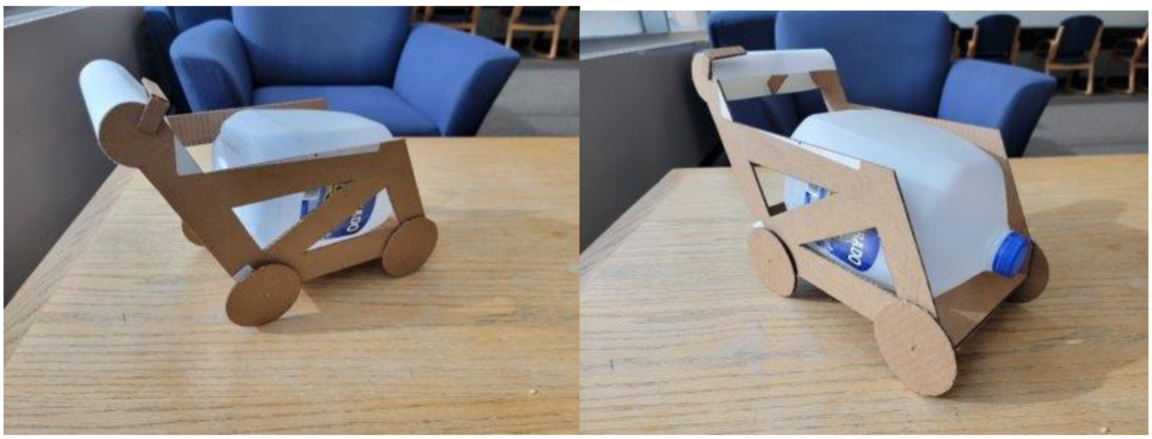


*Figure 2.9: Water Cart Looks-Like-Prototype Views*

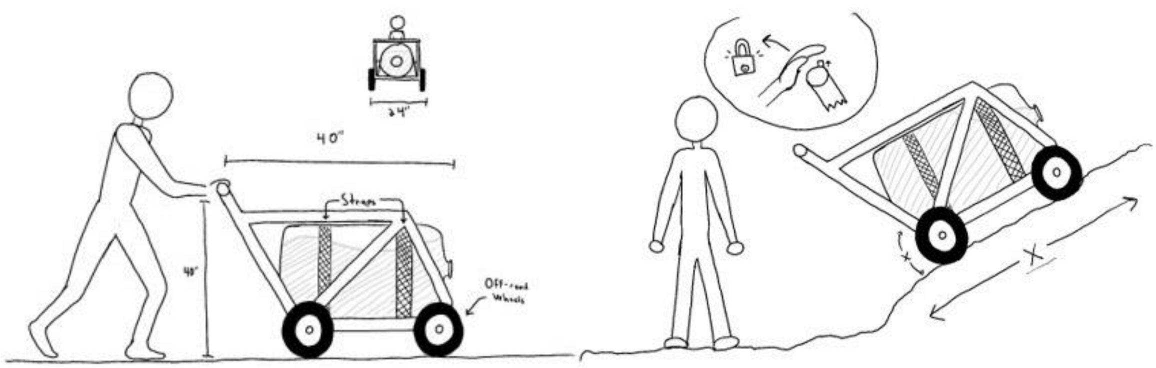



*Figure2.10: Water Cart Field Sketches - Side View and Application*

This design addresses the problem of water transportation in extreme environments by enhancing the user's ability to transport drinking water on extreme terrain beyond what the user can usually carry. The design maintains safety and convenience for the user in these extreme environments, allowing rest and focus on other tasks.

## Sebastian Accetta

For my design I tackled the design of moving water in extreme bumpy conditions. I used a sample motion such as horseback riding to specify my design to create a specific solution. When designing my prototype, I noted a few key futures that were required to meet stakeholder requirements. The important goal that I needed to meet was to move water in bumpy conditions where the water would not spill or leak any liquids. This goal was easily solved by the inclusion of a latch bottle. As shown in figure 2.11, a water bottle will be used to store the water which will prevent any leaks. Secondly, I wanted the user to be able to drink the water during bumpy conditions. This led to my designing a case for the bottle to hold it in easy access. As shown in figure 2.11, the cardboard surrounding shell is responsible for keeping the bottle from falling out the bottom or the sides.

*Figure 2.11 two vertical views and two horizontal views of the horse water prototype, one with the bottle and one without. Important parts include the: latch, button, and connecting string. Scale: 1:1.*

To keep the bottle from falling out the top while simultaneously having it be accessible a latch is required to keep the bottle intact. As seen in figure 2.12, a noncontact latch system is used for locking the bottle. This allows the user to quickly put away the water if for example a bumpier section was approaching. Additionally, by using a spring system with latches this allows the user to fasten the retaining loop very tight around the top of the water as the user can simply push down on the belt until they can no longer. This creates a tight restriction over the top of the bottle. For easy use of access there is a singular release button located on the side of the model. This model pushes the lock backwards allowing the latch to bolt upwards as shown in the released position of figure 2.12. With a combined easy release and a secure locking system a spring-based system was the clear choice of latch for my design.

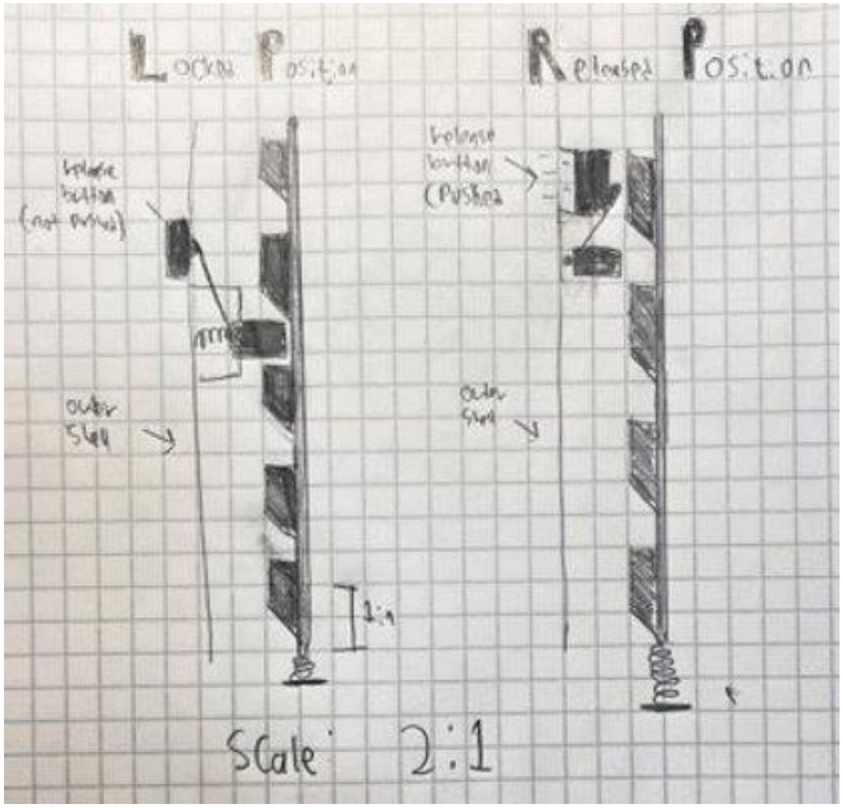



*Figure 2.12 the latching system of horse water. Located next to the button the system uses a spring system to lock the latch into place. The button is used to release the button. The lock position represents the latch being static where the released position shows the latch as it is being forced upwards releasing the bottle. Scale: 2:1.*

Horse water is a unique product as all the current implementations of drinking water that I could find only are meant to be used when a horse is stationary or moving very slowly. My is different in that it allows users to drink water during the intense conditions. An implementation of my design can be seen in figure 2.13 where the horse water contraption is latched onto the saddle of a horse via the leather loop. The location of the prototype implementation is essential to have easy access for the user.

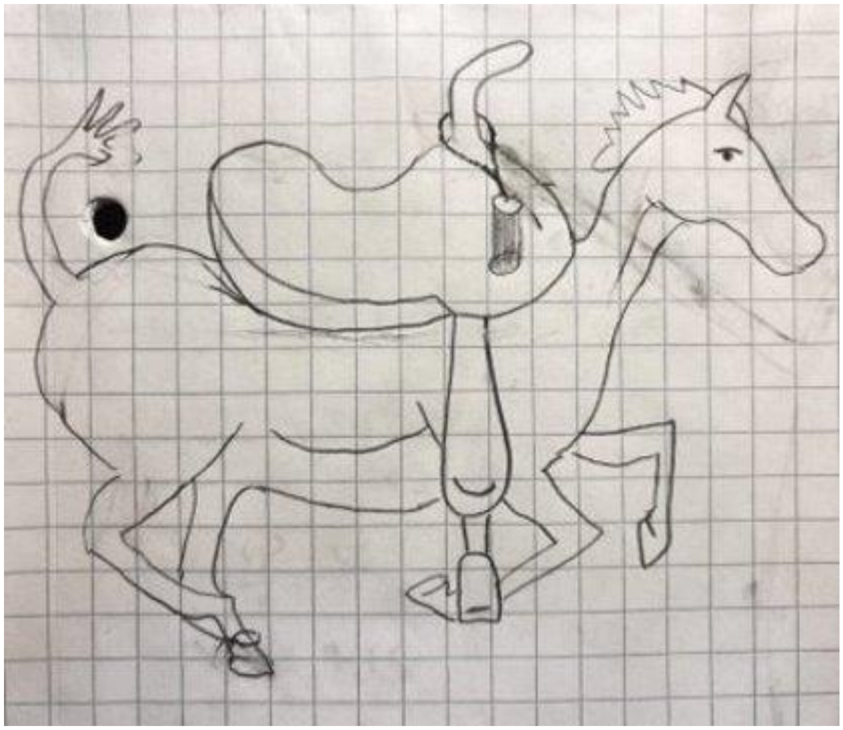


*Figure 2.13: Concept picture of horse water in action as a horse is galloping. The horse water is attached to the head of the saddle though the connecting string allowing for easy access for the user. Scale: not to scale.*

After creating my design and presenting it I have come to the realization that horse water is not only good for bumpy conditions but can also be used for extreme heights. Window washers, construction workers and cell phone tower climbers would also benefit from this product extremely. At extreme heights it is crucial that nothing falls from that height as any object would quickly reach terminal velocity and could greatly harm or hurt anyone below. This means that often these types of workers do not carry any water on them while they work. Not only is this unhealthy and will lower productivity in case of a cell phone tower worker getting stuck on a tower a bottle of water could save their lives. Humans can live without water for around three days but with a single liter of water this can extend to eight days.

Horse water solves the problem of moving water in extreme conditions and storing water at extreme heights. With slight modifications and more creativity, the possibilities of what it can be used for will only increase through time.

## 2.4) Decision Analysis

To determine which one of our prototypes was best we decided to use a decision matrix, group involvement and stakeholder engagement. We created five separate prototypes called, hydration jacket, water barrel, horse water, off-road water cart, and insulated water sleeve.

The hydration jacket shown in figure 2.14 was created to tackle the problem of moving water in freezing conditions. It is a wearable clothing item that is also equipped to carry water inside of its bounds. It uses body heat to keep the water warm in cold conditions and uses a straw to move the water from the jacket to a drinkable location near the user's mouth. Some benefits of the hydration jacket include that it is reusable, allows for an easier way to carry water, and allows the body heat to keep the water warm. Problems of the jacket include that if not warm the jacket could freeze in cool conditions, in hot conditions could burn the user, the jacket is heavy when worn and the user can become cold from using their body heat to keep the water from freezing.


*Figure 2.14: Water Jacket*

The Water Barrel shown in figure 2.15 is used to transport water over hilly and cold terrain. By having a circular cylindrical shape when the transport is moved the water inside the container moves as well. Moving water creates heat within the H2O molecules which would allow the barrel to move water in temperatures below freezing. The water barrel is good at transporting water without it being carried, has the ability to stay unfrozen in below freezing temperatures and can roll easily through difficult terrain. Some negatives include a capacity limit, if the unit is not moving it is unable to stay unfrozen below zero Celsius, and there is no braking system which can become very problematic.

*Figure 2.15: Water Barrel*

The prototype Horse Water as shown in figure 2.16 is used to transport water in bumpy conditions at high speeds and at extreme heights. The detachable strap allows the bottle holder to be harnessed to an animal such as a horse or a human through a belt or another location on the body. The design latch uses a retractable system which does not require a button to close only a button to open. Pros include that it is cheap, useful, applicable for many situations and a seamless design. Negatives include a small market, latch wearing over time, not comfortable for the horse, the strap can be hard to fasten in rough condition, water will slightly bounce, and can be hard to locate while in use.

*Figure 2.16: Horse Water*

The Off Road Water Cart shown in figure 2.17 is designed to move water across bumpy terrain. Unlike the water barrel which is susceptible to punctures from rocks and plants on the ground the off-road water card has an elevated surface. The water cart uses wheels and an elevated surface which allows the water to be separate to the terrain it is being moved in. Some positives include less physical demand, a braking system, secured water, and can hold high amounts of water. Some negatives include the cart being heavy (hard to push uphill), large volume, wheels wear through time, high friction on rough surfaces make the cart hard to move, quick stops can cause the water to fall out.

*Figure 2.17: Off Road Water Cart*

To move water in extreme cold conditions the Insulated Water Sleeve as shown in figure 2.18 uses thermal insulation to keep the water at warmer conditions. Using a neoprene sleeve the water bottle is insulated to prevent the cold from affecting the water temperature. Then with a latching system on the top the full water bottle can be kept at a higher temperature. The problems with the insulated water sleeve include a possible lack of durability, and only excelling in cold condition, although somewhat beneficial in the heat. Benefits of the water sleeve include that it is: reliable, cheap, applicable, reusable, in high demand, common problem with stakeholders, and that there will be a more seamless transition between the prototype and the real model.

*Figure 2.18: Insulated Water Sleeve*

We primarily used a decision matrix to decide which prototype created would be the best to move forward with in our development process. As shown in figure  we used six criteria to decide which idea was the best. We used the criteria of viability, feasibility, desirability, sustainability, realistic and usability. We also weighted different sections more important than others. Usability was scaled the highest as we believed that our product having a real-world application is the most important the final product. We want something that could truly be used and help solve our stakeholders' problems. Desirability and realistic are both weighed lower than usability but then the second most important as we wanted a design that we would be able to build and additionally something that our stakeholders desired. Cost is the next most important criteria slightly above feasibility and sustainability because we have a small budget to work with and we believe that cheaper products will have a higher desirability. Feasibility is tied for weighted the lowest because being convinced of something being done is not one of the values that our group contains. We believe that if something is a better design it should be built independent of the difficulties pertaining to building it. Simultaneous sustainability is tied for the lowest because little to none of our stakeholders mentioned environmental impacts of sustainability and thus it is not one of our main concerns.

As shown in figure 2.19 four of the five prototypes scored a very similar score between 35 and 36.5. Any of these prototypes would make for a good alternative solution. However, the insulated water sleeve scored significantly higher than the others with a score of 45. It scored at the top or the top for all criteria besides for cost. The insulated water sleeve is the clear choice to move forward with our design.

**Design I Decision Matrix Template**

**Team Name:** *Team Transport*

Scale 0 = worst 5 = Best

| | Design Objectives (criteria) | | | | | | Overall Score |
|---|---|---|---|---|---|---|---|
| | Viability (Cost) | Feasibility | Desirability | Sustainability | Realistic | Usability | |
| *criteria weighting* | *1.5* | *1* | *2* | *1* | *2* | 3 | |
| Design Alternatives | | | | | | | |
| Hydration Jacket | 3 | 1 | 3 | 4 | 3 | 5 | **36.5** |
| Water Barrell | 2 | 2 | 4 | 2 | 4 | 4 | **35** |
| Horse Water | 4 | 4 | 2 | 3 | 5 | 3 | **36** |
| Off-Road Water Cart | 5 | 5 | 4 | 2 | 2 | 3 | **35.5** |
| Insulated Water Sleeve | 4 | 5 | 4 | 4 | 5 | 4 | **45** |

Criteria Definition:

| | |
|---|---|
| Viability (Cost) | *How much it costs: higher = cheaper.* |
| Feasibility | *How easy the design can be created* |
| Desirability | *What is the desire for the design* |
| Sustainability | *Is the design enviromentally friendly or easily reusable* |
| Realistic | *Is this something that would could be made* |
| Usability | *Is this something that would be used in todays society* |

*Figure 2.19: Decision Matrix*

## 2.5) Final Proposed Design

After creating and comparing the looks-like prototypes of each concept, we have concluded that our final design concept will be an enhancement Ian's Insulated Water Sleeve. This concept uses insulated material to encase an inside water bottle to keep the water at the center at a still temperature for long sessions even in extreme conditions. A field-sketch and looks-like prototype made of cardboard of the outside sleeve can be seen the figure 2.19 below.

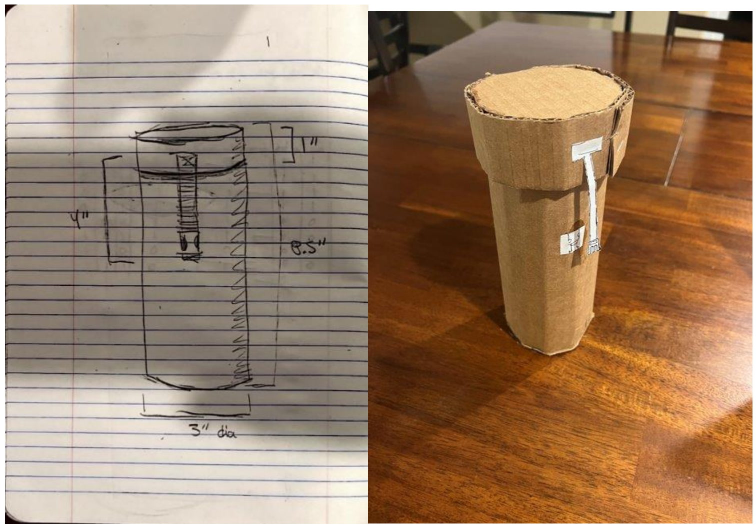



*Figure 2.20: Field Sketch with Dimensions And Looks Like Prototype*

Our design is intended to be used to cheaply, lightly, and conveniently convert cheap reusable plastic water bottles into high-quality water insulators to keep water insulated for long durations of time in extreme conditions. Our intended stakeholders for our product are communities who live in and traverse around extreme climates that need a solution to frequent water-temperature fluctuation. A Figure of a field-sketch and looks-like prototype of our product in use to insulate inside water bottles can be seen in the figure 2.2 below. Making a solution to insulate water cheaply, lightly, and conveniently important because other solutions to the issue of water transportation in extreme climates, such as the insulated metal HydroFlask cost stakeholders upwards of $50 for a single water bottle which is extra problematic because communities in extreme climates that need to deal with this problem the most are typically also those without the sustainable income to purchase luxury water bottles. This would not be a problem for our solution, as we estimate the cost of production of our product to be a mere $15. Additionally, metal water bottles are heavy and difficult to carry, unlike out solution which we estimate to weigh a mere 200 grams. Our design has the potential to revolutionize the way that water is insulated and transported in areas where water frequently becomes undrinkable due to extreme outside temperatures and conditions.

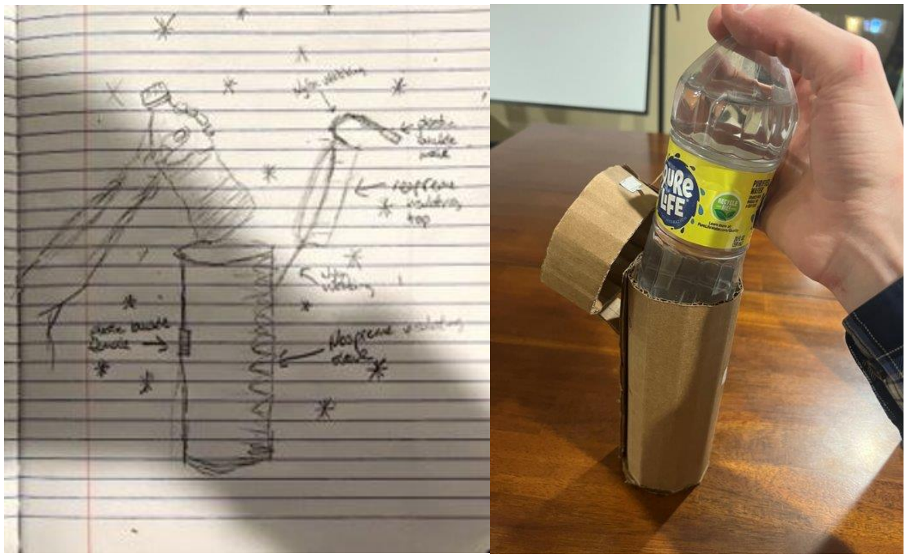


*Figure 2.21: Field Sketch and Looks Like Prototype In Use*

## 2.6) Summary

Rural communities and those in extreme environments are the key stakeholders of this problem, but all people benefit from improvements to water accessibility. Those responsible for the organization and distribution of drinking water are also key stakeholders.

Common existing solutions to this issue are vacuum-insulated water bottles like the HydroFlask, or regular reusable plastic water bottles. These solutions have many strengths for every-day life, but in extreme environments, both could be improved. HydroFlasks offer excellent thermal insulation, but are too heavy for many users to transport on extreme terrain. Regular water bottles work well in a comfortable temperature range, but offer no insulation from environmental temperature extremes.

Having analyzed the shortcomings and strengths of existing solutions, each team member prototyped a potential solution in order to provide the team with further insight before we settled on one solution. These prototypes involved hand-made looks-like prototypes and field sketches to explore their merit.

When we evaluated these prototype designs against each other, the insulated water bottle sleeve stood out as the best of our options. Any of the prototypes could be used, but going forward, we will continue to develop specifically on the idea of an insulating water bottle sleeve.

# 3.0) Subsystem Reports

## Jade Davis: Lid Geometry

### 3.1 Subsystem Description

The overall objective of the lid geometry subsystem is to ensure that the lid will fit perfectly over the body of the prototype. It is important for the lid to be properly dimensioned to ensure maximum protection of thermal heat when under extreme conditions. The stakeholders had issues with other thermal sleeve products because the sleeve only covers the bottom section of the water bottle. By neglecting to cover the top of the bottle, the top of water bottle freezes when under extremely cold conditions. Doing lid geometry will guarantee that no matter what condition the consumer is in, the water will not freeze.

The subsystem will be made using neoprene and nylon. Using lid geometry to measure out the values needed to make a lid for the protype can be seen in the chart below.

| ***Materials*** | ***Functions*** | ***Measured values*** |
|---|---|---|
| Neoprene | Will provide good thermal insulation with an R-value of .19 | Diameter: 81.5875 mm<br>Height: 44.45 mm<br>Thickness: 6.35 mm |
| Nylon | Will allow the lid to be put on/removed easily | Length :2 inches<br>Width: ¾ inch |
| Dimensioning & Geometry | Ensures a perfect fit to the top of the bottle.<br>(Formula used for volume)<br>Volume= $\pi r^2 h = \pi \times 4.079^2 \times 4.445 = 73.956981245\pi =$ **232.34270896097 centimeters$^3$** | -Bottle diameter =80mm<br>Lid needs 80mm+ (1/32) of an inch on each side for a snug fit.<br>-2icnhes of nylon for to allow ¼ inch of slack between subsystems<br>-total volume= 232.3 cm$^3$ |

*Figure 3.1: Subsystem Components [27]*

The general design of the lid will be determined by the dimensions listed above in figure 3.1, but the actual lid should look something like the images below.

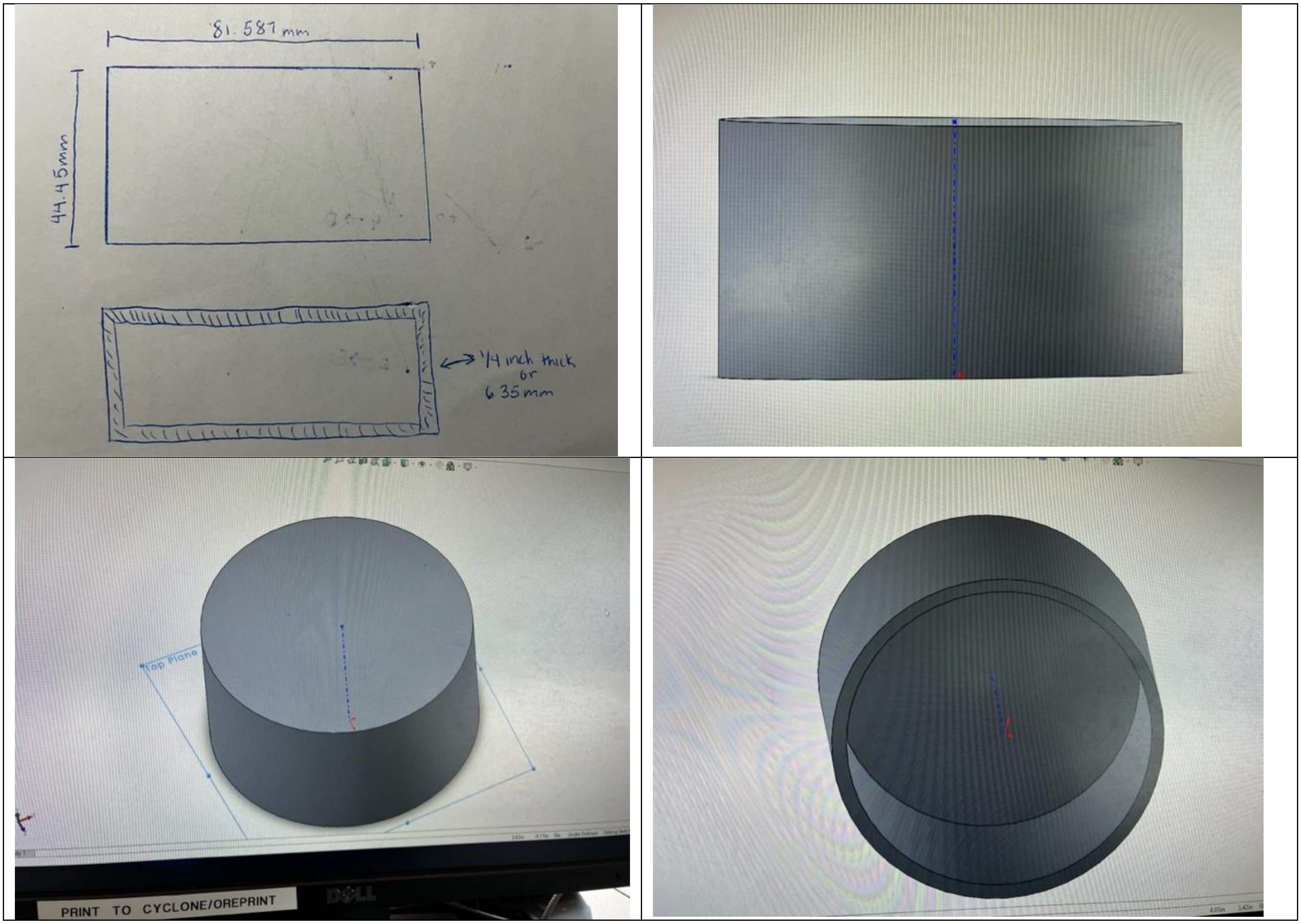



*Figure 3.2: Lid Geometry Physical Application (looks-like model)*

The lid geometry subsystem will help create the lid in the images seen above. With the thickness of the neoprene being considered the diameter of the lid is 81.5875mm to allow 1/32 of an inch gap so the lid can fit over the body of the prototype and snap into the buckle with ease. One thing that cannot be seen clearly in the CAD sketches is the 2 inches of nylon webbing that will be attached to the back of the lid to allow the lid to be put on and removed. All these material and dimensions will come together to make the lid needed to provide thermal protection for the top of the water bottle.

### 3.2 Idea generation

When deciding what materials to use for the lid subsystem, neoprene fabric (polychloroprene), and neoprene rubber. When think about which material to choose, certain factors were taken into consideration. The material would have to be easy to manipulate, water resistant, have good insulation properties. The polychloroprene was chosen over the neoprene rubber due to its elasticity, impermeability, heat retention, and formability. The material used must stretch and be able to take the shape of the bottle, must be easy to sow through and manipulate, must hold in thermal heat/insulation in extreme environments, and it should be water resistant and resistant against different environmental conditions. The nylon webbing was already going to be in making the buckle subsystem, and it's a fairly strong material, so it was decided that the nylon would also be used to provide slack between the lid and the body.

| Criteria | Polychloroprene | Neoprene Rubber | Nylon |
|---|---|---|---|
| Cost | 27.99 for 12" x 54" | 21.99 for 12" x 23" | $0.44 per foot |
| Insulation value | 0.19 k-value | 0.2-0.4 k-value range | n/a |
| Weight | 0.000948697 $lbs/in^2$ | 0.04 pounds per cubic in | 0.041185 $lbs/in^3$ |
| Stretch | Very elastic | Somewhat elastic, more structured | Does not stretch |

*Figure 34.3: Decision Making Analysis [28], [29]*

**3.3 Validation of novel and unique design aspects**

The testing for the lid geometry subsystem consisted of using different dimensions and comparing each of these dimensions to how they would fit with the body of the prototype. There was another test done to see how much slack would be needed for the lid to be able to be removed easily.

The dimensions tested for the lid geometry subsystem consisted of varying dimension for the diameter and height of the lid, while also considering the slack needed for the nylon connection on the back of the lid.

| Testing | Dimensions tested |
|---|---|
| Diameter | 85mm<br>80mm<br>81<br>81.6mm |
| Height | 12.7 mm<br>25.4 mm<br>50.8 mm<br>44.45 mm<br>38.1 mm |
| Nylon Slack | 1inch<br>¼ inch<br>2inches<br>½ inch |

*Figure 3.4: Testing Analysis Results*

Based on the measurements seen above, there were quite a few options when deciding what dimensions would be the best dimensions for this subsystem, while considering the whole prototype as well. The dimensions that were chosen from each section gave the subsystem a diameter of 81.6mm, a height of 44.45mm, and a slack amount of ¼ inch. By using the dimension testing as my first from of validation, the second form of validation being used is secondary research. Based on the dimension found from Fleet Farm which stated the height of a 20 oz smart water bottle is 8.95 inches with a height of 2.58 inches [26]. Based on the dimensions provided by Fleet farm, these values were converted from inches to millimeters using the conversion of (1in=25.4mm). Since the neoprene fabric is ¼ inch thick, 2x( ¼) of an inch was added to the 2.58 inches to account for the 1/4$^{th}$ of an inch on both sides. Once the diameter of the bottle was calculated, the diameter of the lid was calculated by seeing how many extra millimeters were needed to allow room for the lid to fit over the body. (1/32) of an inch was determined to be the amount of "wiggle room" needed to easily remove and put on the lid. Once the diameter needed was determined, the cap size of a smart water bottle was measured; it was around 1 inch. So, I dimensioned the height to be 1.75 inches because the neoprene would save of 0.25 inches leaving the lid with a true height of 1.5 on the inside leaving a half inch on the inside of the lid. With all the dimensioning completed, I looked at a solid works article that instructed me on how to properly dimension my CAD images based on the lid geometry and dimensioning. The last form of validation I used was an in-person interview with a HomeDepot salesperson who works with wood. I asked him, "what is the best possible way to measure the dimensions of an object." John O'Conner replied, "measure twice cut once is what I go by, but when measuring for something such as a lid or cover use the dimension of what your covering, then compare and see how those dimensions match up in comparison with what you expected or estimated the measurement to be."

## Sebastian Accetta: Handle and Latch

**3.1 Subsystem description**

My subsystem is the handle and latch. A handle and latch mechanism is an integral part of a water bottle insulator which will keep water as a liquid at cold temperatures. The handle allows for easy transportation of the bottle, while the latch securely fastens the insulator, preventing any unwanted leaks, spills or loss of heat.

The handle is responsible for a place to carry the bottle. It is important that the handle is large enough for a mitten to carry it as often in cold conditions our users will be wearing mittens or gloves. It also needs to be able to hold the weight of the bottle.

The latch is responsible for closing the shell of neoprene which will insulate the bottle. The latch needs to be easy to open and close.

*Figure 3.5: Latch system. A cad model of the latch with separate color for the input (black) and receiver (red).*

During the strength test the prongs at the end of the input section were the section of the latch that broke. The length of the input is 3 cm and the length of the receiver is 2.75 cm which is to make sure that there is a part of the input left when fully inserted. The material of the latch is Casein plastic.

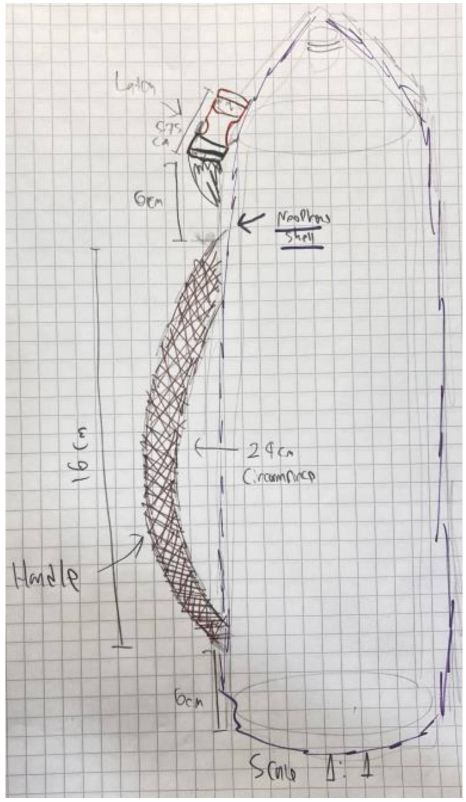



*Figure 3.6: Sketch of the Handle and latch Integrated with Other Subsystems*

Figure 3.6 represents how my subsystem will interphase with other subsystems and will represent how it will be attached to create one single prototype.

### 3.1.1 Scaled up solution

The handle and latch subsystem is crucial to the overall product as without the latch the bottle will not be properly insulated and without the handle there will be no easy way for the user to use the product.

#### 3.1.1.1 Overall objective of the subsystem

The goal of the handle is to create a place for the user to be able to carry and use the insulator. The goal of the latch is to securely close the surrounding shell to keep the water liquid in cold temperatures.

#### 3.1.1.2 How the subsystem works

The subsystem works by closing the main insulator that surrounds the bottle and the lid which will cover the top of the bottle. The handle works by attaching to the neoprene and having a material that a hand can fit through to hold a bottle. Similar to a flashlight.

#### 3.1.1.3 required inputs

The material of the shell must be able to be fastened to the handle. There needs to be a top and main section that are attached but can open and close. This is essential for the latch to work.

#### 3.1.1.4 Key Subsystems

My subsystem is split into two sections. The handle which is made of a nylon webbing which is very strong and easy to fasten [30]. The second section is made of a latch. The latch has an input and receiver part of it. The input part slides into the receiver and creates a secure bond. This bond is only separated by pushing on both sides at the same time.

My subsystem has interfaces with the rest of the subsystems except for insulation. It connects with both the lid geometry and body geometry as the handle is placed on the body and needs to be connected to it and the latch connects the lid and body geometry to each other so it is important that the latch is attached to the corresponding section of both. In relation to ergonomics the handle needs to be located somewhere on the body that does not interfere with the latch and is an easy place for the user to hold that will balance the water inside to make it easy to carry. In connection with the fastening and adhesion that show the latch and handle are being attached to the body. The strength of the handle and latch is only as strong as we can fasten them to the body thus making the fastening the limiting constraint when calculating strength.

#### 3.1.1.5 Off-the-shelf-components

The products used are a nylon webbing and an ordered buckle.

## 3.2 Idea generation

A large part of my idea for this was from my looks-like prototype horsewater. The horsewater used a magnetic latch however due to the cost constraint we have put on ourselves I realized that I can get a similar effect from a plastic buckle. The buckle does not have the same high-end quality that the latch in horse water had but because the price of our model is very cheap it does not make sense for the latch to cost four times more than the cost of the rest of the model.

## 3.3 Validation of novel and unique design aspects

### 3.3.1 Test results

To test my subsystem I tested how much weight they could hold and what temperatures they would break. I found from research that the temperature would have to be below -40 degrees [31]. The nylon temperature would have to be significantly below -100 Fahrenheit which is much colder than any recorded temperature on earth.

For the buckle strength test I slowly added weight to the buckle to determine at what mass it would break. I found that at 75 lbs the buckle released the weight from the bottle. The buckle did not break on the exterior rather a small point on the interior of the receiver. This should be noted because if a buckle is broken it would be near impossible for the user to notice, this should be noted to ask stakeholders if that would be an issue to them.

For the strength test of the nylon I conducted the weight test again. I got up to 200 lbs before I could no longer lift the nylon. Thus I finished my test with research. The nylon is able to withhold 900 lbs which is significantly more than we will ever need [32].

### 3.3.2 Analysis and calculations

Both the latch and the handle can handle conditions below -40 Fahrenheit which is well below the threshold of temperature that we are trying to keep water liquid at. The handle can carry 900 lbs which is significantly more than we will ever need. Lastly the latch can handle 75 lbs which is much less then the handle but because we will never be holding over 75 lbs or water in our container averaging around 1 lbs it will be more than enough

### 3.3.4 Secondary research

Nylon webbing: Nylon webbing is a popular material for straps and handles due to its strength and durability. It is commonly used in outdoor and sports equipment. According to the Nylon Webbing Buying Guide by Strapworks, nylon webbing has a tensile strength of 4,000 pounds and can withstand temperatures ranging from -40 to 212 degrees Fahrenheit [33].

Temperature requirements for water: Water freezes at 32 degrees Fahrenheit (0 degrees Celsius) and boils at 212 degrees Fahrenheit (100 degrees Celsius). In order to keep water liquid in cold temperatures, it must be kept above the freezing point. According to the International Association of Plumbing and Mechanical Officials, the recommended minimum temperature for cold water supply is 50 degrees Fahrenheit (10 degrees Celsius) [34]. However, for water bottles that are meant to keep water cold, the temperature needs to be significantly lower than this, typically below 40 degrees Fahrenheit.

Buckle strength: Buckles come in various materials and strengths. In a study by the American Society of Mechanical Engineers, they tested the strength of different types of buckles and found that the average breaking strength for a plastic buckle was 280 pounds making it much above the buckles that we ordered [35].

### 3.3.4 Stakeholder and expert feedback

For my stakeholder and expert feedback, I talked to my friends who use water bottles when they ski. What I found was that many of them wear puffy gloves to wear their hands. This is included in 3.1.1 as well but it is crucial that the diameter of the handle can fit a mitten in it and the buckle is able to be used with gloves, this may require the purchase of a larger buckle than we included.

## Hunter Hartley: Fastening and Adhesion

### 3.1.1) Subsystem Description

The Fastening and Adhesion subsystem encompasses all mechanical fastening and adhesion between materials within the system. This includes the use of any glues, tapes, and fasteners, and any sewing of materials.

#### 3.1.1.1) Subsystem Objective

The objective of Fastening and Adhesion within our system is to reliably secure system components to each other while preserving technical and aesthetic performance. The fastener or adhesive of choice must provide a mechanical joint that meets system requirements like environmental resilience and strength without compromising other system requirements like thermal performance, dimensional tolerance, or aesthetics.

The subsystem will be comprised, in its instances, of two materials to be joined and a fastener and/or adhesive. Key materials involved will be polypropylene, closed-cell neoprene rubber foam, phosphorescent 150D polyester thread, and urethane permanent fabric adhesive.

#### 3.1.1.2) How the Subsystem Works to Accomplish Outputs

The joining of the two relevant materials is accomplished through the proper application of a chosen fastener/adhesive. The physical characteristics of the fastener/adhesive, as well as the methods used to implement them, will affect the performance of the completed joint.

#### 3.1.1.3) Necessary Inputs

The subsystem inputs necessary to produce the finished joints for the system include the materials being joined, the fastener(s) and/or adhesive(s) of choice, dimensional specifications and tolerances for the finished joints, and careful application of the fastener(s) and/or adhesive(s) of choice. The design specifications for the system, particularly thermal performance, durability, and aesthetics, influence the design choices made in selecting fasteners/adhesives and the methods by which they are applied.

#### 3.1.1.4) Key Subsystem Components Needed

The key subsystem components needed to accomplish material joints per system specifications are the materials being joined, the fastener(s)/adhesive(s) of choice, and their accompanying application methods.

### 3.1.1.5) Off-the-Shelf Components

Within this subsystem, key off-the-shelf components include:

Phosphorescent 150D polyester thread (hereon referred to as thread):


*Figure 3.7: Polyester Thread*

This thread [Figure 3.7] provides utility to the system both as a fastener and as a visibility aid. The phosphorescent dye in the thread allows easier spotting of the system in dark environments. The thread weight is common, and therefore easy to both source and manufacture with without sacrificing strength.

Urethane permanent fabric adhesive (hereon referred to as fabric glue):


*Figure 3.8: Fabric Glue*

This fabric glue [Figure 3.8] provides an alternative solution to thread for joining fabric materials. The fabric glue will be tested against the thread in relevant tests to determine which should be used in each system joint.

The other relevant off-the-shelf items - polypropylene webbing (hereon referred to as webbing) and closed-cell neoprene rubber foam (hereon referred to as neoprene) – are covered in more detail in the subsystem sections they originate from.

### 3.1.2) Subsystem Component Physical Properties

Thread specifications:

| Parameter | Specification | Unit |
|---|---|---|
| **Thread material** | Polyester | |
| **Thread weight** | 150 | Denier |
| **Thread color** | White | |
| **Thread phosphorescence color** | Green | |

*Figure 3.9: Thread Specification*

Fabric glue specifications:

| Parameter | Specification | Unit |
|---|---|---|
| **Glue type** | Urethane,<br>Water-based | |
| **Glue color** | Clear | |
| **Safety** | Non-toxic | |
| **Washing (dry)** | Machine Washable | |
| **Flexibility (dry)** | Flexible | |

*Figure 3.10: Fabric Glue Specification*

### 3.2) Subsystem Idea Generation and Decision Making

In order to compare different adhesives and fasteners for making material joints, the decision matrix shown in Figure 3.11 was used. From this decision matrix, the decision to evaluate thread and fabric glue was made.

**Fastening and Adhesives Decision Matrix**

**Team Name:** *Team Transport*

Scale 0 = worst 5 = Best

| | Design Objectives (criteria) | | | | | | Overall Score |
|---|---|---|---|---|---|---|---|
| | Cost | Prototyping | Manufacturing | Strength | Thermals | Aesthetics | |
| *criteria weighting* | *1.5* | *1* | *1.5* | *2* | *2* | 2 | |
| Design Alternatives | | | | | | | |
| Thread (sewing) | 5 | 1 | 5 | 5 | 4 | 5 | **44** |
| Fabric glue | 4 | 3 | 4 | 4 | 5 | 4 | **41** |
| Hot glue | 4 | 4 | 2 | 0 | 3 | 1 | **21** |
| Stapling | 5 | 5 | 2 | 2 | 2 | 0 | **23.5** |

Criteria Definition:

| | |
|---|---|
| Cost | *How much it costs: higher = cheaper.* |
| Prototyping | *How easily the design can be prototyped* |
| Manufacturing | *How easily the design can be manufactured* |
| Strength | *How strong the resulting joint is* |
| Thermals | *How well the thermal performance of the joint is preserved* |
| Aesthetics | *Does it look nice* |

*Figure 3.11: Decision Matrix*

## 3.3) Design Validation

### 3.3.1) Test Results

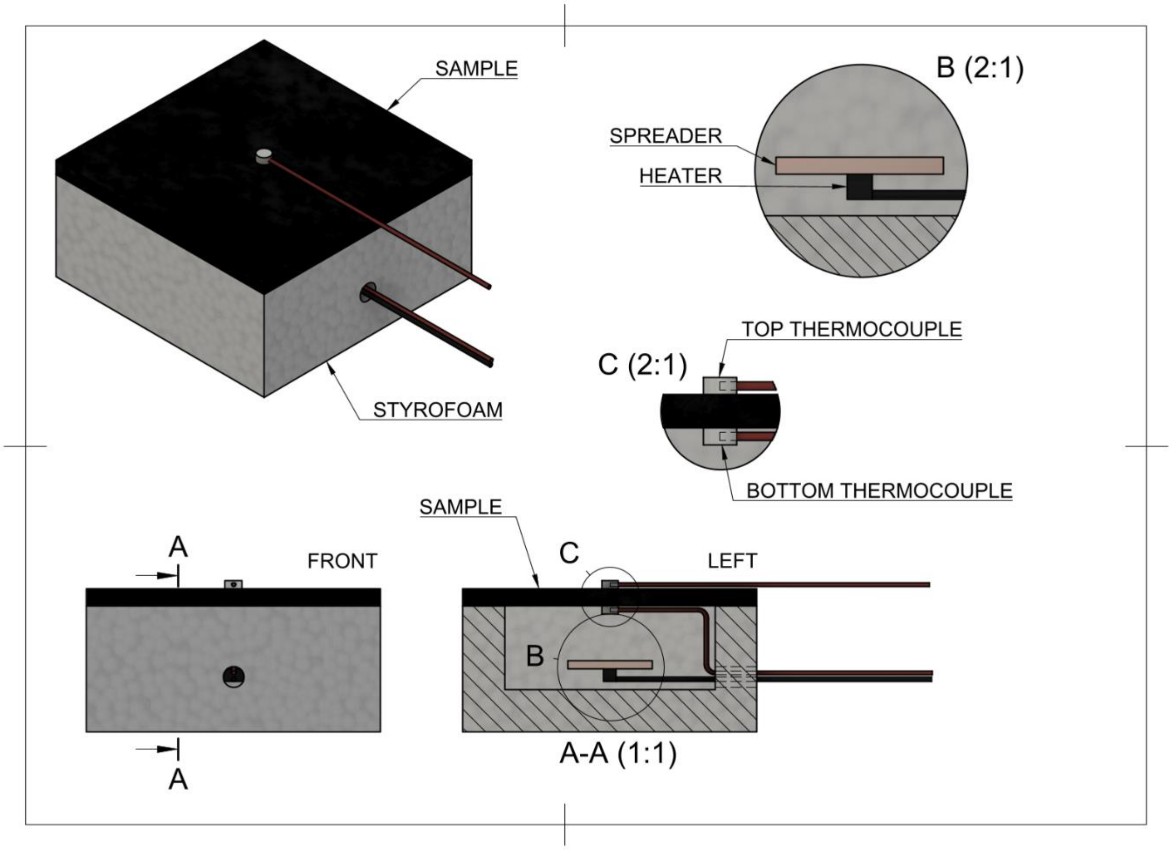



*Figure 3.12: Thermal Test Setup*

For the sample thermal performance tests, the testing setup shown in Figure 3.12 was used to compare the thermal insulation performance of a continuous piece of material to one that has been joined in the middle by the fastener or adhesive under test. Two thermocouples were used to measure the steady-state temperature difference across the sample, while the heater provides steady heat flow into the insulated chamber. Because the Styrofoam insulation encases the heater, the heat flows almost entirely through the sample with a known surface area and thickness. The thermal resistivity of the sample is therefore be given as:

$$R_{THERM} = \frac{\frac{A}{t} \times \Delta ℃}{W}$$

Where W = the steady-state power output of the heater, A = the surface area of the sample exposed to the heat chamber, t = the thickness of the sample, and $\Delta$℃ = the temperature across the sample as measured by the thermocouples.

The control test found that our neoprene sample had a thermal resistivity of 17.2 $mkw^{-1}$. The sewn sample was found to have a thermal resistivity of 16.9 $mkw^{-1}$. The glued sample was found to have a thermal resistivity of 17.0 $mkw^{-1}$ This test result verifies that the use of a sewn or glued seam does not significantly impact the thermal insulation properties of the neoprene material.

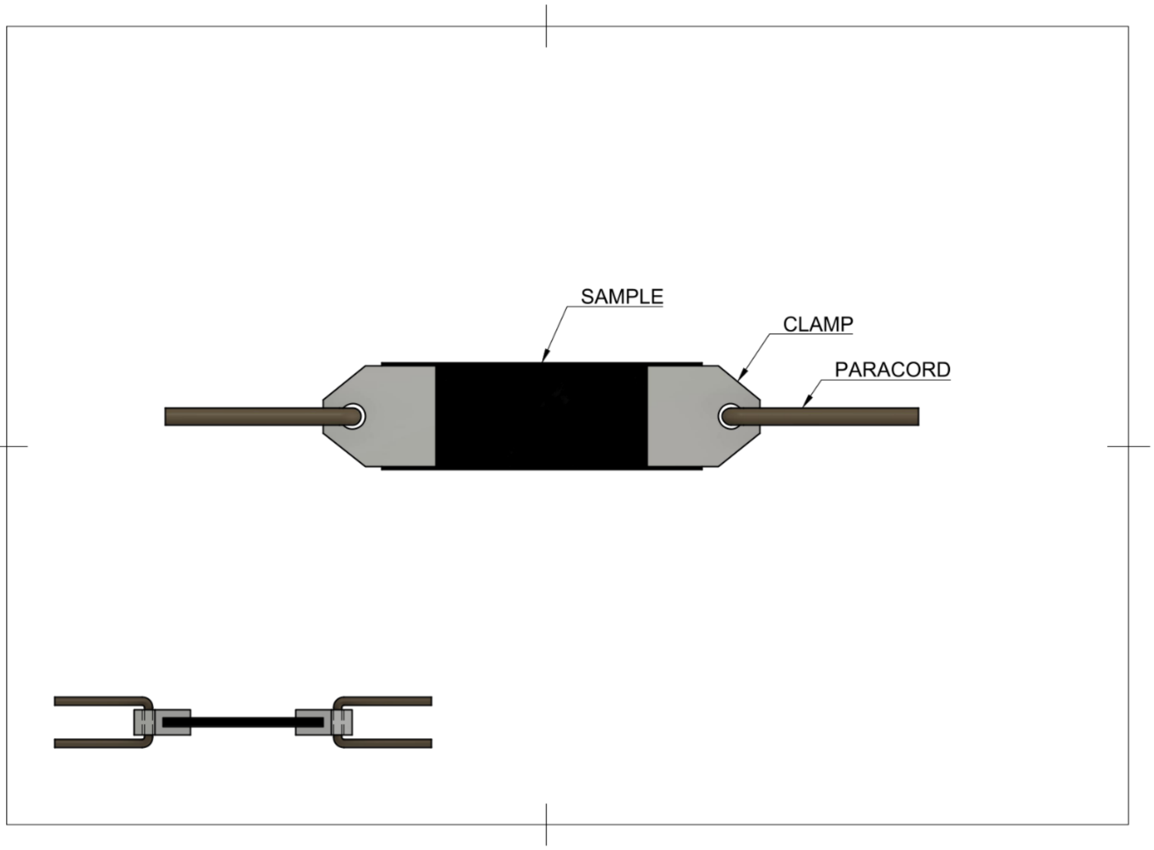



*Figure 3.13: Strength Test Setup*

For the linear tensile strength tests, the testing setup as shown in Figure 6 was used to compare the breaking tensile strength of the fasteners and adhesives being evaluated. Clamps are used on either end of the sample to connect the sample to paracord, which will be loaded with weight. The joint must meet a linear tensile strength of 4lbs/inch to meet design goals. For a one-inch-wide sample, this means the joint must survive with 4lbs of tension applied.

Both fabric glue and thread passed the linear tensile strength test. The sewn seam exceeded 10lbs/inch, while the fabric glue failed at 7.5 lbs/inch. This result allows both fastening methods to be used for a prototype.

### 3.3.2) Analysis and Calculations

| **Thermal Insulation Performance Test** | |
|---|---|
| **Joint** | Test result |
| **Fabric glue** | 17.0 $mkw^{-1}$ |
| **Thread** | 16.9 $mkw^{-1}$ |

*Figure 3.14: Thermal Performance Results*

| Linear Tensile Strength Performance Test | |
|---|---|
| **Joint** | Test result |
| **Fabric glue** | 7.5 lbs/inch |
| **Thread** | >10 lbs/inch |

*Figure 3.15: Strength Performance Results*

**3.3.3) Secondary Research**

According to the Journal of Polymer and Textile Engineering [36], the strength of a seam is not linearly dependent on the stitch density (stitches per inch). For some of their textile samples, increasing stitch density beyond a certain point decreased the tensile strength of the seam. When evaluating stitching methods, we should aim not to push stitch density beyond the similar point for our materials.

U.S. Military Commercial Item Description A-A-59963 [37] provides some insight into typical polyester thread specifications. According to their findings, we can expect around 1.4lbs of breaking strength from a single strand of our thread. To achieve a linear joint tensile strength of 4lbs/inch (four pounds of tensile strength for every inch of continuous joint), we will need to achieve 3 stitches per inch. To account for tolerance and uneven loading, we should strive for 6 or more stitches per inch.

The Bielefeld University of Applied Sciences studied different glues as a method of joining textiles [38]. The researchers found that the choice of glue was critical to performance – specifically, industrial glues achieved much greater seam strengths than alternatives. The research also found that neither sewing nor industrial glue was universally stronger than the other. This research leads us to believe that we need to test the performance of glues and stitches with our own materials to determine which provides a stronger joint.

The Fashion and Textiles paper on wetsuit sewing provides valuable insight into how neoprene material will respond to sewing [39]. This paper evaluates different sewing methods and both their tensile strengths and their water sealing abilities. This research is especially relevant to our system because it evaluates with neoprene material rather than textiles. The research found that machine-sewn seams could withstand tensions upwards of 100lbs for 100mm grip on 21x30cm panels. This research verifies that the strength we aim for is achievable and provides some guidelines on how to reach it.

This paper also references sealing tape, which can be used to improve water resistance of the seams. This could prove helpful if we find it necessary to keep contaminated water out of the interior of the system.

Darrell Nicholson researched hand-stitching to webbing in order to evaluate the strength of the joints he could form [40]. Darrell's research found that, with1-inch nylon webbing, seven 1/8-inch stitches per row, 1/8-inch row spacing, and 8 rows, a breaking load of 3,650lbs could be achieved. We will not be able to achieve such high breaking loads, but his work proves that we can achieve high joint strength between the polypropylene webbing and the neoprene body of the system.

## Ryan Reiser: Sleeve Body Geometry

**3.1.1.1)**

The overall objective of the "body geometry" subsystem is to provide the project with the information required to functionally create an efficient water-bottle insulating sleeve. This information includes the theoretical shape and sizes used in the main body of the sleeve. In order to reach maximum possible efficiency of use, the geometric shape and size of the water-bottle sleeve must be able to fit a designated plastic water-bottle well enough so that the sleeve snugly and firmly holds the bottle, while also being loose enough to be able to easily slide the bottle in and out of the sleeve. Additionally, the thickness of the neoprene insulating walls must be thick enough to well insulate the interior bottle for multiple hours, while also be thin enough to keep costs of production materials low and keep the sleeve light so that it can be carried around with ease and comfort, which is critical considering that our targeted stakeholders are those that frequently do outdoor activities in extreme and dangerous environments.

**3.1.1.2)**

To accomplish these output goals of being able to fit a designated plastic water-bottle well, provide quality insulation to the bottle, and keep the sleeve light and convenient to carry while keeping costs low, it has been concluded that the water-bottle sleeve will be a total of 80mm in diameter, with the perimeter wall of the sleeve being ¼ inch-thick neoprene material. The reasons as to why these decisions were made in order to best meet these goals are later gone over in this document during section 3.2.

**3.1.1.3)**

Inputs that the "body geometry" subsystem processes are firstly, a standard 20oz Glaceau Smart Water plastic water-bottle filled with liquid, and secondly extreme outside temperatures.

**3.1.1.4)**

The following are key subsystem components needed to accomplish the output goals highlighted in section 3.1.1.2: More depth as to why these specific solutions to the are chosen are given in section 3.2.

1. An 80mm total diameter allows for a standard 20oz Glaceau Smart Water plastic water-bottle with a 65.5mm diameter to fit well into the sleeve, even with a ¼ inch or 6.35mm thickness of the surrounding neoprene.
2. The ¼ inch or 6.35mm thickness to the neoprene wall allows the interior water-bottle and the water that it holds to be insulated for long periods of time without the overall sleeve being too heavy.

**3.1.1.5)**

Because the "body geometry" subsystem is entirely theoretical, there are no physical off-the-shelf components that go into the creation of the subsystem. Instead, the subsystem is created with the intention of providing other subsystems with the information they require to functionally create an efficient water-bottle insulating sleeve, and this information was gathered through a combination of scholarly research, testing, CAD modeling, and critical thinking.

**3.2)**

As a business, the most important factor to making profit is to establish the trust and the support of the stakeholders of the general public. The Unites States functions off of a capitalist economy which gives consumers the ability to vote in what they believe in their purchases and transactions. Once the trust and support of the public is lost, boycotts are formed and profits are lost, as reinforced by Valentin Beck in his article *Consumer Boycotts for Instruments of Structural Change*, when it is written "Today, boycotts are often used to target large companies including multinational corporations, which have gained unprecedented influence in the global economy over the last few decades " [41] . One prominent and historic example of boycotting formatting change within our capitalist society was the Montgomery Buss Boycott of 1955. According to Standford.edu's article on the Montgomery Bus Boycott, after being sparked by the imprisonment of Rosa Parks after refusing to sit at the back of the bus out of racial protest, "the Montgomery bus boycott was a 13-month mass protest that ended with the U.S. Supreme Court ruling that segregation on public buses is unconstitutional" [42], proving that boycotts cause change within our society. One important decision necessary to the design of the sleeve was to find which water-bottle brand our sleeve would be shaped around, since different water-bottle brands often have different measurements to their bottles, which will conflict when fitting into the sleeve. To answer this question while gaining the trust and the support of the general public, it has been concluded that our sleeve will be shaped to fit the size of the 20oz Glaceau Smart Water plastic water-bottle. Initially, our group targeted Nestlé water-bottle brands such as Arrowhead, which is the largest and most profitable bottled water brand in Colorado, due to the similar sizing and accessibility of these popular water-bottle brands. However, after doing further research, problems surrounding the Nestlé brand quickly arose. According to Colin Boyd's *The Neslé Infant Formula Controversy and a Strange Web of Subsequent Business Scandals,* Nestlé has a very prevalent history of being subject to boycotts and criticism due to their past propaganda attempts to sway the general public into believing that bottled baby formula provided superior nutrients to natural breast feeding. These marketing ploys created global generations of babies with poor nutrition to increase Nestlé's profits. As mentioned in the article, "In the late 1960s, Nestl*é* was criticized by social activists for its marketing of powdered milk formula for infants in less developed countries. The case became a *cause célèbre* as Nestlé became the victim of a

well-organized boycott campaign" [43]. Additionally, Nestlé is known to drain areas scarce of water as a way of forcing the residents of that area to purchase Nestlé bottled water instead, which is extremely unethical given that, according to Amy Hardberger in her report for the Northwestern Journal of International Human Reports titled *Life, Liberty, and the Pursuit of Water: Evaluating Water as a Human Right and the Duties and Obligations it Creates* while studying at the Northwestern School of Law, "Over two million people die every year due to a lack of safe drinking water" [44] . There are even recent records of Nestlé taking water from California under their recent drought as an attempt to capitalize off of the catastrophe, as written by Dan Bacher in his article *Nestle Continues Stealing World's Water During Drought* when he writes The coalition is protesting Nestlé's virtually unlimited use of water – up to 80 million gallons a year drawn from local aquifers – while Sacramentans (like other Californians) who use a mere 7 to 10 percent of total water used in the State of California, have had severe restrictions and limitations forced upon them, according to the coalition. 'Nestlé pays only 65 cents for each 470 gallons it pumps out of the ground – the same rate as an average residential water user. But the company can turn the area's water around and sell it
back to Sacramento at mammoth profits, the coalition said'" [45]. With all of this in mind, it is easy to see how poor of a decision it would be both morally and economically to have our sleeves support and encourage the sale of Nestlé products. As a result, our group has decided that our sleeves would instead be measured around a standard 20oz Glaceau Smart Water plastic water-bottle, which is a much more ethical brand of bottled-water while still remaining extremely popular. Additionally, due to the normal cylinder-like design of Smart Water bottles, this brand of water would fit well into a sleeve compared to other bottled water which includes grips and unconventional designs what could cause the water to bounce around the sleeve during intense use.

As a result of the decision to use a standard 20oz Glaceau Smart Water plastic water-bottle, the diameter of the sleeve body will be 80mm. Through purchasing and measuring 20oz Smart Water bottles, it is found that each one has a diameter of exactly 2.58 inches or 65.5mm. Accounting for a ¼ inch or 6.45mm thick neoprene sleeve, which was found through testing and calculations to be a sufficient sleeve thickness to keep water insulated for multiple hours under extreme conditions, an 80mm base diameter for the sleeve will allow a standard smart-water bottle to fit into the sleeve comfortably but securely, with a 2mm leeway space, while also keeping the product light enough to carry around comfortably through testing.

### 3.3) Test Results

` As a test to ensure that the dimensions hypothesize worked well for the product, a CAD model of the product sleeve was developed, as shown in Figure 3.16 below, and 3D printed. Because nylon filament has an extremely close density to neoprene, with nylon filament having a density of 1.52 g/cm^3 and standard neoprene having a density of 1.50 g/cm^3, it can be assumed that the weight of the 3D printed sleeve will be virtually the same as the final product made from neoprene. After holding the 3D printed result, the product was given to multiple stakeholders, who all agreed that the product was of good weight while not being too heavy. Additionally, the 3D printed product was able to hold a standard 20oz Glaceau Smart Water plastic water-bottle perfectly, fitting it exactly right.

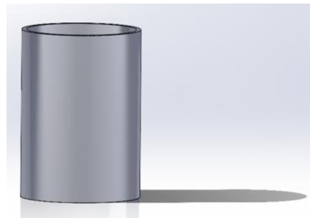


*Figure 3.16: Body Dimensions*

Analysis and Calculations:

As mentioned previously, it was calculated that the diameter of the sleeve body will be 80mm. Through purchasing and measuring 20oz Smart Water bottles, it is found that each one has a diameter of exactly 2.58 inches or 65.5mm. Accounting for a ¼ inch or 6.45mm thick neoprene sleeve, the final diameter of the base of the sleeve is calculated to be 80mm. Figure 3.17 below illustrates exactly how these measurements add up, with the diameter on the far right being the overall 80mm diameter, the diameter of the middle circle being the diameter of a standard 20oz Smart Water plastic bottle, the 6.35mm long measurement on the left being the thickness of the neoprene, and the final 0.90mm measurement allowing for some leeway to allow the water-bottle to easily slide in and out of the sleeve comfortably.

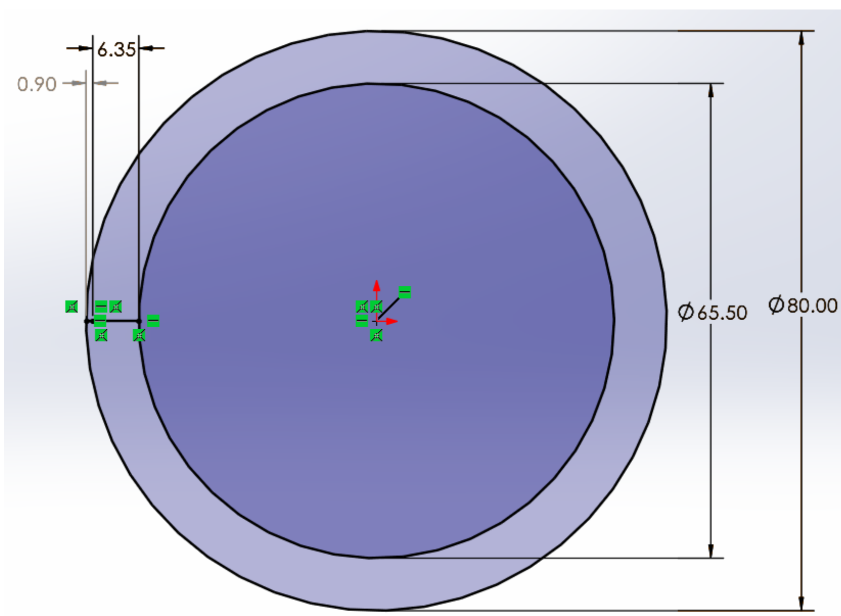



*Figure 3.17: Dimensions of Base*

Stakeholder and Expert Feedback:

As mentioned during the "Test Results" section, a total of 10 stakeholders of friends, random students around the Colorado School of Mines campus, and frequent hikers were all given the opportunity to test the weight and size of the 3D printed model of the sleeve, during which every one of them agreed that the model was of good quality and comfortable weight.

## Ian Keeffe: Insulation

**3.1.1:**

The overall objective of the insulation subsystem is to find an effective medium for our prototype.

The main output objective of this subsystem is to be able to insulate a water bottle effectively. This will be accomplished with a material with a low thermal conductivity. This material also needs to be very durable so it can withstand abrasion in extreme environments. This sleeve needs to be able to withstand being dragged up rough sharp alpine rock as one of the use cases is alpine climbing. It also needs to be lightweight so that the user can move fast and efficiently through such environments. The sleeve will be exposed to water and snow in such environments and needs to be waterproof. It also needs to be able to withstand high g forces. This means that it must have a high tensile strength. In order to work with other subsystems, it must be extremely easy to sew. It also must be highly malleable and shapeable to a tight bend radius. It also must be stretchy to be able to conform to a slight range of sizes and create a well working interface between the lid and body. Very importantly, it also needs to be easy to use and hold with gloves or mittens on.

In order to accomplish this, I decided on 4 mm Neoprene Fabric. This should meet all criteria. Unfortunately, neoprene is produced mainly from a company called Denka performance rubber, which bought all of the original creator DuPont's factories. Denka does not release much data at all about their Neoprene. Most quantitative data I find online varies immensely and is generally not from reputable sources. However, qualitative data points to neoprene being the optimal material for this application. Initial observations validate many of these criteria. It is obvious that the Neoprene will easily conform to these tight radii. Sewing should be easy because it is easy to push a needle through the material. It feels lightweight, durable, and is stretchy. Testing will be done to verify all these constraints.

**3.1.2**

The Neoprene I settled on is 4mm thick and was bought from Joanne Fabric [46]. The dimensions ordered were 36in by 54 in by 4mm. No other data is given from Joanne's except that it is imported. Other physical properties will be determined after testing.

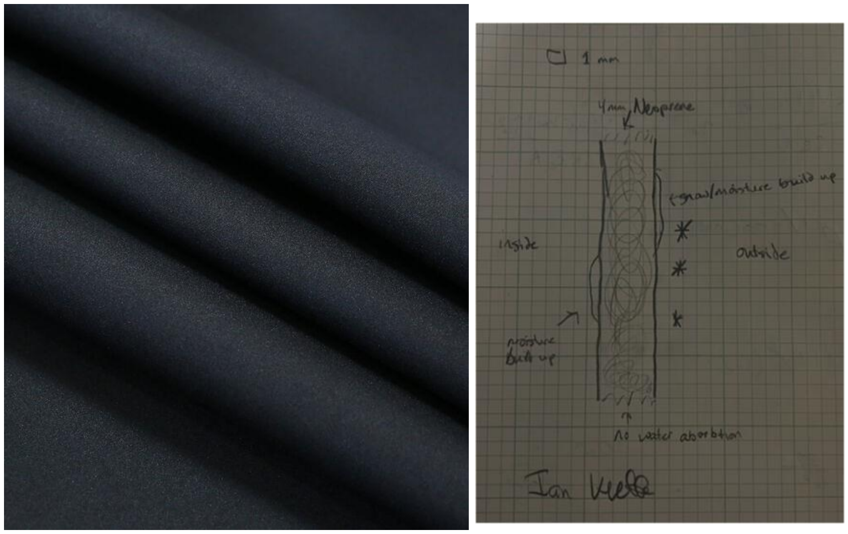



Figure 3.18: 4mm Neoprene

5

**3.2**

Other Materials considered were Primaloft, Thermolite, Polartec, or Reflectix. All these materials failed on account of durability. Primaloft and Thermolite are both synthetic down and therefore not waterproof and would require another layer of waterproof material. Polartec is a fabric that is not waterproof and would also require another layer of waterproof material [47]. Reflectix would not conform to such a tight radius, and would be hard to adhere.

One other design that was considered is a combination of 2 or 4 mm Neoprene with a reflective foil bubble insulation such as Reflectix brand insulation [48] on the inside. This would in theory create a better insulated sleeve.

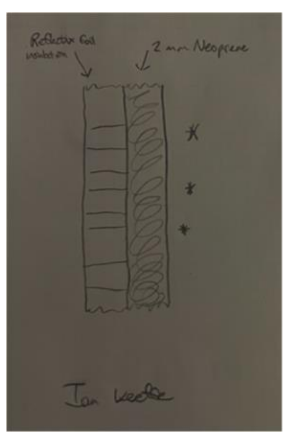



Figure 3.19: 4mm Neoprene and Reflectix

However, I did not pursue this design for many reasons. The first of these was that it would double the cost of the insulation, significantly increasing the cost of the sleeve. The second is that it would not be easy to sew or affix to the neoprene. The third is that it would not easily conform to the tight bend radius of the sleeve. For these reasons, just neoprene was chosen.

**3.3**

Test results

Thermal and tensile strength tests have already been preformed by Hunter Hartley for the fastening and adhesion subsystem.

A durability test was performed. Using 120 grit sandpaper on a 8 inch by 8 inch piece of Neoprene, the Neoprene was slowly worn away until damage was shown. I hypothesized that Neoprene would last around 15 scrapes. After 30 scrapes, the material began to show wear. After 45 scrapes, the material failed, and a hole developed.

The density of our material will be measured by simply measuring the volume and weight. The density was found to be 15 pounds per cubic foot.

The water absorption will be found by measuring the weight of a dry piece of neoprene, and then submerging it for 5 minutes. Then the piece will be removed, and the new weight will be measured. The water absorption (%) will be calculated by:

$$\frac{Final\ Weight}{Inital\ Weight} - 1$$

The water absorption was found to be 5%.

**3.3.1**

You can see that my durability standards were exceeded by Neoprene. 30 scrapes with 120 grit sandpaper before even showing any wear is extremely impressive. More testing has to be done but from my online research Neoprene should prove to be the best choice.

**3.3.2**

Sadly, neoprene specs are extremely limited and impossible to find on the internet. This is why additional testing will need to be performed to fully validate this material. However, other companies have been faced with similar issues of insulation in cold wet environments. Wetsuits have been made from neoprene since their invention. Neoprene works wonders in these situations where something extremely crucial needs to be kept warm in. cold wet environments. Humans stay warm submerged in water temps in the low 50s relying on solely 4mm of neoprene [49]. Its ability to trap in warmth and water and keep out the cold and water is unparalleled. The only reason it is not used more often on humans is the fact that it traps in water so well that we would get way too sweaty.

**3.3.3**

When given a sheet of Neoprene, Tyler Odel said that it felt “grippy”. He thought it would be great material and drops would be unlikely. I then had him feel it with gloves on and his opinion did not change. He also said that it looked durable, “professional”, “like something you would see as a real product”.

## 3.4) Relevant interfaces and how each subsystem works with others.

### 3.4.1 Interface descriptions

The lid geometry subsystem aims to achieve a snug and secure fit between the lid and body of the prototype. This is crucial to provide optimal thermal insulation and protect the contents of the bottle under extreme conditions. Stakeholders have expressed concerns with other thermal sleeve products that only cover the bottom section of the bottle, leaving the top vulnerable to freezing in very cold environments. The lid geometry subsystem addresses this issue by ensuring that the entire bottle is covered and protected from freezing, regardless of the external temperature. This guarantees that the water will remain in its liquid state and readily available for the consumer, no matter the conditions they face.

The dimensions subsystem is responsible for ensuring that the dimensions of each of the other subsystems will combine to create a single model that will fit seamlessly over the water bottle. This subsystem, while descriptively simple, requires a large amount of effort to ensure that all the parts will easily fit together and will create a tight fit. Accuracy and precision are very important in this subsystem, and it is crucial that all the measurements are correct as there is no way to tell if they have done the right calculations until the entire prototype is built.

The fastening and adhesion subsystem is responsible for connecting all the parts together. This subsystem specializes in connection and all the strength tests are limited by how effectively the parts can be connected. This subsystem researches the best way to connect parts and will find the best way to connect our parts. This subsystem is also responsible for the bulk of assembly as most of the other materials will be bought fully and once ordered will only require assembly.

The insulation subsystem is the heart of our design. This subsystem is responsible for finding the best material to design our subsystem out of. This choice is essential as it can be the difference between failing and letting the water freeze or succeeding and keeping the water liquid in extreme cold conditions. They will research many materials and test many materials before ultimately deciding on a material that is the best to fit our decision matrix. The final material needs to primarily be effective and preventing cold but additionally needs to be cheap and easy to assemble.

The handle and latch subsystem is an essential component of a water bottle insulator designed to maintain the temperature of the liquid inside, and it is responsible for ensuring that the bottle is easy to transport and that the contents remain secure. The handle of the bottle insulator is designed to provide a comfortable and convenient grip, allowing users to carry the bottle with ease even while wearing mittens or gloves in cold conditions. Additionally, it is essential that the handle can support the weight of the bottle to prevent any accidents. The latch of the bottle insulator is responsible for keeping the shell of the insulator securely fastened, preventing any unwanted leaks, spills, or loss of heat. The latch mechanism is designed to be easy to open and close, allowing users to access the contents of the bottle quickly and without any hassle. The latch is a critical component of the bottle insulator as it ensures that the bottle remains sealed and insulated, even in the coldest conditions. Overall, the handle and latch subsystem play a vital role in ensuring that the water bottle insulator is both functional and efficient, providing users with a high-quality product that meets their needs.

## 3.4.2 Subsystem Diagram

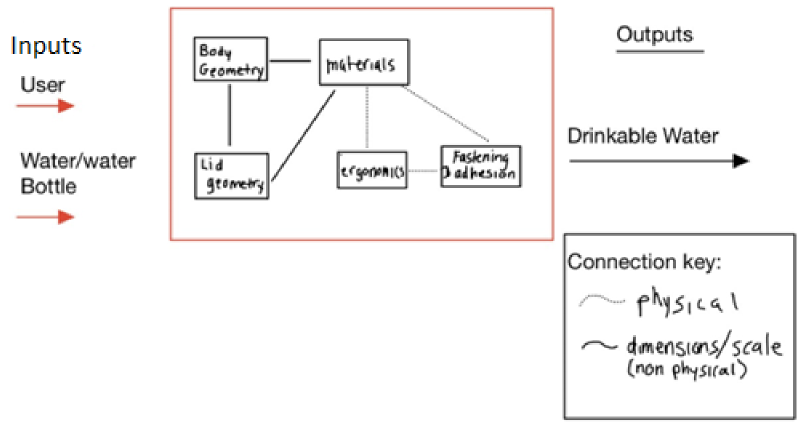



*Figure 3.20: Subsystem Diagram*

## 3.4.3 Key interfaces and exchanges

Each subsystem reacts with each other in order to make a seamless full product. The lid geometry attaches physical with the body geometry. This will surround the water in order to create a close contact barrier to help the water stay liquid. The materials of both the body and lid geometry are marked out by the insulation subsystem. This subsystem finds the idea material to keep liquid insulated and will additionally test the material to make sure that the water will in fact stay liquid at cold temperatures. The handle is attached to the lid geometry and will ensure easy carry for the user. The lid and body are tied together yet again with the buckle. The buckle is what keeps the lid and body fastened together when the user is not drinking water. This ensures that the bottle is tightly attached with the surrounding shell to keep warm inside. Lastly the dimension subsystem ensures that all the sub systems will be the right dimensions to meet the right sized water bottle.

This subsystem has all the measurements and all the necessary specifications to ensure that the water bottle will be functional and portable for the user. The dimensions of the bottle are important as they will dictate how much water the bottle can hold and how easy it will be to store and transport. All these subsystems work together in a coordinated manner to create a high-quality water bottle insulator that is both functional and efficient. By ensuring that each subsystem is optimized for its task, the overall product will be greater than the sum of its parts. The result is a water bottle insulator that is durable, easy to use, and capable of keeping liquids liquid for extended periods of time, making it an ideal choice for anyone who needs to stay hydrated while in cold conditions.

# 4.0) Value Proposition and Risk Report

## 4.1.1) Full-Scale Solution Criteria:

The problem definition our product seeks to solve is "How might we transport water in extreme and difficult conditions?". As a result of this problem outline, the full design system aims to insulate water bottles through the use of an external insulation sleeve that keeps water at its designated temperature for as long as possible. With an original budget of $100 for our prototype, it can be concluded that our prototype is extremely low-cost for the high value that it provides to consumers given that our prototype costs only $2.20 and the mass production projected cost is only $4.55 according to Tables 1 and 2 pictured below. It is critical that our product remains as inexpensive as possible because lowing the costs of production means lowing the costs that we charge customers, which leads to higher sales figures and allows us to compete with more expensive water insulation products such as the popular Hydro Flask, which is listed to cost $32.95 for the same 20oz size. Additionally, since our product is most useful in areas with extreme climate conditions, it is critical that our product remains cheap to sell because those living in areas with extreme climates are typically also those that live in impoverished economic conditions, meaning that if our product was too expensive for low-income consumers, then we would be missing a huge demographic of potential customers. It can easily be seen how the qualitative benefits of our product outweigh the cost for those in extreme conditions, given how difficult it is to transport water over long distances in extreme conditions in our modern times without the water freezing or boiling and evaporating. For those specifically living in the previously mentioned impoverished communities in extreme climates, loss of water to freezing and evaporation can even be a life-threatening daily issue that our product seeks to address at minimal costs.

After creating and presenting our initial prototype during the Works-Like Prototype Presentation, we can conclude that our product successfully solves the aforementioned problem definition, as one test we conducted proved our sleeve successfully insulates interior water after putting two bottles of frozen water under scalding water for 40 seconds, during which it was qualitatively examined that the water-bottle inside our sleeve remained frozen while a regular control water bottle began to melt the ice inside. Despite this, the presentation to the class provided our team valuable feedback proving that our design is not yet perfected, and because of this there are several design changes that our team has decided to include during the production of our final prototype. Firstly, concerns about being able to open the sleeve with thick gloves on were brought up by potential stakeholder Professor Goncalves, which is an important concern to keep in mind considering that our sleeve is specifically intended to be brought into extremely cold environments. To fix this issue with our initial prototype, we will be replacing the buckle that previously opened the sleeve with a Velcro strap that will be easier to use whilst wearing thick gloves. Additionally, with the skills and experience gained from creating the sleeve the first time, we will be able to make our final prototype of the product look overall nicer and more appealing to users by getting rid of unnecessary sewing lines and removing accidental misshaping that could be seen in the first prototype. It is important to ensure the exterior design of the sleeve is as appealing to the eyes of customers as possible, because if users do not like how the product looks, they will not use or purchase the product regardless of how cheap or efficient the product is.

## 4.1.2) Prototype Solution Materials and Costs

| # | Item | Unit | Unit Cost | Qty | Cost @ Qty |
|---|---|---|---|---|---|
| 1 | Clips, Nylon Webbing | per 5 clips, 5 yrds webbing | $1.40 | 1 | $1.40 |
| 2 | Neoprene | 36x58 inchwa | $0.80 | 1 | $0.80 |
| 3 | Thread | 3000yrd | $0.00 | 1 | $0.00 |
| 4 | Needles | 1 needle | $0.00 | 1 | $0.00 |
| 5 | | | | | $0.00 |
| 6 | | | | | $0.00 |
| 7 | | | | | $0.00 |
| 8 | | | | | $0.00 |
| 9 | | | | | $0.00 |
| 10 | | | | | $0.00 |
| 11 | | | | | $0.00 |
| 12 | | | | | $0.00 |
| 13 | | | | | $0.00 |
| 14 | | | | | $0.00 |
| 15 | | | | | $0.00 |
| 16 | | | | | $0.00 |
| 17 | | | | | $0.00 |
| 18 | | | | | $0.00 |
| 19 | | | | | $0.00 |
| | | | | **Total Cost:** | $2.20 |

*Figure 4.1: Prototype material and costs*

### 4.1.3) Projected Costs (per unit)

| Projected Costs | |
|---|---|
| Clips | $0.10 |
| Polypropylene Webbing | $0.20 |
| Labor Cost | $0.80 |
| Thread | $0.02 |
| Sewing Needles | $0.02 |
| Neoprene | $0.02 |
| Velcro | $0.05 |
| **Total Cost: $1.19** | |

| Prototype Spending | |
|---|---|
| Polypropylene Webbing | $1.20 |
| Thread | $0.00 |
| Needles | $0.00 |
| Neoprene | $0.80 |
| Velcro | $0.00 |
| **Total Cost: $2.00** | |

*Figure 4.2: Full Scale Solution Costs*

### 4.1.4) Design Benefits

By designing an insulated covering for water bottles, people will have access to water in any condition they are in. The thermal protection of this "sleeve" allows people in hot or cold conditions to have access to drinkable water so they can stay hydrated. The insulator used is neoprene, which is a light-weight material, this is benefits consumers by allowing easy transport, so they wont feel "weighed down" when carrying the insulator. Additionally, neoprene is flexible, this gives consumers the option to buy any water bottle around 20 oz, so they are not as constrained to one specific brand of water. Another design aspect that benefits users is the buckle; besides attaching the lid to the sleeve, the buckle has an emergency whistle. The whistle buckle is a great idea and may help save someone's life in the case of an emergency. For example, say someone went on a hike and got lost, they can blow the whistle on their water bottle to alert someone in the vicinity that they need help. One of the final design benefits of the water bottle insulator is the nylon straps. Nylon is a very strong material that does not break/rip easily. The strength of the nylon is beneficial for users who may attach the water bottle insulator to their backpack with a carabiner; they will be ensured the water bottle will stay attached to their backpack even if scrapped or dropped, etc. The goal of designing the water bottle insulator is to insure people have access to drinkable water when in extreme conditions. With the lightweight, flexible, durable, and waterproof design of the water bottle isolator, consumers will see the benefits of our product in multiple aspects.

### 4.2.1) Full Scale Solution Risks and Mitigations

To develop a comprehensive and effective solution for a water bottle insulator, thorough consideration of potential risks is crucial. These risks can impact the performance, safety, and overall success of the product. Among the primary risks to be addressed, material selection and compatibility stand out as significant factors.

The materials chosen for the insulator must possess the ability to withstand temperature changes, exposure to moisture, and regular wear and tear without compromising the integrity of the bottle. Material testing and analysis play a vital role in mitigating this risk, ensuring that the selected materials are capable of meeting the required standards for the intended use of the product. To systematically analyze and address risks associated with the product, a risk matrix (as shown in Figure 1) was utilized. This matrix employs two criteria for risk assessment: the likelihood of the risk occurring, ranging from unlikely to very likely, and the impact of the risk, ranging from minor to major. Based on the results of this analysis, risks were categorized into three tiers: low, medium, and high, allowing for a prioritized approach to risk mitigation.

By employing a structured risk assessment methodology, the development process for the water bottle insulator can effectively identify and mitigate potential risks, leading to a safer, more reliable, and higher-performing product. Through comprehensive material testing, analysis, and risk prioritization, the product can be designed to meet the necessary requirements and standards, minimizing potential issues, and ensuring its success in the market.

| Likelihood - what is the chance it will happen? | | | | |
|---|---|---|---|---|
| | Very Likely | Acceptable risk MEDIUM | Unacceptable risk HIGH | Unacceptable risk EXTREME |
| | Likely | Acceptable risk LOW | Acceptable risk MEDIUM | Unacceptable risk HIGH |
| | Unlikely | Acceptable risk LOW | Acceptable risk LOW | Acceptable risk MEDIUM |
| | | Minor | Moderate | Major |
| | | Impact - how serious is the risk? | | |

*Figure 4.3: The decision matrix for risks within our product.*

## 4.2.2) Risk Analysis Matrix/Plan

**Risk Assessment and Mitigation Plan**

| | Risk | Likelihood | X | Impact | = | Magnitude | Mitigation Plan (only for MEDIUM, HIGH, and EXTREME Risks) |
|---|---|---|---|---|---|---|---|
| 1 | Water leaking and Contamination | *Unlikely* | | *Moderate* | | *LOW* | *To reduce impact we will......* |
| 2 | Latch breaks and become a choking hazard | *unlikely* | | *moderate* | | *LOW* | |
| 3 | Neoprene breaks from overuse | *unlikely* | | *moderate* | | *LOW* | |
| 4 | handle breaks off | *Unlikely* | | *Minor* | | *LOW* | |
| 5 | latch stops working | *Unlikely* | | *Moderate* | | *LOW* | |
| 6 | drops the model | *Likely* | | *Minor* | | *LOW* | |
| 7 | Latch freezes shut | *Unlikely* | | *Moderate* | | *LOW* | |
| 8 | water spills inside the containor | *Likely* | | *Minor* | | *LOW* | |
| 9 | Hinge breaks | *Unlikely* | | *Major* | | *MEDIUM* | *Special care will be taken to ensure strong joint from hinge to body* |
| 10 | person buys the wrong waterbottle | *Likely* | | *Minor* | | *LOW* | |
| 11 | Neoprene is cut to the wrong size | *Unlikely* | | *major* | | *MEDIUM* | *Have a subsystem purly just for dimentions* |
| 12 | Someone cuts a whole in neoprene | *Unlikely* | | *Moderate* | | *LOW* | *advise people not to use knifes around the container* |
| 13 | Losing the bottle in the wilderness | *Unlikely* | | *Major* | | *MEDIUM* | *Create an attachable string that they can tie to their backback as an addon* |

*Table 4.4: Risks involved with our product their respective likelihood, impact, magnitude and mitigation plan.*

To mitigate our risks, we are dividing the risks into two separate categories: main model and addons. For a model change, an example is the risk of our hinge breaking. We are planning on double sewing the handle to the shell to ensure that there is no way for it to break off. An example of an addon change would be to fix the risk of losing the bottle in the wilderness. This is not a problem that pertains to our customers as some will not be using them in the wilderness and some are better at keeping track of their bottles. Thus, we can sell an additional cord that attaches to the shell that allows a user to clip it to themselves or their backpack. For any future risk that we encounter we will decide if it is best fixed by changing our core model or adding purchasable additions that are suited to solve a specific problem.

As you can see from our projected cost (Figure 4.2), our product will be extremely cheap to manufacture. Using the same source for neoprene as we used for our prototype, our cost per unit will be 80 cents [50]. Our cost of plastic buckles will cost 5 cents [51]. We will need 4 yards of thread per unit which will cost us 2 cents [52]. If we use one needle per unit our cost will be 2 cents [53]. We will need one foot of webbing per unit which will be 20 cents [54]. If each unit takes 15 minutes to assemble, our labor cost will be $3.41 based off Colorado minimum wage.

We will be able to sell our prototype at an extremely low cost. A 20 oz smart water bottle costs $2.99. If we were to sell our sleeve for $11.99, the user would save about $25.00 buying our product over a Hydro Flask, which is the most common competitor in water bottle insulation. Our product is also easier to transport, lighter, and more durable.

## 5.1) Description of Concept in Real World Environments

The overall concept of the insulated water sleeve is to provide water access to those who are in extreme or harsh conditions. The material of the water sleeve, which is neoprene provides peak thermal insulation for hot and cold environments. For instance, if you put a cold-water bottle in the sleeve, it will keep it cool for a long period of time while under heat, and if you put a room temperature water bottle in sleeve it will not freeze in cold conditions for about 3+ hours. The water sleeve also provides a way to easily transport water in the real world by having the ability to be attached to a harness or belt buckle for those who are on the move and active in their everyday lives. Another important factor of the water sleeve is its water resistibility. For example, say a person went for a walk in the rain or snow, the moisture from the outside environment would not impact the thermal capacity of the sleeve and it will maintain its properties.

Below are some pictures of the prototype:

*Figure 5.0: Prototype*

## 5.1.1) Relevant Isometric Views and CAD Models

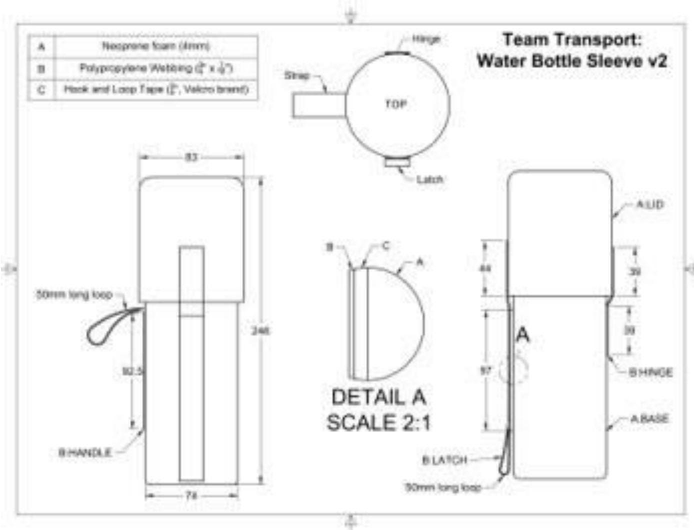



*Figure 5.1 – Version 2 of the sleeve*

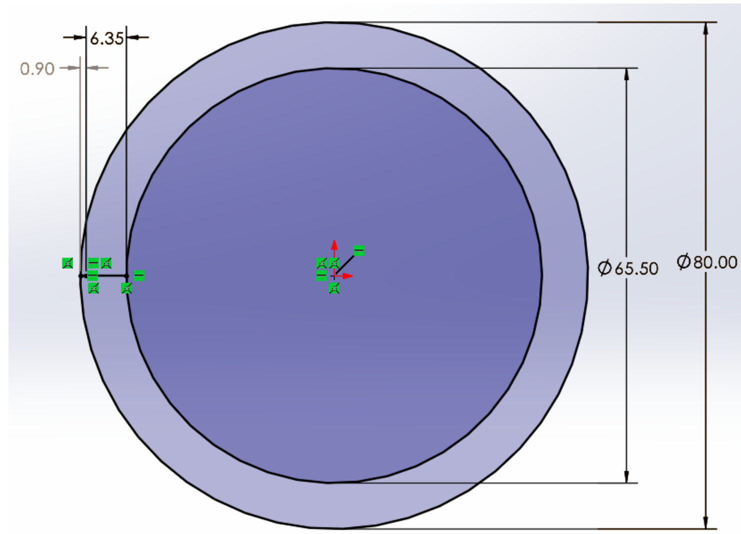



*Figure 5.2 – Version 1 of the sleeve*

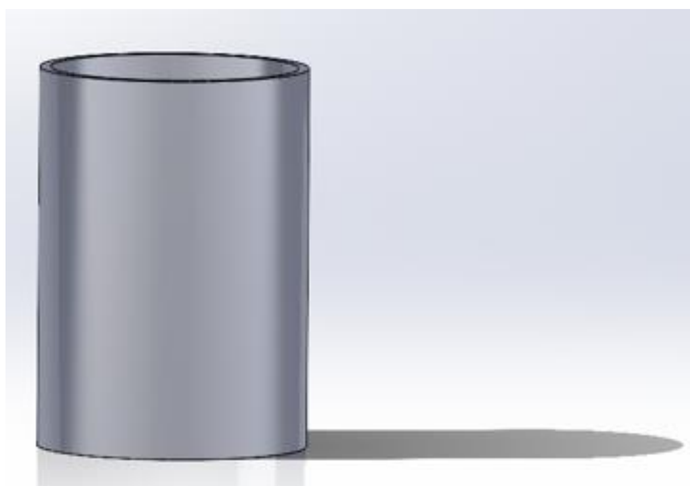
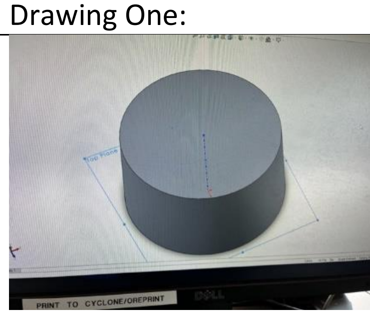
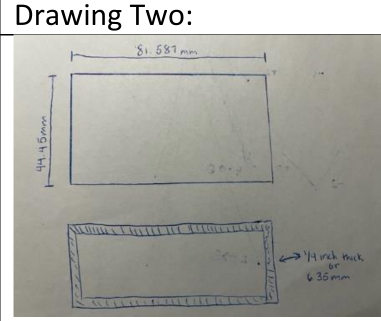


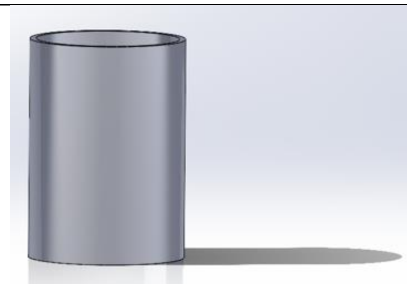
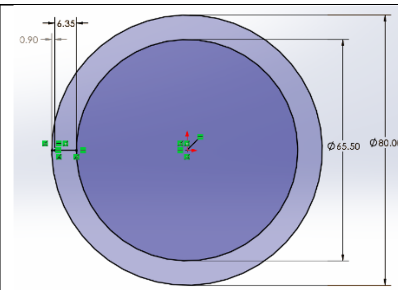
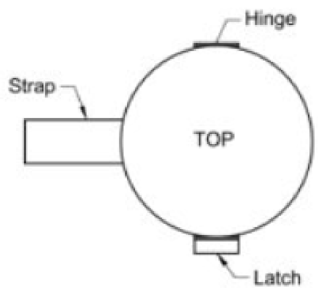
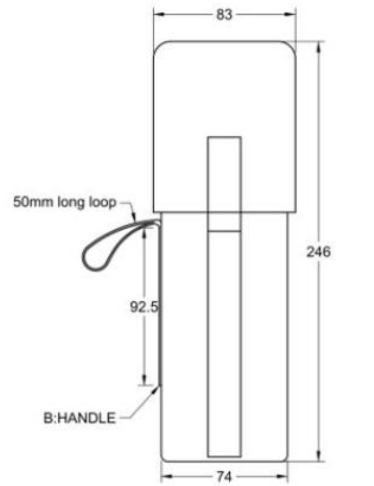
*Figure 5.3*

## 5.2) Overall Concept

In order to ensure that our design is able to effectively meet the problem statement of transporting water in extreme environments, there are many factors that go into the design of our prototype. Firstly, it is critical that our sleeve is created out of highly insulating material to be able to keep the internal water temperature at the desired temperature for as long as possible. After much research and testing, our team concluded that neoprene would be the best product for this solution due to its low cost, comfort of touch, and high insulating properties. Another key factor that went into our design was the ergonomics of our product and making it as convenient to carry as possible to be able to meet the high transportability demands of our stakeholders. To solve these demands, our team specifically designed the sleeve around the common 20oz (about 591.47 ml) water bottle for maximum transportability, as it was the size of water bottle that our stakeholders found to be the most convenient to use. Additionally, we incorporated handles and buckles throughout our bottle to allow it to be clipped onto common travel gear as was a requirement of our stakeholders. Upon request of stakeholder Carlos Goncalves, our design removed the latch mechanism previously used to open the sleeve with a Velcro brand hook and loop strap to allow it to be opened and closed easier with highly insulating gloves, as are commonly used in areas with extreme climates. The final main factor that went into the design of our prototype was keeping the costs low of our materials to allow for a low cost of sale. It is necessary that the costs of production remain low for our product because a major portion of the stakeholders we target our product towards are people who tend to live in extreme climates, which also happen to be those that typically live in impoverished conditions. Therefore, to be able to reach and impact these stakeholders as much as possible, we designed our product to be able to be manufactured and sold at extremely low prices. To account for this demand, we purposefully designed our product to use as little material as possible, which is another reason why we used cheap and highly insulating neoprene as the main material for our design.

### 5.2.1) Relevant Finalized Specifications

| Part | Material: | Drawing One: | Drawing Two: |
|---|---|---|---|
| Lid Piece | Neoprene |  *Figure 5.8* |   *Figure 5.9* |

| | | | |
|---|---|---|---|
| Body Piece | Neoprene | <br>*Figure 5.4* | <br><br>*Figure 5.5* |
| Ergonomics (Strap, Hinge, and Latch) | Strap: 3/4'' Polypropylene Webbing<br><br>Latch: 3/4'' Velcro<br><br>Hinge: Neoprene | <br><br>*Figure 5.6* | <br><br>*Figure 5.7* |

## 5.2.2) Relevant Full-Solution Models, Drawings, and Data

Below is a calculation table measuring the Thermal Time Constant of the design in figure 5.10. This calculation set shows the effectiveness of the insulation sleeve and its ability to keep the temperature of the internal water bottle the same over time. Other figures of this section give relative models and perspective of the design fully put together.

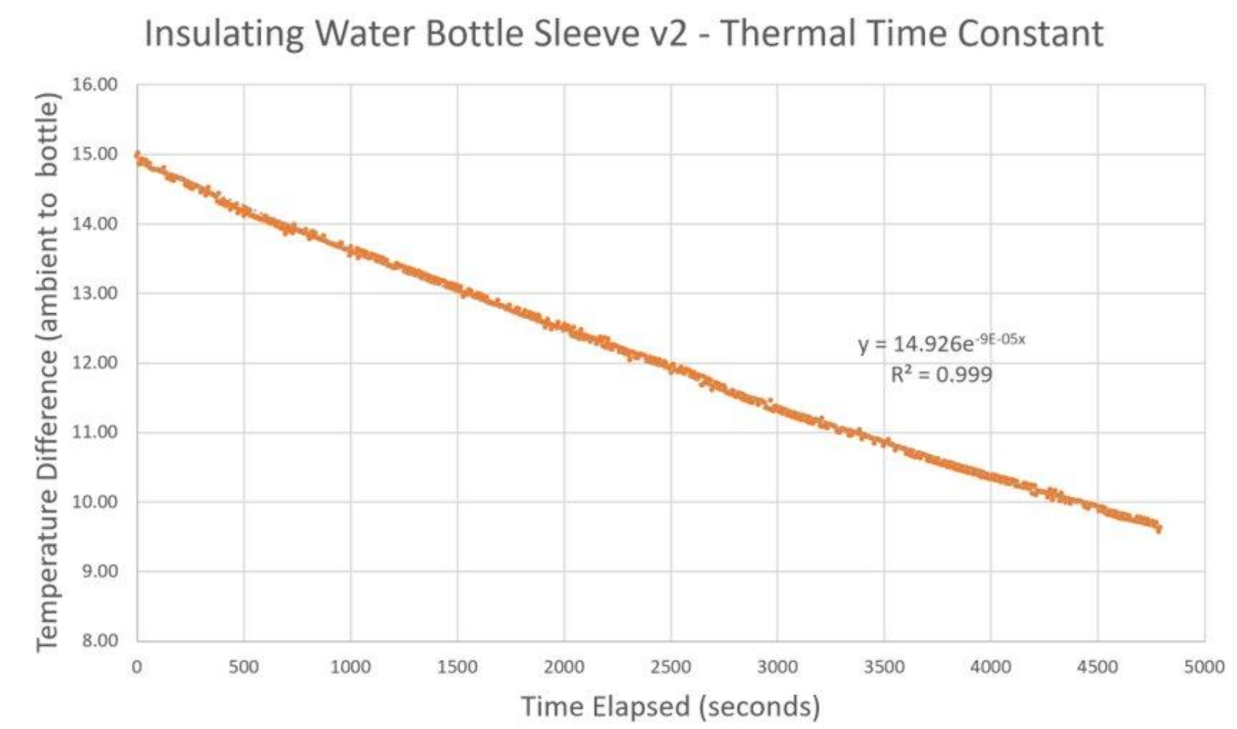



*Figure 5.10*

*Figure 5.11*

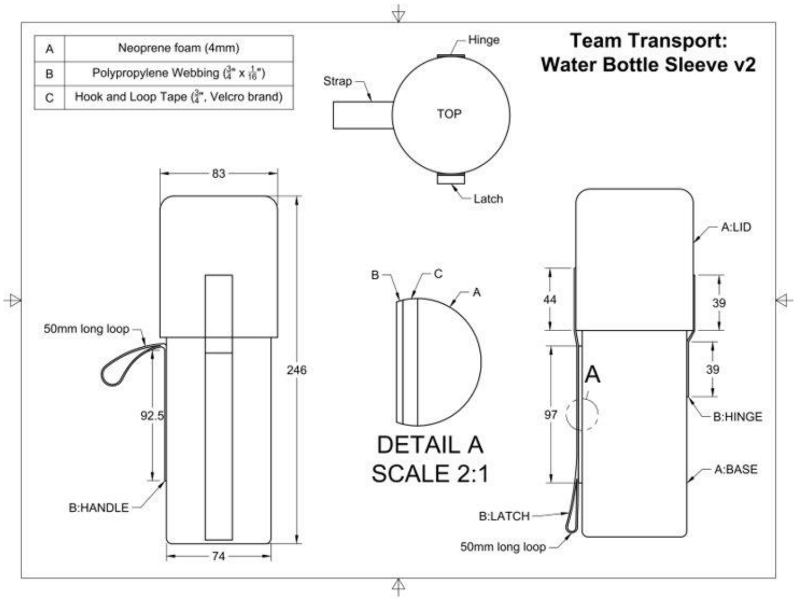



*Figure 5.12*

## 5.2.3) User Interfaces

The main interfaces of our design are the hole of the sleeve and the ergonomic buckle and handle around the sleeve. With the sleeve hole interface, users of our product input 20oz plastic Smart Water water bottles of desired temperature and enjoy their water staying at the desired temperature for long periods of time. Therefore, the output of our product system is water staying at its desired temperature. Regarding the ergonomic interfaces, users can hold onto the handle attached to the sleeve or use the clip to attach the sleeve to other buckles, as are common on traveling gear. A diagram of the product's inputs and outputs are referenced earlier in figure 5.12 below:

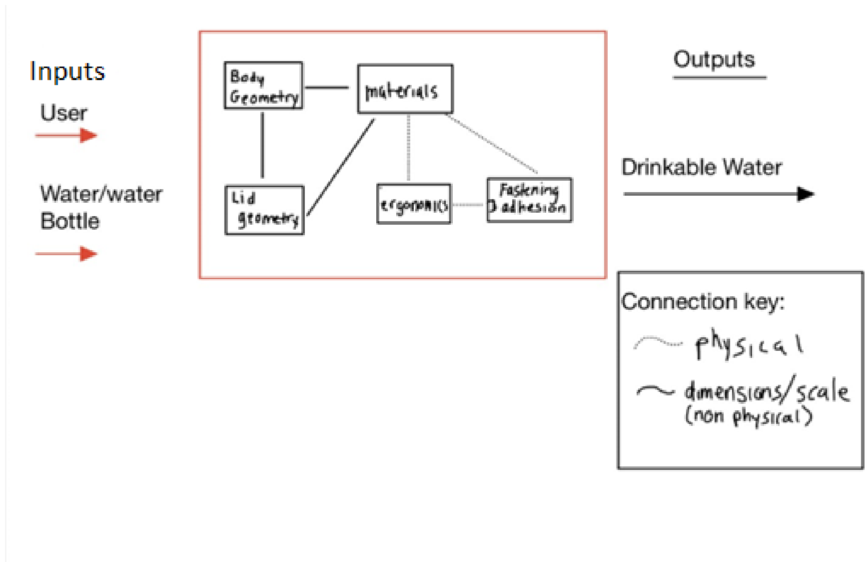

Inputs
User
Water/water Bottle
Body Geometry
materials
Lid geometry
ergonomics
Fastening & adhesion
Outputs
Drinkable Water
Connection key:
physical
dimensions/scale (non physical)

*Figure 5.13*

## 5.3) Concept Validation

### 5.3.1

Certain design decisions made for the final protype we decided by our stakeholder and user engagement inputs. One of the adjustments that we made going forward into the final prototype design was adjustments with the way you open the sleeve. Instead of using a buckle as planned in the original design we found that it was too hard to fasten and unfasten with gloves on, or cold hands. The adjustment or suggestion to switch the buckle to another version of a latch was taken into consideration from an engager. When brainstorming what to use we wanted something durable, easily removable, and something that would sow onto the neoprene in an aesthetically pleasing way. The solution derived was hook and loop tape which is kind of the same material as Velcro. The hook and loop tape provides a durable and easy way to remove and close the lid of the sleeve, and it can withstand extreme conditions. The last modification we made to the final design of the protype were little decorations on the outside of the sleeve to make it more appealing to users/consumers and the latch was customized so that it can be attached to a belt loop, backpack, or harness.

### 5.3.2 Scholarly and Authoritative Research

The projected cost of the sleeve was researched in-depth to verify the market viability of the sleeve. To succeed not just in our technical goals, but in our social and financial goals, the sleeve must be able to reach and appeal to the stakeholders. The results of our cost research verified that the finished prototype would be accessible to all of our stakeholders with a substantial margin for error and profit [Figure 4.2].

An additional concern in a high-yield environment is the continued ability to source the necessary materials for making our sleeves. The most critical material in our construction – the neoprene insulating foam [50] – is a common material used in wetsuit manufacturing among other insulation industries. This common use of our most critical material means that long-term manufacturing and support of the material is more likely than with comparable insulating materials.

### 5.3.3 Testing

When first testing our design, we ran the sleeve under boiling hot water for 45 seconds, the sleeve contained a frozen water bottle inside. Once the 45 seconds was up, the water bottle was removed, and it remained frozen to the core.

A slightly different test was run for the cold trial. The sleeve was put into the freezer for 1 min with a room temperature water bottle placed inside the sleeve. Once the 1 minute was up, the sleeve was removed from the freezer, and we found that the waters temperature had not changed. In a mathematical aspect we calculated the time it would take for a water bottle to start to freeze when the initial temperature of the water bottle was around average room temperature and the temperature outside was -10 degrees. The results showed that it would take a little over 6 hours for the water to start to freeze, and even then, it would slowly start to freeze and not be completely frozen due to the high k-value of insulation that the neoprene provides. The original issue with other forms of isolators like camelbacks is that they freeze in the tubes or with Nalgene's they freeze at the top. With our sleeve and the several tests that have been run, and not a single water bottle has frozen in any of the trials. This just goes to validate and prove that our solution works.

The thermal time constant of the sleeve was evaluated by refrigerating a filled bottle until it reached a low temperature. Thermal time constant refers to the time it takes for the temperature difference from ambient to water to decrease by 60%. The bottle was then removed and placed into the sleeve, where it would warm to room temperature in a fixed-temperature environment. A thermocouple was placed into the water to measure the temperature over time.

### 5.3.4 Analysis and Calculations

The thermal time constant test yielded a series of temperature measurements taken over roughly one hour. The collected data was regressed as exponential decay [Figure 5.10]. The change in temperature of an object with heat capacity in constant environmental temperature is expressed in the form $Te^{-\frac{t}{\tau}}$, where T denotes the initial difference in temperature, t denotes the time that has elapsed, and τ (tau) denotes the thermal time constant of the system. From the exponential regression, the thermal time constant was derived to be 11,000 seconds, or just over 3 hours.

5.3.5 Stakeholder Interviews/Feedback

To improve our prototype, we engaged with stakeholders and requested their thoughts on our first prototype. We received comments on the aesthetics of the prototype – our manufacturing methods were not refined enough to produce a visually appealing prototype. To respond to this feedback, the team continued to practice manufacturing with the materials of interest.

The team also received feedback on the ease of opening and closing the sleeve. The first prototype used a plastic buckle to keep the lid closed. This buckle was rugged and cheap, but stakeholders pointed out that the buckle would be difficult to operate when the user's dexterity was impaired – either by thick gloves or by low temperatures. To respond to this feedback, we switched our latching mechanism to use Velcro brand hook and loop tape. This latching mechanism can be more easily operated by a user with impaired motion and dexterity, while preserving mechanical and cost performance.

## 5.4) Conclusion

In order to solve our problem statement of "how to effectively transport water in extreme environments" the design that was decided on was the insulated water sleeve. This design used four materials, neoprene sleeving, polyester thread, polypropylene webbing, and Velcro brand hook and loop tape. Neoprene is the core of our design, being responsible for the insulation of the water on the inside to keep it from changing temperature. The polyester thread was the binding material we used to shape the material to surround a water bottle. The polypropylene webbing was responsible for the handle of the bottle. Lastly the Velcro brand hook and loop tape was created for the latch for easy opening and closing in extreme conditions.

The final model measured a time constant of three hours meaning that across a length of three hours the temperature will only change by 60% of the difference of inside versus outside temperature. The final cost per unit is $1.19 when mass produced. Additionally, the model only weighs 75 grams before the addition of the water bottle.

Many different people could benefit from the insulated water sleeve. Alpinists, skiers, those who work outside in cold environments are a few examples of users who would use the insulated water sleeve in cold conditions. Impoverished individuals in cold climates could use our model as it is a better and more affordable solution compared to other options such as camelbacks or Hydro Flasks. Additionally, our solution can be used in extreme heat in environments such as deserts and arid biomes. Water that would normally be smoldering hot would instead stay similar to the starting temperature making for a better experience for the user.

Our model is the best way to transport water in extreme conditions because of its extremely cheap cost, ease of transportation due to low weight, strong temperature conservation and simplistic user interface.

## 5.5) Appendix Items

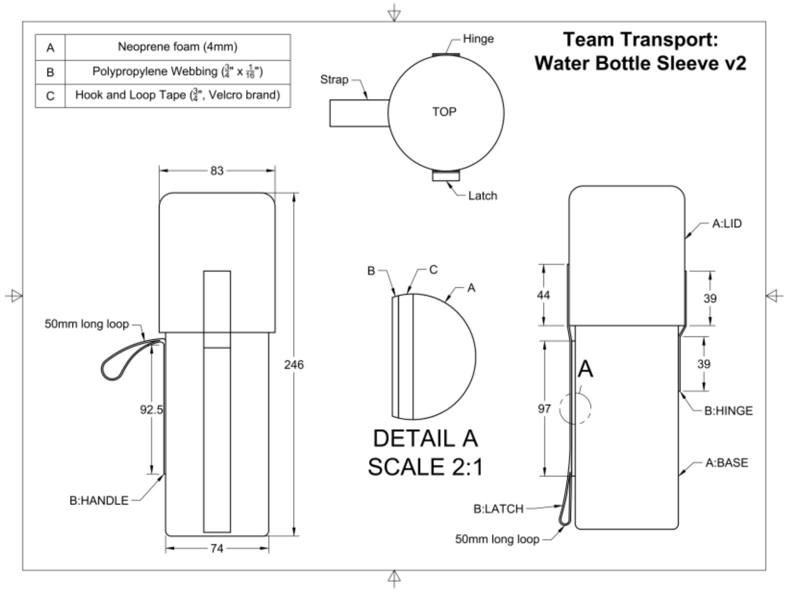



*Figure 5.14*

### About Our Team

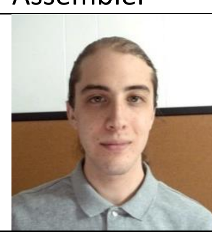
| Ian Keeffe | Jade Davis | Ryan Reiser | Hunter Hartley | Sebastien Accetta |
|---|---|---|---|---|
| Team Leader | Designer | Accountant | Assembler | Researcher |
|  |  |  |  |  |
| Insulation | Lid Geometry | Body Geometry | Sewing and Fastening | Handle and Latch |
| Electrical Engineering | Chemical Engineering | Computer Science | Electrical Engineering | Mechanical Engineering |

*Figure 5.15*

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