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Design of a Shallow-Aero Ebb and Flow Hydroponics System and Associated Educational Module for Tri Cycle Farms

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Project Summary

Tri Cycle Farms, whose main mission is to reduce food insecurity in their community, is a non-profit urban farm in Fayetteville, Arkansas. The "Tri" in their name refers to the three parts of their foundation: giving a third of their yield to volunteers, giving a third to local food pantries, and selling a third to sustain the farm and demonstrate the economy of local food production. They want to expand on the third part and have a vision of building a hydroponic greenhouse with the intention that it will create more crops to sell and give, as well as provide more educational opportunities for members of the local community. The framework planning for this greenhouse was done in part by Sarah Gould and Laura Gray, as part of their honors theses in 2019 where they designed the internal layout, one hydroponics system, and chose the most profitable crops (Gould, 2019 and Gray, 2019). My objective for this work is to pick up where they left off and design a different hydroponics system to be implemented in the greenhouse. In addition, I will design an educational program for students to experience when they visit the farm. I utilized the engineering design process to size the layout and water return for a system of hydroponics called Shallow-Aero Ebb and Flow (SAEF), which is a new technique that strengthens the root system and is versatile for many plants (Chidiac, 2018). I then used this technical information to begin Tri Cycle's mission of "grow growers and farm farmers" to produce a method to communicate to elementary-age students. I created a plan for an interactive prototype to demonstrate relevant principles of the SAEF system that includes an activity and reflection sheet for students to complete after the tour. The educational goals I used to create the module were set by the Arkansas K-4 Science Standards (Arkansas Department of Education, 2016) and were applied to a lesson to teach students that hydroponics is a viable solution for improving food sustainability. Tri Cycle can use these plans for the implementation of their hydroponic house and educational outreach.

Introduction

Feeding the world is an important task that will only become more challenging as global population increases and the rate of climate change accelerates (Ehrlich et al., 1993). This global problem may be easy to ignore because it either seems overwhelming or does not affect those in our community. In reality, it is estimated that 1 in 6 people struggle with hunger in Arkansas, including 1 in 4 children (Feeding America, n.d.). These staggering numbers are what prompted Tri Cycle Farms to be founded as a means to combat food insecurity in the area and mitigate the large global problem by solving local community problems one-by-one. A registered 501c-non-profit, their mission is "growing community through soil". They provide fresh, healthy food for the community while at the same time teaching citizens how to grow it themselves. This was the inspiration for their vision of a hydroponic greenhouse project that will provide a higher crop yield per year, and make a goal profit of $70,000 annually, which they can use to hire a full-time staff and buy more supplies for the farm. The goal of this greenhouse is to have a working system of five different hydroponics systems all growing different crops, with an eventually connected storage area and office space. Much of this internal design has been completed by Gray (2019) and Gould (2019), with the chosen hydroponic systems being Deep Flow Technique, Nutrient Film Technique, Dutch Bucket System, Strawberry Vertical Walls, and Shallow-Aero Ebb and Flow (SAEF). The optimal crops were chosen to be lettuce, tomatoes, strawberries, and basil, which were selected based on sustainability metrics and profitability. The Dutch bucket system has been designed for this greenhouse, leaving four systems in need of sizing. I chose to design the SAEF system due to its interesting operations and capabilities.

The other hope Tri Cycle has for their hydroponics house is to expand its educational program for teaching the community the sources of food and how to grow it. This is an expansive goal, as their programs range from field trip tours for elementary students, volunteer programs with university students, to farming and gardening programs for adults. All of these are equally important, but I chose to focus on elementary students taking field trips to the farm. The goal was, using Arkansas Science Standards as a guide, to help them understand that plants do not necessarily need soil, that hydroponics is useful, and the role it plays in food sustainability.

Literature Review

Hydroponics

Hydroponics refers to the practice of growing plants without soil, relying instead on the circulation of water to provide necessary nutrients for plants. This practice is not new. Evidence of hydroponic farming can be found from 600 B.C. Mesopotamia (Turner, 2008). Even though it has a long history, hydroponics can provide a promising future in sustainable farming. The nature of hydroponics has been proven to use 90% less water than traditional practices, produces a higher yield in shorter amounts of time, uses less space, and has more metrics to precisely control resources such as lighting, atmospheric conditions, and nutrient/water delivery (Popsop, 2015). Other benefits include more predictable growing conditions and a lower probability of damaging microorganisms present compared to soil (Chidiac, 2018). In the age of rapidly growing human populations and changing climate, the world is going to need a method to consistently and reliably produce food. This directly relates to Tri Cycle Farm's mission and their plans to build a hydroponic greenhouse, with the goal they will be able to sell high quality, uniform produce. The following background information is presented on each of the five selected hydroponics systems for the Tri Cycle greenhouse (Chidiac, 2018).

Nutrient Film Technique (NFT) is the oldest and most common hydroponic system. It involves two to three millimeters of constantly flowing water across the plant roots, which develops a film of nutrients which the plants absorb. This requires a continuous but small water pump for circulation, and plants receive oxygen through diffusion through the water. Common problems with this system include clogging pumps and difficult to control water temperatures since the high surface area of the thin layer of flowing water reaches ambient temperatures quickly. A common example of an NFT system is shown in Figure 1.

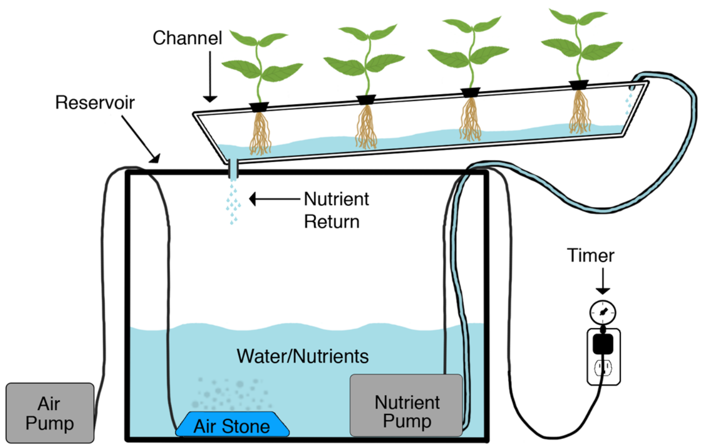

Figure 1. Example layout of Nutrient Film Technique (NFT) (DIY Aquaponics Australia, 2017).

Deep Flow Technique (DFT) includes a system of deep water with the plants residing on the surface. This is commonly seen in rice production or nature in swamps or ponds where algae and bacteria are the primary producers of oxygen in the water. These systems are cheaper than other techniques, and water temperature is easier to control. However, because of the deep water with most not being exposed to the surface, oxygen levels can become low, requiring monitoring and supplemental dissolved oxygen.

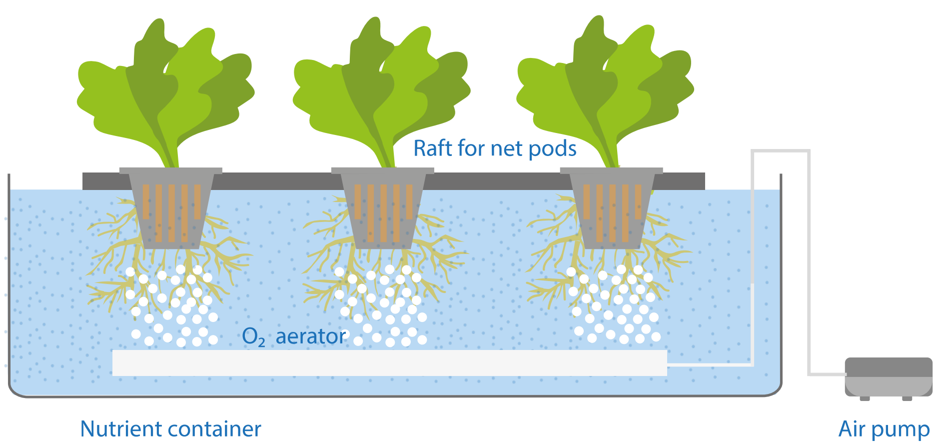

Figure 2. Example layout of Deep Flow Technique (DFT) (Hydroponic Urban Gardening, 2019).

Shallow-Aero Ebb and Flow (SAEF) systems combine shallow irrigation techniques from NFT, raft implementation of floating plants from DFT, and root strengthening qualities from aeroponics. Water is pumped up from a reservoir which floods an elevated shallow tray of plants. The pump is then turned off and water then drains by gravity back down to the reservoir, leaving the root zone exposed. The exposed roots can then take in oxygen. The flooding and draining occur on a timed cycle that is energy and space-efficient, and the constant exposure to oxygen hardens the roots and makes them stronger and more resilient in the case of pump failure. More details of this system are provided in the remainder of this report, and a detailed outline of the layout can be found in Figure 6.

Dutch bucket systems involve components of ebb and flow systems of flooding and draining, but split up the flow into fragmented media beds, mainly buckets, for optimal nutrient uptake. Water flows from a reservoir and is then diverted into different nozzles to be distributed to their respective planters (Figure 3). Separate buckets can be useful for crops that require more nutrients, and can also be useful in managing pests (Storey, 2016). Plants that require more water or nutrients can have the correct amount directed to them without negatively affecting the surrounding plants.

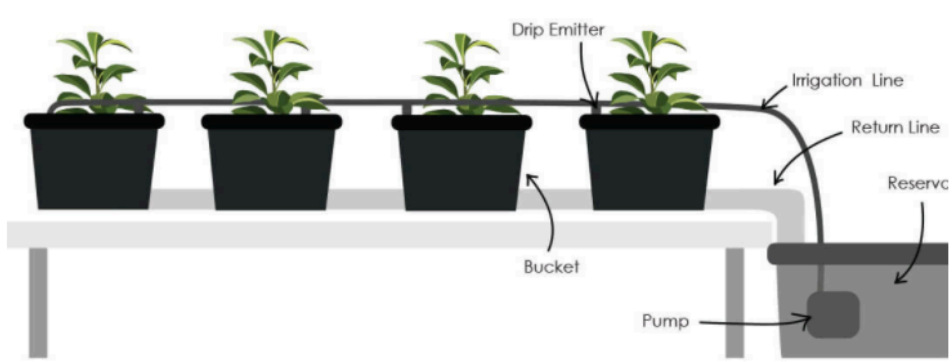

Figure 3. Example layout of Dutch bucket system (Storey, 2016).

Tri Cycle has also planned to implement vertical wall hydroponics to be used for strawberry production. This type of system utilizes gravity to feed the water at the top and allow it to disperse down the wall. It also allows for high-density production per area and can adapt to many different plants (Singh, 2017). Vertical walls also provide aesthetic value to the greenhouse and are easily accessed for harvest.

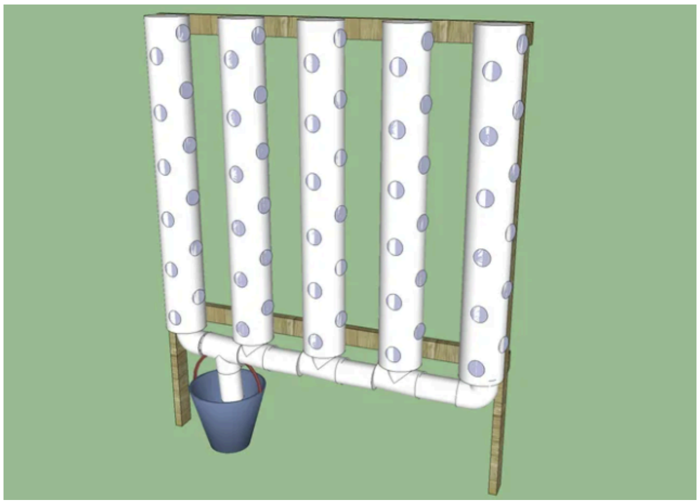

Figure 4. Example of a hydroponic vertical wall planter (3D Warehouse, 2017).

Education Module

When designing a module with the intent of teaching a specific concept to an appropriate audience, decisions must be made about the best approach. The target audience in this project is third through fifth graders, so understanding how they best learn science concepts is important. A study completed in Nigeria found that school-age children were able to learn science and math concepts using a hands-on approach with demonstrations, even before they were exposed to any formal curriculum on the subjects (Ekwueme et al., 2015). In terms of my project, if students who have not been exposed in the classroom to hydroponics or sustainable agriculture practices are given hands-on learning tools at the farm, they could be able to gain meaningful knowledge still. Elementary age children are an important group to educate about agriculture and the source of their food, as this understanding can be a framework on which to place additional knowledge they will gain as they get older to hopefully improve food sustainability for the world around them. Students are willing and able to learn about such concepts, and in response, more STEM curricula are being integrated with agriculture literacy (Vallera, 2019). Any curriculum that is used to teach these concepts should be reflective of the Arkansas K-12 Science Standards (2016) which provide specific goals that each age group should be learning each year. In order to teach third through fifth graders these topics in science, they must have an underlying goal that can be found in these standards (Arkansas Department of Education, 2016).

Engineering Design

Hydroponics House

The designs of the hydroponics systems are based on the internal layout designed by Sarah Gould and Laura Gray in Spring 2019. That layout includes five different irrigation systems designed for different crops: Nutrient Flow Technique, Deep Flow Technique, Dutch Buckets, Strawberry Vertical Walls, and Shallow-Aero Ebb and Flow. The layout of the greenhouse is shown in Figure 5, with dimensions and future additional space. Each one of these hydroponics systems was chosen based on what was best for the proposed crops to sell. Gould and Gray selected these systems and crops, as well as designed the irrigation system for Dutch Bucket systems. This left four different systems to be sized, including the SAEF system, which I designed to grow lettuce in this work. Information for the design was provided by horticulture engineer JC Chidiac, who developed the SAEF system.

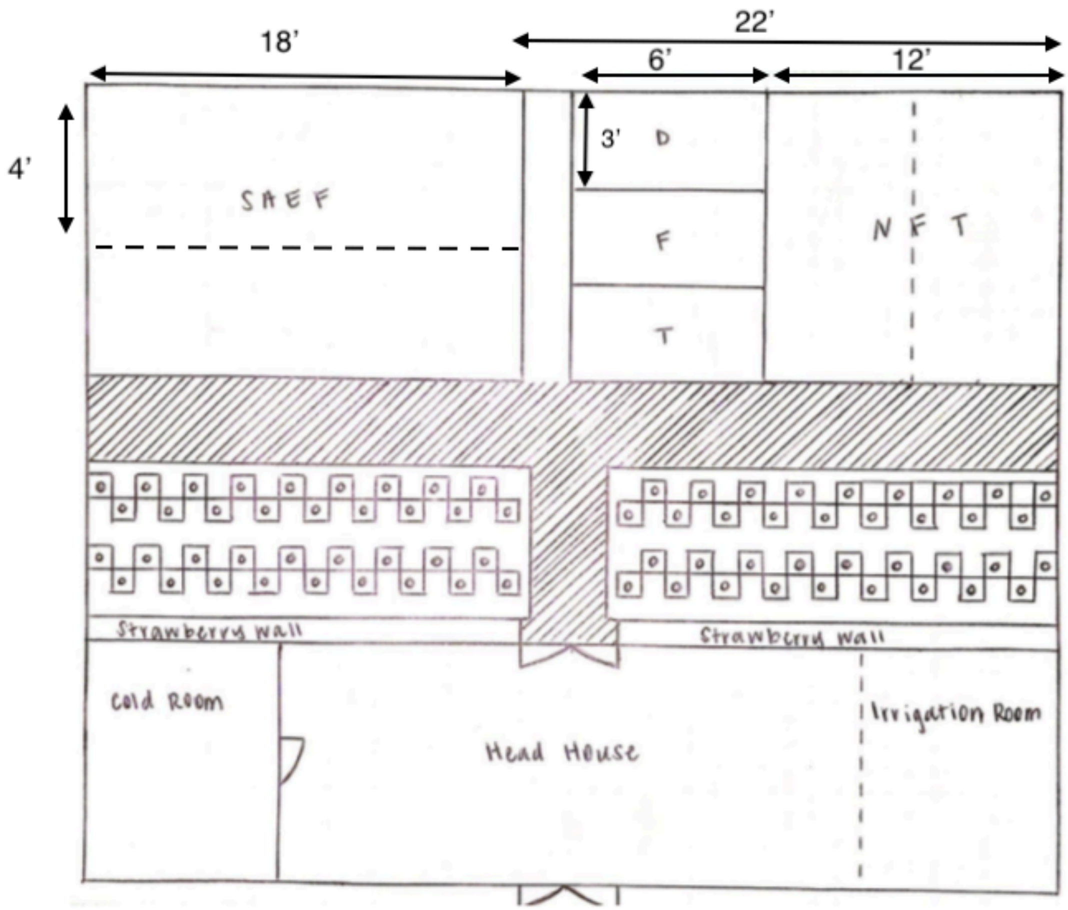

Figure 5. Internal Layout of Hydroponic House for Tri Cycle Farms (Gould 2019).

SAEF System and Requirements

The main concept of the SAEF system is that it uses one of the most common systems of hydroponics, ebb and flow, and creates more durable roots by utilizing a sealed, insulated, cool root zone. Water is pumped over the roots and drained back down into a reservoir on a time interval of approximately 15 minutes. The water contains added nutrients necessary to the plant while draining hardens the roots to make them more resilient if the pumping system were to fail.

The ideal environment produced in the greenhouse will mimic the natural growing conditions in Arkansas as much as possible, so local produce can be grown and sold as traditional local produce was the product market identified by Tri Cycle Farms. The chosen crop for this system is lettuce, and its ideal conditions and requirements for the SAEF system are shown below (Andersen, n.d.):

- Sunny conditions
- pH of 6.0-7.0
- Ambient temperature from 15-21º C
- Water temperature from 18-26º C
- 20% safety factor on water reservoir volume
- Provide flooded roots in 1-5 minutes
- Tray drain of water within 10 minutes

The volume of the reservoir, flooding time, and draining time will be the guiding constraints to size the pipe and pump system. The given dimensions show how the system fits within the greenhouse (Figure 5). The plants are placed on polystyrene rafts that lay on a rectangular flood tray. Water will flood these trays from a reservoir underneath the raised system, where it will gravity drain after the filling cycle is completed. This system will house two identical rafts for ease of maintenance and allow rotation of different crops, but both rafts will operate using the same tray and reservoir.

The required calculations and sizing are as followed:

- Volume of reservoir and flood tray
- Rate of flooding
- Rate of draining
- Size of pipe/tubing

- Size and power requirement of pump
- Lighting requirements

The depth of the plant trays is 0.5 inches, which will provide the optimal amount of water and air to cover the root zone. Since the reservoir capacity will need to be of sufficient volume to spread water to both trays, its capacity will be 2x the volume of one tray, plus a safety factor of 20%. This gives a volume of $7.2ft^3$, (54 gallons, 0.204 m^3). This will be the amount of water that floods the trays and subsequently drains. The next step in the process was sizing the pipe and pump system.

These calculations are dependent on the chosen layout for the system. The relationships between length, height, velocity, and pressure are used to size an appropriate system to achieve the minimum flowrates. These decisions made for the final layout are outlined below (Figure 6), after iterations were done using different parameters.

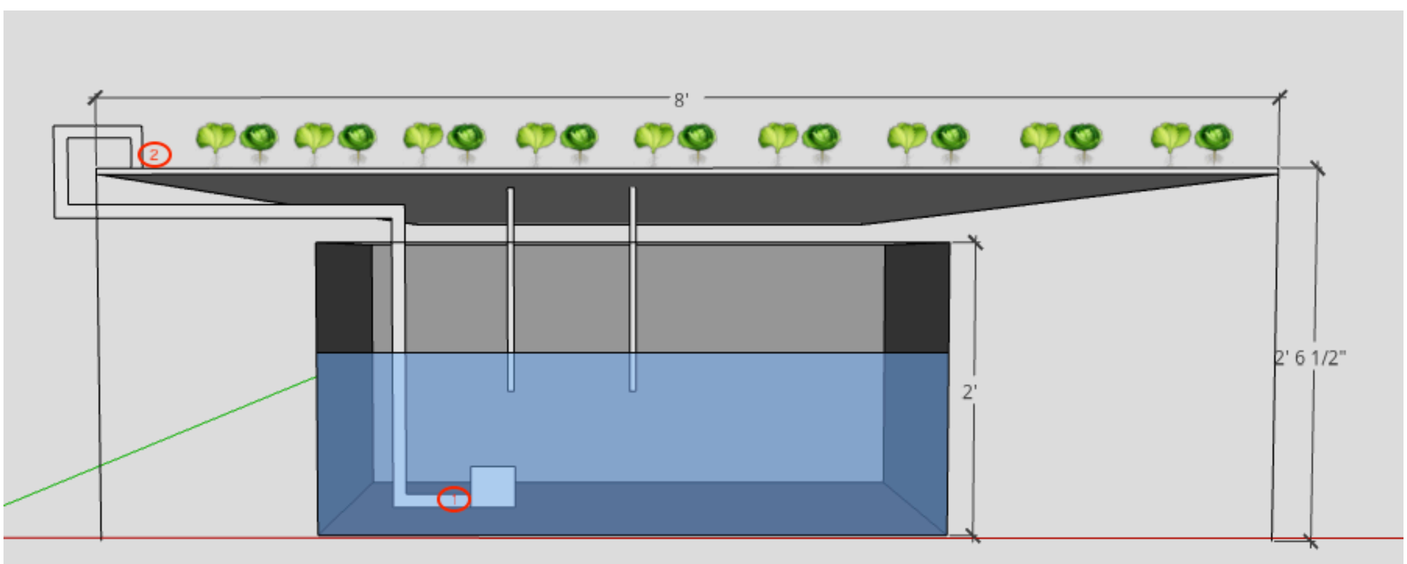

Figure 6. Elevation view of final proposed design of SAEF system growing lettuce. Point 1 and Point 2 are shown for calculation references.

This diagram shows a submersible pump in the water reservoir beneath the raised trays of plants. The trays receive the water from the submersible pump. Since the depth of the trays is only 0.5" the side walls of each tray are too short for tubing to penetrate the side, so the tubing will enter the trays through the top of the rafts. The trays are also equipped with an overflow tube to set the water height, as well as the tube to gravity drain the water. Because of this, the containers are open to the atmosphere, and therefore the pressure difference between them will be negligible. The total pipe length will be 6.86 ft. The pipe material was chosen to be PVC flexible tubing because it is a food-grade material. These parameters will be used to make design decisions for the best system for lettuce growth.

Flooding

The required water flow rate to flood the trays determines the flow rate used for the rest of the calculations. Water flow rate was determined from the previously found tray volume and average flood rate of 3 to 5 minutes. This results in a flow rate using a 3 minute flood time of 0.068 m^3/min. The relationship between the area of the pipe and the velocity of the water is as follows:

$$Q = VA \tag{1}$$

Where Q is flowrate (m^3/s)*, V is velocity (m/s), and A is area of pipe* (m^2)

It is assumed that the ideal maximum velocity of water in the system for noise control and longevity is 2 m/s. Therefore, the minimum area inner diameter is 0.027 m, or 1.05 in. According to US Plastics, PVC is considered food safe if it is labeled NSF-51 (US Plastics, 2013). The closest nominal size of this tubing has an ID of 1.0 in. Using this diameter resulted in a flow rate that did not flood the required volume within 3 minutes. However, since the requirement is that it needs to flood in less than 5 minutes, 4 minutes meets the requirement. A flood time of 4 minutes and an ID of 1.0 in will be used in the remainder of the flooding calculations.

Work needs to be added to the system to pump the water from the reservoir up and over the plant trays. This is dependent on the height, velocity, and pressure specifications that were decided earlier, and are related in Bernoulli's equation 2.

$$W = (h_2 - h_1) + \left(\frac{P_2 - P_1}{\gamma}\right) + \left(\frac{{v_2}^2 - {v_1}^2}{2g}\right) + F_{1-2} \tag{2}$$

Where W is work (m), h is height (m), P is pressure (atm), V is velocity (m/s), F is friction losses (m)

This equation is dependent on the placement of point 1 and point 2. Referring back to Figure 6, point 1 was chosen to be at the bottom of the reservoir (empty, for the worst-case scenario), attached to the submersible pump. Point 2 will be at the top of the plant tray containers, and since the system will be open to the atmosphere, the pressure will be 0 gauge. There is no velocity at the bottom of the reservoir, and the total vertical height of the system is 3 feet. This leaves a simplification of Bernoulli's Equation to be:

$$W = (0.9144\ m) + \left(\frac{(2\frac{m}{s})^2}{2g}\right) + F_{1-2} \tag{3}$$

Where F_{1-2} is described as the energy losses due to friction, which is dependent upon the properties of the chosen pipe and the water flowing through it for major losses, and any bends or entrances for the minor losses. These are also dependent upon a friction factor, f, and the equations used are outlined below, as well as iterated in Table 1.

$$F_{1-2} = F_{sp} + F_{fit} \tag{4}$$

$$F_{sp} = f * \frac{L}{D} * \frac{v^2}{2g}$$

$$F_{fit} = k\frac{v^2}{2g} + minor\ losses\ from\ entrance$$

$$f' = 0.11\left(\frac{\varepsilon}{D} + \frac{68}{Re}\right)^{0.25}$$

If f'≥ 0.018: f=f'

If f'<0.018:

$$f = 0.85f' + 0.0028$$

Where L is length of straight pipe (m), D is diameter of pipe (m), V is velocity (m/s), k is fitting coefficient, ε is roughness coefficient, Re is Reynold's number.

Since the pipe chosen is smooth plastic, it will have a very small roughness coefficient of 0.0015 mm. The tubing is flexible PVC, and the bends in the system total to 5-45º angles.

Table 1. Bernoulli's equation calculations to find power requirements of pump.

Friction Factor					Bernoulli's		
Length of Straight Pipe	2.09	m			h1	0	
Number of Fittings (45º)	5	type B			h2	0.9144	m
					P1	0	
Find f					P2	0	
V	2	m/s			v1	0	
d	0.02540005	m			v2	1	m/s
density	998	kg/m3			F 1-2	0.81477013	m
viscosity	9.84E-04	Pa s					
Re	5.15E+04				W	1.78019053	m
epsilon	0.0015	mm					
f'	0.02119691				**Power**		
f (if <0.018)					W	1.78019053	m
					Q	0.00085	m3/s
Fsp	0.35558645				density	998	kg/m3
					gravity	9.81	m/s2
K fittings	0.25						
Entrances	1	type C			P	14.8144305	W, delivered
F minor	0.45918367					0.2	assuming 20
						74.0721527	W, consume
F 1-2	0.81477013	m				0.09929243	hp
						Use 0.1 hp pump	

The viscosity and density of the pumped water were retrieved from *Principle of Process Engineering* (1997) at the normal temperature of 25º C. Other assumptions in this table to account for are the 20% efficiency of the pump, since pumps of this size are relatively inefficient, and it will need to run its cycle continuously. This also assumes that the bends in the tubing are consistent with that of type B, or 45º angles, as well as one type C entrance into the plant trays. The findings of these calculations conclude that a 0.1 hp pump with a 1200 GPH capacity will be the best fit for this system (Figure 7). A pump of this nature can be easily purchased at Lowe's for $119. While this pump is not specified as food-grade, commercial options were limited to choose the right specifications for this system.

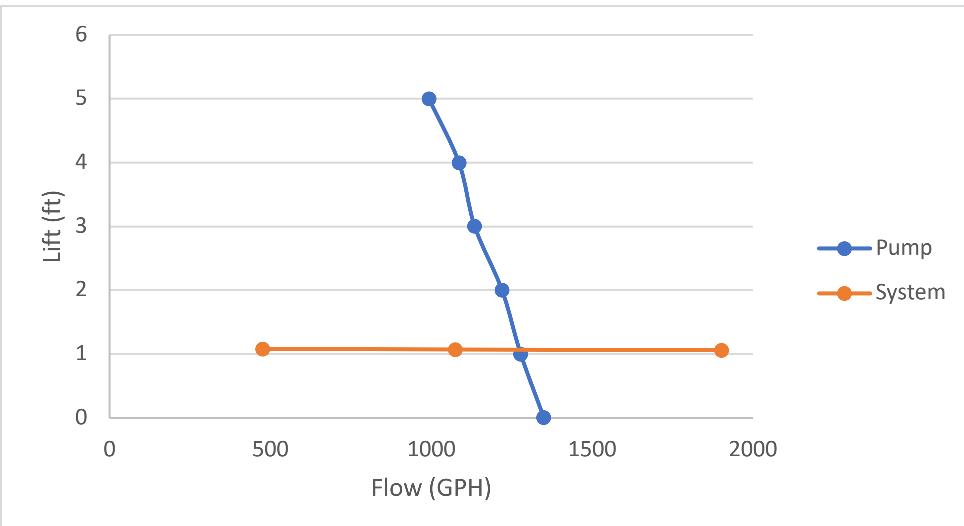

Figure 7. Pump curve of the selected pump (blue) v. system curve (orange). Operating point is determined to be at 1200 GPH.

Draining

The tubing for draining will be performed by gravity, and therefore no work will be required to add to the system. There is a minimum flowrate that the draining process must meet, the full volume in no longer than 10 minutes (JC Chidiac, personal communication). Using the same source for NSF-51 flexible tubing, different diameters of tube were iterated to find their corresponding drain times. This was done by using the previously described Bernoulli's equation and friction factor equations, solving for the velocity using a theoretical pipe size, and consequently deriving the flowrate. The acceptable pipe size would have a flow rate of no less than 0.00034 m^3/s.

$$0 = (h_2 - h_1) + \frac{v^2}{2g} + F_{1-2} \tag{5}$$

$$F_{1-2} = f * \frac{L}{d} * \frac{v^2}{2g} + k\frac{v^2}{2g} \tag{6}$$

Subsitututing equation (5) into equation (6) gives a formula to iterate diameters to check for an acceptable flowrate. The minimum diameter for this to occur is 1-1/4”, which gives a drain time of 8.46 minutes. This design will also have an overflow tube installed next to the drain pipe, in which the opening will be at the top of the plant tray. This will allow for any extra volume of water to drain back down into the reservoir, as well as leaving the root zone partially open to atmospheric pressure.

Lighting

One of the main benefits of hydroponics systems is that it can produce crops at their optimal conditions year-round. An important condition to control is lighting, as during the winter the greenhouse will receive less natural sunlight. For this worst-case scenario, light will enter the greenhouse for 8 hours at a rate of 100 μmol/m^2/day (Chidiac, 2020), a photosynthetic photon flux density (PPFD). This translates to a daily light integral (DLI) of 2.88 mol/m^2/s, using equation 7.

$$DLI = PPFD\ \frac{\mu mol}{m^2 * s}\ x\ \frac{3600\ s}{d}\ x\ \frac{12\ h}{d}\ x\ \frac{1\ mol}{1x10^6 \mu mol} \tag{7}$$

This is assuming a 12 hour photoperiod day (Gray, 2019). Lettuce grown in Arkansas requires a minimum of 10 mol/m^2/s (Chidiac, 2020), leaving a deficit of 7.12 mol/m^2/s that will need to be provided with supplemental lighting. The required lights will have to provide a PPFD of 165 μmol/m^2/s, using the inverse of **Error! Reference source not found.**equation 8.

$$PPFD\ \frac{\mu mol}{m^2 * s} = DLI\ \frac{mol}{m^2 * day}\ x\ \frac{1x10^6 \mu mol}{mol}\ x\ \frac{1\ day}{12\ hr}\ x\ \frac{3600\ s}{day} \tag{8}$$

Tri Cycle owns lights that can emit 350 μmol/m^2/s, which will be enough to supplement the lettuce crops. These particular lights have a light print of 3ft x 6ft (18 ft^2) when hung at the height of 3 ft from the plant canopy. The SAEF system has a surface area of 8 ft x 18ft (144ft^2), which concludes 8 light fixtures will be able to provide light to the entire area. Each light emits a wattage of 330 W, and the annual power requirement can be calculated as follows. The yearly hours refer to 12 hour days needed to light the greenhouse for 4 months during the winter.

$$Annual\ Power\ (kWh) = \frac{330\ W}{light}\ x\ \frac{1344\ hr}{yr}\ x\ \frac{kW}{1000\ W}\ x\ 8\ lights = 3{,}548\ kWh \tag{9}$$

The average cost of electricity of Fayetteville, AR, is \$0.0674/kWh (Electricity Local, 2020), which can be used to determine the annual operating costs of lighting the greenhouse.

$$Annual\ Power\ Cost = Annual\ Power\ Req'd(kWh) x\ \frac{\$0.067}{kWh} \tag{10}$$

The annual operating costs for the proper amount of lighting for the SAEF system is $240.

Complete Parts List

Table 2. Complete parts list for SAEF system construction. Completed system will cover 144 ft^2.

Component	Cost per unit	Note
Heavy Duty 100 Gallon Reservoir (Figure 8a)	$109.73	This provides an optimal shape and height for ease of access and maintenance, only half of the container's volume will need to be filled
Hydroponic Adjustable Bench Stand (Figure 8c)	$1,652.95	This is an adjustable bench stand that is very customizable to systems, so it could be used elsewhere as well. The height of the water will be set by only pumping the exact amount of water into the bench.
Polystyrene Plant Rafts	$270	These will be custom cut to fit the number of plants needed
Food Grade Flexible PVC Tubing, 1.0" flooding, 5/8" draining (Figure 8b)	$18.30	
1200 GPH Submersible Waterfall Pump (Figure 8d	$119	

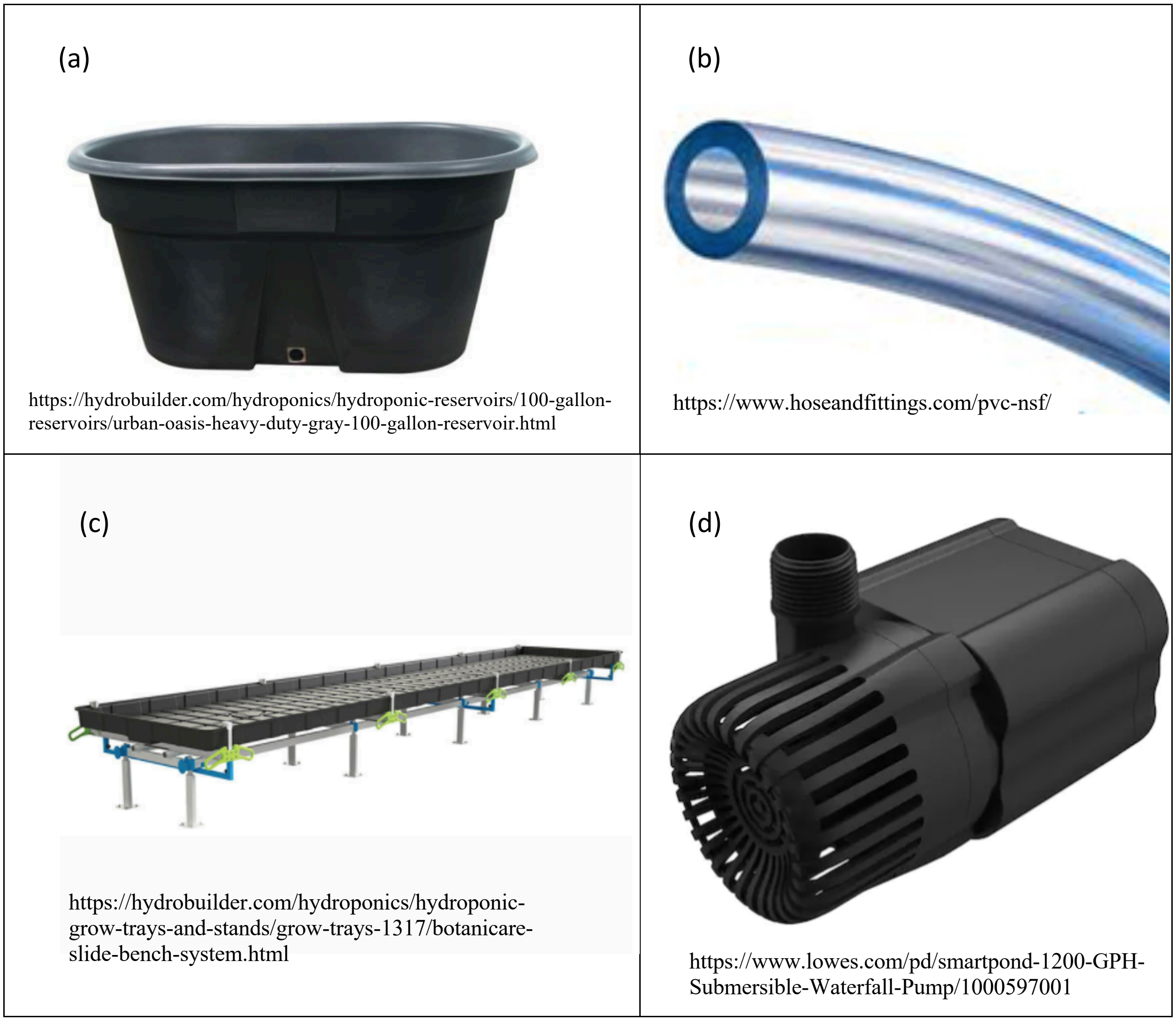

Figure 8. Parts needed to obtain and build SAEF system.

Cleaning and Safety Considerations

Since the goal of this greenhouse will be to sell the produce, food safety is an important consideration. Everything the plants could touch needs to be food-safe, including pipes, trays, and pumps. However, for the purposes of this project, it was not possible to achieve complete success. The water pipes and polystyrene rafts will be food-safe, as well as the grow tray bench. A different, more custom pump composed of food-safe materials could be chosen for a safer system. The chosen parts of this system need to be routinely cleaned to maintain its efficiency and sanitation purposes. The timing of the cleanings is dependent on the rate of algae growth in the system. Since the root zone will be in a low light environment, algae will be an issue to resolve and the rafts will have to be lifted and scrubbed, as well as the reservoir tank. The system will need to be monitored upon installation for optimal time intervals to clean. Other considerations related to maintenance include mosquito or redworm infestation. Maintaining movement of water throughout the system will reduce this risk, as they are more prone to stagnant areas of water. Corrosion is another factor to consider with routine cleaning, as any exposed metal on the pump or fittings could become susceptible. Depending on where the final location of the system is in regards to the electrical outlet, a ground-fault circuit interrupter should be used if the installation is within 6 ft of the system, to avoid electric shocks and damage.

Educational Outreach

Part of Tri Cycle Farms' vision for their hydroponic house is to expand their educational programming to reach a larger audience. The engineering principles used, such as pipe and pump sizing, energy savings, and optimized plant growth, provide great opportunities to teach the community about sustainable farming, especially in an age of rapidly changing climate. Tri Cycle already conducts many school field trips that visit the farm every year, as well as teaching programs for adults. While speaking with Don Bennett, founder of Tri Cycle, he mentioned the best way to pique interest and involvement includes hands-on learning so audiences can see, touch, and even taste what is being grown. This may not be possible when touring the anticipated hydroponic house, as Tri Cycle will want to maintain food safety guidelines as much as possible, making hosting visitors problematic. Too many people walking in and out without following proper sanitary measures could result in contaminated food, which they cannot sell or use.

To account for this, while still providing a meaningful learning experience, an idea we had was an interactive prototype of the ebb and flow hydroponics system that will sit outside the greenhouse where individual parts can be observed and the goal of using hydroponics as a viable option for sustainable farming can be demonstrated. Before creating an educational prototype, a target audience should be chosen. I chose to focus on elementary-age students, 3^{rd}-5^{th} grade, because they are the future farmers, scientists, and leaders that already have a curiosity about the world around them. The students will be able to learn about hydroponics while thinking about how it can apply to everyday life.

When creating an educational program for students, every decision was guided by the Arkansas K-12 Science Standards for curriculum. The standards are divided into topics that each age group should be learning at their grade level. The goals of this project are to teach students that plants can thrive even without soil, and that hydroponics can be an option for a more sustainable farming future. I found the relevant science education standards for hydroponics and sustainability (Table 3), and my final module design will be measured against them. The program will be split up into three deliverables: a prototype display of an ebb and flow system, an accompanying poster describing hydroponics, and an activity sheet for the students to reflect and complete after making observations.

Table 3. Arkansas 3-5 Elementary Science Standards, sorted by relevance to hydroponics (Arkansas Department of Education, 2016).

3rd Grade
Weather and Climate **3-ESS3-1 Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.*** [Clarification Statement: Examples of design solutions to weather-related hazards could include barriers to prevent flooding, wind resistant roofs, and lightning rods.]
Engineering, Technology, and Applications of Science **3-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.** **3-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.** **3-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.**
Interdependent Relationships in Ecosystems **3-LS2-1 Construct an argument that some animals form groups that help members survive.** [**AR** Clarification Statement: Examples could include ant colonies, herds of bison, or hives of bees.] **3-LS4-3Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.** [**AR** Clarification Statement: Examples of evidence could include needs and characteristics of the organisms and habitats involved. The organisms and their habitat make up a system in which the parts depend on each other for survival.] **3-LS4-4 Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.*** [Clarification Statement: Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.] [Assessment Boundary: Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.]
5th Grade
Matter and Energy in Organisms and Ecosystems **5-LS1-Support an argument that plants get the materials they need for growth chiefly from air and water.** [Clarification Statement: Emphasis is on the idea that plant water comes mostly from air and water, not from the soil.] **5-LS2-Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.** [Clarification Statement: Emphasis is on the idea that matter that is not food (air, water, decomposed materials in soil) is changed by plants into matter that is food Examples of systems could include organisms, ecosystems, and the Earth.] [Assessment Boundary: Assessment does not include molecular explanations.]

While this table provides a list of standards that could apply to themes present at Tri Cycle, it will be important to note that my overall goal of this project will be for the students to arrive at the idea that plants can grow, and thrive, in water. The standard that most nearly reflects this is 5-LS1, “Support an argument that plants get the materials they need for growth chiefly from air and water.” This ultimately means the project will be aimed towards fifth-grade students, but it will be informational for all age groups, either recalling concepts they have already learned, or introducing them to new concepts they will later expand upon.

The prototype display, depicted in Figure 9, will be similar to the designed SAEF system described in the earlier section of this report. However, it will be simplified to a much smaller scale ebb and flow system. This will account for the ease of taking apart the system and observing the individual components while considering the target audience of elementary age students. The system does not have to be sized for proper function because the purpose of any plants grown will be illustrative and not for actual production. A proposed list of construction materials is as follows:

- Durable plastic bin acting as reservoir
- Small submersible pump
- PVC piping
- Shallow tray on stand
- Polystyrene plant rafts to lift and observe roots

Figure 9. Proposed simple prototype of Ebb and Flow hydroponics system to be displayed outside Tri Cycle Farm Hydro House

Vision of the Field Trip

Ideally, the students will begin the field trip by walking through the gardens and observing the produce grown in the soil around them, touching, smelling, and tasting the plants as guided by the staff. They will then come upon the greenhouse where pictures or a short video about the greenhouse and the crops grown inside can lead to discussion. They can then look at the prototype and turn on the pump, watch water flow over the roots, and observe how a plant can survive in a hydroponic system. The most important aspect of the prototype will be to observe healthy plant structure and roots, which they can compare to the plants they have already observed in the gardens.

Accompanying the prototype, outside the greenhouse will also be a poster describing the benefits of hydroponics and its connection to food sustainability. The poster is written with respect to the previously mentioned 5th grade standard, so the reading level will be appropriate.

However, to accommodate any other age groups visiting the greenhouse, visual graphics and illustrations are included. A rough draft of the poster (Figure 10) provides an example of how the idea could be displayed. It includes adequate information but will need to be redone by an illustrator or someone with more artistic capabilities than I possess. Regardless, the connection between plant growth and the benefits of hydroponics can be made. The poster emphasizes themes of sustainability, such as a higher yield with lower water and energy usage, as well as having more control over how the plants grow.

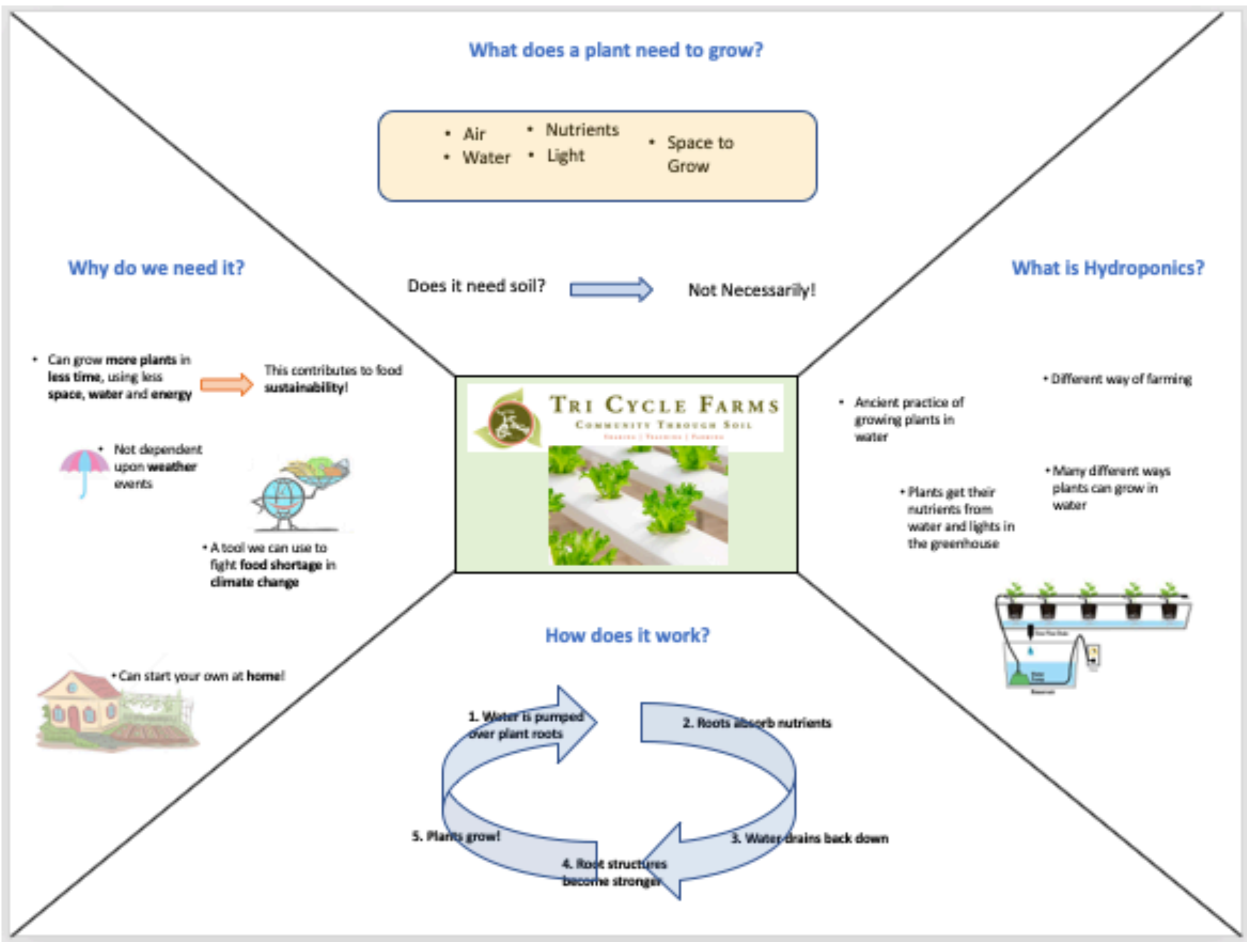

Figure 10. Informational poster about hydroponics to be displayed outside the completed greenhouse.

One last tool that the students and teachers will have the opportunity to use will be an activity sheet that sums up the goal of the hydroponics display. The sheet will encourage the students to present model ideas that they have about plant growth and then modify them accordingly from what they learned at Tri Cycle. This can either be done at the site, using the poster and prototype to help guide them to some of the target ideas, or can be administered at a later time once they are back in a classroom setting. The worksheet is attached in the Appendix of this report because of length but includes drawing comparisons between the crops grown in the gardens they toured and the plants grown in the greenhouse. There are two columns for them to make this comparison, and in the end, it asks them to draw conclusions about how each one is needed and used. This encourages students to think about mental models they might have about plant growth, and allows them to make changes and expand on those ideas as they learn, setting them up for more science based learning where challenging models is crucial to the process. I also ask the audience an open ended question about food sustainability at the end of the worksheet. This is not for them to arrive at a direct answer, but rather to begin to think about what sustainability means as a whole. The earlier they can begin to understand these concepts, the better equipped they will be to solve problems in the world around them.

Conclusions and Future Plans

While this project has produced usable results, they are intermediate. The next immediate steps would be to physically build the prototype of the display ebb and flow system, and test to ensure it functions properly. The poster accompaniment has suitable information for educational purposes, but more illustrations added for visual effects would be beneficial. After this, testing these programs with groups of field trip students, or in the classrooms, to gauge the effectiveness and make adjustments accordingly. When the greenhouse is eventually built, videos to show the inside workings would be useful for those large groups or those who do not follow proper food safety precautions, but an eventual procedure to “scrub in” before entering the greenhouse is necessary. While elementary education is important to Tri Cycle, adult educational programming associated with sustainable practices should also be explored. Tri Cycle has also expressed interest in created a more formal “Service Learning” project with the University of Arkansas for students to complete research and projects with them. Moving into the future, there is a need for these plans to be implemented for other students to continue the work and relationships cultured within the community. Other students can use these ideas and build upon them as I used the work form students last year to build my thesis. There is still a need for sizing the other three hydroponic systems. Other considerations for the greenhouse include automated control of pumps, lights, and ventilation systems.

Tri Cycle can use the theoretical design for the SAEF system as a guideline for installation after it has been tested and checked by licensed engineers. The SAEF systems will provide an efficient and versatile method to grow lettuce, among other crops, that Tri Cycle can use for becoming a more self-sustaining operation. This project will provide the community with fresh food to eat, and the opportunity to learn how food is grown sustainably.

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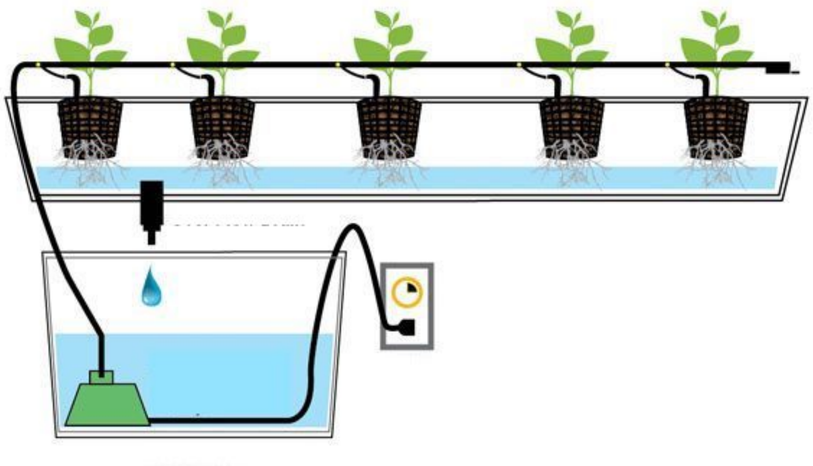
Appendix

Activity Sheet for Tri Cycle Farms Hydroponics House Field Trip

What do plants need to grow? Circle all that apply. NUTRIENTS WATER LIGHT SOIL SPACE STABILITY

Comparing Plants at Tri Cycle **Question: How do the plants you saw in the gardens compare to the ones inside the greenhouse?** - Observe and feel the plants surrounding you in the gardens at Tri Cycle, feel the soil and how the roots look	
Lettuce A  https://gardenerspath.com/plants/vegetables/successful-lettuce-patch/	**Lettuce B**  https://www.greenandvibrant.com/grow-hydroponic-lettuces
What type of environment does each lettuce grow in?	
What does each lettuce leaf feel like?	
Where do these plants get their nutrients?	
Is there a taste difference between the two?	
Can lettuce still grow properly in water?	

Label the parts of the hydroponics system below:



Word Bank

Reservoir

Plant Roots

Water Pump

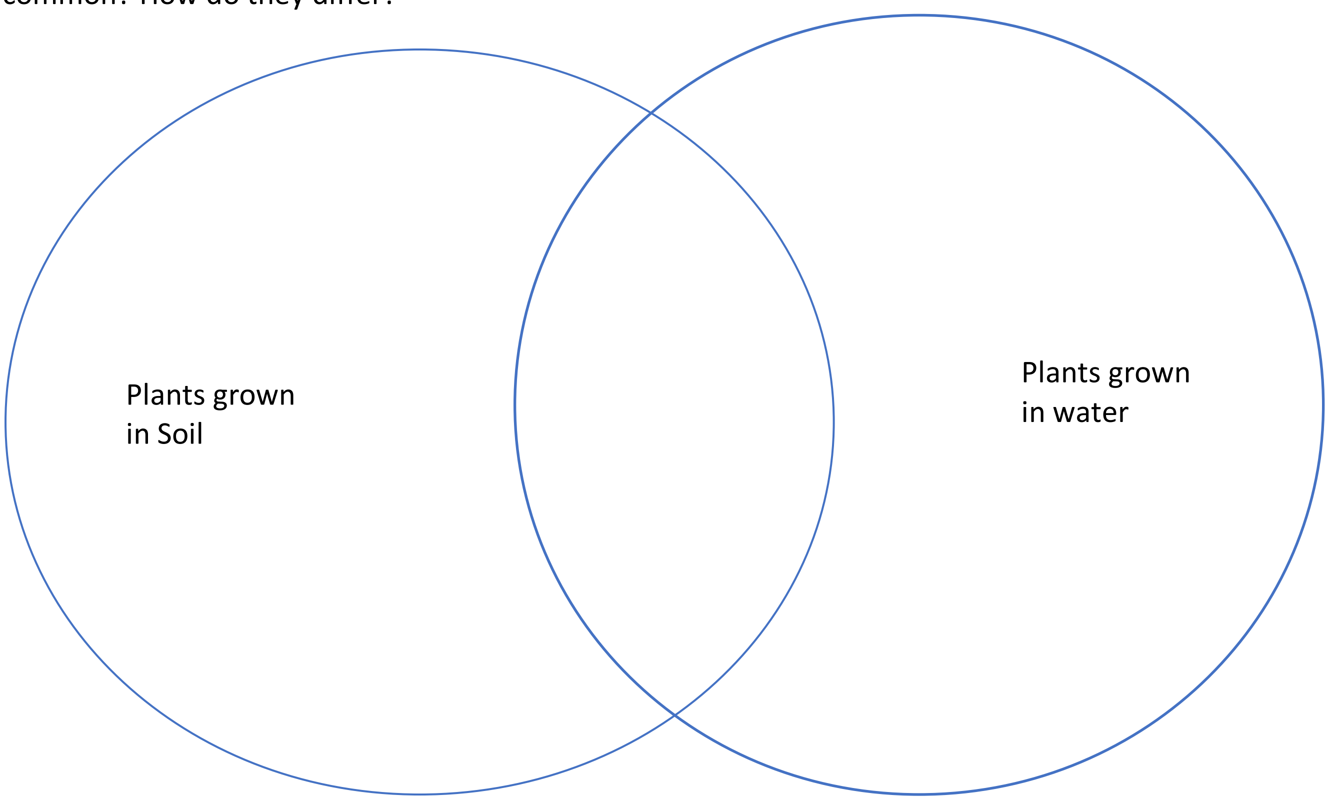
Rafts

Timer

Drain

https://www.epicgardening.com/hydroponic-systems/

Draw connections to plants grown in soil to plants grown in water. What do they have in common? How do they differ?



What is “food sustainability”?