# Water Reuse System for Crop Wash Station

Final Report D-LAB II

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# 1.0 Design Brief

Currently, the New Roots Farm in West Sacramento drains their water to the soil after washing crops such as potatoes, radishes, lettuce, and other crops. Instead of disposing of the water as runoff in the dirt, our client would like to repurpose the water back into the crop wash station. This will be done by means of sediment removal, filtration, and UV sanitation. A water reuse system is essential to reduce the amount of water consumption. To come up with a conclusive model, our team reviewed the D-LAB I report and consulted with Laura Reynolds (New Roots Outreach and Educational Specialist). Eventually, we came up with a preliminary design that worked in real-time for the farmers to use nearly instantly. After conversing with Maureen Kinyua, we found out that it is not feasible to have a real-time system and decided to transition to a batch-based storage system.

The client is the International Rescue Committee (IRC), they provide opportunities for refugees, asylees, victims of human trafficking, survivors of torture, and other immigrants to thrive in America. In Sacramento and other offices across the country, the IRC helps them to rebuild their lives. One avenue through which they do this is through the New Roots program where refugees can learn how to farm and eventually grow crops to be sold for profit.

This project aims to design a low-cost water reuse system based on natural resources and an innovative UV chamber. The goal is to design a crop water reuse station that suits the client's needs. Another goal is to investigate relevant prior art related to water re-use and filtration. Since there is a time restriction of one quarter, we will only prototype for the sedimentation and filtration system, meaning the stage before the UV sanitization. The target audience is the New Roots farmers and hopefully, our project will expand to other local farms.

# 2.0 Design Specifications

Before coming up with a design schematic for our system, we must take into account the specifications required to deliver an adequate model. The following specifications were provided by the D-LAB I report.

## 2.1 Considerations

**Technical**

The Technical considerations that were taken into account were ease of use, compatibility with the existing infrastructure, usage of the ultraviolet purifying chamber, and pressure/energy requirements. We had to make sure our prototype would fit underneath the crop wash station while serving its purpose. Our design was also limited by the ultraviolet chamber's specifications such as the flowrate and turbidity. The pump used in our system needed to pump 5 feet of water to our storage tank.

**Environmental**

The Environmental considerations consisted of safety (low risk of cross-contamination) and water use reduction. We didn't want the repeated addition of chlorine to affect the crops being washed. Also if the reused water were to get drained, we had to make sure the chlorine concentration wouldn't affect the surrounding soil. Water reduction is the whole purpose of our design.

**Economical**

The Economical considerations that were evaluated were minimizing cost (upfront and operational/maintenance), added value, and amount of the grant provided to the project. We wanted to lessen the overall water bill the farm was paying to the city but to do that, we needed to account for the materials we were using. The prototype would be a new addition to the farm, hopefully bringing more local farmers to try our system. The $3000 grant provided for our testing and prototype building. Thankfully, we managed to save most of that grant to be used for the next group to work on the project.

**Social**

Social considerations that were taken into account were providing a learning opportunity and minimal upkeep. Our design can help teach the farmers something new such as how a filtration system work, flow rate of fluids, effects of turbidity, bacteria growth, and pressure head. These learning skills will directly correlate with other learning outcomes the IRC is teaching the farmers.

## 2.2 Design Ideas for Crop Wash Station

The D-LAB I report suggested 5 ways to reuse water from the crop wash. Using an evaluative matrix, our team decided that the best way to mitigate water usage was to deviate the water to furrow irrigation.

Table 1. Evaluative Matrix

| Option | Performance: Food Safety | w | Initial Cost | w | Ease of Use | w | Performance: Amount of Water Reused | w | Learning Opportunity | w | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Crop Wash** | 3 | 5 | 2 | 4 | 3 | 3 | 5 | 4 | 5 | 3 | 67 |
| **Drip Irrigation** | 4 | 5 | 2 | 4 | 3 | 3 | 5 | 4 | 3 | 3 | 66 |
| **Furrow Irrigation** | 4 | 5 | 3 | 4 | 3 | 3 | 4 | 4 | 4 | 3 | 69 |
| **Rain Garden** | 5 | 5 | 4 | 4 | 5 | 3 | 2 | 4 | 3 | 3 | 73 |
| **Hand Wash** | 3 | 5 | 3 | 4 | 3 | 3 | 4 | 4 | 5 | 3 | 67 |

Table 2. Pros and Cons of Ideas

| **Pros** | **Cons** |
|---|---|
| **Crop Wash** | |
| ● It would be easy to filter reused water back into an already existing system<br>● No water is wasted in the closed-loop system | ● High maintenance and installation cost<br>● Requires water storage and pump<br>● Stored water has to be protected from mosquitos<br>● Requires water to be pressurized<br>● Filtration required due to high food safety requirement |
| **Furrow Irrigation** | |
| ● Repurposes water to create more crops<br>● Gravity fed system which reduces the need for water storage of pumps<br>● Water does not need to be pressurized as much as crop wash<br>● Filtration of soil particles not required | ● High Cost<br>● Excessive crop wash could cause flooding<br>● The very high pressure needed<br>● Other contaminants may be picked up from the soil that isn’t part of the filtration design |
| **Rain Garden** | |
| ● Ease of Use<br>● Extremely simple because it doesn't require UV filter or pumps<br>● Low food safety requirement because water is not used for growing or processing food | ● Only for aesthetic purposes<br>● A rain garden is only marginally better than letting water flow to bare ground<br>● Excessive crop wash could cause flooding |

After speaking with Laura Reynolds, she had wanted us to repurpose the water back into the crop wash station instead of for irrigation or rain garden. This decision directed us to look at prior art ideas that included closed-loop filtration systems and viable sediment tanks.

## 2.3 Criteria, Metrics, and Target Values

After reviewing prior art related to water reuse systems and discussing with our client Laura, we came up with the evaluative criteria for the design. The criteria are given in the table in this section.

Table 3. Table of criteria and metrics

| **Criteria** | **Qualitative/ Quantitative** | **Testing Procedure** | **Target Value** | **Metric / Functional Unit** | **Source** |
|---|---|---|---|---|---|
| Performance | | | | | |
| Water turbidity[1] | Quantitative | Take a sample of the water after the filtration process and test its turbidity | <5 | NTU (Nephelometric Turbidity Unit) | USDA |
| Water flow rate[1] | Quantitative | Measure the flow rate of the water after the filtration process | <2 | GPM (gallons per minute) | Prof. Younis |
| The proportion of water reused | Quantitative | Measure the amount of water that is reused and divide it with the amount of water used for crop wash | >50 | % | The water to be reused at least once |
| Economics | | | | | |
| Payback period | Quantitative | Calculate the time required for the accumulated money saved due to water saved to cover the cost required to produce and run the system | <2 | Years | Typical payback period |
| Fabrication cost | Quantitative | Add up the cost of materials and labor for prototypes and the final product | <3000 | USD | Amount of grant |
| Operation and | Quantitative | Add up the cost of electricity | <200 | USD per year | Client |

[1] It should be noted that the criteria on water quality are based on water before entering each UV chamber, but not water that comes out of the whole system.

| | | | | | |
|---|---|---|---|---|---|
| maintenance cost | | required and components to be replaced per year | | | |
| Ergonomics | | | | | |
| Ease of use | Qualitative | Conduct a focus group of farm workers reporting on whether it is easy to use | >4 | People say it is easy to use on a scale of 1 to 5 (on average) | Client |
| Maintenance time | Quantitative | The time required for maintenance (e.g. changing the filter, clearing sediment in settlement tank) | <10 | Minutes per month | Client |

# 3.0 Methodology

## 3.1 Background research

In order to design a system that best suits our client's needs and utilizes the UV chamber, we did some research on the farm and specifications of the UV chamber.

### 3.1.1 Information about Farm and Crop Wash Station

We visited the farm twice to collect information about the crop washing process, water turbidity and other information. We also gathered information from our client Laura the farm manager Ram, through email and in person.

**Crop wash station details**

Harvesting and crop washing happen twice a week, on Thursday and Saturday. It starts in the morning at about 8:30 and usually lasts for two hours. The wash station is used solely for washing crops and farmers are told not to use it in any other ways. The farm grows a wide range of crops, including cleaner leaf crops like lettuce and dirtier root crops like potatoes and carrots.

Fig. 1: Crop wash station in New Roots Farm (photographer facing west)

The current crop wash station is divided into 3 parts: a mesh grid at the south end for spraying, 6 sinks in the middle, and a mesh grid at the north end for drying crops. Water from the mesh grids drops directly to the ground below and that in the sinks is collected in a PVC pipe and also discharged to the soil.

Before starting the crop wash process, a farmer would remove large chunks of soil particles on the crop by hand. Currently, the washing process consists of 2 steps: spraying and dipping. In the first step, a farmer puts the crops on the mesh grid on the left, and uses a hose to spray water to the crops. At the same time, soil particles is removed by rubbing the crops with a brush or hand. In the second step, crops are dipped into pre-filled sinks. There are 3 sinks on each side, and crops are dipped into each of them. So the water in the south sink is the dirtiest and that in the north sink is the cleanest. After washing, the crops would be placed on the mesh grid to dry. It should be noted that not all crops go through both steps. For example, potatoes are only sprayed and lettuce is only washed by dipping.

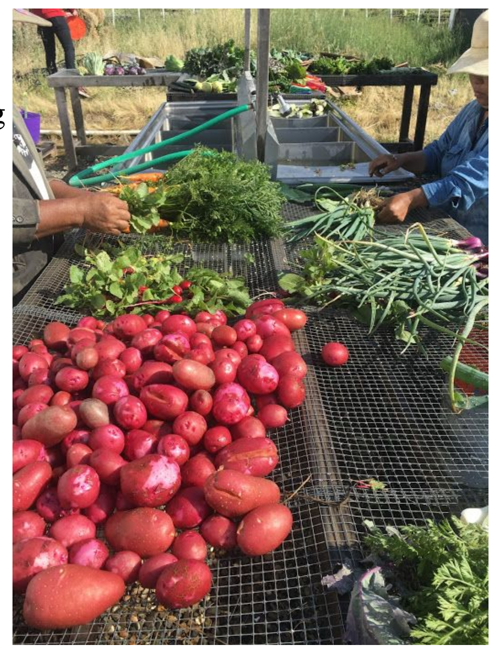


Fig. 2: Crop wash station (photographer facing north)

The crop wash station has only one hose, which delivers water from the city. Water comes out of the hose in 6GPM. 1.37 minutes is used to clean potatoes from figure 3 to figure 4, that corresponds to 2.2 gallons of water.

Fig. 3: Potatoes before spraying

Fig. 4: Potatoes after spraying

The water in the sink is replaced when farmers think the water is too dirty. Each sink is filled up to about 10 gallons and is drained in the speed approximately every 30 minutes in the flow rate of 6GPM.

The turbidity of water collected after spraying is 240NTU. We also measured the turbidity of water in the dirtiest sink to be 7NTU, but it should be noted that the water at that time was not yet at turbid enough for replacement.

**Extra considerations**

Currently, only one hose is present in the wash station. Ram expressed interest in installing a sprayer in the spraying area so farmers do not need to hold the hose while spraying. He also plans to install taps on each sink. Our design should try to incorporate or be compatible with these improvements.

According to Laura, an ideal washing process should not involve sitting water in sinks because there is if one contaminated crop is dipped in the water, all the crops washed in the same water will get contaminated. But currently, farmers fill up sinks for washing in the second step. That might be due to the lack of extra hoses, or the fact that filling up sinks can save water. We should consider whether to design for the ideal washing process or the current washing process that the farmers are used to.

The farm practice organic farming, so no chemical fertilizers or pesticides are used. However, organic pesticides including diatomaceous earth, neem oil, Sluggo are used. There may be pesticide residue on crops and they might enter the crop wash water. If water is reused in a closed loop system, the concentration of them would keep increasing. So more research should be done on how much pesticide is present in the crops and what are the safety levels.

### 3.1.2. Information about UV disinfection chamber

Professor Bassam Younis in UC Davis has been cooperating with the farm for a while. He designed a UV disinfection chamber that we can use in the crop wash station. We visited Prof. Younis and reviewed his paper on the system to gather information about the UV chamber.

Fig. 5: UV disinfection chamber with 1 UV lamp

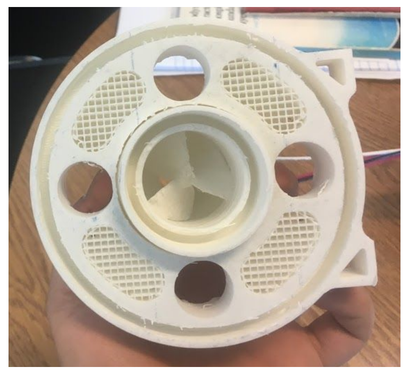


Fig. 6: 3D printed inlet with static guide vanes in the middle

In his design, the UV lamps are located outside the water tube and do not come in contact with the water directly. The inlet of the chamber have some static guide vanes, which make the water swirls inside the chamber. This increases the water's exposure to UV light and creates a self-cleansing mechanism for the walls.

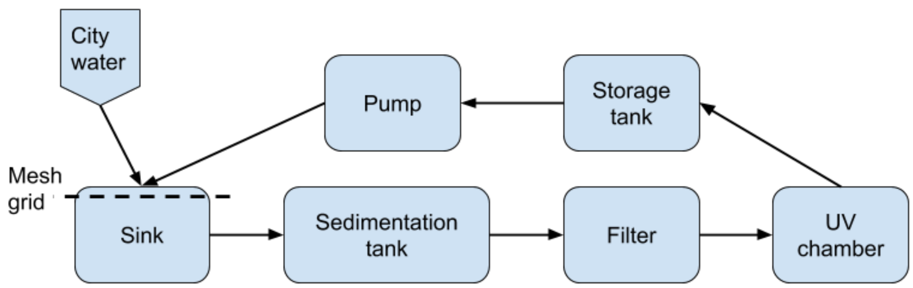
The UV chamber consists of a quartz tube for water flow and 3D printed parts for creating the swirling motion and holding the UV lamps. The UV chamber can accommodate up to four UV lamps. According to his paper, each has a rating of 30W. Water through each chamber should not exceed 2 GPM.

## 3.2 Prototype Designs

The design of the system evolved over the course of the experiment as ideas were tested and experts consulted.

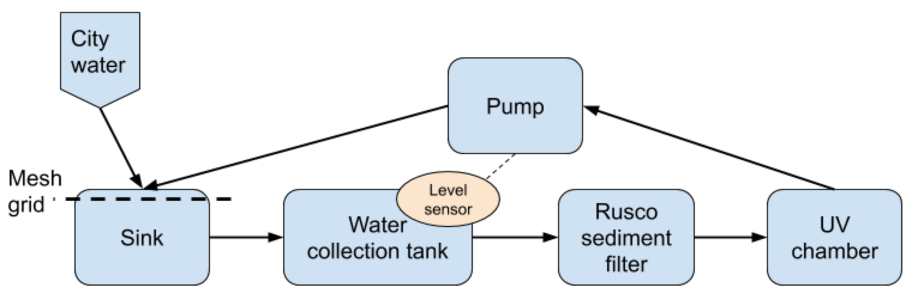
**Design #1**

In the initial design, we decided to combine the spraying and dipping process together to make the water capturing process easier. The initial design consisted of capturing the water and passing it through a sediment tank and filter system. This water would then pass through the UV tube, into a storage tank, into a pump, and then back to the system.




**Design #2**

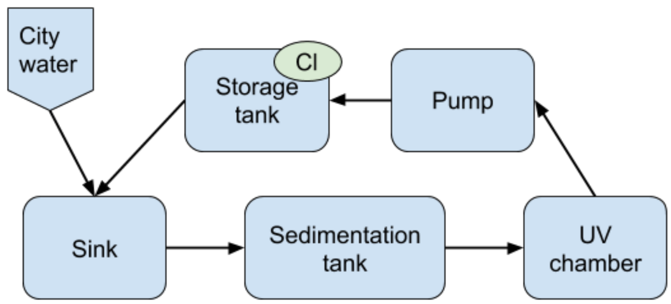
During a meeting with Prof. Younis and Laura, we decided to do a real-time reuse system so that the water after UV sanitization would not be contaminated during storage. Hoping to achieve a real-time system, the second iteration of the design removed the sedimentation tank as the settling time may be too long to ensure real-time reuse. A water collection tank is inserted after the sink, and a level sensor would trigger the start of the system when there is a certain amount of water. A sediment filter called Rusco Sediment Trapper was found online,  was thought to remove particles fast enough to allow the farmers immediate use of recycled water. The storage tank was also removed.




**Design #3**

The rusco sediment filter used in Design #2 proved to be ineffective in removing the majority of particulates found in the water. Crop wash water from the student farm was passed through the filter with a #100 mesh. The filter removes larger particles and bugs from the water but did nothing to remove the very small particles. This was concerning as the small particles had a very large influence on turbidity. Rusco provides mesh with smaller holes, which may remove the smaller particles. But they may get clogged up quickly and require frequent changing. As a result, Professor Kinyua was consulted for advice on how to properly remove the small particulates by means of sedimentation. She maintained that a real-time system was not feasible because sedimentation takes a long time.

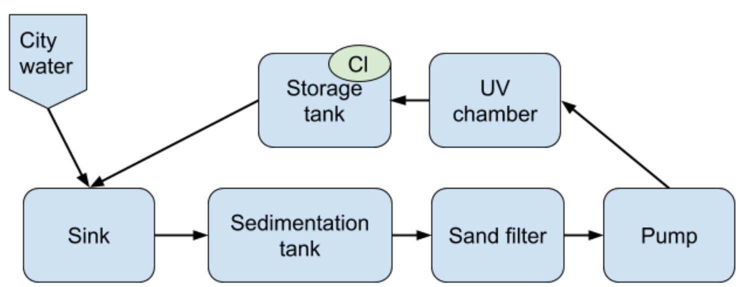
Design #3 focused on a large sedimentation tank, to allow the particles to settle and for the clear water to be collected from the top. The storage tank was added and chlorine would be used to keep stored water from being contaminated. We also decided to only prototype for the collection of sink water but not the spraying water.




**Design #4**

The sediment tank prototype constructed for Design #3 proved to take too long for the water to settle to acceptable turbidity. We tried to recreate the farm's crop wash water by adding soil collected from the farm into clear water, until the turbidity reaches 240NTU. The turbidity of the water was then measured over 4 days by a DIY turbidity tester. [X] It was found that 3 days are required for the water to reach 5NTU, the turbidity required before entering sanitization according to the WHO.

Design #4 was changed to include a sand filter in addition to the sediment tank. The idea is to let the water settle for 1 day and then use the sand filter to remove the remainder of the sediment. The pump was moved to before the UV chamber, so we can control the flow rate into the UV chamber.




## 3.3 Materials

| Part | Dimensions | Use |
|---|---|---|
| PVC Tubing | Inside Diameter: 1.5'',1'',¾'' | Transport water in the reuse system |
| Utilatub | Volume: | Act as a model crop wash sink and as a sediment tank |

| | | |
|---|---|---|
| Rusco Sediment Filter | ID: 1’’ | FIlter out particulates |
| Pump | | Move water through the filter & UV tube |
| 5 gallon bucket | | Contain the sand filter |
| Sand | | FIlter out sediment |
| Gravel | | Support Sand |
| Wire mesh | | Separate sand and gravel in filter |

## 3.4 Design of System Components

### Sand Filter Construction

1. The materials were collected:
    a. 5 gallon bucket with a spigot attached on the bottom
    b. Gravel
    c. Sand
    d. Mesh
2. The gravel was prewashed in a sink until the wash water was clear
    a. Note: The sand was not washed as the bag said ‘Pre-Washed’ but in hindsight the sand should also be washed at this step
3. 2 circles that fit the size of the bucket was cut out from the mesh
    a. Note: The mesh should hold the sand in place, but the hole size of the mesh we used was too large.
4. The bucket was filled with 15% gravel by volume
5. The mesh was placed on top of the gravel layer
6. 75% by volume was filled with the sand
7. The second circle was placed on top of the sand
    a. This helps to prevent the erosion of the sand by the force of water inflow
8. The remaining 10% of the bucket is left for water collection


Fig. 7: Prototypes of different parts of our design (Silver sink: sink for crop wash, White sink: sedimentation tank, Blue bucket at the bottom: sand filter, White tube on table: UV chamber, White bucket on the right: Storage tank)

# 4.0 Results and Discussion

## 4.1 Rusco Filtration

The Rusco filter did not adequately remove enough particles to be considered effective. The larger particles were removed but the minute particles that made the water brown were not removed. It is important to note that a 100 mesh filter was used while mesh sizes up to 1000 were available.[2] A Rusco filter solution may only work as a series of filters with each successive filter having a higher mesh filter. However, this solution only works if the finest filters are able to remove the microscopic particles effectively. In addition, a series of filters would require regular maintenance to clean them out or else the system would cease to work.

## 4.2 Sediment Tank

The time required by the sediment talk for adequate settling varied based on the concentration and composition of soil in the water used. Root vegetables such as carrots or potatoes generated very dirty wash water (240NTU) that 3 days to settle to an acceptable turbidity. The leafy vegetables that were dunked in the sink such as lettuce generated clearer water (estimated to be 10NTU) and as a result the sink water should take less than 1 day to settle. The 3 day figure was used for future design considerations as it was considered the worst case scenario. With this

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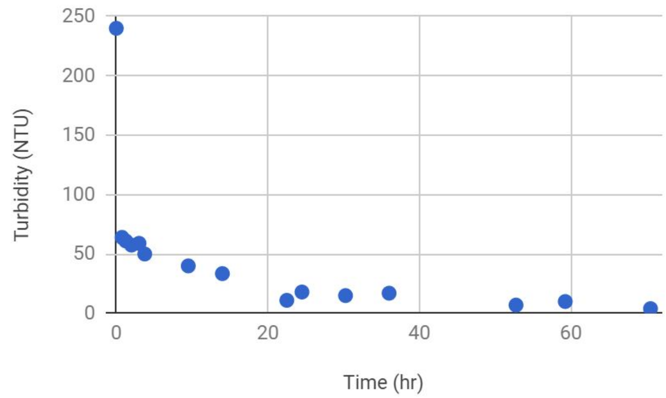
[2] The larger the mesh # the smaller the particles it can filter out

figure in mind, it was concluded that a real-time system may not be viable due to the time required to settle.

The graph below shows the turbidity of water over 3 days. It shows that turbidity drops quickly in the first hour as most of the larger particles settle quickly. The remaining small particles settle slowly over the next three days.




## 4.3 Sand Filtration

The sand filter constructed and tested did not work as intended as the turbidity of the water did not significantly increase after going through it. The mesh used to separate the gravel and sand was not fine enough and as a result it did not adequately keep the layers separated. Pre-washed sand was used but it was found that the sand still contains a large amount of small particles. We tried to wash some of the sand, but a huge amount of water was required, defeating this project's purpose of saving water. We should look for sand that is designed for water filtration (with absence of very fine particles). The first trial increased the turbidity of the water as the sand was not clean enough to remove contaminants and added its own.

It was found that the 5 gallon bucket sand filter outputted a flow rate of 0.35 GPM implying that 4 must be used in parallel to increase the flow rate to 2 GPM. However, this might vary with the type of sand used and the height of the filter.

## 4.4 Water Collection

A visit to the farm to observe farmer's washing habits challenged the initial assumptions made concerning the flow rate of the system. Initially, the assumed input flow rate would be 6 GPM as that is the output rate of the hose connected to the city water supply. It was envisioned that the farmers would wash their crops in the sink and thus the flow rate would be conserved. In actuality, the farmers fill the sink up to dunk the crops in and then drain it when it gets too dirty. This changes the flow rate assumptions as a batch system was needed to handle the draining of the sink. An accumulator tank would need to be implemented to accept water at the higher flow rate and output it at 2 GPM for the UV chamber.

### 4.5 Pump

The pump did not undergo enough testing to make any significant conclusions from them. The pump purchased proved to be a little difficult to operate as it needed to be run with water in the line. This means that the pump would have to be below the holding tank in order to run properly. However, the connections between the in and out valves on the pump and the hose were not snug enough and air was able to enter. Because of this, the pump was not able to pump water through any of the components in the system. The input of the pump was placed in a tank of water to demonstrate that it did work and the difficulty in pumping originated from the connections and not the pump quality.

### 4.6 UV Chamber

Even though the UV chamber was to be included in the design of the system, a physical model was not received and so a prototype was made. The 3D printer files for the end of the chamber were obtained via Professor Younis' research paper and printed. These parts were attached to a 1 ½'' PVC pipe that was approximately the length of the actual chamber to model the pressure loss through it. Unfortunately, as the pump was unable to be setup properly, the head loss was not found for this prototype. As a result, the design scope was reduced to not include the head loss through the tube and instead only focused on delivering the 2-3 GPM required by the chamber.

## 5.0 Conclusions

This project found that a real-time water reuse system is not feasible for the farm. The sedimentation time required to turn the wash water into water with acceptable turbidity took 1-2 days. Even though sedimentation took time, it was cheaper than a series of filters which would get clogged very easily. This means that a real-time system would be expensive and high maintenance. The batch system with a holding tank may be more useful as the recycled water can be used for crop wash or a hand washing station.

## 6.0 Recommendations

The first recommendation when designing the next iteration of the system is to test and modify sand filters to ensure that they can remove enough sediment so the water can reach an acceptable level. A possible solution is to ensure the sand & gravel is completely clean before use or try other filtration media such as activated carbon.

The second recommendation is to research possible ways to chlorinate water for long term storage. Since water held in a tank for a long period of time is susceptible to algae growth, chlorine needs to be added to ensure sanitation. However, care must be taken to dispense the correct amount as too little could mean disease and too high could mean poisoning someone.

The third recommendation is to install a water monitoring system to determine how much water the crop wash system uses. A flowmeter such as the one from adafruit is an inline meter that records flow rate as electrical signals.[3] An arduino microcontroller can be attached to it with a small power source and it can be left to gather data over a span of time.[4] It may be difficult to implement and prevent overheating but it may put the crop wash water usage in perspective with the water used for irrigation.

In designing a usable batch system, special care must be taken in ensuring that the flow rate captured does not result in overwhelming the system. The flow can be diverted to a settling tank and switched to another tank after a set collection tank. This is so each tank has 1 day to allow settling before the water enters the sand filter. Once the water exits the sand filter, passes through the UV chamber, and is stored in a tank, it must be presented in such a way so the farmers will be inclined to use it. If the reused water is to have a similar pressure to the city water, a large pressure head is required. This can be achieved by either an additional pump or a very large height, both which are unfavorable. A recommended solution is to have a low pressure head but to use the water to fill up the sink for washing which would not need high pressure. Lastly, farmers must be convinced to use the reused water as well as city water or else the system will go unused.

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[3] Adafruit Liquid Flow Meter - Brass 1/2" Nominal Threaded
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# 8.0 Appendix

**Appendix 1. D-LAB I Report - Evaluation of Treatment Options for Reusing Water Generated from a Crop Wash Station at New Roots Farm**

**Appendix 2. D-LAB I PowerPoint - Crop Wash Station from Drain to Faucet**

**Appendix 3. Professor Younis' Research Paper - A Novel System for Water Disinfection with UV Radiation**

**Appendix 4. Experimental data on turbidity test**

| | time | Time after addition (hr) | height of water (cm) | corresponding turbidity (NTU) |
|---|---|---|---|---|
| Before addition of soil | | / | <118 | <3 |
| Day 1 | 12:45 | 0 | 6.7 | 240 |
| | 13:30 | 0.75 | 15.5 | 64 |
| | 14:00 | 1.25 | 16 | 61 |
| | 14:45 | 2 | 16.7 | 57.5 |
| | 15:45 | 3 | 16.4 | 59 |
| | 16:30 | 3.75 | 17.9 | 50 |
| | 22:15 | 9.5 | 20.4 | 40 |
| | 2:45 | 14 | 23.8 | 33.5 |
| | 11:15 | 22.5 | 50.9 | 11 |
| | 13:15 | 24.5 | 36 | 18 |
| | 19:00 | 30.25 | 40.7 | 15 |
| Day 2 | 0:45 | 36 | 38.2 | 17 |
| | 17:30 | 52.75 | 67.3 | 7 |
| Day 3 | 0:00 | 59.25 | 53.4 | 10 |
| | 11:15 | 70.5 | 97.5 | 4 |
| Day 4 | 12:15 | 95.5 | <118 | <3 |