Wash Station Redesign for World Farmers

A Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

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Mechanical Engineering

By

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Report Submitted to:

<u>Project Sponsor</u>
World Farmers

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Abstract

The goal of this project was to redesign a wash station for our sponsors, a local agricultural farm called World Farmers. The farm reached out to Worcester Polytechnic Institute seeking a new wash station that would allow for a quicker washing process with less manual labor input. To achieve this goal, our team assessed the problems with the existing wash station at the farm. Based on the findings, we developed our final functional requirements for the new system design. Considering the volume and types of crops harvested at the farm, we created a new wash station design. In the new design, there are three separate sections that are two washing sections and one drying section. Throughout the semester we built and tested the design we created. The performance of the new design was evaluated with experimental trials to ensure user safety. We further examined the risks of the system through conducting calculations and comparing our theoretical values to our experimental findings. Our experimental data allowed us to analyze the system on a quantifiable level to confirm the system is safe. We defined the potential risks within our designs and provided solutions accordingly.

Acknowledgements

We would like to thank the following individuals for their assistance and guidance throughout our project terms. With the unusual project environment due to COVID-19, these individuals guided our team in many ways to ensure the project turned out successfully.

- Advisor, Professor Ahmet Can Sabuncu
- Assistant Director of the World Farmers, Jessy Gill
- Executive Director and Co-Founder of the World Farmers, Maria Moreira

Executive Summary

According to the Centers for Disease Control and Prevention (CDC), roughly 48 million (one in six) Americans get sick, 128,000 are hospitalized, and 3,000 die each year from foodborne diseases (Center of Disease Control and Prevention [CDC], 2018, November 5). While food poisoning may be a common ailment in the United States, most cases are preventable by improving the cleanliness of food; both during the pre- and post-harvesting processes. To aid in the prevention of foodborne illnesses, the United States provides federal guidelines to reduce the spread of pathogens while handling food. These guidelines may vary between states. For instance, the state of Massachusetts has its own set of standards, called Commonwealth Quality Program (CQP).

Our goal was to redesign the existing communal wash station(s) at World Farmers in Lancaster to meet the needs of the client. The client statement specified that they were looking for a redesign with hopes of making the crop washing process faster and less user dependent. Specifically, the new design needed to be suitable to wash about 400 pounds of crops per day while still complying with Massachusetts Commonwealth Quality Program certification standards.

To achieve the goals of the project, our team needed to define the existing problems with the original wash stations. From there, we went on to define, develop, and finalize the functional requirement(s) for our design. Due to COVID-19 restrictions, our team had to rely on photos and measurements provided by our sponsors. Once we received photos of the original setup, we noticed that the farm had used a wood table for crop washing. This is an unsustainable material choice for a wash station, especially considering that the farm washes 400 pounds of vegetables per day. Additionally, the existing station only utilized the triple rinse method where the farmer would submerge vegetables into a water-filled bucket, then transfer the rinsed crops into another water-filled bucket, and then repeat into another bucket. This method uses a lot of water because it must be changed often such as when a new crop is being washed, a different farmer is using the buckets, or the water becomes cloudy. Most importantly, this method is very slow which is what lead the World Farmers to sponsor this Major Qualifying Project (MQP).

It is important to note that the farm has multiple communal wash stations, but due to a limited timeline and budget, we focused on one example. However, we considered for our design elements that could easily be replicated and moved for different shaped or sized spaces.

Throughout our 2-term MQP we were able to design 3 areas to implement at the farm. Area 1 innovates the existing triple rinse system. We used a lazy-Susan bearing plate, large buckets, and a spout to create a triple rinse unit that is easy to drain, refill, and wash multiple crops at once. It is suitable for tuber and other hard walled crops. Area 2 utilizes a sprinkler system to wash leafy crops and other soft crops that would be damaged in the triple rinse solution. The sponsor informed us that the majority of the crops their farmers produce fall into this leafy green category. Therefore, we focused heavily on this area of the project. Area 3 is a designated drying area so that after the crops are washed, they have a set location to dry. We ended up not having excess money in our budget to implement Area 3, but we provided recommendations on the future installation of this area.

Furthermore, before passing on the system to the sponsor we had to conduct experiments. These experiments served not only to validate our design choices, but also to ensure the safety and longevity of the design. For instance, we tested the stress, flow rate, and pressure within the system. These test each quantify that the design is safe and that we have considered steps to mitigate the risks of the project. We also included a set of instructions and a bill of materials to guarantee that the farmers would be able to replicate the design at other wash stations around the farm.

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1.0 Introduction

Our sponsor, World Farmers, is a nonprofit organization located in Lancaster, Massachusetts. Since 1984, World Farmers has provided the space and infrastructure for small immigrant and refugee farmers to get started. Their mission is to "support small farmers in sustainable agricultural production and successful marketing practices to connect culturally relevant product to viable markets" (World Farmers). World Farmers offer mentoring, training, and hands-on assistance when working with each farmer to build the capacity needed to operate individual farming enterprises. They carry out their mission throughout various means, the most prominent initiative being the Flats Mentor Farm Program.

Our goal is to redesign existing communal wash station(s) to meet the needs of the client. A wash station is a unit that is attached to a water supply and provides a stream of water. There are many different types of wash station with variety of purposes. We see wash stations in the form of sinks for handwashing in a restroom or in a kitchen for cleaning dishes or food. We also see wash stations for sanitizing medical devices or laboratory equipment in hospitals and laboratory spaces. As we see with our project, wash stations are present in the agricultural industry and is utilized to cleanse crops and produce for human consumption. On farms, people utilize wash stations to remove visible debris, bacteria, and other pathogens from the surface of produce, to prevent food poisoning.

The client statement specified that they were looking for a redesign of their existing wash stations with hopes of making the crop washing process less user dependent. Most importantly, the new design needed to be suitable to wash about 400 pounds of crops per day by CQP (Commonwealth Quality Program) certification standards. We wanted to incorporate multiple sections to thoroughly wash and dry different types of crops such as tubulars, fruiting vegetables, and greens. Having these distinct sections would allow the user to streamline the crop washing process because multiple farmers could use the station at the same time or various crops could be washed simultaneously. Currently the wash station uses the triple rinse method where there are three different buckets that farmers must use to wash their crops. Ideally, we would to be able to add another section that is less user dependent, similar to a sprinkler system. We would also like to incorporate a drying rack in the overall wash station area. Finally, we would want to power our system by the generators already existing on the farm or by solar energy.

It is important to acknowledge the unusual circumstances surrounding our project terms. Due to COVID-19, travel to project sites was limited by WPI. At the beginning of the semester, we applied to visit the farm so that we could get an idea of the space and see the current set up and test the existing system. However, because of heightened restrictions enforced later in the semester we were ultimately unable to see the site in person. Therefore, we had to rely on communication with the sponsors to obtain information about the location, setup, and measurements.

Based on photos and early conversations with our sponsor, we learned that the existing wash stations have slightly different set ups, dimensions, and layouts of the space. While brainstorming our designs we needed to account for each space being different and think of solutions that can be scaled up or down and modifications that can easily be made to accommodate each space. We also needed to think about the layouts of different stations and create designs that could be incorporated in other areas.

2.0 Background

2.1 Agricultural Standards for Wash Stations

Initially, we wanted the wash station to be compliant with both the United States Department of Agriculture's (USDA) and the Food and Drug Administration's (FDA) guidelines for safe crop washing practices. However, upon further research we discovered that the FDA does not have a strict set of guidelines on how to wash crops on a farm. We did some background research on the national and state level to compare codes. At the national level, the standards are set by Good Agricultural Practices (GAP) and vary within different states. For the state of Massachusetts, our wash station should meet Commonwealth Quality Program (CQP) certification standards (Mass.Gov).

2.11 Federal Standards (Good Agricultural Practices)

According to the Centers for Disease Control and Prevention (CDC), in America roughly 48 million (one in six) people get sick, 128,000 are hospitalized, and 3,000 die each year from foodborne diseases ("Burden of Foodborne Illness: Findings"). Foodborne illnesses are caused by consuming food that has been contaminated by pathogens. There are many different types of foodborne illness since there are many different types of pathogens such as norovirus, salmonella, and E. coli to name a few. While food poisoning is a common ailment in the United States, most cases are preventable by enhancing the cleanliness of food, during both the pre- and post-harvesting processes.

To aid in the prevention of foodborne illnesses, the United States provides federal guidelines to reduce the spread of pathogens while handling food. These guidelines may vary between states since some states, like Massachusetts, have their own set of more specific standards.

There are several departments that help to reduce the spread of foodborne illnesses and set standards at the federal stage. The United States Department of Agriculture (USDA) manages industries including farming, forestry, and ranching. This department also regulates the aspects of quality, safety, and labeling for foods. The Food Safety and Inspection Service (FSIS) offers examinations on meat, poultry, and egg products, but since World Farmers' farm is not being used for livestock, we are not concerned with the FSIS guidelines. Alternatively, we are interested in the United States Food and Drug Administration (FDA) which provides safety guidelines for fruits and vegetables.

In 2011, the Food Safety Modernization Act (FSMA) was signed by former President Barack Obama to shift the agricultural industry's focus from responding to foodborne illness to preventing them (Food and Drug Administration, 2017). The FSMA gave the FDA new authority to supervise and regulate the methods practiced for crop farming, harvesting, and processing. For the FSMA implementation, the FDA established the final rules and regulations explaining the standards for all procedures including growing, harvesting, packaging, and storing of produce for human consumption.

In the final guidelines, the FDA established two major criteria for agricultural water quality (Food and Drug Administration, n.d.) According to the rules and regulations, agricultural water used for washing hands during and after harvest, cleaning food-contact surfaces, and crop washing produces must have no detectable traces of generic Escherichia coli (E. coli) pathogens. If there is any generic E. coli is detected during the water quality testing, then the usage of the water must be discontinued immediately. Before resuming use of the previously contaminated water, corrective measurements must be enforced. The FDA establishes quantitative criteria for agricultural water by measuring E. coli with colony-forming units (CFU).

As described in *Hayes' Handbook of Pesticide Toxicology*, a CFU is a visible population of cells that forms on a growth medium (Doull). The CFUs tell us if the water is clean or not at the microbial level. To determine the number of individual colonies of the microorganism, in our case E. coli, that grow on a plate of media is the CFU (Doull). The CFU is crucial in the evaluation of water quality because the CFU value represents the number of bacterial capable of replicating, meaning the bacteria that have created colonies on the plate. This standard for agricultural water is based on two numerical standards: geometric mean (GM), and statistical threshold (STV). The geometric mean represents the average amount of generic E.coli in a water source and STV indicates the amount of variability with the water quality. To meet the FDA set standards, the GM of a sample must be less than 126 CFU, and the STV should be less than 410 CFU of generic E.coli per 100 milliliters of water.

2.12 State Standards (Commonwealth Quality Program)

In addition to standards set forth by the federal government, state governments have also established their own policies and programs regarding agricultural practices to guarantee the safety of crops for human consumption. Though the state regulations follow the federal guidelines, they include some modified features depending on the different conditions for each state. Getting a farm certified by their state's standards is also often more affordable than getting the federal GAP certification. By having statewide regulations, farmers can have flexibility for their farming practices while ensuring food safety and quality for consumers.

Farms have the choice to abide by either federal or state set standards for washing their crops. Our client wanted to maintain CQP certification since the guidelines are very similar, but certification is more cost effective. The Commonwealth Quality Program was founded by the Massachusetts Department of Agricultural Resources (MDAR). The program follows the most of federal government's suggested guidelines for agricultural practices for consumers' safety. Any farm in Massachusetts can apply for the CQP and if approved, the certification can be used as proof to their customers that the farm is following proper safety precautions for their produce as defined by the state. To receive CQP certification, the farm must apply to the program and are subjected to an audit conducted by government officials from organizations such as MDAR and USDA.

As an establisher of the program, MDAR provides the compliance criteria for the CQP and inspections under the Produce Safety Rule (PSR) of the Food Safety Modernization Act. According to the guidelines, there are six categories considered which are Food Safety Plan(s), Training/Worker Hygiene/Health, Soil Amendments, Animal Activity, Agricultural Water, and Harvest and Post-Harvest activities. Each category contains a checklist of the requirements with the corresponding criteria, allowing the inspection process to go smoothly and accurately.

Since World Farmers currently holds CQP certification, we needed to uphold these standards with the newly redesigned wash station. Our team needed to familiarize ourselves on CQP requirements, especially the compliance criteria relating to the washing process for harvested produce. According to Section 5 of the Commonwealth Quality Program/Massachusetts Good Agricultural Practices' safety checklist (see Appendix A), there are no specific requirements for the manner in which crops are washed. However, any water that the crops will interact with must comply with the guidelines, this includes bodies of water near the crops while they grow and the water they are washed with. All water used on and around produce must be free of generic E. coli, which poses a great threat of foodborne illness to the public. According to the requirements, "any water used for post-harvest activities that comes into direct contact with produce, food contact surfaces, or is used for handwashing must be free of generic E.coli (0 CFU per 100ml)"

(Massachusetts Department of Agricultural Resources [MDAR], 2020). To verify the quality and safety of the water used at the farm, regular water tests should be conducted by the water testing facilities that are approved by the MDAR Produce Safety Program. In terms of frequency for water testing, MDAR recommends farmers to space out tests from pre-season, early season, mid-season, and late season to obtain a wide sample of water quality.

2.2 Washing Techniques

The inclusion of better agricultural practices is essential to improve sustainability, productivity, and food security (Obeyelu et al., 2016). As a crop seller, farmers are responsible to provide safe and qualified produce to their customers. To meet the various standards developed by the federal and state government for ensuring the quality of crops, crop sellers have adopted variety of techniques for their agricultural practices. For instance, farmers should provide clean produce to fulfill their customer's expectations. In order to satisfy this need, there are several different types of washing procedures farmed use. Based on a study from the University of Vermont (Blevins & Grubinger, 2012), most common washing methods are using a rinse system with one to three rinses, adding sanitizer into wash water, and a combination of the first two methods.

The first method uses a rinse system with anywhere from one to three rinses cycles. This is also called single, double, or triple wash system, respectively depending on the number of rinses. As previously mentioned, the World Farmers are currently washing all their crops using the triple rinse technique. The rinse method is simple because it only calls for clean water to wash the crops as well as vessel to clean the crops, whether it be a washing machine or the farmers selling the crops. Alternatively, farmers can add a specific, food-safe sanitizer into the wash water. This second method has the benefit of a more efficient clean in less time but has the drawback of being more expensive due to the cost of sanitizer. Furthermore, crop producers could wash with a combination of method one and two by add sanitizer into their wash water and utilize a single, double, or triple wash system.

Each washing method has a different level of effectiveness in terms of reducing visible debris and other contaminants from the surface of the produce. According to the research from the University of Vermont, a single rinse with full dose of sanitizer (SaniDate 5.0) was reported to be the most effective washing method, reducing 99.8% of E.coli and dirt from food surfaces (Blevins & Grubinger). However, the triple rinse method without applying sanitizer reduces 96.9% of contaminants. Since the effectiveness of applying sanitizer to wash water was not drastically changed and the farmers are familiar with the process they are currently using, we decided to not include sanitizer in our new design. By not adding a sanitizer to the routine, we avoid the learning curb of everyone having to start adding sanitizer to their washes and save the farm money.

3.0 Design

We must note that there are multiple communal wash stations on the farm. However, with a time frame of 15 weeks and a budget of $500, we needed to focus on one wash station to innovate. This fact took a role in our design process though, as we wanted our designs to be replicable for future implementation at other wash stations. Additionally, having designs with easy-to-follow instructions (see Appendix D and E) allowed for easier maintenance. By understanding the construction of the systems, it is easier to disassemble elements for cleaning or replacement if something were to break. Even with our limited budget and time, we wanted to create a project that will last and considers the future applications.

3.1 Existing Problems

In order to start the redesign process, our team needed to define the existing problems with the original wash stations. From there we went on to define, develop, and finalize the functional requirement(s) for our design and installed the system. While there are multiple wash stations on the farm, due to limited time and budget we focused our efforts on one of the wash stations and aimed to create a design that could easily be replicated and scaled to fit different shapes and sizes.

Figure 1 shows the existing wash station we focused on. As seen in Figure 1, each 275-gallon water tank sits on three wooden pallets on opposite ends of the wooden table. Furthermore, we had to keep in mind that the sponsors planned to replace the tent with a permanent roof-like structure.

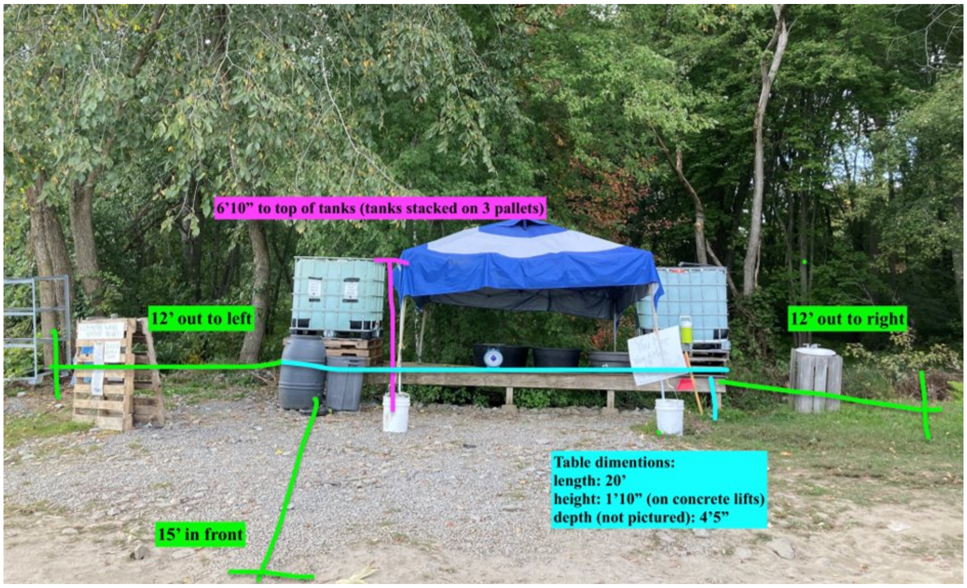

Figure 1. Wash Station Layout 1 Provided by World Farmers

After receiving photos of the existing setup, we soon noticed that wood is unusual material choice for a wash station, especially considering that the farm washes 400 pounds of crops per day. The crops are washed via the triple rinse method using three plastic buckets on top of the wooden table. Given that the table is constantly exposed to water, it is prone to rotting. A material such as metal or plastic would be more durable for this application and would save money over time as opposed to replacing rotting wood.

Additionally, the existing station only utilized the triple rinse method. As detailed earlier, the triple rinse method requires the water to be dumped in between crops, after each farmer, and when the water becomes murky. Therefore, we wanted to streamline the process so that crops can be washed faster while still maintaining the same quality of cleanliness.

As shown in Figure 1, the World Farmers had quite a large space for us to create our design. However, not all their wash stations are as open and laid out. For instance, while an assembly line structure might be a good fit for the wash station shown in Figure 1, it would not be a good fit for the one in Figure 2. Therefore, we made each of the three main areas of our design unattached from one another to allow for different configurations to tailor and fit in any space.

Figure 2. Panoramic View of Wash Station Layout 2 Provided by World Farmers

3.2 Functional Goals

Based on the flaws with the current wash stations and discussion with the sponsors, our team identified the final functionality requirements for the new system. To solve the existing problems, the new design must follow these criteria:

1. Meet Commonwealth Quality Program (CQP) standards relating to washing crops post-harvest
2. Be less user dependent
3. Clean dirt from crop surfaces
4. Expedite the washing process

3.3 Proposed Design

To ensure the highest performance of the wash station, there are three sections in the proposed design. Based on discussions with the sponsor and the sponsor's website, World Farmers produces mostly two types of crops: root/tuber and leafy greens. While not every crop grown at the farms fits into either of these technical categories, for our design purposes, we generalized crops into these two groupings. Examples of root/tuber crops include carrots, potatoes, radishes, and more. Leafy greens are crops such as kale, lettuce, and spinach. Applying the same expedited washing technique would not be the most efficient considering the vastly different shapes and strengths of the crops. For instance, the updated triple rinse solution we designed is well-suited for tubers or crops such as pumpkins and eggplants. However, the technique can cause damages on leafy greens or a tomato since these types of crops have softer, delicate surfaces. To combat this issue, our team utilized two washing sections in our design to accommodate both tubers and leafy greens.

3.31 Area 1: Triple Rinse Station

Based on information provided by our sponsor, the World Farmers wash about 400 pounds of crops daily. To wash the huge quantity of crops, the farmers have used the triple washing method; manually dunking crops into three separate buckets full of water. Farmers then transferring the crops to a different place for drying. This process requires a lot of time, physical labor, and water. As previously stated, the water must be changed in between crops and farmers as well as when the water becomes too turbid. Furthermore, the act of replacing the water requires even more time and energy from the farmers.

To expedite the washing process for tubulars, and other durable crops, our team wanted to implement strainers into the washing buckets as shown in the figures below.

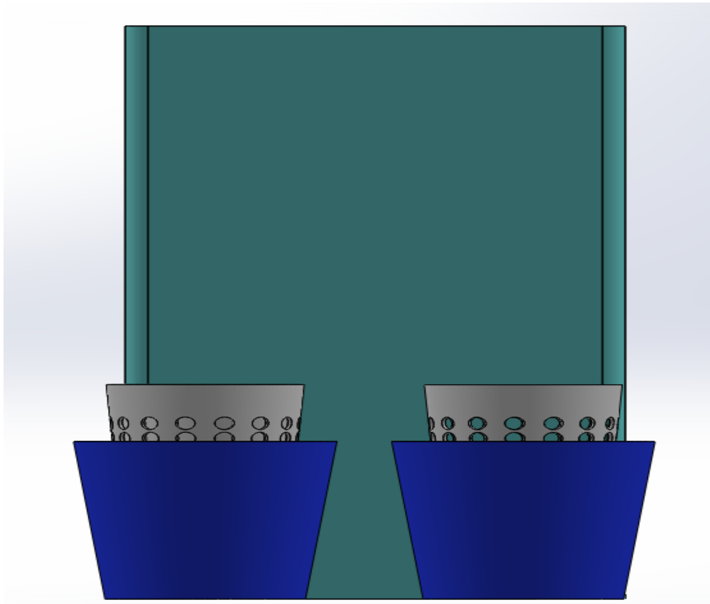

Figure 3. Area 1 – CAD Model [Front View]

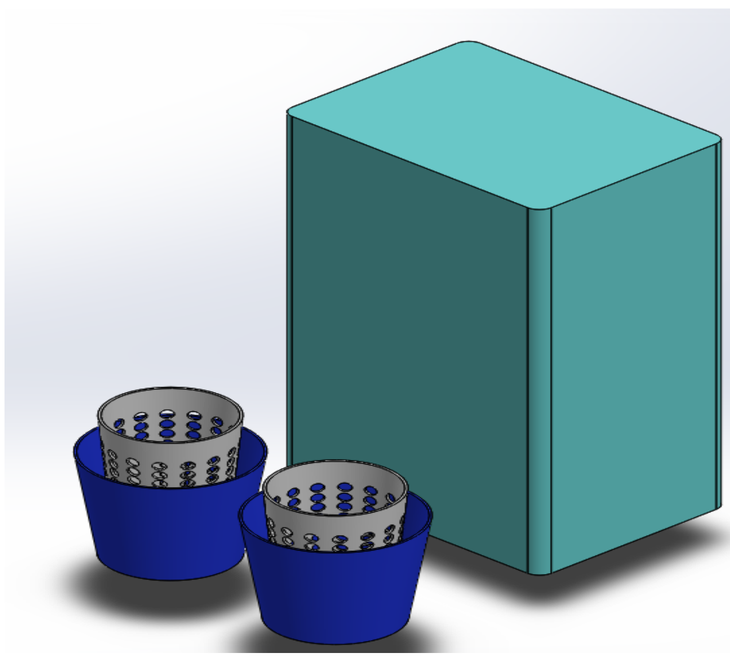

Figure 4. Area 1 – CAD Model [Isometric View]

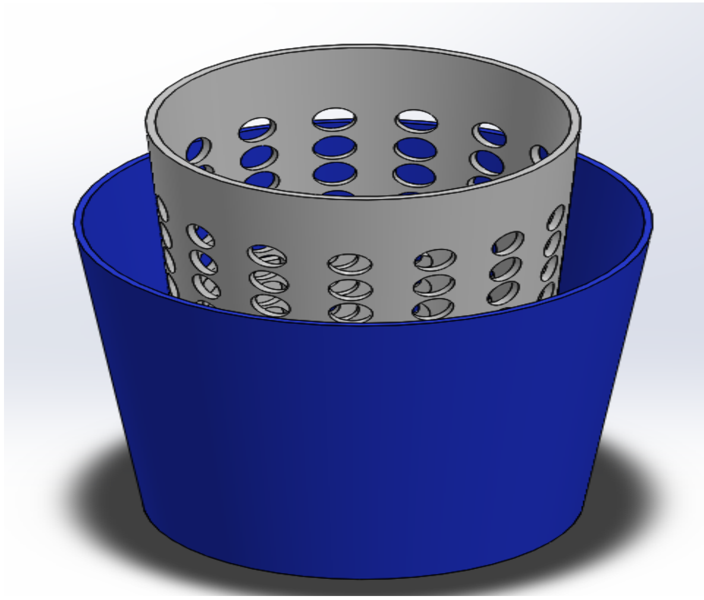

Figure 5. Area 1 – Bucket with a strainer and bearing plate [Isometric View]

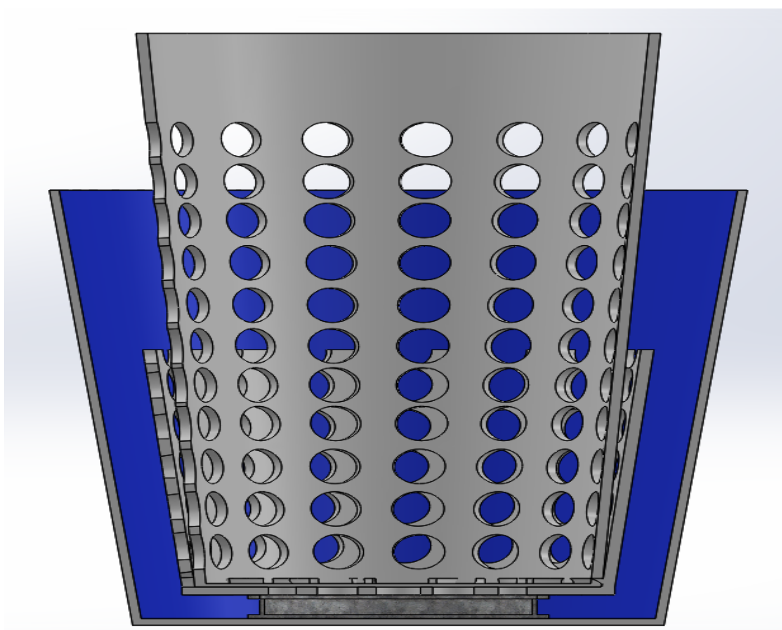

Figure 6. Area 1 – Bucket with a strainer and bearing plate [Section View]

Figure 7. Lazy Susan Turntable Hardware

We thought this would expedite the process mainly because of the strainer system shown in Figure 6. Figure 7 illustrates a Lazy Susan turntable which attaches the shorter strainer to the external blue bucket. The Lazy Susan hardware (see Figure 7) consists of two plates connected by a large ball bearing that allows it to swivel smoothly, even when submerged. One plate is fixed to the blue bucket and the other plate is attached to the short strainer (see Appendix D for further assembly instructions). The taller strainer, which is removable, would then be filled with crops and nest in the shorter strainer. The farmer would then spin the taller strainer in order to rinse the debris from the crops. Once the first rise is complete, the farmer would then transfer the taller strainer into another water filled bucket and repeat the process for the second and move to another blue bucket for the third rinse. The tall strainer can then be removed from the water buckets to be relocated for drying quicker. This design would save the farmers time because instead of conducting the triple rinse on each individual vegetable, they can wash a basket full at the same time.

3.32 Area 2: Sprinkler Station

Area 2 was designed as a wash station for leafy greens and other delicate crops. Considering the thin and fragile nature of the crops, our team determined that triple rinse method might be too aggressive and leave bruises or tears on the crops. For this reason, our team included a sprinkler section, which can gently distribute water onto the crops to remove dirt from the surface.

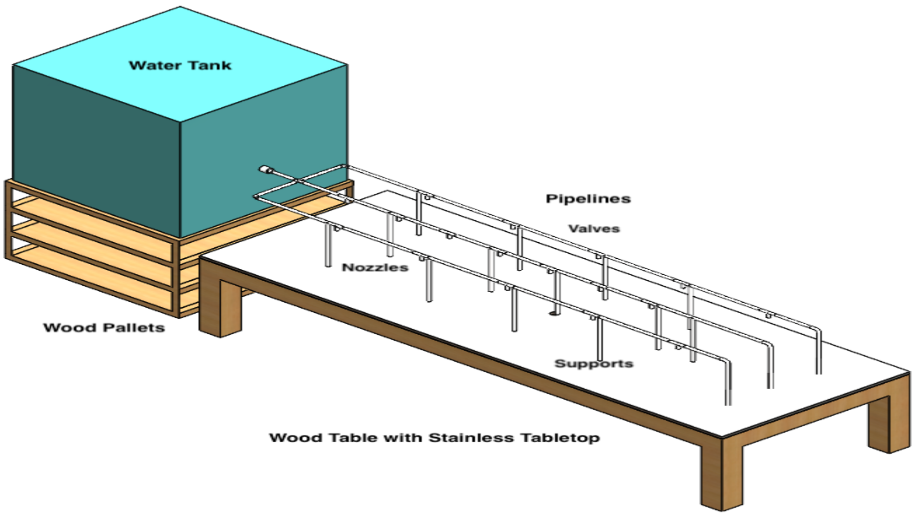

Figure 8. Area 2 [Isometric View] – In this schematic the pump is not shown for brevity

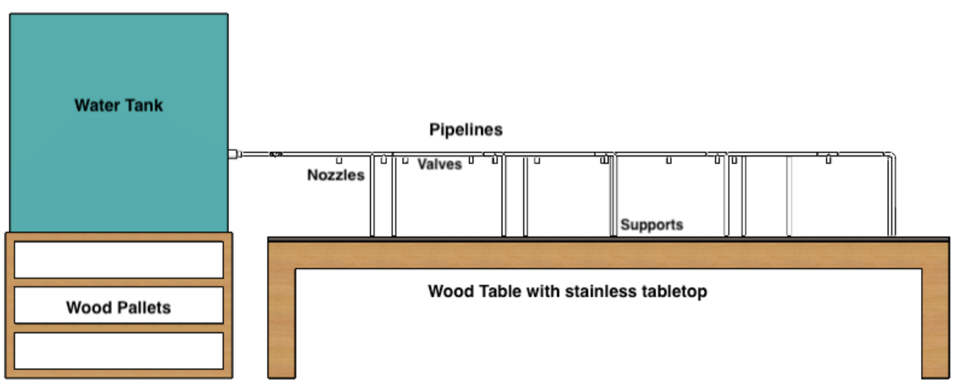

Figure 9. Area 2 [Front View] – In this schematic the pump is not shown for brevity

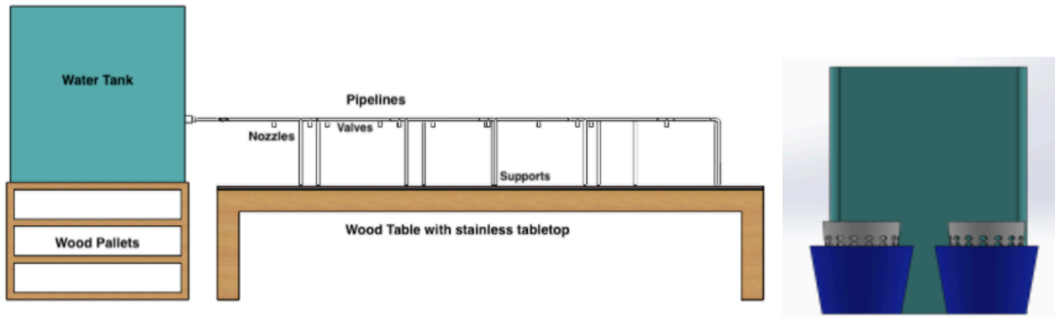

Figure 10. Area 1 and 2 [Front View] – In this schematic the pump is not shown for brevity

Our team created a design with 20 feet of polyvinyl chloride (PVC) piping with spray nozzles placed intermittently to get good water coverage. Based off the dimensions provided in Figure 1, the wooden table is 20 feet long and we wanted the sprinklers to span the entire length of the table so that many farmers could wash their crops simultaneously. The entire piping system would attach to the 275-gallon water tank currently existing on the farm. We would implement supports using the excess PVC material we purchased. We plan to tie or clip the supports in place until the permanent roof is installed. The PVC tubing itself shows signs of stress due to the length and the mass of the pipes, but the system experiences more sagging and deformation when the water runs through the system. Since PVC is a flexible material with high yield strength, we were not concerned about the tubing breaking, but given the length of the system we needed supports (see Figure 29, the deflection diagram). Furthermore, the planned support is temporary since once World Farmers upgrades the tent, the sprinkler system would then be secured to the roof.

As Figure 8 shows, Area 2 has three separate pipelines with different numbers of spray nozzles connected. To maximize the water coverage over the crops, our team aimed to have overlapping areas from the spray nozzles. To find proper locations of the nozzles, our team conducted basic calculations using Pythagorean theorem with the given specifications of the nozzles provided by the supplier's website (Dripdepot.com).

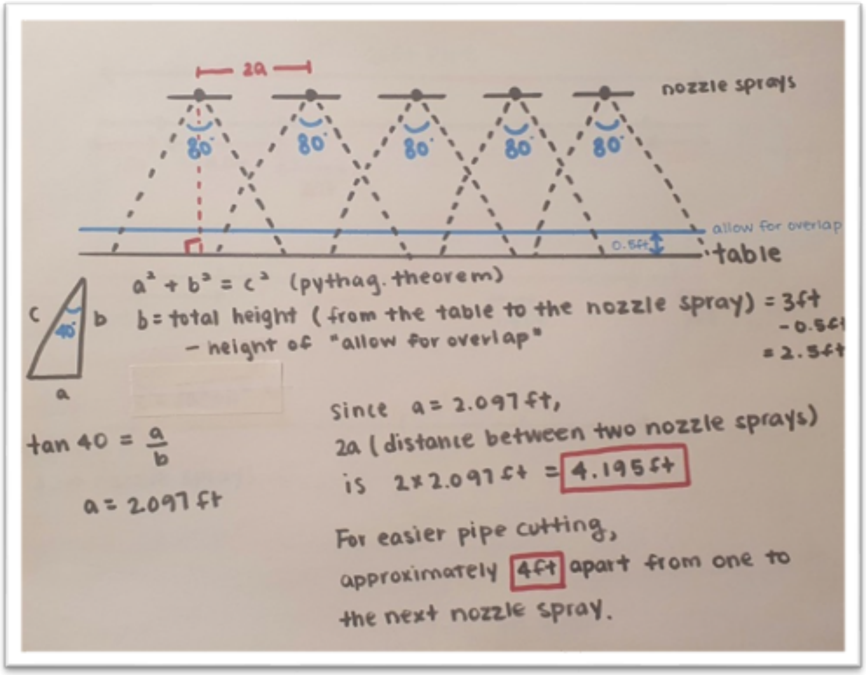

Figure 11. Nozzle spray distance calculation

In the calculations, the spray angle of the nozzle and the height between tabletop to the nozzle are known values based on what the nozzle manufacture's website provided and how high we wanted our system. With the given specifications, we found that the space between each nozzle spray should be approximately 4.2 feet. However, our team decided to use 4-foot sections of PVC pipe between nozzles for ease during pipe cutting. We also had to take into account that the T-connectors that the nozzles sit in add a few inches to the system.

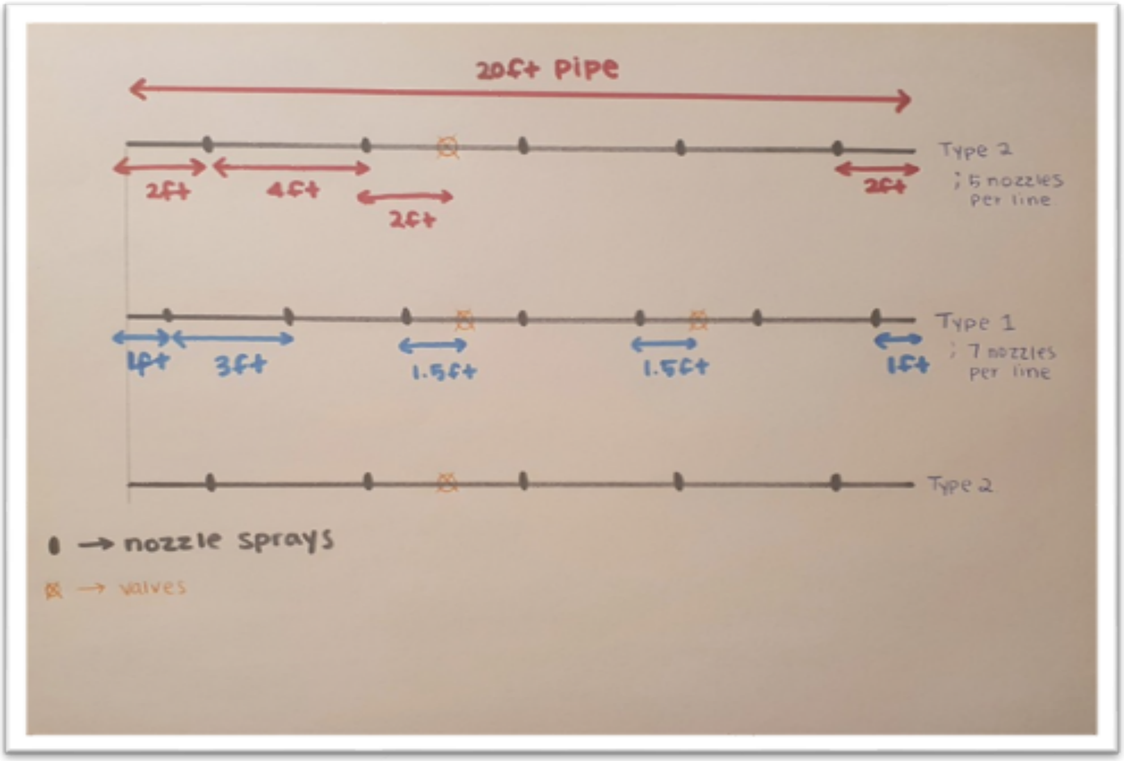

Figure 12. Number of nozzles and valve placement for each pipeline

Additionally, each pipeline contains one or two ball valves to divide sections and prevent excessive water usage. This way multiple farmers can wash their crops at once; or if only one farmer is using the sprinklers, then the valves can be closed off to save water. As Figure 12 shows, there are two types of nozzle configurations: Type 1 and Type 2. For the center pipeline, Type 1 configuration is applied, including seven nozzles and two ball valves. For the Type 1, our team started the placing the nozzles 1 foot in from each end and subsequently for every 3 feet. Valves are located after the third and fifth nozzles. By installing these two valves, the center pipeline has three sections, allowing the farmers to turn on and off valves depending on the quantity of crops to wash. Compared to Type 1, the Type 2 configuration has five nozzles and one ball valve, between the second and third nozzles. In the Type 2 layout, the first and fifth nozzles are located 2 feet apart from each end.

For successful water distribution throughout the spray nozzles, our team had to choose between a gravity fed system or a pump. The gravity fed system would require the tank to be placed above the sprinklers in order to utilize the head loss from the tank to the water outlet. The pump would require us to complete a set of calculations to ensure we buy the correct pump size.

We decided against the gravity fed system for a few reasons. One concern was safety, we did not want to risk the water tank falling and hurting someone, breaking, or damaging the sprinkler set up. Another concern was pressure; through testing we found that gravity did not provide enough pressure for the nozzles to spray water. Thus, we went through with calculations to determine the power and pressure of the pump we would need in Area 2.

First, we needed to find the total pressure loss in the system due to the pipe's resistance and fittings. Figure 13 below is a simplified diagram of the proposed design, showing the configuration of the nozzles, valves, a pump, and a water tank.

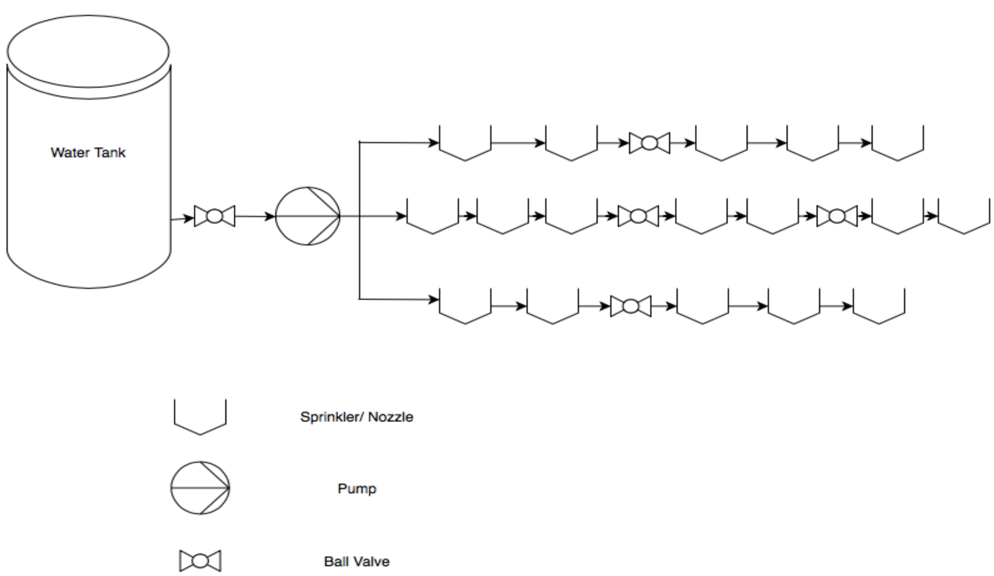

Figure 13. Pump and Instrumentation Diagram (P&ID) of the proposed design

**The figure is created by using the website https://online.visual-paradigm.com*

For the head loss calculation, we had to make a few assumptions. We assumed that there would be the biggest head loss for the two outermost pipelines (Type 2) due to a greater distance from the water source to the first nozzle in the pipeline. Thus, we conducted the head loss calculation only for the one of Type 2 configuration. We also divided one Type 2 pipeline into three parts for an accurate prediction of the proposed model. We must consider in our calculations the fact that Parts 1-3 have different fixtures and lengths which result in different head losses, so we must compute the parts separately for the highest accuracy. Furthermore, Part 1 and Part 3 have water flowing in the same direction, but for Part 2 the water is changing its flow direction perpendicularly to both 1 and 3, causing pressure loss. Having separate calculations allows us to take these details into consideration for a more accurate system.

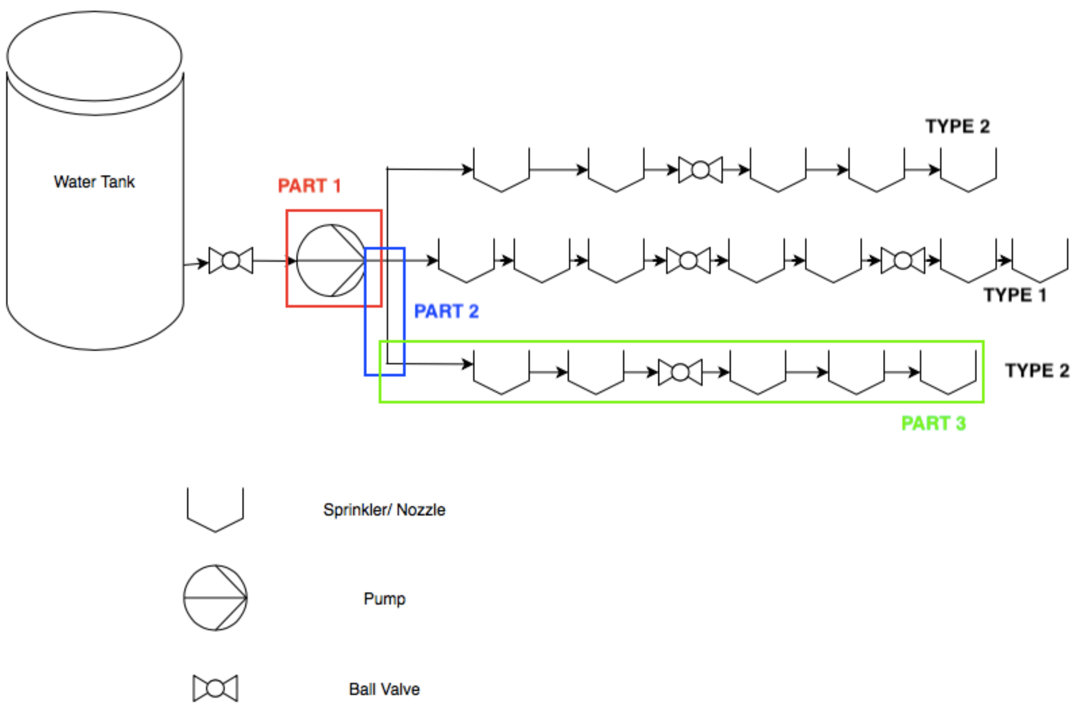

Figure 14. the P&ID with indication of divided parts for the calculation

**The figure is created by using the website https://online.visual-paradigm.com*

In the design, we aimed to deliver water with a flowrate of 5 gallons per minute (GPM) per branch. Considering each pipeline delivers the same amount of water, our team assumed that the discharge flowrate would be 15 GPM. The reason we aimed for 5 GPM was because of the initial information provided by the sponsor. Based on the client statement, we know that 400 pounds of crops are washed per day. According to a study conducted by the University of Missouri, outdoor hydrants for uses other than firefighting require a minimum of 3 GPM and a preferred of 5 GPM (Agricultural Plan Service). Similarly, an outdoor hose at a home also requires 5 GPM. If we assume that these 400 pounds of crops are washed over an 8-hour period, that means 50 pounds are washed per hour and 0.83 pounds are washed per minute. If a garden hose can use 3 to 5 gallons of water to wash a pound of crops in a minute, then we can safely assume that our calculations will provide enough water for the crops to satisfactorily be washed. It is reasonable to believe that 5 gallons of water can wash a single pound of crops.

With these assumptions, the total head loss for each part is calculated using the equations shown below (White, 2011).

Head loss due to friction: $h_f = f\left(\frac{L}{d}\right)\left(\frac{V}{2g}\right)$ ----------------------(1)

Where f = friction factor

L = length of the pipe

D = inner diameter of the pipe,

V = velocity, g = gravity

Minor losses due to fittings: $h_m = k\frac{V^2}{2g}$ -------------------------(2)

Where k = friction coefficient

<u>For Part 1,</u>

i. Find velocity of flowing water

$$Q = vA \text{ ----------------(3)}$$

$$where\ A = crosssectional\ area = \pi r^2$$

$$Q = flowrate = 15GPM = 0.0009\ \frac{m^3}{s}$$

According to equation (3), $v = 2.86\ m/s$

ii. Find Reynolds Number

$$Reynolds\ Number = \rho \frac{VD}{\mu} \text{ -------- (4)}$$

$$where\ \rho = density\ of\ water,$$

$$\mu = dynamic\ viscosity\ of\ water\ (0.0010518\ \frac{N * s}{m^2})$$

From equation (4), Reynolds number = 54219.8

iii. Find relative roughness of a pipe

$$Relative\ roughness = \frac{\varepsilon}{d} \text{ ------------(5)}$$

$$where\ \varepsilon = absolute\ wall\ roughness\ of\ PVC\ pipe$$

$$d = inner\ diameter\ of\ a\ pipe$$

From equation (5), relative roughness = 0.000075

iv. Find Darcy-friction factor of a pipe, f

$$\frac{1}{f^{1/2}} = -1.8\log(\frac{6.9}{Re} + (\frac{\varepsilon/d}{3.7})^{1.11}) \text{ -------(6)}$$

According to the equation (6), *f*=0.0206.

v. Find major head loss due to friction, use equation (1)

$$h_f = f\left(\frac{L}{d}\right)\left(\frac{V}{2g}\right)$$

From obtained values from equations above, $h_f = 0.26m$

vi. Find minor head loss due to fittings, use equation (2)

$$h_m = k\frac{V^2}{2g}$$

$$h_{m,total} = \Sigma h_m = h_{m,valve} + h_{m,T-connectors} + h_{m,90°\ elbow} \text{ -------------(7)}$$

where $k_{valve} = 0.08, k_{T-connector} = 0.54, k_{90°\ elbow} = 0.81$

Using equation 2 and 7, $h_{m,total} = 0.03m$

<u>For Part 2,</u>

Though the equations used are same from Part 1 calculation, the values are different due to changed flowrate from 15 GPM to 5 GPM, considering the pressure loss due to change of flow direction, and division of three separate pipelines.

i. Find velocity of flowing water

$$Q = vA \text{ ----------------(3)}$$

$$where\ A = crosssectional\ area = \pi r^2$$

$$Q = flowrate = 5GPM = 0.0003\ \frac{m^3}{s}$$

According to the equation (3), $v = 0.95\ m/s$

ii. Find Reynolds Number

$$Reynolds\ Number = \rho \frac{VD}{\mu} \text{-------- (4)}$$

$$where\ \rho = density\ of\ water,$$

$$\mu = dynamic\ viscosity\ of\ water\ (0.0010518\ \frac{N*s}{m^2})$$

From equation (4), Reynolds number = 18010.1

iii. Find relative roughness of a pipe

$$Relative\ roughness = \frac{\varepsilon}{d} \text{------------(5)}$$

$$where\ \varepsilon = absolute\ wall\ roughness\ of\ PVC\ pipe$$

$$d = inner\ diameter\ of\ a\ pipe$$

From equation (5), relative roughness = 0.000075

iv. Find Darcy-friction factor of a pipe, f

$$\frac{1}{f^{1/2}} = -1.8\log(\frac{6.9}{Re} + (\frac{\varepsilon/d}{3.7})^{1.11}) \text{-------(6)}$$

According to the equation (6), f=0.0206

v. Find major head loss due to friction, use equation (1)

$$h_f = f\left(\frac{L}{d}\right)\left(\frac{V}{2g}\right)$$

where L = 2ft = 0.61m

From obtained values from equations above, $h_f = 0.029m$

vi. Find minor head loss due to fittings, use equation (2)

$$h_m = k\frac{V^2}{2g}$$

$$h_{m,total} = \Sigma h_m = h_{m,valve} + h_{m,T-connectors} + h_{m,90°\ elbow}$$ -------------(7)

where $k_{valve} = 0.08, k_{T-connector} = 0.54, k_{90°\ elbow} = 0.81$

Using equation 2 and 7, $h_{m,total} = 0.04m$

For Part 3,

While the velocity, Reynolds number, relative roughness, and friction factors are the same as Part 2, total major and minor head loss are different due to the length of pipe.

i. Find major head loss due to friction, use equation (1)

$$h_f = f\left(\frac{L}{d}\right)\left(\frac{V}{2g}\right)$$

where L = 20ft = 6.1m

From obtained values from equations above, $h_f = 0.26m$

ii. Find minor head loss due to fittings, using equation (2),

$$h_m = k\frac{V^2}{2g}$$

$$h_{m,total} = \Sigma h_m = h_{m,valve} + h_{m,T-connectors} + h_{m,90°\ elbow}$$ -------------(7)

where $k_{valve} = 0.08, k_{T-connector} = 0.54, k_{90°\ elbow} = 0.81$

Using equation 2 and 7, $h_{m,total} = 0.13m$

According to the calculation above, the total head loss can be identified as the equation (8) below,

$$h_{total} = h_f + \Sigma h_m \text{ -----------(8)}$$

From the calculation above, the total head loss of the one entire Type 2 pipeline is $0.779m$ which is equivalent to 1.1 pounds per square inch (psi).

After finding total head loss of the pipe, our team calculated required power of a pump to be installed.

i. Find pump head, h_p

Starting with Steady Flow Energy Equation,

$$\frac{p_1}{\rho g} + \frac{{v_1}^2}{2} + z_1 = \frac{p_2}{\rho g} + \frac{{v_2}^2}{2} + z_2 + h_{total} - h_p \text{ ---------------------------(9)}$$

For the new design, our team assumed constant pressure and velocity. Additionally, there is no elevation difference in the design. Thus, the equation (9) is simplified as shown:

$$h_{total} = h_p \text{ ------(10)}$$

Though the equation (10) shows the pump head is equal to total head loss of a pipe only, the required pressure for the spray nozzles is added to h_{total}. According to the nozzle specification, the nozzles need 60 psi to distribute 1.3 gallons of water per hour. Thus, the pump head is 61.1 psi.

ii. Find the power of a pump

$$P_{pump} = \frac{\rho g h_{total} Q}{\eta} \text{------------------(11)}$$

where $\rho = density\ of\ water\ \left[\frac{lb}{ft^3}\right]$

$$g = gravity\ \left[\frac{ft}{s^2}\right]$$

$$h_{total} = total\ head\ loss\ [ft]$$

$$Q = flowrate\ \left[\frac{ft^3}{s}\right]$$

$$\eta = efficiency\ of\ a\ pump\ (assumed\ 70\%)$$

From using equation 11, the power required power for a pump that will work for our system is 388 ${lbf * ft}/{s}$ which is equal to 0.8 horsepower (hp) approximately. In terms of pump efficiency, we assumed 70% which is typical for small scale water delivery system (Emiliawati, 2017). Based on the calculation, our team determined that a pump for the new system should be able to generate 0.8 hp of power and 61.1 psi of pressure. Considering the calculation above, our team selected the WAYN PLS 100 Stainless Steel Lawn Sprinkler Pump which consumes 1-hp with maximum pressure of 80 psi. The figure below is the curve showing the performance of the selected pump, retrieved from the manufacturer's website (Wayne). Since the height of the discharge head is 4 feet, the performance would be 648 GPH (10.8 GPM) because from 0 to 5 feet, 18 GPH is lost per foot.

PERFORMANCE						
Model	**HP**	**Discharge Head**	**0'**	**5'**	**10'**	**15'**
PLS100	1	Gallons/Hour	720	630	520	390

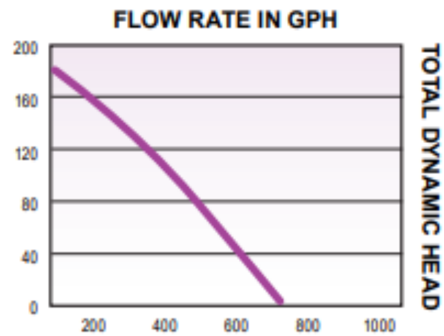

Figure 15. Pump Performance Curve

3.33 Area 3 – Drying Section for Washed Crops

Area 3 is a drying station that allows farmers to set their crops somewhere to dry before packaging and preparing the items for sale. For the drying section, our team decided on two main components: plastic trays and slanted, stainless-steel drying rack.

Figure 16. Drying rack

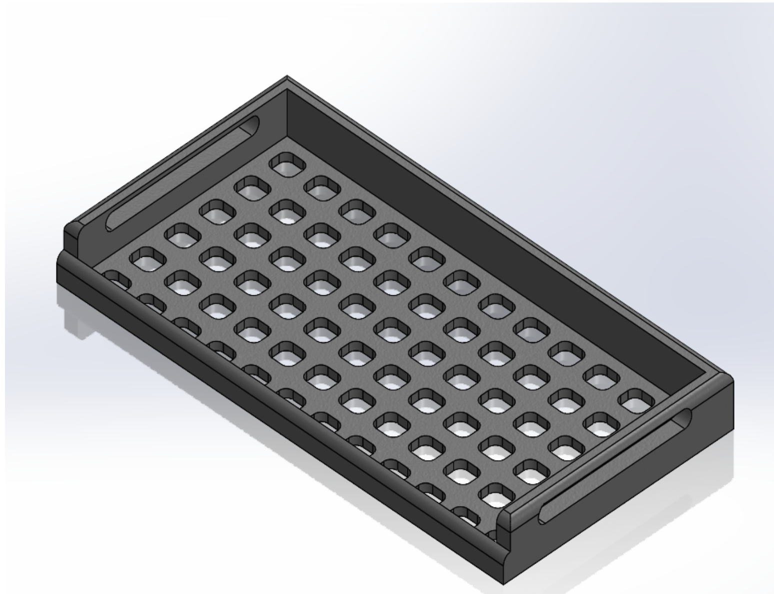

Figure 17. Plastic Tray

As mentioned in section 3.2, the goal of the new system is to be faster and less user dependent. Area 3 would satisfy these goals because the previous design did not incorporate a designated location for washed crops that need to dry. Ideally, the crops would be washed and dried in these plastic crates with drainage holes in them. This will save the farmers time by being able to wash and dry their crops within the same container and in larger quantities. Furthermore, a meshed bottom plate will speed up the drying process by allowing the water to drip off the crops versus a solid bottomed tray. Additionally, we wanted a stainless-steel drying rack with slanted, plastic lined shelves to prevent the accumulation of water from plastic trays. The plastic lining would prevent the top crops' water from dipping below and would enable the water to drain off the sides of the shelves.

3.4 Final Design

Due to our limited budget and timeline, we were unable to implement all the elements we wanted to in our design, and we ultimately moved some aspects to recommendations that World Farmers can hopefully include in the future. Area 3, the drying section, had to become a recommendation so that we could focus more on Areas 1 and 2.

Area 1 had some slight modifications. As shown in Figure 18 below, we decided that we wanted to add a spout to the buckets to that each bucket is its own unit as opposed to changing the strainer between buckets. This way when the water becomes turbid or there is a change of crops or farmer, it is easy to drain the unit and refill it from the water tank. Therefore, the process is quicker, less user-depended, and remains CQP compliant.

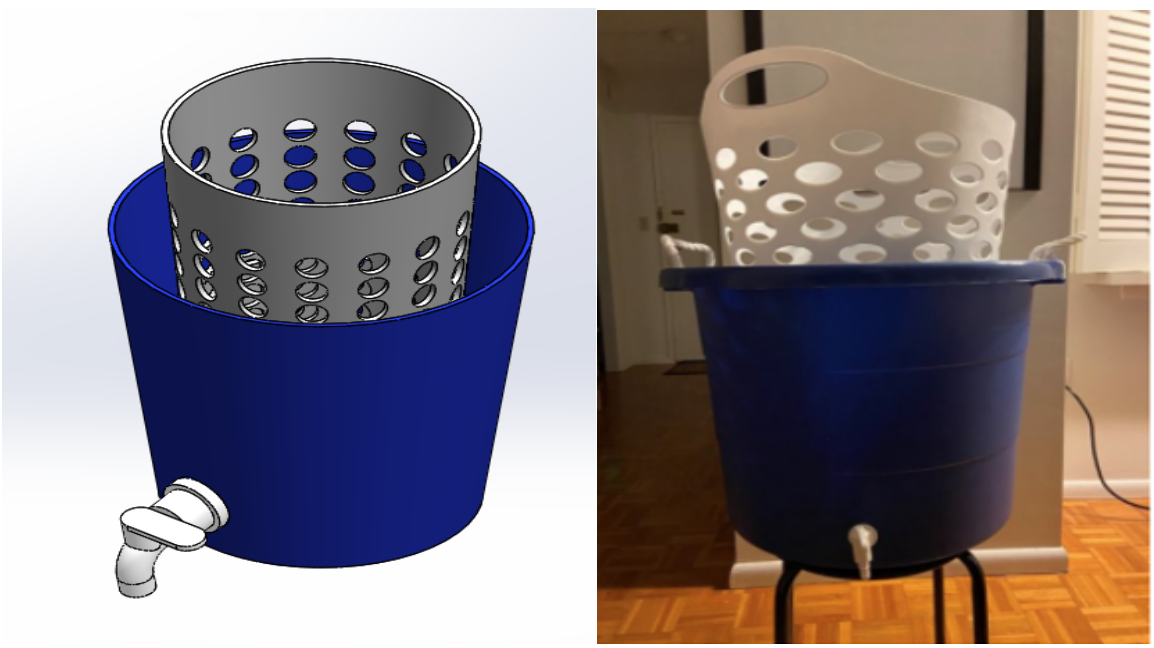

Figure 18. Area 1 – Area 1 Final Design for Bucket [Isometric View (left) Build (right)]

Area 2 went through a decent number of changes throughout the experimentation process (see Figures 19-21).

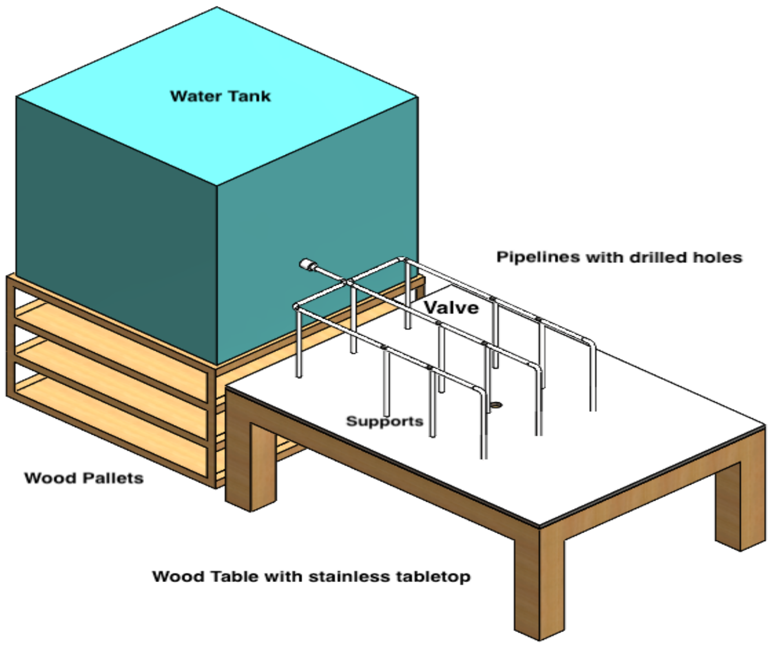

Figure 19. Area 2 Final Design Isometric View – omitted a pump

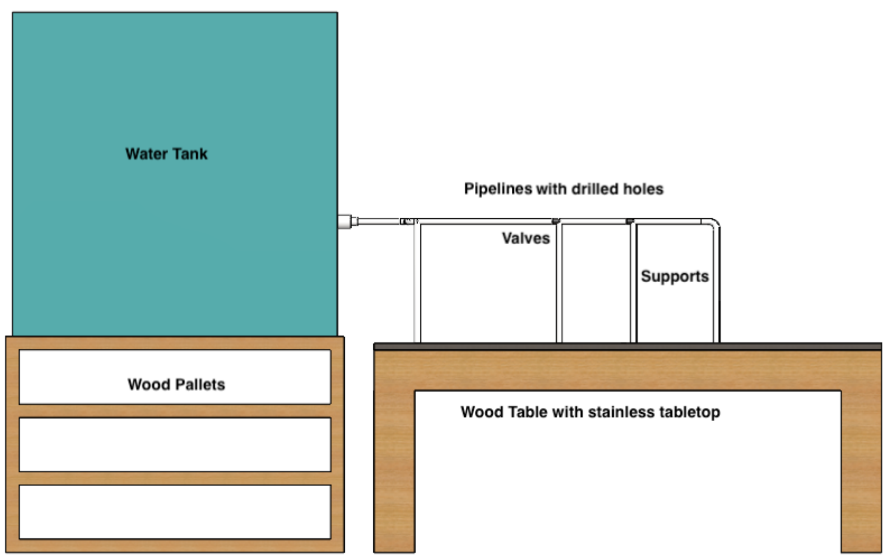

Figure 20. Area 2 Final Design Front View – omitted a pump

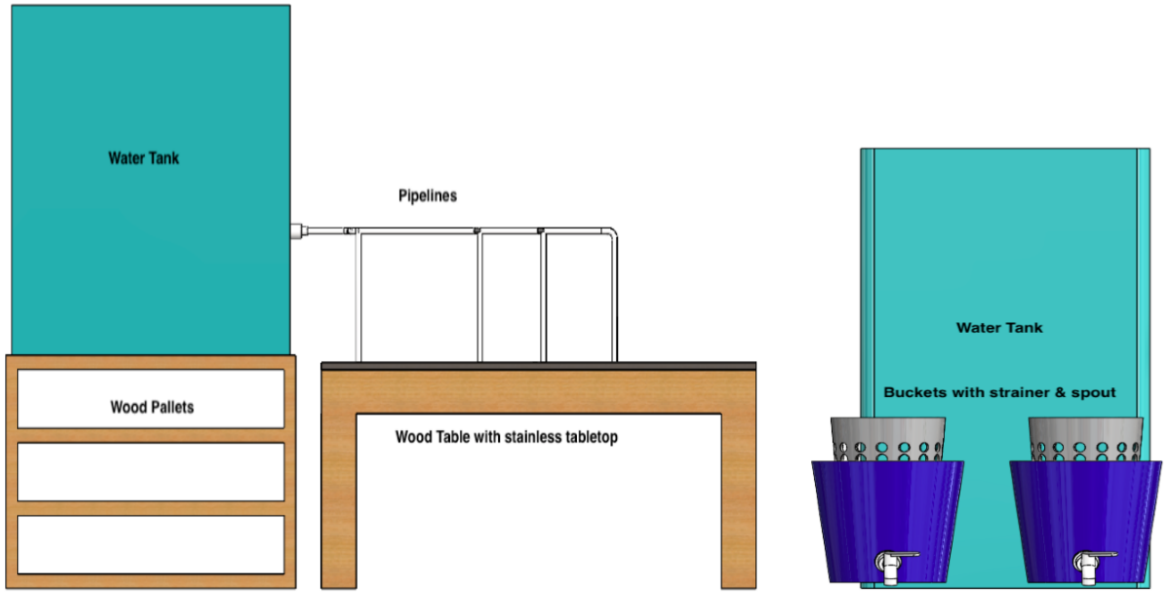

Figure 21. Area 1 and Area 2 [Front View]

As Figure 20 shows, the piping system in Area 2 has slightly changed. First, the length of the Part 3 (See Figure 14) in the Area 2 was reduced from 20 feet to 13. Since the length of the pipe is changed, the head loss calculation result is changed as well from 0.26m to 0.18m. Because the dimensions for the Part 1 and 2 remain the same, the calculations is same to the original result. In addition to the shortened length of pipeline, there are no longer two separate configurations for the final design. Instead of having Type 1 and 2 configurations, the final design only consists of one uniform configuration. Each pipeline includes two ball valves, two 4-foot-long sections, and one 3-foot-long section. With the two valves, each pipeline is divided into three sections; 4-feet followed by a ball valve, 3-feet followed by a ball valve, and then the other 4-feet at the end.

Second, there are no spray nozzles in the final design. From preliminary experimental trials, our team discovered that the nozzles we purchased did not work as they were supposed to. Though the required pressure for the targeted water distribution flowrate was applied, the nozzles could not spray water (see more in section 4.0). Due to the limited timeline for the project, our team needed to find a quick replacement for the nozzles. The solution we decided upon was to manually drill holes into the pipes. We drilled 5/64-inch holes every inch along the pipe, leaving 1-½ inches untouched at each end. By adding these holes, we found a low cost solution to reduce the pressure and create a working system.

4.0 Experiment and Results

4.1 Area 2

While we were able to redesign Area 1 based on feedback from the sponsors and advisor, the design of Area 2 was changed based on experimental results. We found that the spray nozzles we initially purchased for the project were not releasing any water. We had considered utilizing gravity or a pump for our sprinkler system. To avoid exceeding our budget, we had borrowed a 700 GPH pump from the lab where we conducted our testing. At first, we suspected that the pump we were borrowing was not powerful enough since the pump barely worked. After researching and calculating for our system, we purchased the pump referenced in Figure 15. We then tested the same pipe layout with the nozzles, we quickly noticed that pressure built up to the point where the system was unsafe. Since the pump we purchased was discharging 10.8 GPM (see Figure 15), we confirmed that the first pump we tested with was broken and not an accurate reflection of the system. The piping popped out of their fixtures due to the pressure buildup with the new pump. While the system would be more secure if we had cemented the whole pipeline, we still were unsure if the nozzles would work. Cementing the pipes would not have fixed the issue of pressure buildup if the nozzles were faulty and it would have been a waste of materials if it did not fix our problems. Furthermore, since we were still testing and developing the system and because the sponsors had to transport the system, we decided against cementing.

We decided that we would try drilling holes throughout the piping instead of using the t-connectors and nozzles. To find the hole size and since the nozzles were not spraying any water, we took out all but one of the nozzles from the t-connectors and then drilled small holes into the remaining nozzle. The reason we had to take the nozzles out was to reduce the pressure so that we could safely find the hole size we needed. We started with the smallest drill bit and worked up until we figured out which size hole allowed water to flow through. We needed to find the smallest value for the hole so that we would save water and to avoid decreasing the pressure too much. We found that a 5/64 drilled hole was large enough for water to flow through. Taking a 1-foot section of the piping, we drilled 5/64 holes into the pipe about 1 inch away from each other starting 1 ½ inches on either side so it would not interfere with the ball valves and end caps. We added this 1-foot segment to the end of one of the pipelines (with the nozzles out to avoid pressure buildup). The test was successful, so we decided to switch to drilling holes for our final design and reformatted our pipelines accordingly.

4.2 Flow Rate

To evaluate the performance of Area 2, our team measured the water flow rate for each pipeline. During the design phase, our team aimed to generate 5 gallons of water per minute for each pipeline. To find the flow rate of each pipeline, we ran the system, and collected water into a 9-quart bucket. We timed from when the water reached the bucket until when it was fully filled. From here we were able to calculate the flow rate of each pipeline. Based on the experimental data we collected, the center pipeline generates 8.2 gallons per minute and the outer two pipes each generate 5.1 gallons of water per minute, which satisfies the expectation from our design phase for the new system.

4.3 Washing performance

To ensure the performance of the final design of the wash station, our team conducted experiments using the new designs. For Area 1, triple rinse wash station for tubulars, our team used onions and a kabocha squash to observe if the dirt on crop surfaces can be removed. Due to COVID-19 delays, our team could not gain access to the WPI laboratory. Thus, we ran our experiments for the triple rinse section in a team member's apartment.

Figure 22. Vegetables Before Wash

As seen in Figure 22, our team used 306 grams of dirt on our vegetables. The top row shows the dirt measured out and the “clean” vegetables before any testing or any previous washing. The second row shows the dirt covered vegetables before the washing process using the triple rinse system we created.

Figure 23. Vegetables After First, Second, and Third Rinse

To wash our vegetables, we rotated the tall strainer clockwise and counterclockwise to loosen the dirt from the surface of the crops. We drained and refilled the bucket in between rinses as the farmers would on the farm. Figure 23 shows the vegetables sequentially after each rinse of the triple rinse process from left to right.

Figure 24. Vegetables Before and After Triple Rinse Experiment

Based on the results of our experiment and considering that there would likely be less dirt clumps dumped into the strainers, we determined that our system was successful.

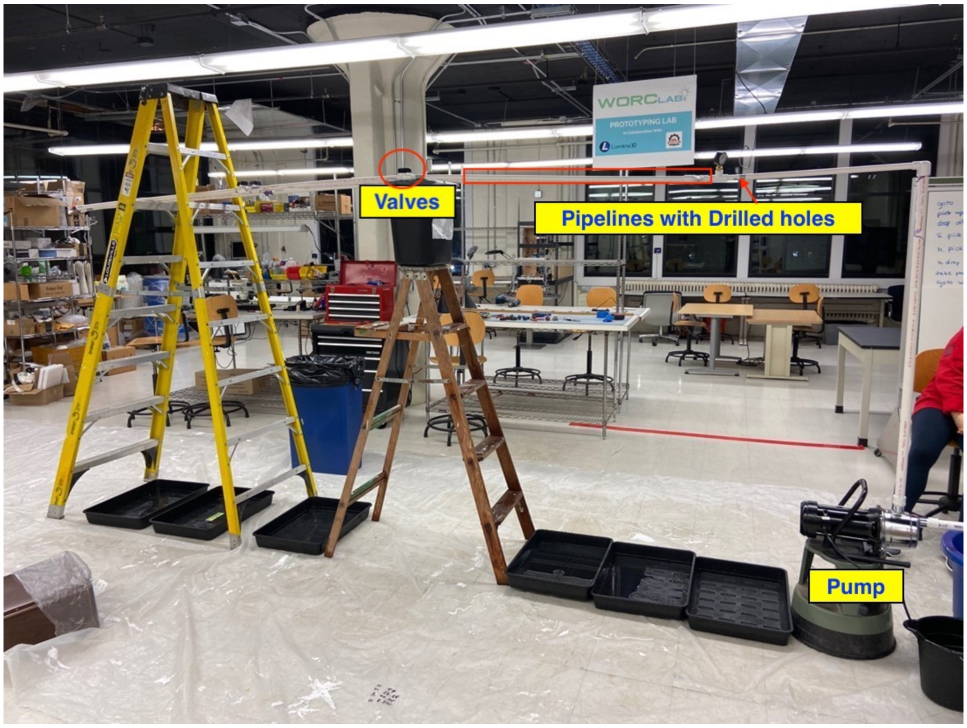

Figure 25. Experimental Setup of Area 2 (see Appendix E for further instructions)

For Area 2, sprinkler station for leafy greens, our team used 3 heads iceberg lettuce in the experiment. The lettuce we bought was advertised as weighing 6 ounces per head which makes a total of 18 ounces, just over a pound. According to our earlier calculations we want be able to wash the pound with about 5 gallons of water. As we did for the Area 1 experiment, our team manually put dirt on the crop surfaces. As shown in the figures below, the lettuce heads are under the sprinklers so that water can be distributed onto the crop surfaces. In the experimental setup, a bucket is used as a water source for the entire Area 2 system. As established earlier, we purchased a 1 horsepower pump with 1-inch inlet and outlets.

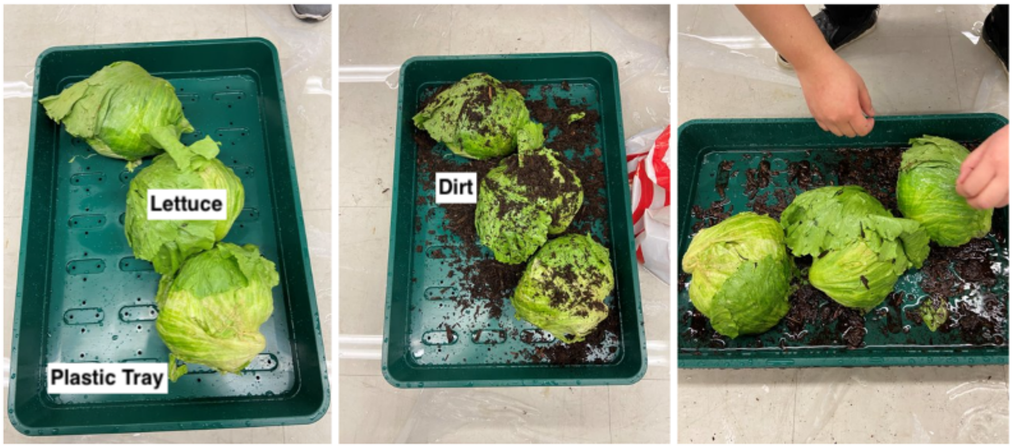

Figure 26. Prewashed, Dirty, and Washed Crops

With this setup, our team ran the sprinklers to observe the performance of Area 2. In the experiment, the lettuce was successfully cleaned after about 14 seconds of water distribution. Similar to the testing on Area 1, we assume that the farmers would not be adding excess dirt into their crops to be washed. The trays available to us had small drainage holes that the larger dirt particles got stuck in. To avoid this issue, we would recommend that the World Farmers buy trays with larger holes so that big dirt or mulch does not get clogged. Additionally, we tested the system with a few closed valves. As shown in Figure 19 and 20, there are two ball valves that are installed for each pipeline to create three separate sections. The users can either open or close the valves depending on the number of crops that need to be washed or how many farmers need the wash station at a time. Based on the trials with closed valves, Area 2 can function fully whether 4 feet of sprinklers are being used up to its 11-foot length.

5.0 Risk Management

While we conducted experiments to ensure our system worked, we also needed to test that our system is safe for use at the farm. As students from Worcester Polytechnic Institute working on a MQP team redesigning a wash station for World Farmers, we have done our best to ensure that we are providing a safe design. We are aware that our design bears potential risks, and we have outlined them below in addition to providing solutions to help minimize the probability of an accident.

5.1 Deflection

One of the potential risks of the system is deflection of the pipes due to the water flow and mass of the piping setup. To test how much of deflection occurs in the redesigned system, our team conducted a simple stress analysis by using the online calculator, MechaniCalc (MechaniCalc.com). The distributed load was solved by knowing the density of water, the volume of the pipe, and the weight of the pipe. The weight of the pipe plus the weight of volume of water that can fit in the pipe gives us our load which is evenly distributed along the length of the pipe.

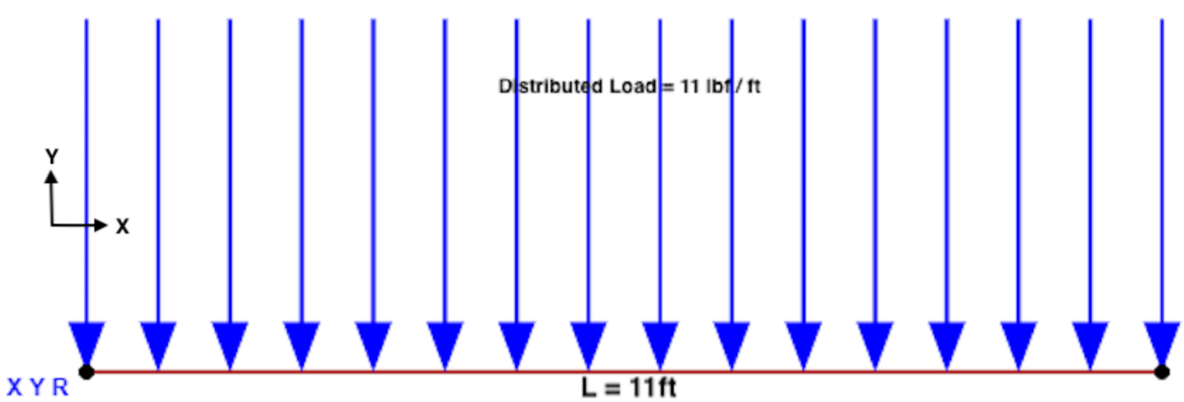

Figure 27. the pipe in the new design with distributed load

For the analysis, our team treated the pipeline as one beam. We considered the maximum water flow rate and applied it as a distributed load for one pipeline. At room temperature, 1 gallon of water weighs 8.34 pounds. Assuming 15 gallons of water flows inside the pipelines per minute and calculating the volume of the piping, we know that the pipelines hold approximately 125 pounds of water. This means we have 11 lbf/ft as the uniformly distributed load.

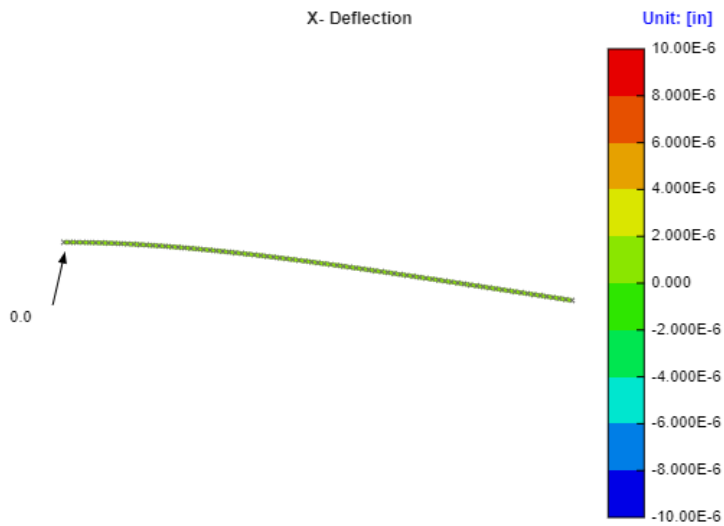

Figure 28. Deflection in x-axis (horizontal)

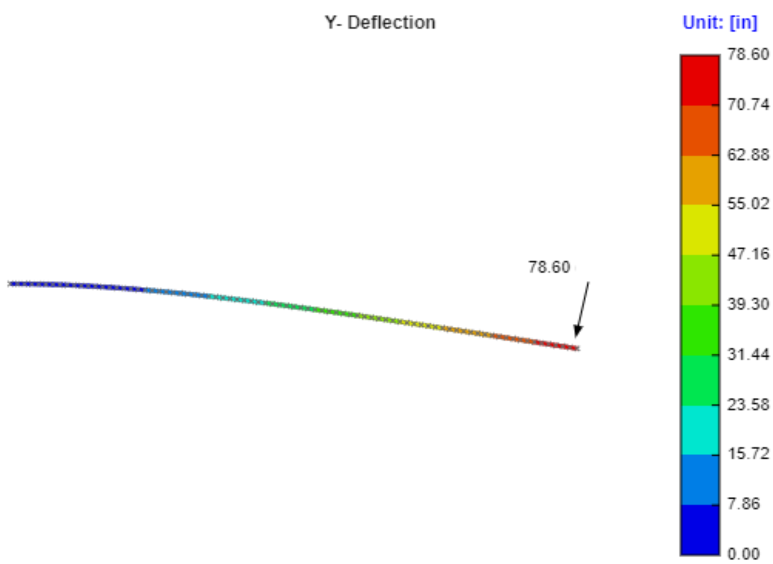

Figure 29. Deflection in y-axis (vertical)

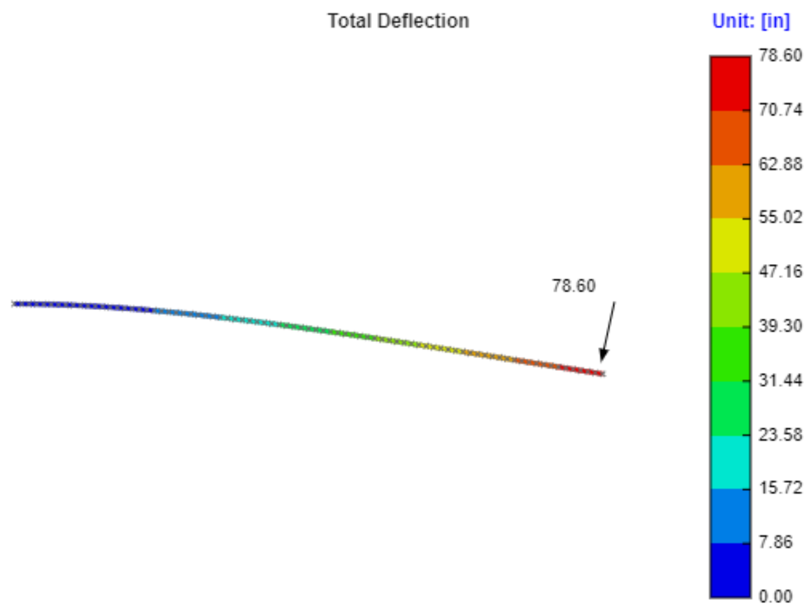

Figure 30. Total Deflection

Based on the calculations, the maximum deflection of 78.6 inches occurs at the end of a pipeline. As Figures 28,29, and 30 show, there is only deflection in y-direction (vertical), since there is no applied force horizontally. To prevent deflection of the pipelines and failure of the new system, our team added supports along the pipelines (see Figures 32 to 35 below).

Furthermore, we know that the flexural yield strength of rigid polyvinyl chloride at ambient temperature is between 73.1 and 95.1 megapascals (MPa) or 10602.26 and 13793.09 psi (Polymer Database). From the simulation, each pipeline experience maximum stress of 113,203 psi as shown in the figure below. For the calculation, the bending stress equation $\sigma_b = \frac{M_c}{I}$ is used (MechaniCalc).

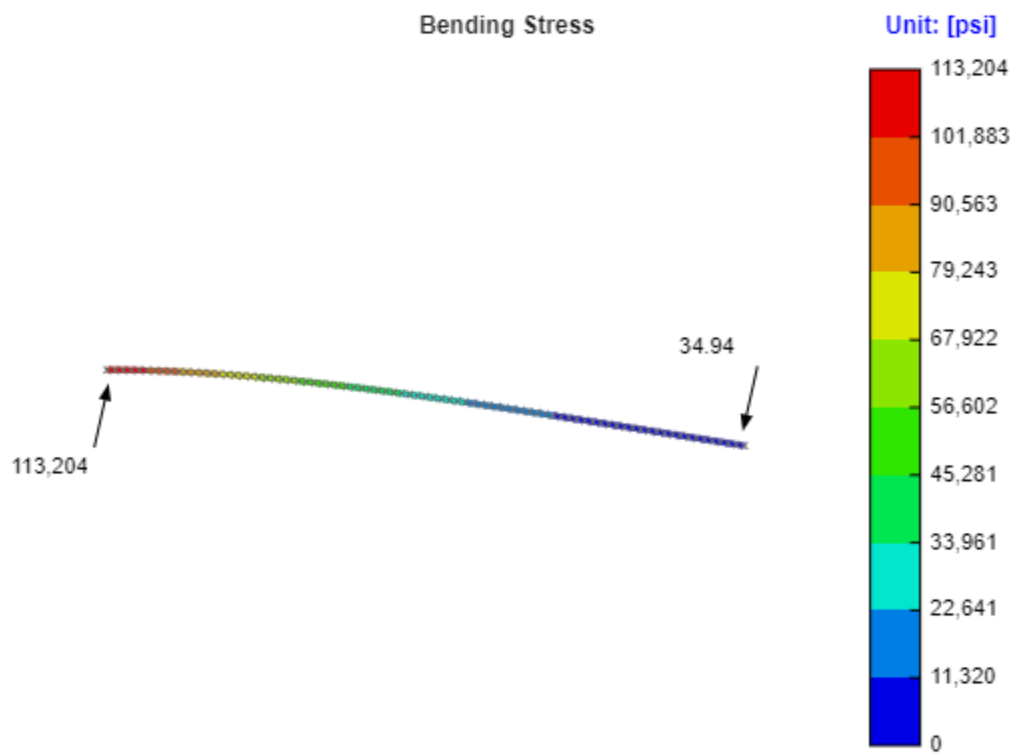

Figure 31. Bending Stress Diagram

We can assume that the PVC piping will be around ambient temperature because according to CQP guidelines, post-harvest crops should be treated with cool water and since there is a roof over the system, we can assume that the pipe will not overheat in the summer. While the system is unlikely to snap, it will experience too much deflection which could cause a pipe that is not cemented in place to pop out of its fixture.

Considering that the deflection has a greater effect towards the end both theoretically and experimentally, we figured we could reuse the cut pieces from our earlier designs that did not work. We used t-connectors to connect shorter pieces of pipe from the earlier sprinkler design to add support throughout the system. Obviously, vertically placing PVC piping directly under the sprinklers would not be effective because it could easily fall over. As a solution, we modeled adapters in SolidWorks to 3D print using polyethylene terephthalate (PETG), a durable, food safe, and water-resistant plastic material (ACME Plastics, Inc).

To avoid interfering with the sprinkler's efficacy, we wanted to put supports where there are not water holes; at the 4-way connector, ball valves, and end caps. All these designs needed to fit into a piece of ½ inch PVC pipe for ease of assembly so they all include a 1-inch extruded cylinder so that they can satisfy the need.

For the 4-way connector, we created a simple design where the connector can rest inside an indentation. As previously mentioned, it also needed to be attached to the ½ inch PVC pipe. Figure 32 below shows the design in trimetric view.

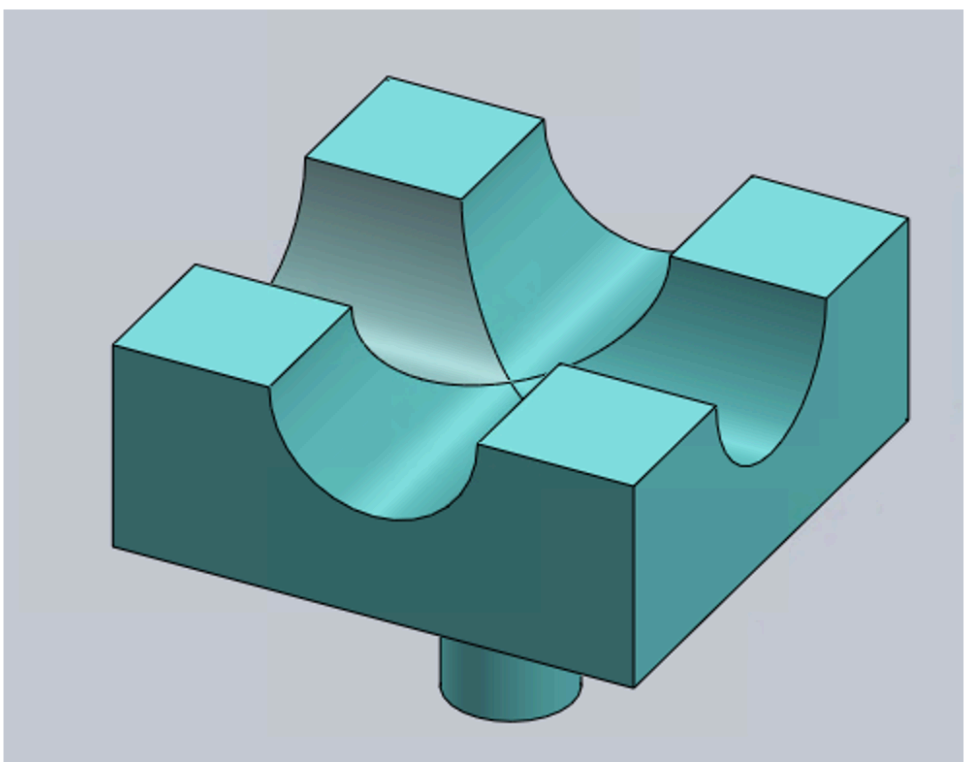

Figure 32. 4-way connector support trimetric view

We designed something very similar for the ball valves where they simply sit inside of cutout which then goes into the PVC. We printed one for each ball valve to ensure support and safety to the best of our abilities. Figure 33 shows the SolidWorks model in trimetric view.

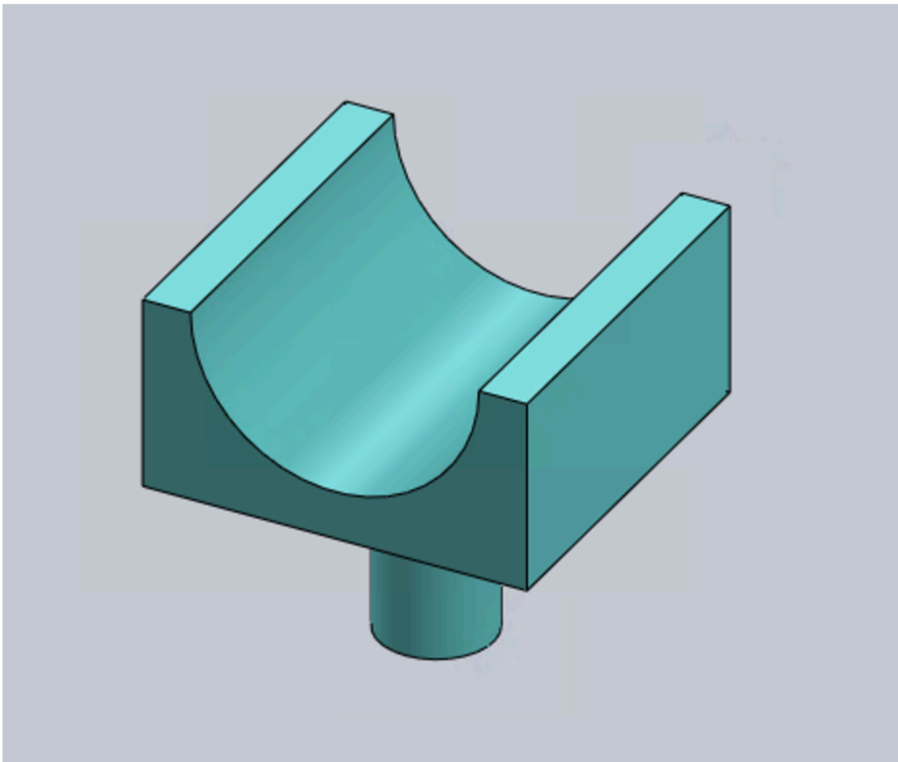

Figure 33. Ball value support in trimetric view

For the end caps, we knew we still had extra ½ inch 90-degree elbows so we created a cove for the end cap that could attach to the elbows. The elbow would then attach to the vertical piping. Having these elbows made the design process easier since we did not have to account for printing 90 degrees with a cylindrical shape. Figure 34 shows this end cap to elbow adaptor.

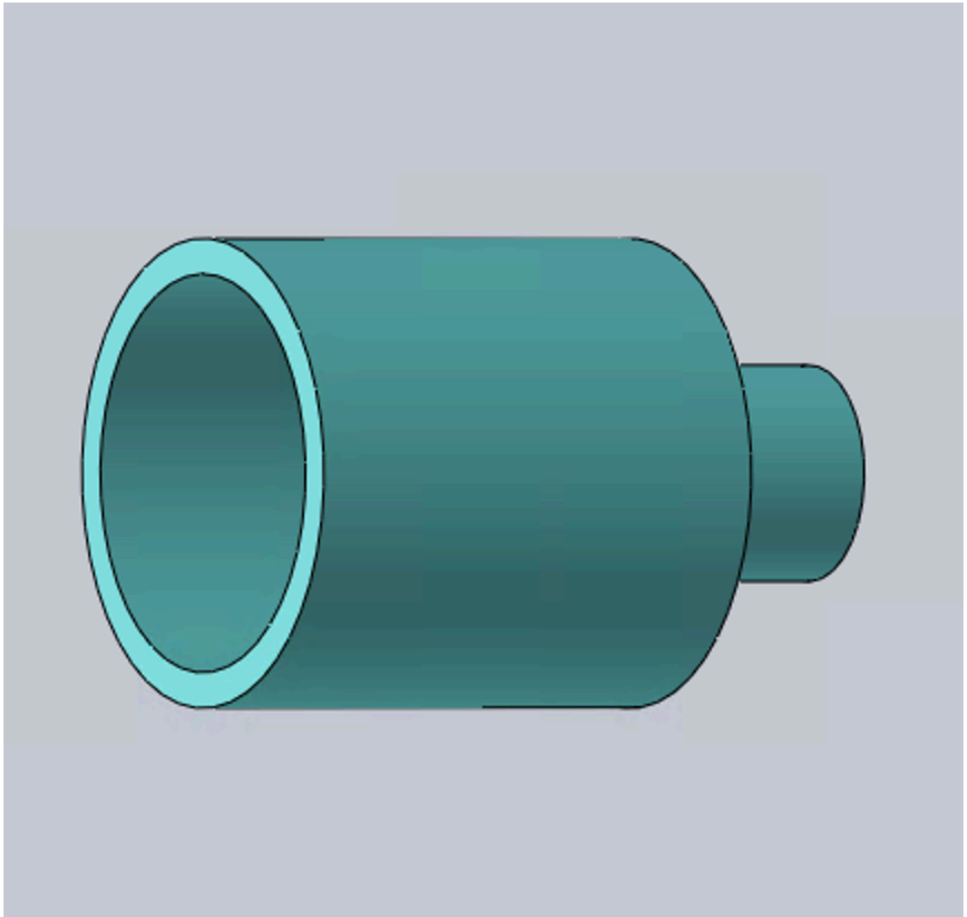

Figure 34. End cap supports in trimetric view rotated 90 degrees counterclockwise

We also needed to consider that the bottom of the PVC support pipes needs extra surface area to stay upright since the ½ inch PVC would not do well on the slated table at the farm. We modeled and printed flanges for each support rod to add surface area for weight distribution and so that the piping would not get stuck in a slat. Figure 35 shows the flange. The inner diameter would fit inside the PVC, but we also included an outer wall to ensure the pipe is secure without having to be cemented so they can be reused.

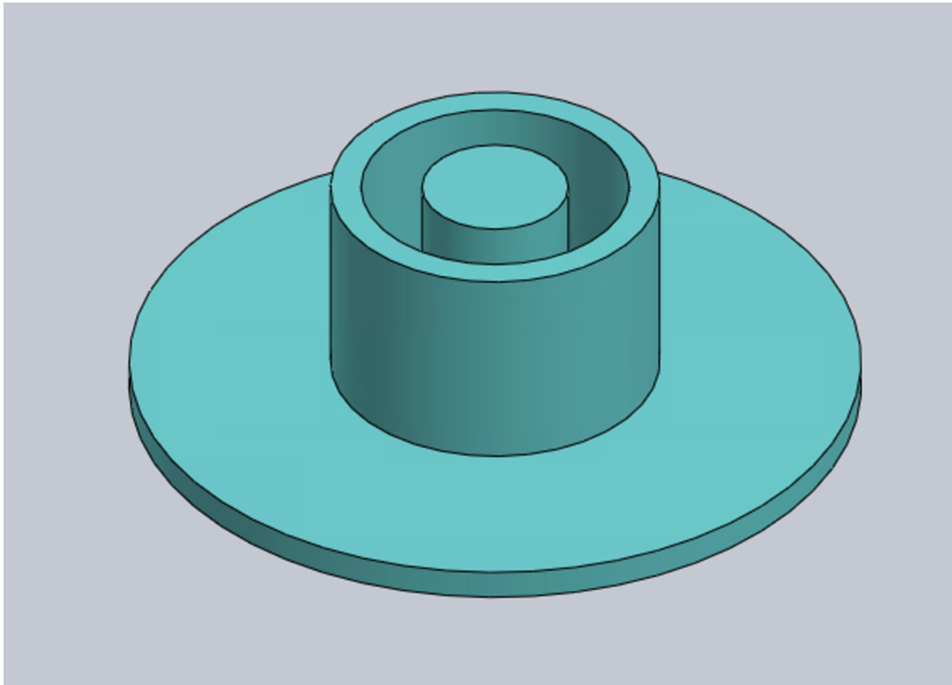

Figure 35. Base support flange in isometric view

Another way to reduce the risk of the system failing is to consider the upkeep of the design. If there is significant deflection in the system and a pipe needs to be replaced, the users can easily disassemble the system and replace the weakened pipe with a new section of PVC pipe. Since PVC is a relatively cheap material and the entire design is not cemented together, it allows for portions of the system to be replaced as needed.

5.2 Clogging

At the farm, the existing 275-gallon water tank is filled using unfiltered well water. Our team had to consider the possibility of debris such as dirt clogging at the tank spout in Area 2. Clogging would be an issue for cleanliness purposes and interrupt the functionality of the system. For Area 1 we were not so worried about clogging the nozzles since it is easy to remove the spout to clear out any debris. For Area 2, the sprinklers would be harder to clear out periodically. To avoid this issue, we incorporated filters into our design (see Figure 36).

Figure 36. Filtration System Laid Out

Figure 36 shows the layout of the filtration set up which must go between the water tank outlet and the inlet of the pump. Specifically, the larger filter is on the tank side and the finer mesh is on the pump side. On the left of Figure 36, we see a 2-inch vent screen which nests inside one half of the 2-inch PVC union connector. This filter will keep out larger debris from the system. In between the halves of the union connector sits a 120-micron screen of mesh cut to size to sit perfectly within the threads. The finer mesh is able to filter sediment, sand, and rust flakes from clogging the sprinkler system. On each end of the union connector, we added 4-inch sections of 2-inch diameter PVC piping which secures the vent filter and connects the filtration to the tank and the pump (see Appendix E for detailed assembly instructions). This setup not only allows for the filters to be taken out for cleaning, but also replaced as needed in the future.

6.0 Conclusions and Recommendations

Through the project, our team redesigned the existing wash station at the farm. To create the new design, our team diagnosed the existing problems of the previous wash station. Based on our assessment and the initial client statement, we determined that the original wash station is heavily user-dependent and time consuming. To solve these problems, our team set the final functional goals for the new system: to be less user-dependent and expedite the washing process while remaining CQP compliant.

Based on the experimental results, our new system satisfies the final functional goals as long as the well water remains up to CQP code. In Area 1, our team reduced the labor input for washing tuber vegetables. With the original wash station, the farmers had to manually wash the crops by rubbing the dirt off each in a water-filled bucket. However, Area 1 in the new system has the farmers put multiple vegetables into a strainer and swivel the strainer within a bucket. By attaching the bearing plate (lazy-Susan hardware) in between the inner bottom of a water bucket and the outer bottom of a strainer, the farmers can wash multiple crops at once without applying too much force. For leafy greens, which need a more delicate washing technique, our team developed Area 2 in the new system. Instead of hand washing each of the crops, Area 2 gently and efficiently dispenses water from drilled holes in the PVC pipes onto crop surfaces. According to the experiment, the system requires approximately 16 seconds to remove dirt completely from the surfaces. Since we know that the system produces 18.4 GPM at its full length, this means that washing the 18 ounces with all the valves open only used about 4.6 gallons of water. As the experiment results prove, the World Farmers will be able to wash their crops with less labor and relatively quickly.

For the longevity of the newly designed system, our team completed calculations and analysis to ensure that the system is safe to use and will last. Based on the stress analysis, our team added support structures to prevent and reduce the deflection of the pipes, which can cause failure of the entire system. In Area 2, the water tank is filled with well water. Due to the usage of well water, our team and sponsor considered there could potentially be a clogging problem inside the pipes. To solve the problem, our team attached a vent filter and a 120-micron mesh screen as a filtration system. For the distribution of water in Area 2, our team implemented a pump in which generates 80 psi of pressure. Though our team selected the pump based on our calculations, we needed to ensure that the system works fine without exploding because of pressure buildup. To ensure the safety of the pump in the system, our team measured the generated pressure. The measured generated pressure from the pump is almost negligible and is not exceeding the limit pressure within the pipes.

Since our team had budget and time constraints in the project, our team developed suggestions for the drying of washed crops. The detailed suggestions with links, pictures, and descriptions can be found in the Bill of Materials (see Appendix F). We recommend that the sponsors buy plastic trays with large holes in the bottom so that crops can be washed and dried in the same trays. For the drying area itself, we recommend the sponsors get a stainless-steel drying rack with slanted, plastic lined shelves to prevent the accumulation of water from the plastic trays.

Finally, because of WPI's COVID-19 restrictions, we were unable to go to the farm to deliver and implement the project. We considered shipping everything to the farm, but this was unrealistic since shipping costs are expensive and the system might be damaged in the process. We scheduled a socially distanced pick up with the sponsors so they could pick up the project. To prepare for their pickup, our team assembled as much of the system as we could in advance. We fully assembled Area 1's triple rinse buckets and cemented the pipes that needed it for Area 2. We also had to take into consideration that everything needed to fit into a standard car for Transportation and to disassemble at the end of each harvest season. We also provided the sponsors with electronic copies of the instructions in Appendix D and E for clarification on setting up the triple rinse buckets and sprinklers. This way, they may make their own modifications to the files in the future or create copies for separate wash stations.

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Appendix A: Commonwealth Quality Program Standards Section 5

Agricultural Water

The full checklist can be found on Massachusetts Government's webpage dedicated to the Commonwealth Quality Program

Massachusetts Department of Agricultural Resources Produce Safety Program
MDAR Produce Safety/mGAPs Compliance Criteria

UMass Extension
CENTER FOR AGRICULTURE

Produce Safety Checklist

Q #	Requirement	Compliance Criteria	
5	**Agricultural Water**		
5.0.1	Are initial (pre-season) risk assessments performed and documented, taking into consideration the water source history, characteristics/stage of crop, and the method of application?	**§112.42, §112.50(b)(1):** At the beginning of each growing season, and at least once annually, the agricultural water systems must be inspected to identify conditions that are reasonably likely to introduce hazards or contaminants into or onto covered produce or food contact surfaces. Factors that should be taken into consideration: type of water source, ability to control water source, degree of protection of each agricultural water source, use of adjacent and nearby land, and the likelihood of a contaminant being introduced prior to the water entering the operation's distribution system. A water managed system should be in place reflective of the results of the risk assessments.	§ R
5.1	**Pre-Harvest Water**		
5.1.1	Is the water used for pre-harvest use equal or less than 126 CFU or less per 100ml of generic E. coli?	**§112.41, §112.44(b):** Water tests should not exceed 126 CFU or less per 100ml (generic E. coli) for pre-harvest/agricultural water. Pre-harvest includes but is not limited to activities such as: irrigation, spraying, and frost protection. If agricultural water does meet this criteria, any alternative and/or treatments should comply with PSR parts **§112.43 and §112.45.**	§ R
5.2	**Post-Harvest Water**		
5.2.1	Is the water and ice used in post-harvest activities and hand washing free of generic E. coli?	**§112.44(a):** Any water used for post-harvest activities that comes into direct contact with produce, food contact surfaces, or is used for handwashing must be free of generic E. coli (0 CFU per 100 ml). Water tests and/or documentation must be present for validation. If post-harvest water does meet this criteria, any alternative and/or treatments should comply with PSR parts **§112.43 and §112.45.**	§ R
5.2.2	If a dunking method or re-circulated water is utilized, is there a water change-out schedule SOP?	**§112.48(a):** For dunk tanks or other re-circulated water, water-change schedules must be established to maintain its safety and adequate sanitary quality and minimize the potential for contamination (for example, hazards that may be introduced into the water from soil adhering to the covered produce).	§

10

Produce Safety Checklist

Q#	Requirement	Compliance Criteria	
5.2.3	Dependent upon what type of wash system is utilized, is water temperature or turbidity monitored?	**§112.48(b)(c):** Water must be visually monitored for buildup of organic material and indications of necessitating a change. Depending on commodity, temperature should be monitored to prevent infiltration of microorganisms.	§
5.2.4	If sanitizer(s) are used in rinse/wash water, are they approved for food contact use and is the use monitored appropriately and documented?	**§112.43:** The use of sanitizing agents is not required, but if such agents are used in post-harvest/washing activities, ensure that the sanitizer is approved for this specific purpose and that usage reflects the instructions on the product label.	§ R
5.2.5	Is waste/wash/cooling water disposed in a manner that will minimize the risk of contamination?	**§112.130(c), §112.133(b)(c)(d):** Waste/wash/cooling water should be discharged in a way that minimizes the risk of contamination. Discharge water should not pool outside and should be sited in a way that would not run off into active production acreage.	§
5.2.6	If water tanks are utilized, are there SOPs and records regarding the frequency and method of cleaning?	**§112.123(a)(d)(1):** Water tanks must be adequate for use, maintained, and cleaned/sanitized as frequently as reasonably necessary to protect stored water from contamination. There must be corresponding records that indicate when, who, and how tanks were cleaned and sanitized.	§ W R
5.3	**Water Testing**		
5.3.1	Is the water testing laboratory utilized for the above testing a state certified laboratory that performs the FDA approved methodology for generic E. coli testing?	**§112.151:** The lab(s) should be listed on the MDAR Produce Safety Program list of approved water testing facilities.	§
5.3.2	Are all surface water sources, including those that are not routinely utilized, tested (3) three times a year in line with mGAPS program requirements?	Surface water includes ponds, lakes, rivers, brooks, etc. These tests should be spaced out pre-season/early season, mid-season, and late season to get a wide sample of water quality. Whether or not the water comes into direct with the edible portion of the crop will factor into testing frequency.	R
5.3.3	Are surface water source test results properly identified (per farm map) and recorded?	**§112.50(b)(2):** The location where the water sample(s) have been taken should be identified on the farm map. Water source test results should be centrally located and easily accessible for review.	§ R
5.3.4	Are all ground water sources, including those that are not routinely utilized, tested (2) two times a year in line with mGAPS program requirements?	Well tests should be spaced evenly to get a wide sample of water quality. Whether or not the water comes into direct with the edible portion of the crop will factor into testing frequency. If well water is being used for post-harvest activities, the frequency must remain at twice annually at a minimum.	R

MDAR Massachusetts Department of Agricultural Resources Produce Safety Program
MDAR Produce Safety/mGAPs Compliance Criteria
UMass Extension CENTER FOR AGRICULTURE

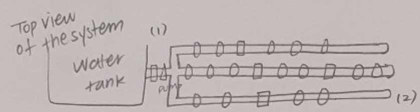
Produce Safety Checklist

Q#	Requirement	Compliance Criteria	
5.3.5	Are ground water source test results properly identified (per farm map) and recorded?	**§112.50(b)(2):** The location where the water sample(s) have been taken should be identified on the farm map. Water source test results should be centrally located and easily accessible for review.	§ R
5.3.6	Are municipal water source test results properly identified and recorded (municipal reporting of water quality)?	**§112.46(a), §112.50(b)(7):** For municipal water, the proper report/certification from the corresponding municipality is required for water quality verification. A copy of this report/certification should be kept with any additional surface or ground water source tests. While not required, it is considered a best practice to independently test municipal water for validation of the report's findings. If agricultural water does meet this criteria, any alternative and/or treatments should comply with PSR parts **§112.43 and §112.45.**	§ R

Appendix B: Pump Power Calculation

pump horse power required

Steady Flow Energy Equation.



$h_f + h_m = h_{total} = 7.5\,ft = 0.779\,m$

$$\frac{P_1}{\rho g} + \frac{1}{2}V_1^2 + z_1 = \frac{P_2}{\rho g} + \frac{1}{2}V_2^2 + z_2 + h_f + \Sigma h_m - h_p$$

$P_1 = P_2$, $z_1 = z_2$, $V_1 = V_2$

$h_p = h_{tot}$ And add required pressure for nozzles 60 psi $\sim 138\,ft$

$= 7.5\,ft + 138\,ft$

$= 145.5\,ft$

head pump $(h_p) = 145.5\,ft$.

pump power $= \rho g h_p Q / \eta$

$$= \frac{(62.41\,lb/ft^3)(32.17\,ft/s^2)(145.5\,ft)(0.03\,ft^3/s)}{0.7}$$

$\rho = 62.41\,lb/ft^3$

$g = 32.17\,ft/s^2$

$h_p = 145.5\,ft$

$Q = 15\,gpm = 0.03\,ft^3/s$

$\eta = 0.7$ (70% efficiency)

$= 12519.63\,lb \cdot ft^2/s^3$

$\Rightarrow (12519.63\,lb \cdot ft^2/s^3)\left(\frac{1\,lbf}{32.2\,ft\,lb/s^2}\right)$

$1\,lbf = 32.2\,ft \cdot lb/s^2$

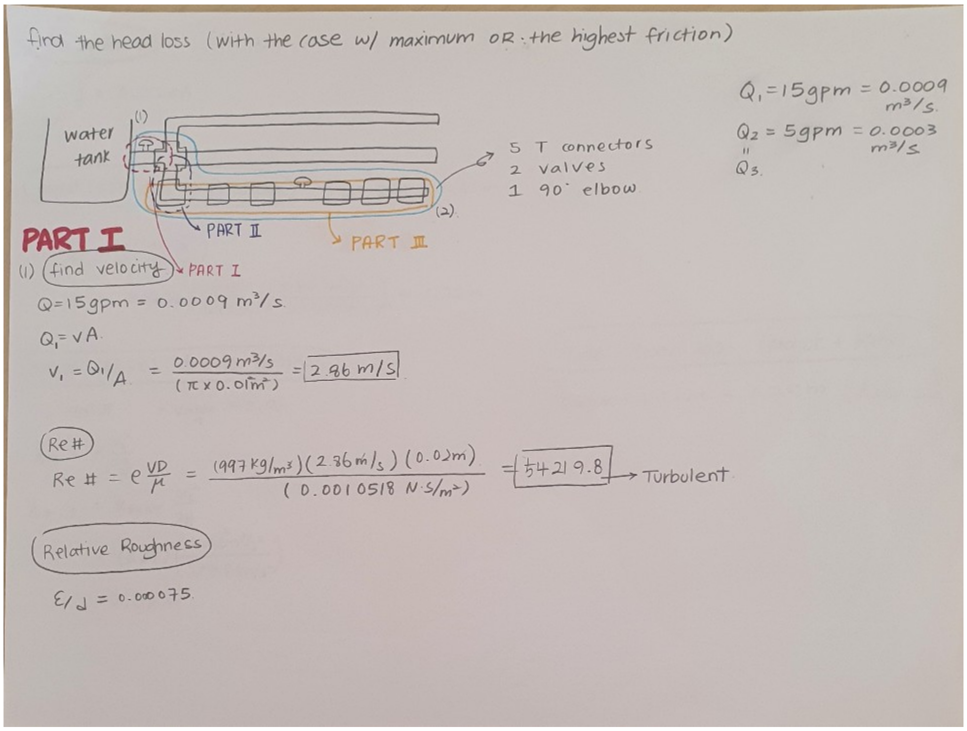
$= 388\,lbf \cdot ft/s$

Conversion factor ; $1\,hp = 500\,lbf \cdot ft/s$

$(388\,lbf \cdot ft/s)(1\,hp / 500\,lbf \cdot ft/s)$

$= 0.776\,hp \sim$ (0.8 hp) is needed for a pump

Appendix C: Head Loss Calculation



find the head loss (with the case w/ maximum OR : the highest friction)

$Q_1 = 15 gpm = 0.0009\ m^3/s$

$Q_2 = 5 gpm = 0.0003\ m^3/s$ = Q_3

PART I

(1) find velocity

$Q = 15 gpm = 0.0009\ m^3/s$

$Q_1 = vA$

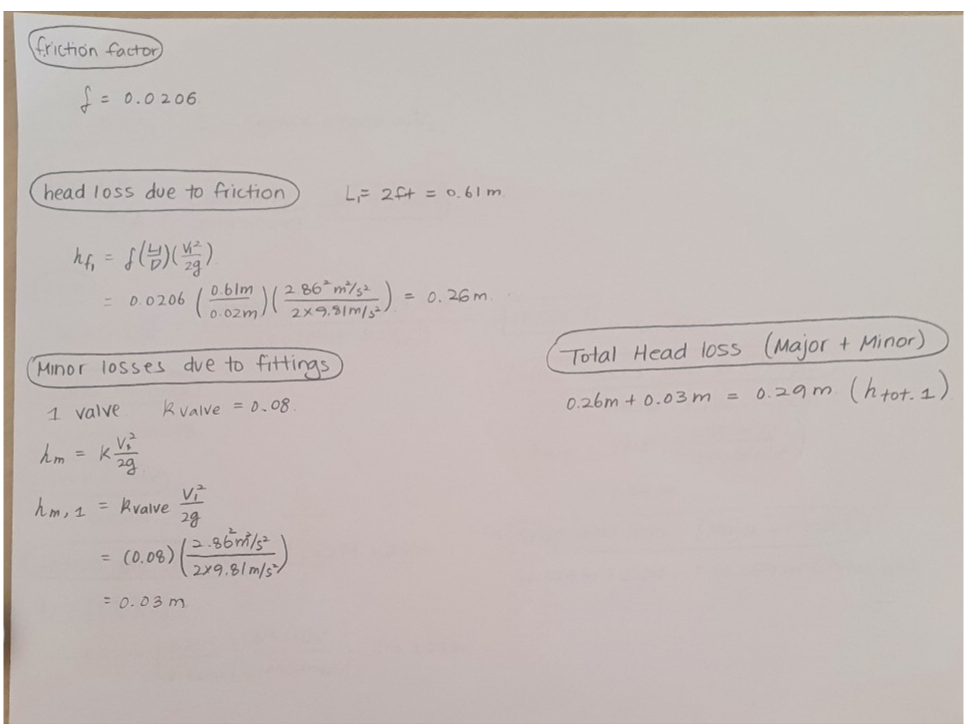
$v_1 = Q_1/A = \frac{0.0009\ m^3/s}{(\pi \times 0.01 m^2)} = \boxed{2.86\ m/s}$

Re#

$Re\ \# = \rho \frac{VD}{\mu} = \frac{(997\ kg/m^3)(2.86\ m/s)(0.02 m)}{(0.0010518\ N \cdot s/m^2)} = \boxed{54219.8}$ → Turbulent

Relative Roughness

$\varepsilon/d = 0.000075$



friction factor

$f = 0.0206$

head loss due to friction $L_1 = 2ft = 0.61 m$

$h_{f_1} = f\left(\frac{L}{D}\right)\left(\frac{V_1^2}{2g}\right)$

$= 0.0206\left(\frac{0.61 m}{0.02 m}\right)\left(\frac{2.86^2\ m^2/s^2}{2 \times 9.81\ m/s^2}\right) = 0.26 m$

Minor losses due to fittings

1 valve $k_{valve} = 0.08$

$h_m = K\frac{V_1^2}{2g}$

$h_{m,1} = k_{valve}\frac{V_1^2}{2g}$

$= (0.08)\left(\frac{2.86^2\ m^2/s^2}{2 \times 9.81\ m/s^2}\right)$

$= 0.03 m$

Total Head loss (Major + Minor)

$0.26 m + 0.03 m = 0.29 m$ ($h_{tot,1}$)

PART II

find velocity $Q_2 = 5gpm = 0.0003\ m^3/s$.

$Q_2 = V_2 A$

$V_2 = Q_2/A = \frac{0.0003m^3/s}{(0.01^2m^2 \times \pi)} = \boxed{0.95\ m/s}$

Re #

$Re\ \# = \rho\frac{VD}{\mu} = \frac{(997kg/m^3)(0.95m/s)(0.02m)}{(0.0010518\ Ns/m^2)} = \boxed{18\,010.1} \rightarrow$ Turbulent.

Relative Roughness

$\varepsilon/d = 0.000075$

friction factor

$f = 0.0206$

head loss due to friction $L_2 = 2ft = 0.61m$.

$h_{f_2} = f\left(\frac{L_2}{D}\right)\left(\frac{V_2^2}{2g}\right)$

$= 0.0206\left(\frac{0.61m}{0.02m}\right)\left(\frac{0.95^2m^2/s^2}{2\times9.81m/s^2}\right) = 0.029m$.

Minor losses due to fittings

1 × 90° elbow $k_{elbow} = 0.81$

$h_{m,2} = (0.81)\left(\frac{0.95^2 m^2/s^2}{2\times9.81m/s^2}\right)$

$= 0.04\ m$

Total head loss (Major + Minor)

$0.029m + 0.04m = 0.069m\ (h_{tot.,2})$

PART III

find velocity $Q_3 = 5gpm = 0.0003m^3/s$.

$Q_3 = V_3 A$

$V_3 = Q_3/A = \frac{0.0003m^3/s}{(0.01^2m^2 \times \pi)} = \boxed{0.95m/s}$

Re #

$Re\ \# = \rho\frac{VD}{\mu} = \boxed{18010.1} \rightarrow$ Turbulent

Relative Roughness

$\varepsilon/d = 0.000075$

friction factor

$f = 0.0206$

head loss due to friction $L_3 = 20ft = 6.1m$.

$h_{f_3} = f\left(\frac{L_3}{D}\right)\left(\frac{V_3^2}{2g}\right)$

$= 0.0206\left(\frac{6.1m}{0.02m}\right)\left(\frac{0.95^2m^2/s^2}{2\times9.81m/s^2}\right) = 0.29m$.

Minor losses due to fittings

1 valve $k_{valve} = 0.08$

5 T connectors $k_{connector} = 0.54$

$h_{m,3} = (0.08)\left(\frac{0.95^2m^2/s^2}{2\times9.81m/s^2}\right) + 5\times(0.54)\left(\frac{0.95^2m^2/s^2}{2\times9.81m/s^2}\right)$

$= 0.13\ m$

Total head loss (Major + Minor)

$0.29m + 0.13m = 0.42m\ (h_{tot.3})$

Total Head loss of the pipe (expected to be highest resistant).

$$h_{tot.1} + h_{tot.2} + h_{tot.3} = 0.29m + 0.069m + 0.42m$$

$$= 0.779\,m$$

$$\sim 2.56\,ft \longrightarrow 1.1\,psi$$

Appendix D: Assembly Instructions for Triple Rinse Buckets

Triple Rinse Bucket Assembly

For specific notes, pictures, and links please go to: Final BOM > Build-Suggestions

This project was designed to be modified for different spaces (the buckets/strainers do not need to be exactly what we bought, but many steps are dependent on the specific item purchased for sizing); these instructions follow the design we initially made

Tools:

- Drill (variety of drill bit sizes)
- Bolt cutter/rotary cutting drill bit (to trim screws)
- Thin, strong string (we used dental floss)
- Spade drill bits to cut large circles (optional)

Materials:

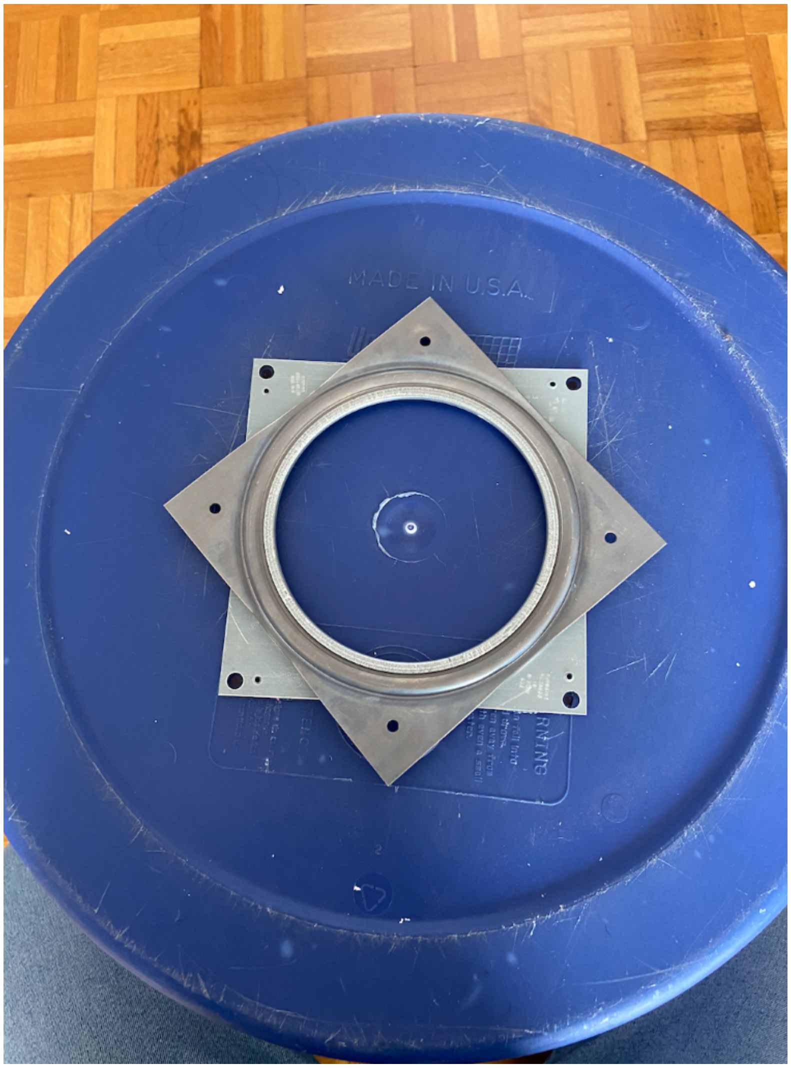
- (1) large durable plastic bucket (recommended 20 gallon)
- (2) flexible plastic baskets (must fit inside the durable plastic bucket, preferably with holes but you can add holes)
- (1) drainage spout (kit we bought came with spout, silicone washers, and nut)
- (1) lazy Susan turntable hardware (bullets below are dependent on the size of the lazy Susan's holes)
    - (8) long fully threaded bolts (at least 2" long)
    - (8) hex nuts
    - (16) flat washers

Outer Bucket

1. Take the drainage spout and line it up with the bottom of the bucket (when the spout is attached it should be barely above the ground). Trace inside the silicone washer

2. Drill a hole the size of the washer opening and attach the spout. The order of assembling the spout should be as shown below where the bucket is sitting in between the silicone washers

3. Center the lazy Susan on the bottom of the bucket as shown. Mark and drill the 4 holes of the plate touching the bucket (Our lazy Susan recommended drilling 3/32 holes). Set aside until later

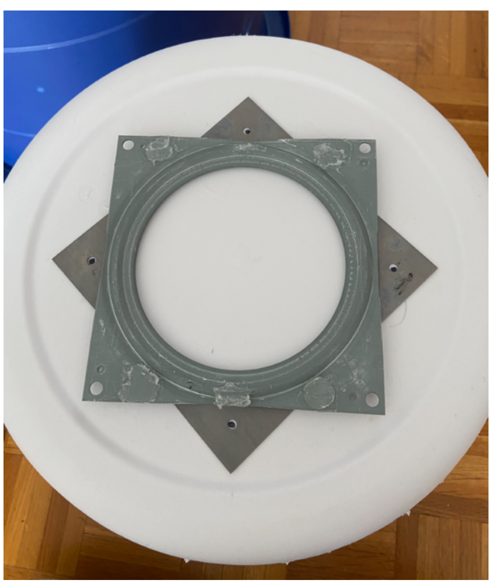

MADE IN U.S.A.

Strainers

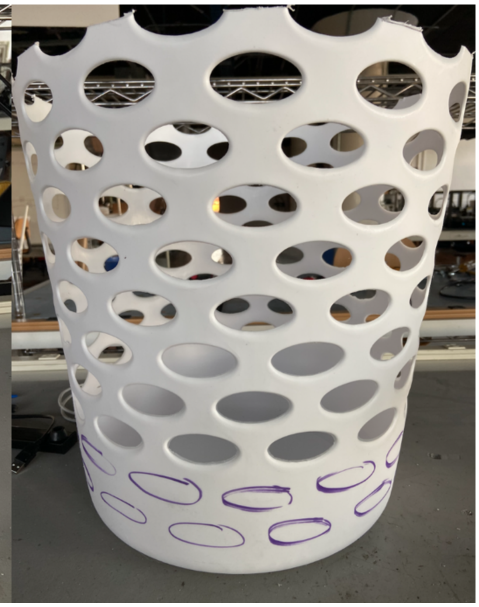
1. Take a flexible basket inside the outer bucket and mark a line slightly below the top of the outer bucket. Cut around the basket to this line (you shouldn't see the basket inside the bucket). See progress picture below

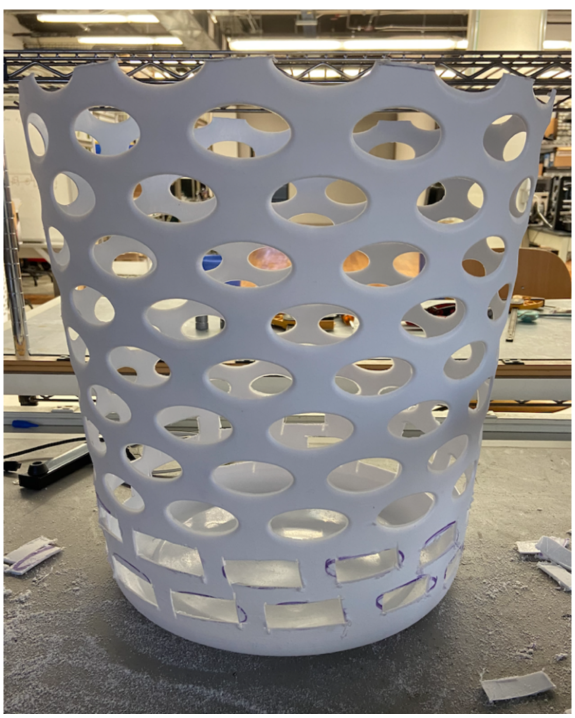


2. Center the lazy Susan on the bottom of the basket you just cut (make sure you are working with the **opposite** side of the plate than the outer bucket). Mark and drill the 4 holes



3. If the flexible basket you got does not have holes it in, you will need to drill them. The ones we bought did have holes, but we needed to add extra so the baskets wouldn't suction together. We loosely followed the original hole pattern. Only add the bottom holes for the shortened strainer

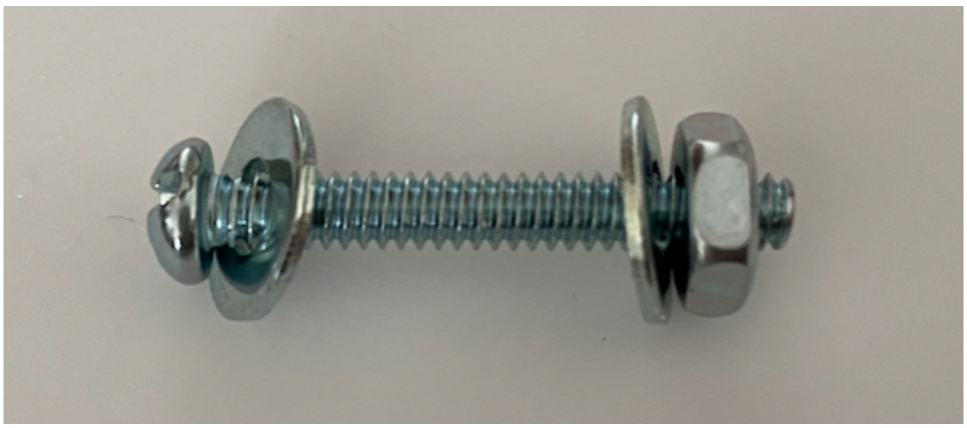





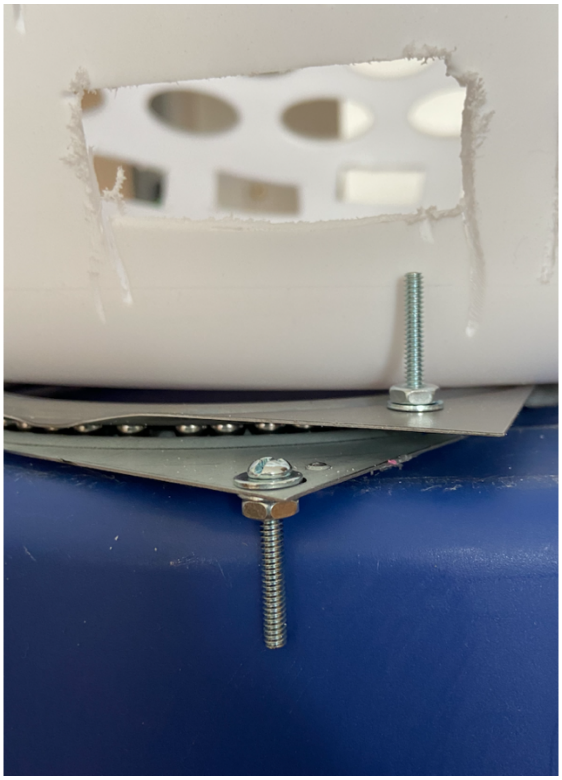
Assemble the Buckets

highly recommend this be a 2-person job because of awkward positioning

1. Bolt the 4 holes of the lazy Susan to the short basket following the layout below. The plastic goes in between the washers (ours needed #6 size bolts, washers, and nuts. We are using 3" long bolts, but they will be trimmed later). The nut should be on tightly, but **do NOT trim** the bolt yet



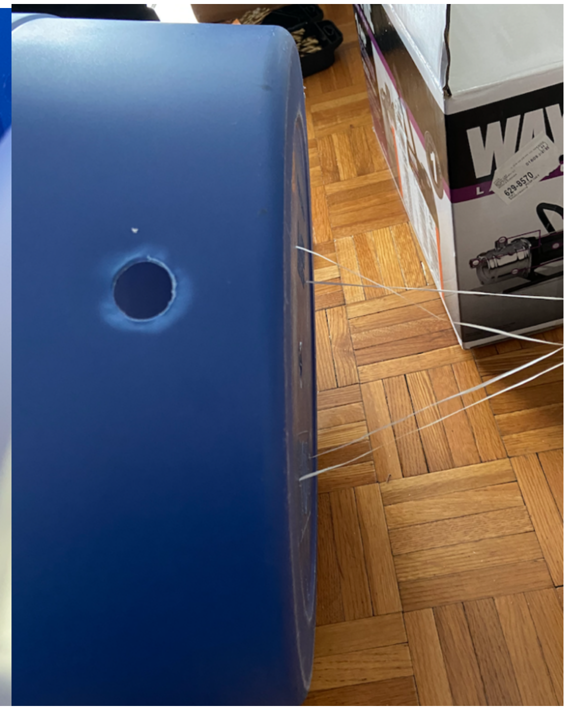
2. Add **ONLY** the bolt and first washer to the 4 holes in the other half of the lazy Susan plate. The setup should look like below except the bolts will be attached to the white basket



3. Flip the white basket so the unfinished bolts are facing up (the reason you need long bolts is so they are less likely to fall out/apart during these steps)

4. Tie a string (about 18" long) securely to each bolt

5. Put both the outer bucket and the basket on their sides (good to have another person so they don't roll). Feed each string through a hole and hold/tape it on the other side. **DO NOT PULL**. View inside on left, outside on right



6. Making sure not to pull on the strings, rotate the buckets so the bottoms are facing up. One person needs to hold/guide the outer bucket. Using the string, gently guide each bolt out of the hole. When a bolt comes out, loosely put the washer and nut on.

7. Secure the bolts tightly and take off the strings. You may then trim the bolts on the inside and out (do not cut too close or else the nut may become loose)

8. The system is done, load unwashed crops in the untouched plastic basket and then add to the water bucket

Appendix E: Assembly Instructions for Sprinkler System

Sprinkler System Assembly

For specific notes, pictures, and links please go to: Final BOM > Build-Suggestions

This project was designed to be scaled (in reference to the pipe lengths) for different spaces; these instructions follow the design we initially made

Tools:

- Drill (need 5/64 drill bit)
- PVC cement and primer
- Ruler/tape measure
- Threaded seal tape
- PVC pipe cutters (optional)

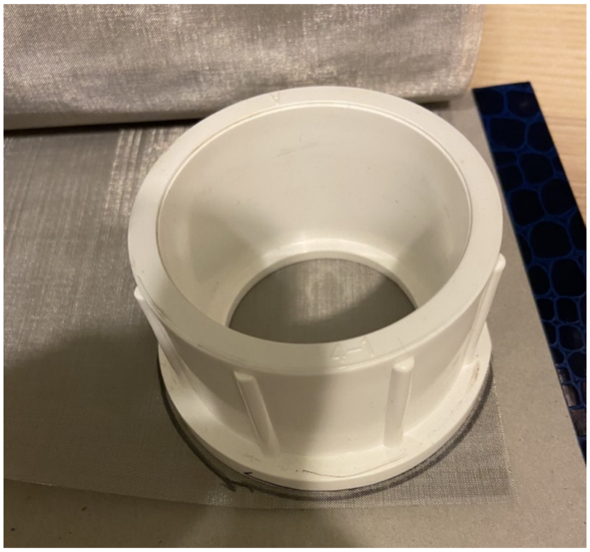
Materials: *for PVC assume slip connector unless stated otherwise*

- (1) Pump and power source
- (1) 4-inch to 3-inch reducer coupling
- (1) 3-inch to 2-inch PVC bushing
- (2) 4-inch sections of 2-inch PVC pipe
- (1) 2-inch PVC union
- (1) mesh strainer for 2-inch PVC pipe
- (1) 3.5-inch by 3.5-inch square of 120 micron mesh sheet
- (1) 2-inch to 1.5-inch reducer
- (1) 1.5-inch to 1-inch bushing

- (2) threaded 1-inch PVC adapters
- (1) 4-foot section of 1-inch PVC pipe
- (1) 8-inch section of 1-inch PVC pipe
- (1) 1-inch to ½ inch 90 degree PVC connector
- (6) 4-foot sections of ½ inch PVC pipe
- (3) 3-foot sections of ½ inch PVC pipe
- (1) 2-foot section of ½ inch PVC pipe
- (2) 6-inch sections of ½ inch PVC pipe
- (1) 4-way ½ inch PVC connector
- (2) 90 degree ½ inch elbows
- (6) ½ inch ball valves
- (3) ½ inch end caps

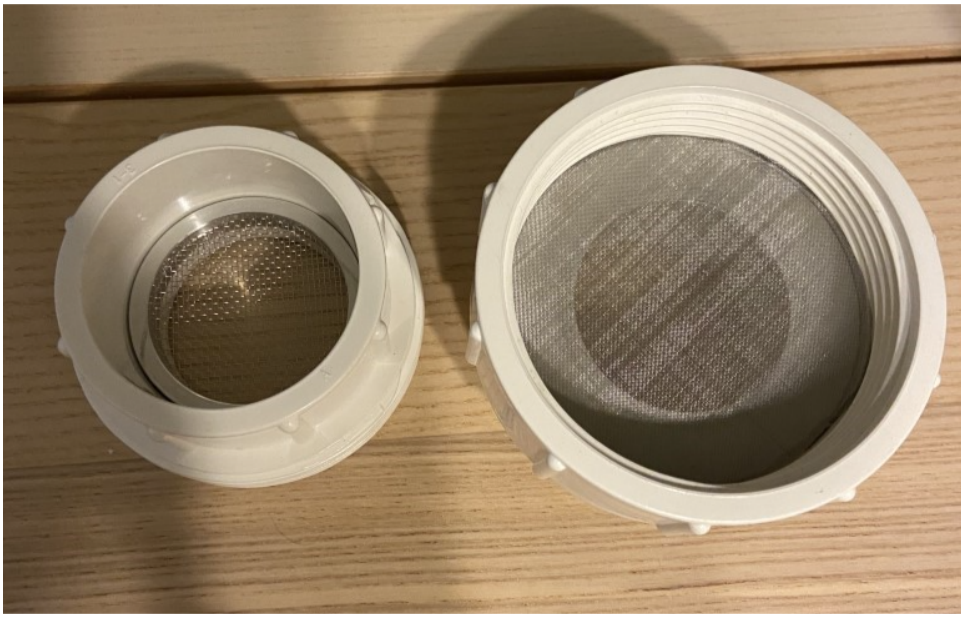
Water Tank to the Pump

1. Put together the filtration system
    a. Trace the union onto the 120-micron mesh and cut out the circle



    b. Assemble the filter in this order (remember that the water needs to flow through the filter with larger holes first). The strainer nests in the smooth part of the union, the micron is set inside the threaded part of the union

Filters should look like this (then put the union halves together)



2. Setup the rest of the connectors

a. From left to right

    i. 4” to 3” reducer

    ii. 3” to 2” bushing

    iii. 4” piece of 2” PVC

    iv. Filtration system from step 1 (larger filter would be on the left)

v. 4” piece of 2” PVC

vi. 2” to 1.5” reducer

vii. 1.5” to 1” bushing

b. Attach the 4” end to the water tank

c. Insert the 8” section of 1” PVC to the pump

Pump

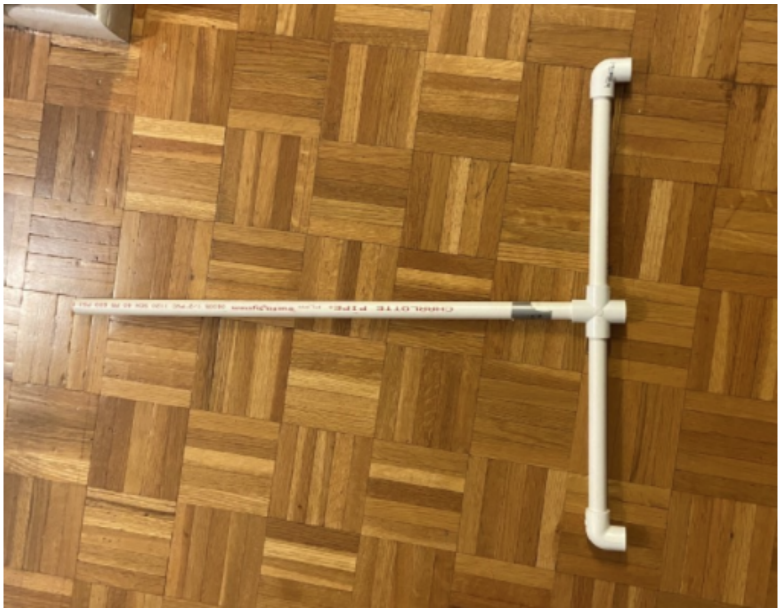
1. Screw the 1” threaded PVC adapters into the inlet and outlet valves for the pump (use thread tape for a secure connection)

2. Cement the 1” to ½" elbow to the 4’ section of 1” pipe then connect to the pump

Sprinklers

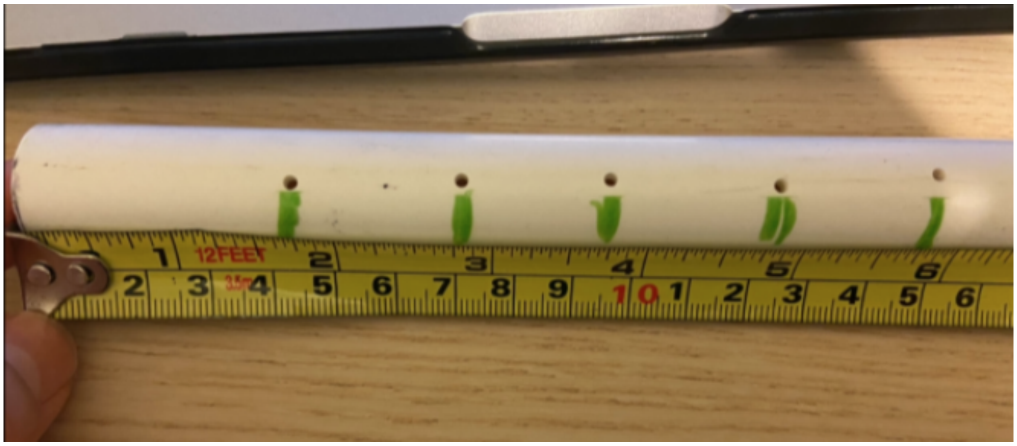
For this section we are working entirely with ½” PVC piping

1. Assemble the base of the pipelines



   a. From left to right
      i. Take the 2’ section of ½” PVC and cement it to the 4-way connector
      ii. Cement the 6” sections of ½" PVC to the 4-way connector as shown
      iii. Cement the 90-degree elbows to the ends of the 6” pipes (want this to be as straight as possible to avoid extra deflection or pipes popping out)

2. Drill holes in the rest of the PVC
   a. For the (6) 4’ sections and the (3) 3’ sections, mark a vertical line 1.5” from each end of the section. From these points, mark each inch along the pipes. Drill a hole at each line using the 5/64 drill bit



The markings do not have to be exact but try to have the holes be in a straight line (we found that using a piece of tape as a guide helped). Crooked holes cause the water to spray at an angle

3. Cement valves and end caps
   a. Take 3 of the 4’ sections and cement a ball valve to one end of each section

   b. Cement a ball valve to the end of each 3’ section

c. Cement an end cap to one end of each 4’ section remaining

This makes it easier to disassemble and reassemble the system at the end of each season (less likely to lose parts, ensure things are in the correct order)

4. Assemble the system

    a. Each line of the pipe is a 4’ section, 3’ section, then another 4’ section. Because the endcaps are cemented, there is only one way to connect the system

b. Attach the pipelines to the pump and add supports where needed

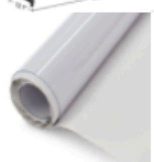
Appendix F: Bill of Materials Recommendations

This is an excerpt of the finalized bill of materials the sponsors will have.

Tools

Photo	Description	Quantity per package	Quantity Needed	Price ea	Price total	Suggestions
	Bolt cuters/saw	1	1	$ 14.98	$ 14.98	something to cut extra metal. adding under assumption building from scratch. could also secure extra metal and cut with a rotary cutter
	Drill	1	1	$ 79.00	$ 79.00	need for both aspects of the project
	Drill bit set	14 piece (drill bits only, not drill)	1	$ 14.98	$ 14.98	includes the 5/64 drill bit needed for the sprinklers. for the blue bucket we used small holes to carve a large hole for the spout (alternatively could get a spade drill bit set see below)
	Spade drill bit set	14 piece (drill bits only not drill)	1	$ 29.98	$ 29.98	Easier to drill large holes, optional
	rotary cutting bit	1	1	$ 7.48	$ 7.48	For cutting slots in the plastic basket
	pvc cutter	1	1	$ 24.98	$ 24.98	cuts up to 2 inch PVC (should be good for whole project). alternatively could use a saw

Area 3: Drying

	trays for washing and drying (plant tray)	1	10	$ 5.50	$ 55.00	durable, would need more holes added (see alternative below) 15.94" W x 22.83" L x 2.75" H	[illegible]
	trays for washing and drying (breadtray)	1	10	$ 11.49	$ 114.90	26" L x 22" W x 6" H	[illegible]
	slanted metal rack for drying	1	1	$ 59.99	$ 59.99	would need plastic lining (designed for shoes, but more afforable than resturant shelves)	[illegible]
	plastic sheeting	54" by 27 yards	1	$ 74.00	$ 74.00	Cut to size based on trays selected. To add extra length and support in the back of the rack, could glue rulers/meter sticks/paint sticks from hardware store under the shelves to help support	[illegible]