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Design of a Deep Flow Technique Hydroponic System and an Elementary Education Module for Tri Cycle Farms

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Project Summary

Hydroponics is an agricultural technique in which plants are grown without soil and are instead grown in water systems that include nutrients and other growth-supporting media. Hydroponic systems typically reside inside, so that the system can be fully controlled by the grower by manipulating the temperature and amount of light the plants receive. The benefits of growing plants using hydroponics include: the amount of water used is reduced, it is less labor to grow organic produce with an indoor system, less space used, and it allows for growing food anywhere. Tri Cycle Farms is planning for the construction of a Hydro House to contain hydroponics systems. Products from this facility will provide a source of sustainable income, an opportunity for education in the community, and a means to battle food insecurity. Tri Cycle hopes to enhance its capacity to be self-sustaining through its Hydro House project.

For this project, I designed one of the hydroponic systems that will be in the Hydro House and created an educational module that can be utilized by nearby elementary schools. This meets two of the goals of Tri Cycle by providing community education and a sustainable agricultural method to fight food insecurity in Northwest Arkansas. The hydroponics system that I have designed is a Deep Flow Technique (DFT) hydroponic system where the plants are placed in a floating raft on top of a water reservoir containing a plant nutrient solution. An air compressor and bubbler provide the necessary dissolved oxygen to the plant's roots. The lighting of the system was designed to grow basil but could easily be adjusted to grow other crops. I have also worked to create an education module that meets the State of Arkansas science education standards for 5th grade students. This educational opportunity will allow Tri Cycle to teach elementary students not only about hydroponic systems, but also why these systems are important to support Tri Cycle's missions including water conservation, battling food insecurity, and the importance of sustainable farming practices. This report demonstrates the processes to design the DFT system, the components in the system that needed to be monitored, a demonstrative educational poster, and discussion of the steps to be taken to fully implement the multiple goals for the Hydro House for Tri Cycle Farms.

Introduction

Almost 50% of the water that is used for irrigation is lost due to wind, evaporation, and runoff and is caused by inefficient irrigation methods and systems (US EPA, 2017). Because of a growing population and a limited supply of drinking water on Earth, water conservation is essential. Growing crops using hydroponics can save 70-90% more water than traditional farming because the water is recirculated and reused (Greenhouse Management, 2016). Hydroponics also gives full control of the system to the grower, allowing them to decide the amount of light and nutrients the plants receive, as well as the temperature and humidity of the air. Because of this control, hydroponic growers are not as susceptible to unpredictable environmental conditions like weather patterns, droughts, and soil erosion. Growing crops indoors protects the plants from outside conditions and allows the farmers to produce crops out of season when lack of availability can result in higher prices and profits and also without added pesticides.

Aside from the environmental benefits, hydroponic systems also provide many practical benefits to growers. Hydroponic systems allow the growers to control the nutrients and root zone pH, regulate root and shoot temperature separately, and can result in higher efficiencies and high yields per area. These systems also help growers to avoid contaminating their food by maintaining the growing area under contained and cleaned conditions (Franz et al., 2007).

Tri Cycle Farms is a 502-(c)(3) nonprofit urban farm located in Fayetteville, Arkansas. Tri Cycle Farms gets their name from their mission to fight food insecurity by giving a third, sharing a third, and selling a third of all the produce harvested on the farm. Tri Cycle is currently building a greenhouse with plans for many different hydroponics systems actively growing produce. The greenhouse for the hydroponic systems, which Tri Cycle has deemed the Hydro House, will further Tri Cycle's mission of battling food insecurity in Northwest Arkansas. This Hydro House has been in the planning stages for over five years and it will allow the farm to continue providing their three main pillars of sharing, teaching, and farming. The Hydro House will allow Tri Cycle to create a sustainable profit through their high-end products grown in the greenhouse, which will then keep Tri Cycle open to provide the community education and continue donations to local food pantries. Since Tri Cycle is an advocate of sustainable farming, the hydroponic house will continue its methods of sustainable agriculture, considering the many benefits hydroponics provides. The educational program outlined in this project will provide Tri Cycle a method to showcase the benefits of hydroponic farming and inspire elementary students to learn more about ways they can grow their own food.

This project is a continuation of work conducted by biological engineering students and students in the sustainability minor over the past three years in honors thesis projects and sustainability capstone projects. In this prior work, the layout and lighting of the greenhouse have been designed, as well as a Dutch bucket system. The objective of this project is to design the light and set up a Deep Flow Technique (DFT) system as well as create an educational module that could be used in local elementary schools. The lighting and design of the system are applications of engineering I learned in my biological engineering degree program, but the educational module was added to expand my skills outside of the traditional STEM skillset. Creating an educational program will allow me to share why hydroponic systems are so important, and how they can make a big difference in the way the world currently produces food. I also hope to inspire elementary students to become curious about the source of their food, the potential benefits of sustainable agriculture, and how they can help improve food security now.

Literature Review

Types of Hydroponic Systems

Plants have a variety of needs and requirements, and there are many different types of hydroponic systems to fit those needs. For Tri Cycle's Hydro House, there will be five different hydroponic systems being implemented. Each system has advantages and disadvantages, but all will be used for producing premium produce and education. Described below are the five systems that will be placed in the Hydro House, with descriptions of their advantages and disadvantages.

Deep Flow Technique (DFT), also known as a floating raft system, or Deep-Water Culture (DWC) system in non-academic sources (Figure 1). This type of system needs to be monitored to maintain the necessary water level, electrical conductivity (E.C.), pH, and dissolved oxygen levels. The system, shown in Figure 1 includes an air compressor and air-stones so that the reservoir is actively aerated, and the nutrients are mixed. The plants float on top of the water using a raft, typically made of extruded polystyrene foam or low-density polyethylene, and the roots of the plant grow into the water and fertilizer solution. The DFT systems require a large amount of water and nutrients to operate successfully, and the dissolved oxygen levels are not always homogenized. It is easier to maintain a stable fertilizer solution temperature in a DFT system compared to an NFT system (Chidiac, 2017).

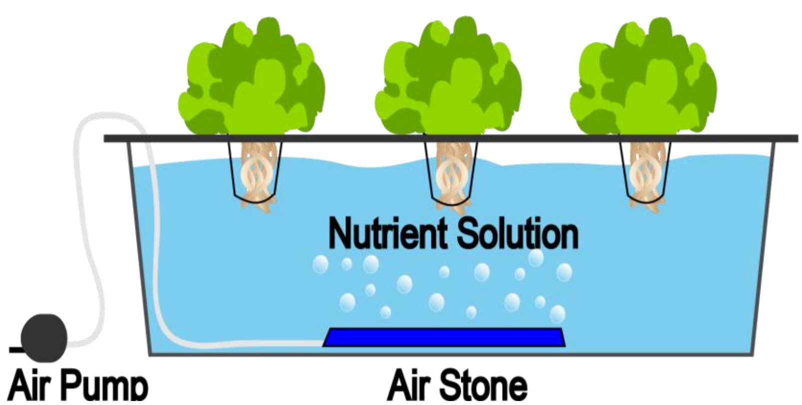

Figure 1. Deep Flow Technique system diagram, (NoSoilSolutions, 2014)

Nutrient Film Technique (NFT), as seen in Figure 2, uses a sloped trough or tube to move the nutrient solution through the system. The liquid fertilizer solution is pumped from the reservoir to the high side of the inclined plane and is then the thin film flows down through the system. The flow of nutrients is returned to the reservoir through a gutter at the low end of the plane and is recirculated through the system. For most NFT systems, a solid substrate to hold roots is not used so that the roots have better access to the nutrient film to improve growth. Because of the thin film of water containing the nutrients, the water has a high surface area and can carry enough dissolved oxygen unless the ambient air is too warm, causing the water's temperature to rise. Warmer water can hold less oxygen than cold water. NFT systems can use a Venturi device that supplies oxygen to the system by entraining ambient air bubbles into the water. The system's potential limitations are potential pump failures (which quickly endanger the plants because of loss of water to the roots), the nutrient solution might need to be chilled to dissolve sufficient oxygen, there are unequal distributions of temperature, oxygen, and nutrients in the water for long sloped planes, and there is potential for the tubing in the system to clog due to algal growth (Chidiac, 2017).

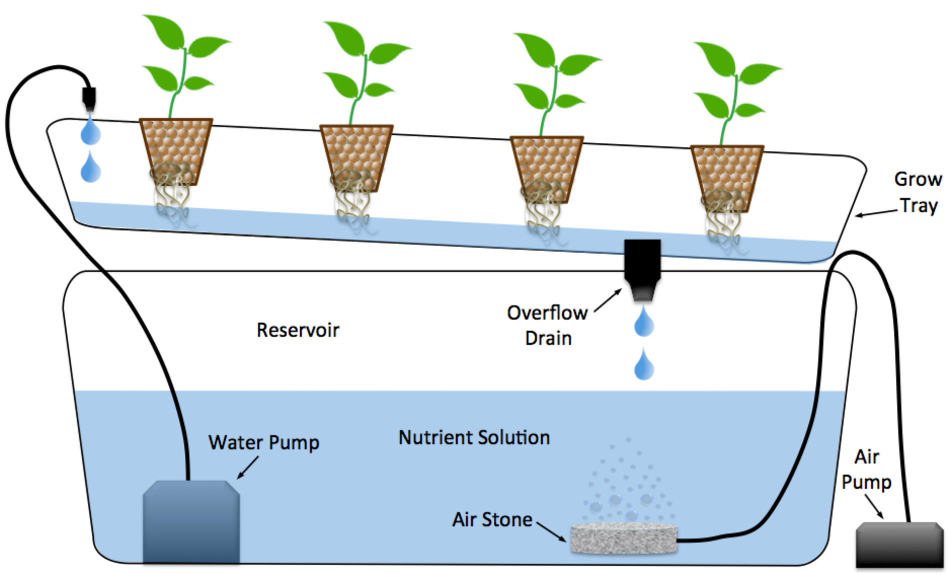

Figure 2. Nutrient Film Technique system diagram, (Off-Grid Gorilla, 2015)

Vertical wall systems (Figure 3) provide efficient use of growing space and can create an aesthetically pleasing living wall. This system is ideal for growing strawberries because of their shallow root systems. Tri Cycle plans to grow strawberries in their vertical wall system (Forney, 2020). The vertical walls maximize growing space per floor footprint, shown in Figure 3, allowing them to be useful in areas that would otherwise not be productive. Tri Cycle plans to use a vertical wall into their Hydro House to maximize on space efficiency of the system.

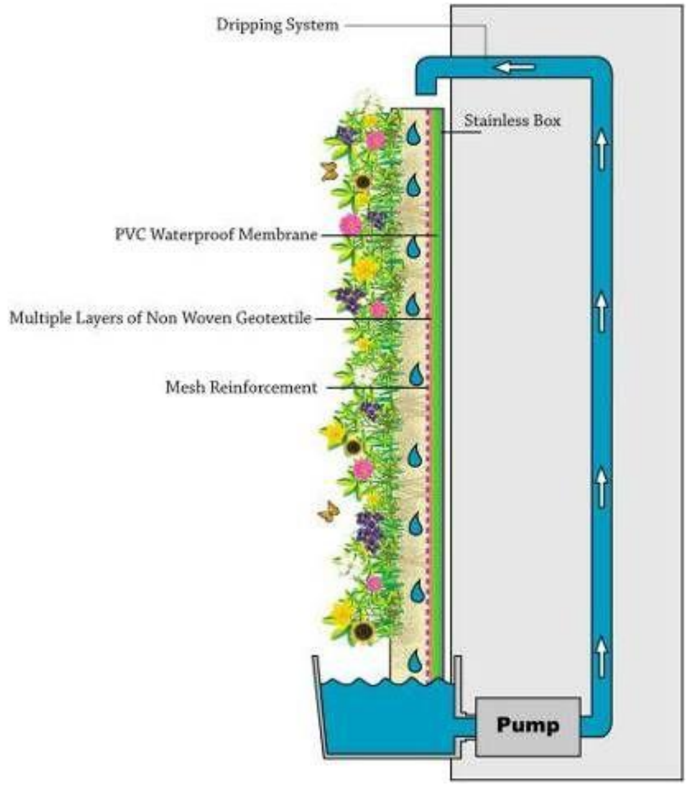

Figure 3. Vertical wall system diagram, (Seek an Idea, 2012)

The Dutch bucket method (Figure 4) is a low-footprint type of drip system that allows the grower to arrange the system's layout considering the building spacing and type of crop. Displayed in Figure 4, the buckets are connected through an irrigation line that pumps water and nutrient solution from the system's reservoir. The system can be set to water the plants at certain times and durations. This system is ideal for crops like tomatoes, which grow best using cycled watering times rather than continuous water flows (Gould, 2019).

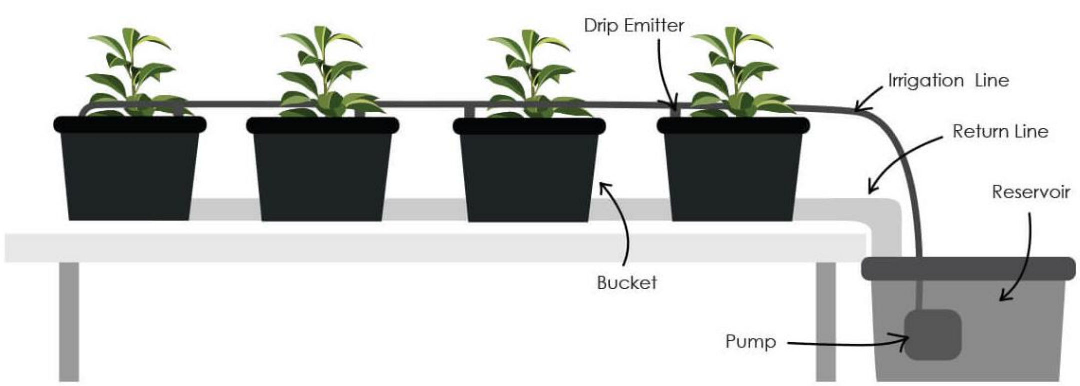

Figure 4. Dutch bucket system diagram, (Storey, 2016)

The Shallow-Aero Ebb-and-Flow System (SAEF) (Figure 5). is the second iteration of a system that has been designed by Joseph (JC) Chidiac that includes elements from multiple other hydroponic systems. He has created a new cultivation system by implementing elements from NFT, aggregate beds, and ebb-and-flow irrigation. The system includes irrigation trays containing a shallow layer of aggregate, which is then flooded to a shallow depth and requires very little water and energy (Chidiac, 2017). Chidiac has been working on the second generation of this system, which will allow for the roots to go without water at times, creating a stronger, hardier root system.

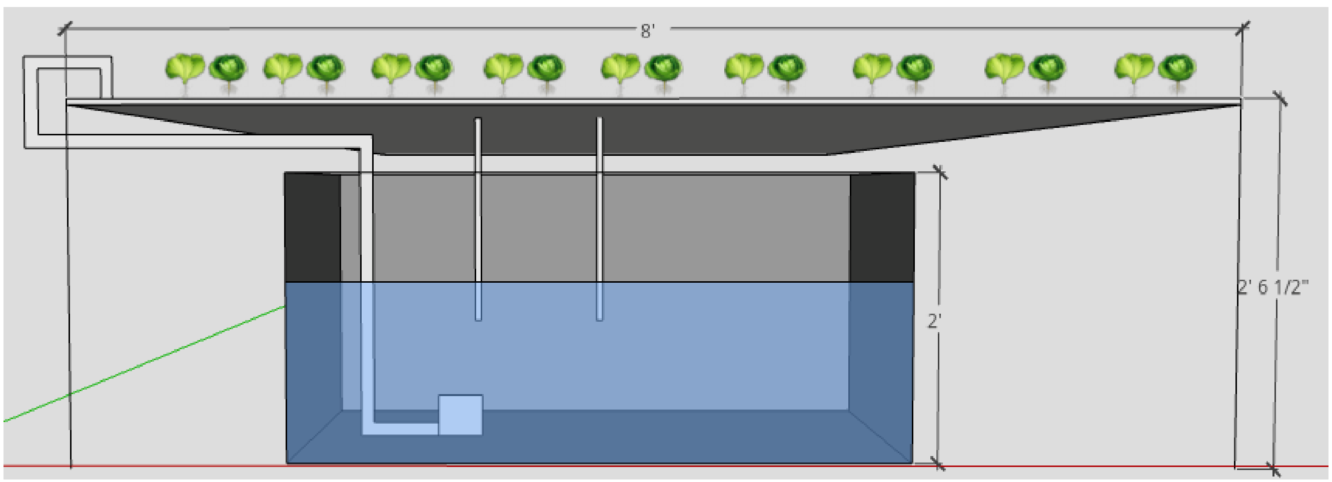

Figure 5. Shallow-Aero Ebb-and-Flow system diagram (Halveland, 2020)

Importance of Hydroponic Systems

Hydroponics has the potential to completely change the way our food is grown, making a positive difference for the world. One benefit of hydroponic growing is the system's efficient use of water to grow the same product as using traditional field methods. The water in a hydroponic system is re-circulated and has minimal losses, whereas typical farming practices have leakage of water into the soil and a greater amount of evaporation. Since agricultural use is a major contributor to the depletion of the world's freshwater sources, hydroponics provides a way to grow food and minimize water usage (FAO, 2002). Another area in which hydroponics is beneficial is nutrient efficiency. Nutrients are applied to the closed system, so there is no nutrient loss caused by leakage into the ground or nutrients getting swept away in runoff water as with field systems. This closed system for nutrients reduces the pollution of lakes and rivers, creating better water quality compared to land used for agriculture. Lastly, hydroponic systems can be much more space efficient than typical farming methods and can grow produce in large cities that lack space for growing it outside. (Foley et al., 2011) stated, “to meet the world’s future food security and sustainability needs, the production of food must grow with the population, but the agricultural footprint must substantially shrink.” As the global population continues to increase, agricultural production methods need to provide more food as well. Since there is often limited space available and open land farming methods can endanger surrounding water systems, hydroponics is a potential solution to food insecurity as well as water scarcity.

Methods of Design

Project Scope and Objectives

The scope and objectives for this project were created after meeting with the Founder and Executive Director of Tri Cycle Farms, Don Bennett. He explained that the motivation for the Hydro House is to create a sustainable source of income for Tri Cycle and provide a place of education for those who visit Tri Cycle, especially children. Mr. Bennett would also like the Hydro House to be a method of outreach to the community and to increase awareness of Tri Cycle’s mission. Based on Tri Cycle’s goals, the engineering aspect of my project was to design a Deep Flow Technique Hydroponic system. The design was to include providing the lighting requirements for growing basil. Then based on Tri Cycle’s desire to use the Hydro House for education and outreach, I will be creating an educational module that can be used in local elementary schools.

DFT System Design and Consideration

The requirements and constraints of designing a DFT hydroponic system must first be considered. The system that Tri Cycle plans to build will be a small, self-contained DFT system, meaning no external reservoir. The nutrient solution will be applied directly to the reservoir containing the plant roots, and the air stones within the growing bed will mix the solution so that it is homogenized. The main components to be designed or sized include:

- The number of lights required for a healthy basil crop;
- A typical oxygen uptake rate for water at a design temperature;
- The number of aerators required to meet minimum oxygenation requirements;
- The layout of the system;
- The parts and materials for the system.

The design will be tailored to the scale of Tri Cycle's chosen DFT system and will be adjustable if Tri Cycle decides to grow products other than basil in the system.

After determining the requirements and constraints, the next step was to research the DFT system to better understand its advantages and disadvantages to more quickly design the components. After the system has been designed, an educational module will then be created to use in an elementary school. Dr. Peggy Ward, a University of Arkansas faculty member from the Department of Curriculum and Instruction, will serve as a resource to develop appropriate educational materials to match both age requirements and to meet any educational standards in science for the State of Arkansas. The deliverable for this part of my thesis includes a poster that can demonstrate the information that will be conveyed and a fully developed hands-on component relating to the information that will be taught. Both the poster and the activity need to meet appropriate educational standards and convey important information in language and concepts that can be understood by the chosen age group.

Design Results

Lighting Design

Each crop that will be grown in the Hydro House will have varying lighting requirements, and although the building was designed to allow a large amount of sunlight in, there may be days when the amount of sunlight available is limited. Therefore, the lighting system needs to be prepared for the worst-case scenario, which is no natural light available. The considerations for the lighting required include the light footprint, the daily light integral required for the chosen crop, the photon flux density (PPFD) provided by the lights, and the capital and operating costs for the lighting system. The daily light integral is the amount of photosynthetically active photons that are delivered to an area of the plant each day and the photosynthetic photo flux density (PPFD) is the light intensity or density of the photons in the light (Ledtonic, 2019). Tri Cycle has identified grow lights they prefer to use, so for buying efficiency, redundancy, and replaceability, the same lights will be used for this design. The next step was to calculate the number of lights required for the system to meet plant requirements. The lights that Tri Cycle uses have the following specifications:

- 4-feet length
- Power requirement per unit is 330 watts
- Hanging height is 3 feet above the plants
- Light footprint is 3 ft by 6 ft, totaling an 18 ft^2 area
- Provides a photon flux density (PPFD) of 350 $\mu mol/m^2/s$

Assuming the worst-case scenario is a day with no light, the given lights have been designed to provide all necessary lighting requirements for the chosen crop, which is basil. The minimum daily light integral required for basil is 15 $mol/m^2/day$, as specified by Joseph Chidiac, a horticultural engineer who has worked with Tri Cycle Farms. The chosen lights need to be sized to provide a minimum DLI of 15 mol/m^2/day over a 12-hour day. Since no natural light is the absolute worst-case scenario, no safety factor will need to be added.

$$\text{PPFD} = \frac{15\ \text{mol}}{\text{m}^2 \cdot \text{day}} \times \frac{1{,}000{,}000\ \mu\text{mol}}{1\ \text{mol}} \times \frac{1\ \text{day}}{12\ \text{hours}} \times \frac{1\ \text{hour}}{3600\ \text{s}} = 347.22\ \mu\text{mol/m}^2\text{/s}$$

Based on the above calculation, the given lights provide the minimum amount of light required for healthy basil. The required PPFD of 347 μmol/m^2/s is less than the provided PPFD of 350 μmol/m^2/s, so the light footprint just needs to cover the growing area. At a hanging height of 3 feet, the lights create a footprint of 3 ft by 6 ft, which matches the dimensions of one DFT system. Since the layout calls for three systems, the DFT system requires three lights. The provided lights will work for the worst-case scenario without any adjustments of hanging height. The entire DFT system will fit beneath the light footprint of three of the chosen lights. Although the lights will be able to provide all of the necessary sunlight for the basil, to reduce electricity usage, the lights will only be on when necessary. In the summer, most days provide enough sunlight so that no supplemental light is needed, but as sunlight hours and intensities lessen, supplemental light will be required for at least part of the day.

DFT System Design

The layout of the Deep Flow Technique system was important and needed to determine first. Since Tri Cycle already has the containers for the DFT system, the design needs to follow established dimensions and layouts. The DFT system for Tri Cycle will be three small, self-contained systems, meaning there will not be an additional reservoir for nutrient mixing. This reduces the need for a water pump and monitoring any flow in the system and creates a more compact system. The set up must include an aerator with attached air stones for mixing of the nutrient solution and providing dissolved oxygen to the roots. Other materials required are a floating raft to hold the plants, tubing for the aerator, nutrient solution, basil plants, the chosen grow lights, and the containers for the system. The layouts of the systems show a side view (Figure 6) of the system with all of the necessary components and a top view (Figure 7) of the system showing the footprint area. Figure 8 displays the layout of the entire Hydro House and the five hydroponic systems that will be included. The diagram also includes the head house with a cold room and an irrigation room. This design is not included in this work and will be implemented in the second phase of Tri Cycle's Hydro House project.

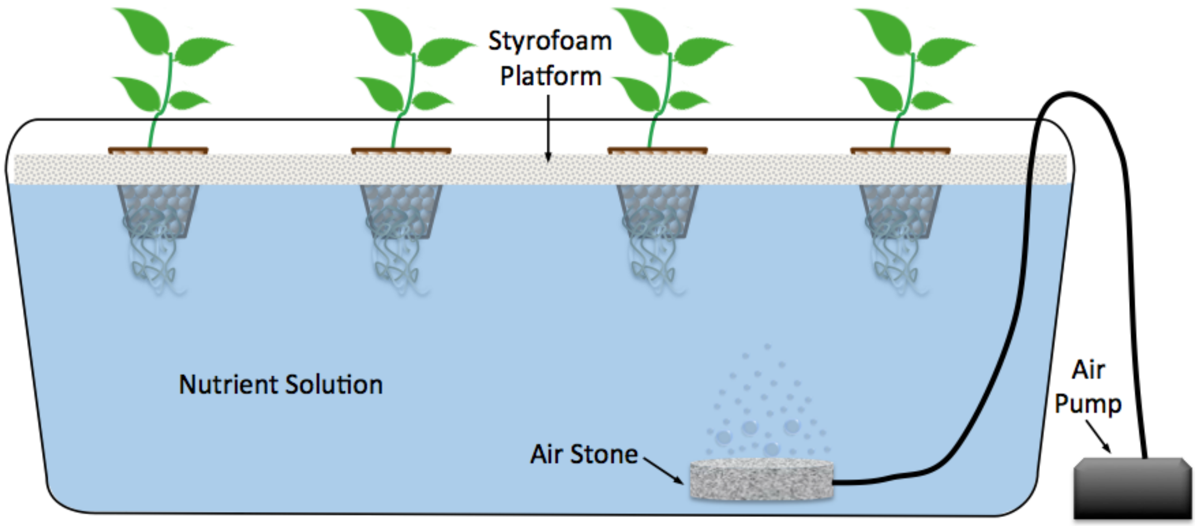

Figure 6. Side view of Deep Flow Technique system, design depth of 8 inches (Off-Grid Gorilla, 2015)

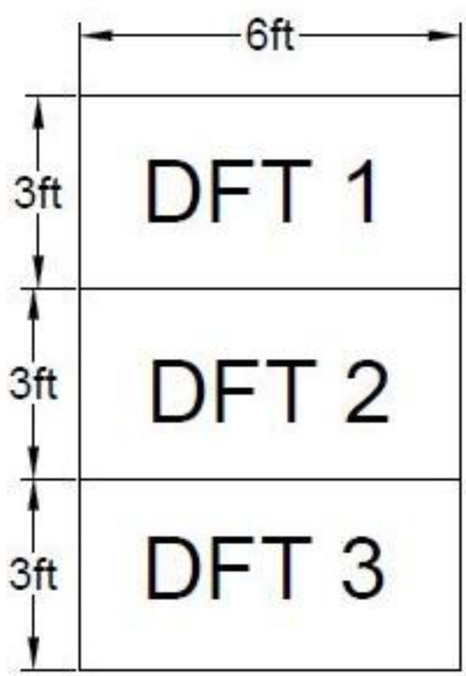

Figure 7. Top view of Deep Flow Technique system in Hydro House, drawn in AutoCAD

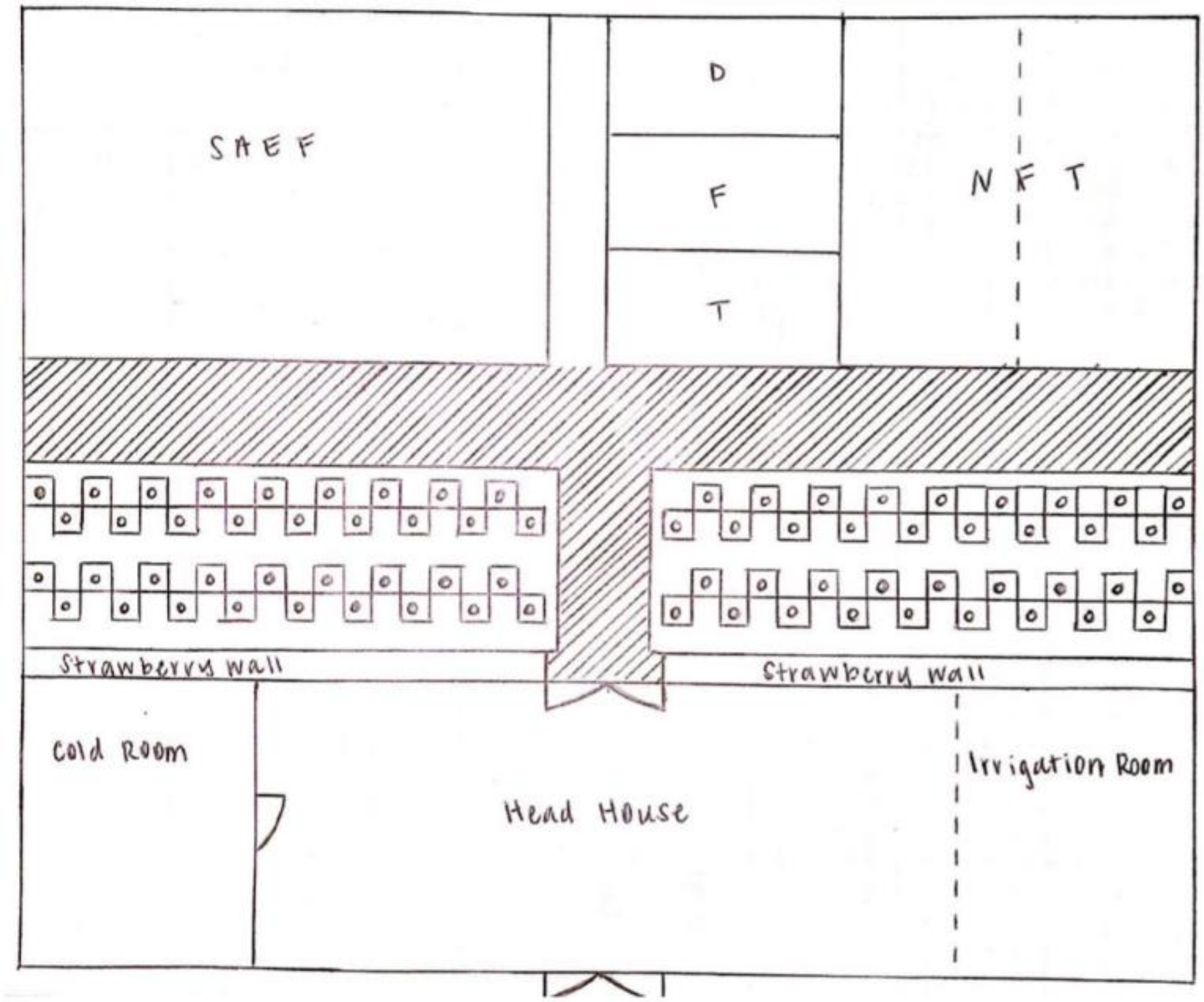

Figure 8. Entire layout of Tri Cycle's Hydro House including planned secondary phase's head house (Gould, 2019)

Oxygen Uptake Rate (OUR) data measured for fish tank water was used to estimate the oxygen requirements for the system. This data was measured as part of a class, BENG 2632 Biological Engineering Design Studio, and should represent oxygen requirements for water well in excess of those to be found in this system. The OUR determines the oxygen consumption by the microorganisms in the water. The data was collected from 12 teams, giving the data 12 trials shown in Table 1. I averaged the data and found the standard deviation for the 12 trials. Any data points more than three standard deviations from the average was considered an outlier to be removed from the data set. There were no outliers in this data set. The water in which this test was performed was maintained at 20°C, but the given range of water temperatures for the Hydro House will remain within the 20°C - 25°C range. The higher the water temperature, the less oxygen is dissolved in the water. This is due to the solubility of oxygen being reduced as the temperature increases, as described in Henry's Law. As an example, in standard atmospheric air, the saturated amount of dissolved oxygen held at 20°C is 9.09 mg/L, while the saturated amount held at 25°C water is 8.26 mg/L (Fondriest Environmental, Inc., 2013).

Table 1. Experimental Oxygen Uptake Rate data provided from Biological Engineering Design Studio class

Trial	**OUR (mg/L*d)**
1	-2.470
2	-2.679
3	-1.504
4	-2.840
5	-4.790
6	-0.922
7	-2.739
8	-2.597
9	-1.720
10	-2.363
11	-2.086
12	-1.629
Average	-2.361

The OUR from the trials was calculated to be 2.36 $\frac{mg\ DO}{L \cdot d}$. Since the water in the data trials was held at 20 °C and the design temperature of the water in the DFT system is 25 °C, the increase in OUR because of temperature will be estimated using the van't Hoff relationship (Ito et al., 2015). For this situation, we are assuming the worst case, which would be a temperature of 25°C, so that the system to add dissolved oxygen can be designed to meet a higher demand in the case that the dissolved oxygen levels drop. The temperature coefficient equation is a derivation of the van't Hoff equation. It is shown below, along with the calculations to determine OUR at 25°C from a reference condition at 20 °C.

$$R_2 = R_1 \times Q_{10}^{\frac{T_2 - T_1}{10}} = 2.36 \times 2.2^{\frac{25°C - 20°C}{10}} = 3.5\ \frac{mg\ DO}{L \cdot d}$$

Where $Q_{10} = 2.2$ for respiration (such as OUR), the factor by which the reaction rate increases when the temperature is raised by ten degrees, averaged from the typical range of 2.0 – 2.4 for respiration (Keane, 2019)

$R_1 = 2.36\ \frac{mg\ DO}{L \cdot d}$, the measured reaction rate at temperature T_1

$R_2 =$ the reaction rate being solved for which is at T_2

$T_1 = 20°C$, the temperature at which the OUR reaction was measured

$T_2 = 25°C$, the design temperature of the water in the system

After calculating the OUR, which is 3.5 $\frac{mg\ DO}{L \cdot day}$ for $25°C$ water, the next step is to determine many aerators need to be in the system based on this OUR. The Biological Engineering Design Studio Data also provided estimations on the output per aeration bubble bar (standard fish tank equipment) in a water tank system, which is 5.44 $\frac{g\ DO}{day \cdot bubbler}$ for water that was at 5 $\frac{mg\ DO}{L}$. The system I am designing includes three DFT systems, each approximately 340 liters in volume for a total system volume of 1,020 liters. Based on these experimental numbers, each DFT system needs 0.2 bubblers to replenish the oxygen leaving the system, or 0.7 bubblers for the entire system. There was also a difference in depth of the water between the system in which the data was measured and the DFT system being designed. The DFT system will have of water depth of 8 inches, while the system the data was from had a depth of approximately 15 inches. This decrease in depth will limit the amount of time the oxygen has to dissolve into the water, resulting in the bubble bars in the DFT providing approximately half the rate of the bubbler in the fish tank, which increases the total required number of bubblers to 1.3. In the case of dissolved oxygen, one bubbler per container should provide enough oxygen for the system, but the bubblers are also necessary for mixing and distributing the nutrients in the water. Since the system should be mixed by the bubblers and based on the estimated numbers provided, I recommend including two bubble bars for each system, totaling six bubble bars. After building the system, I recommend the DO be measured in different areas of the tank to determine if there is enough mixing for the system. If the water is not being mixed and distributed throughout the system insufficient, more air stones or bubble bars can be added to the system.

The required materials for setting up the DFT system are three system containers, six bubble bars, a sheet of lightweight, food-grade material, typically polystyrene, three of the grow lights that Tri Cycle has chosen to use, and liquid nutrient solution. All of these materials can be combined to grow a healthy crop, in this case basil, in a Deep Flow Technique system. The system will need to be monitored to make sure the aerator is always mixing the water and providing oxygen to the roots, and the nutrient levels should be routinely checked. I have listed the necessary materials below in Table 2, with examples of products that can be chosen. I chose the raft to be made of Low-Density Polyethylene due to LDPE's sustainability benefits: capable of reuse, non-toxic, recyclable as a class 4 material, and an increased rate of recycling compared to polystyrene and Styrofoam (EPE USA, 2019). For the airline tubing, I recommend the tubing be a solid dark color to prevent the growth of algae. All of the costs listed are estimates based on products found online to give an estimate for the cost of the DFT system, but they are not set costs.

Table 2. Required DFT materials and costs

Item	Details	Supplier	Units Needed	Unit Cost ($)	Total Cost ($)
Reservoir	8 in deep	Donated	3	0.00	0.00
Raft	LDPE Sheet, 48"L x 24"W x 0.063"T	Grainger	7	14.55	101.85
Pump	320 gph, 8 watts, 4 outlets	General Hydroponics	2	86.80	173.60
Air Stone	Imagitarium 18" Aquarium Bubble	Petco	6	11.99	71.94
Airline tubing	Solid color	Petco	1	8.00	8.00
Total Costs					**$355.39**

Education Discussion

To educate elementary school children on why hydroponic systems are important, I created an education module to be brought to the classroom. Tri Cycle is particularly focused on educating children because they are the next generation of farmers, scientists, and community members, and Tri Cycle hopes to inspire decisions to support sustainable food production from an early age. The focused age range is 5th grade students, and the educational poster and information portrayed reflect the Arkansas Science Standards for 5th grade as outlined by the Arkansas Department of Education. The education component of this project will hopefully not also educate the next generation on the importance of sustainable food and water systems, but also help educate me in how better to communicate with non-technical audiences and allowed me to expand my thinking out of a STEM-based project. Whether a student wants to go into a STEM-based career or not, I want them to know that they can make a difference in their home and that growing their food in soil or water is something they can easily do.

After deciding to pursue an educational component for my thesis, Julie Halveland and I met with Dr. Peggy Ward, a clinical assistant professor in the College of Education and Health Professions at the University of Arkansas, who specializes in curriculum and instruction. Halveland is a fellow biological engineering student working with Tri Cycle to design a separate hydroponic system and educational component to be taught on-site. Dr. Ward agreed to help Ms. Halveland and I find educational standards that apply to teach about hydroponic systems and the conservation of natural resources. Dr. Ward also helped us to understand how to read the educational standards and determine what is important to convey to a set age group. The following standards relate to my topic of hydroponics and the standards state that students who demonstrate an understanding can do the following based on their age group:

- **Performance Expectation:**
  - **5-ESS3-1 Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.**

    - **5-LS1-1 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 matter comes mostly from air and water, not from the soil.]
- **Disciplinary Core Ideas:**
    - **ESS3.C: Human Impacts on Earth Systems**
        - § Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. (5-ESS3-1)
    - **LS1.C: Organization for Matter and Energy Flow in Organisms**
        - § Plants acquire their material for growth chiefly from air and water. (5-LS1-1)
- **Science and Engineering Practice:**
    - **Obtaining, Evaluating, and Communicating Information**
        - § Obtaining, evaluating, and communicating information in 3–5 builds on K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods.
        - § Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem. (5-ESS3-1)
    - **Engaging in Argument from Evidence:**
        - § Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).
        - § Support an argument with evidence, data, or a model. (5-LS1-1)

The above standards have been important in considering how to convey the information of what a hydroponic system is, how it works, and why this system is important to a group of 5th grade students. The information included on the educational poster is intended to teach the students at a level they can fully understand and comprehend, while also attempting to engage the students and convey the importance of water conservation. I hope to demonstrate how hydroponics relates to water conservation and inspire the students to care about how their choices can affect the environment.

I started by creating a poster where I included all of the information I would like to present to the students, not worrying about the grade level of information or language being presented. I then sent the poster to Dr. Ward, who read through the poster and explained how to make this more presentable to the target age group. The first draft of the poster can be seen in Figure 9, and is a poster that conveys the standards for 5th grade education, but has a reading level of 10th grade or above. After receiving suggestions for revisions, I worked with Dr. Ward to create a 5th grade level poster, one that would better capture and keep the attention of the students. The improvements included adjusting the language of the poster, limiting the number of words, and adding pre pictures for a better visual understanding. The poster colors were also changed to be more vibrant and colorful to draw the student's attention. The final draft of the poster, seen in Figure 10, also includes four distinct sections, mimicking science posters created for this age group. Next, the second draft needed to be analyzed for readability and understanding for 5th grade students.

To ensure that the educational poster I have created will meet the level of the target audience, Dr. Ward calculated the Flesch-Kincaid Grade Level test for the poster. The Flesch-Kincaid Grade Level is a readability test that is useful to measure how easily people will understand a portion of text. The score my poster received was a 4.6, which is right where the score should be for a 5th grade poster, and the equation performed for the test can be seen below:

$$\text{Flesch} - \text{Kincaid Grade Level} = 0.39 \times \left(\frac{\text{total words}}{\text{total sentences}}\right) + 11.8 \times \left(\frac{\text{total syllables}}{\text{total words}}\right) - 15.59$$

This reading level is based on two factors: sentence length and word length. These factors are based on the idea that longer sentences are more difficult to follow than short sentences, and words that contain fewer syllables are more easily understandable. The score generated by this equation relates to the U.S.

grade level of education, so a Flesch-Kincaid Grade Level of 4.6 means that the poster I have created will be understandable for the target age of 5th grade students (Linney, 2017).

The main sections of the poster include the questions (1) What do plants need to survive?, (2) What is Hydroponics?, (3) Why is Hydroponics Important?, and (4) Did you know? The first section asks the students what components plants need to survive and list out the answers. This allows the presenter to describe how most of the necessary plant requirements do not come from the soil, but from air and water. The soil provides root support for the plant and the necessary nutrients for growth, but both of these components can be supplied from other materials. The poster then describes hydroponics in the next section, which is an agricultural technique that utilizes water instead of soil. The water contains a nutrient solution that supplies the plant the nutrients it requires, a grow light can supply the necessary sunlight, there are air pumps or water pumps to provide the necessary oxygen for the roots, and most systems utilize various growing mediums to provide support for the roots. The next section of the poster describes why hydroponic systems are important. The section discusses the reduction of water usage, how hydroponic systems can be located anywhere, and that the produce grown in these systems is not limited to a certain growing season like plants grown outdoors. Lastly, the “Did you know?” section describes how the students can get involved and learn more about growing food using water. The example demonstrated by visuals on the poster is cutting the ends off of green onions, sticking the end with the roots on it in water, and growing another green onion just from food scraps. After this section, the presenter will ask the class some questions to gauge the understanding level. The questions will allow the students to brainstorm about what they just learned and share their thoughts. For example, what kind of environments would benefit from growing their food hydroponically and what all can be controlled when a farmer grows using a hydroponic system? The questions were included in the first draft of the poster but will be presented verbally based on the second draft of the poster. These questions will verify that the students have been paying attention, learning, and the lesson has met the standards listed above. As this lesson plan develops, the questions may change or more may be added, but I believe it is important to get the students thinking and talking about how this system works and how it can benefit different people.

After the presentation, the class can then perform a hands-on activity to allow the lesson to better sink in. There are many options for this hands-on project, and the project can be tailored to what the class has available, but I will be focusing on one of the activities that can be performed. After learning about hydroponic systems and their environmental benefit, the students will be split into groups and given a scenario for a farmer who would benefit from having a hydroponic system. The scenarios could be different for each group of students, allowing them to create solutions that are tailored to the need of the specific farmer. If available, the class should have materials to build a simple hydroponic system. The materials needed are:

- A water reservoir, can be varying sizes depending on the space available
- A floating raft: Styrofoam sheets of polyethylene for a more sustainable option
- Materials to cut the floating raft to fit the container
- Cubes of growing medium, can have different kinds to allow students to be creative
- Plants, like basil or lettuce
- Small aquarium pump and tubing
- The nutrient solution, make sure it is for hydroponic systems

Using the materials listed, allow the students in their groups to design their own system ("Classroom Hydroponics Lesson Plan," 2017). If materials are not available, use cutouts to represent things like a plastic tub and aerator. Create a scenario for the groups, like they are a farmer in a cold northern state, or they are in an urban area and want to provide a local source of produce. This will allow the students to think of creative solutions to problems that are presented and understand how the system works. The students can then present their design to the class and explain why they made certain choices for their design, fulfilling another one of the standards above, 4-ETS1-2. After thinking through their system and getting the chance to build something, the students will have a much better grasp of how hydroponic systems look and they will have utilized their creative problem-solving skillset.

Other activities that could be performed with the class include planting seeds as a class or starting a comparison activity to outline the similarities and differences between traditional farming and hydroponic growing. Due to current social distancing policies, I will be unable to test this educational module at any local elementary school, but after schools reopen a Tri Cycle volunteer will be able to present this information to elementary students in the area. Based on feedback from the poster and activity, the presenter can make changes as they see fit, as long as the educational standards are being met and the students have a certain level of understanding of the topic.

Figure 9. First iteration of educational poster, includes all information to convey but with a higher reading level than 5th grade

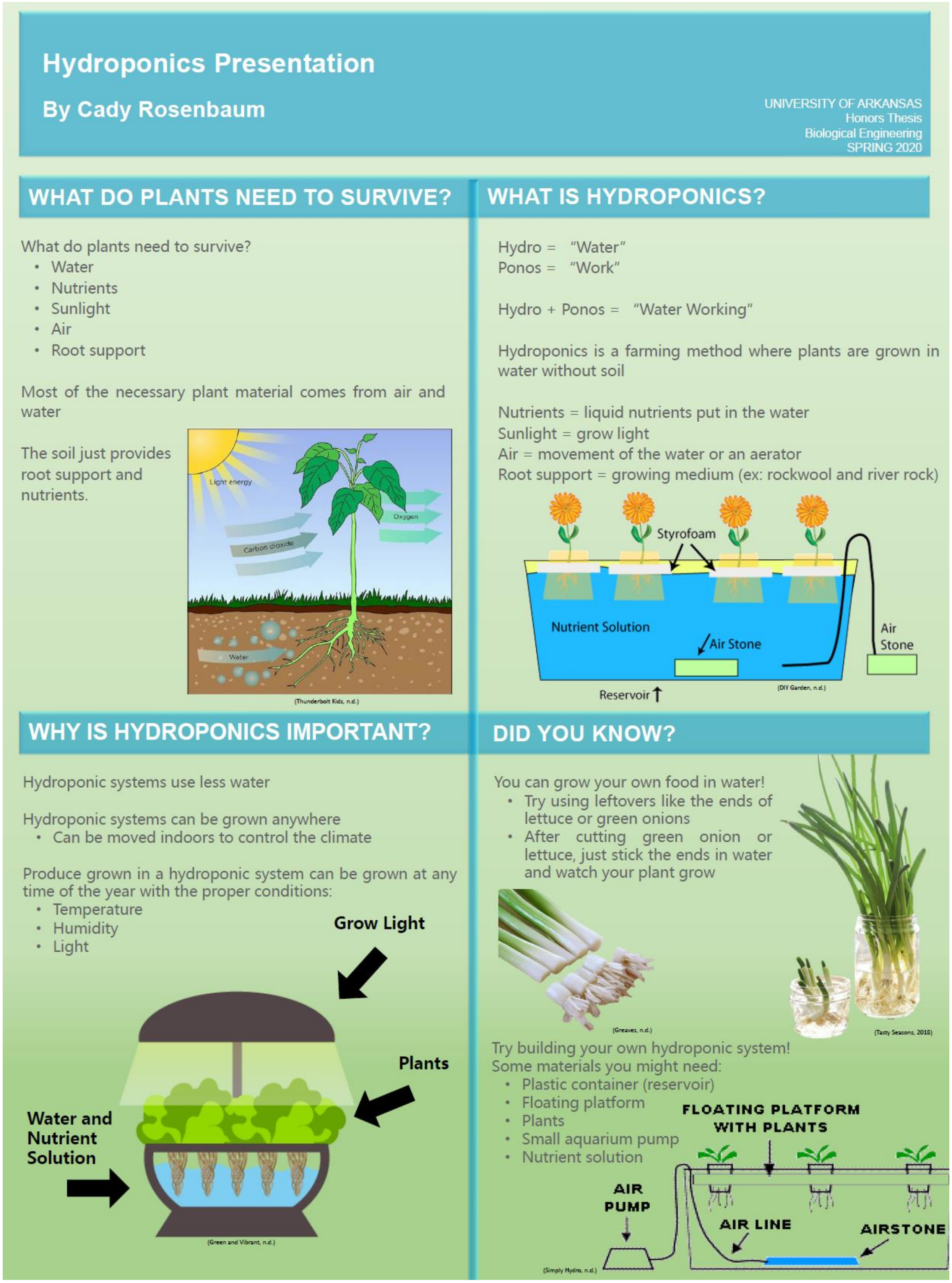

Figure 10. Second draft of educational poster, geared more towards 5th grade learning

Discussion and Future Opportunities

As this project continues to evolve, there will be more design project opportunities at Tri Cycle Farms to complete. Of the five systems in the Hydro House, there is only one system remaining to design. A previous honors student designed the Dutch bucket system, Ms. Halveland designed the SAEF system, I designed the DFT system, and a member from the Tri Cycle community is designing the vertical strawberry wall. The only hydroponic system design remaining for the Hydro House is the Nutrient Flow Technique (NFT), but that is not the last component needing attention. Don Bennett, the Executive Director of Tri Cycle, plans for the second phase of development to include a head house that will be attached to the Hydro House. The head house will be able to provide an irrigation room and cold room, allowing for a seed starting location before the plants are moved to the hydroponic systems and allowing Tri Cycle to begin their "Seed to Sell Learning Initiative." This initiative will be another way for students of the University of Arkansas to get involved with Tri Cycle, starting as a service-learning program for students to volunteer or take a service-learning class. This initiative will need volunteers and students of all skill sets, as Tri Cycle starts the plants from seeds, grows them in the Hydro House, and then sells the produce to local retailers and restaurants. There is also the option to add in sensors to connect the main house to the Hydro House, which would allow for more manageable and efficient monitoring of the crops. The hydroponic systems can also all be part of research teams, which is why the systems were all created with multiple units in the case there needs to be a comparison between different growing methods. There are many areas for students and volunteers to get involved with Tri Cycle and the Hydro House and make a positive impact on the northwest Arkansas community while learning about hydroponic systems.

Construction of the Hydro House has been delayed for a variety of reasons over the past year, the most reason delays have been due to bad weather and a global pandemic. Tri Cycle plans to finish the construction of the first phase of the Hydro House before implementing additional ideas, but the room for growth and improvement is limitless. As construction begins on the Hydro House, Don Bennett believes that Tri Cycle will be able to better fundraise for the continuation of this project, and the Hydro House will continue to adapt to the needs of Tri Cycle as well as the surrounding community. After the Hydro House is built, Tri Cycle will begin growing and selling produce that is in high demand or out of season, so that they can capitalize on the benefits of a completely controlled growing environment. As they start building up a larger client base for their hydroponic produce, Tri Cycle will continue to give back to their community and work towards a more food-secure community. The Hydro House will allow for a more stable income, perhaps even allowing them to hire more full-time staff members. Tri Cycle and their community is growing, and the impact they have on their community continues to grow. Although I have only been part of a small piece of this project, I am honored to have been part of this community and excited to see the Hydro House up and running in the future.

After two years of volunteering with Tri Cycle, I have learned a lot about sustainable farming and the impact one person can have over an entire community. Don Bennett started Tri Cycle Farms to meet a need in his community, and the non-profit farm has connected and provided for hundreds of people in Northwest Arkansas. I personally have met many amazing people through volunteering at the farm, and I was able to bring healthy and local food home to my own kitchen. I have greatly enjoyed learning more about composting, reducing food waste, and how easy it is to grow your own food. I am honored to be working with Tri Cycle now, playing a small part in their Hydro House project and seeing firsthand the plans and dreams Mr. Bennett has for Tri Cycle's growth. Tri Cycle started as a response to one neighbor's food insecurity and has grown to provide food, learning, and joy to an entire community. Tri Cycle will continue serving their community by providing education and food security, and I could not be more proud to have worked with such a determined and selfless group of people.

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References

Bumgarner, N. (2013). From the CropKing greenhouse: Spring to summer romaine lettuce trial.

Chidiac, J. R. (2017). Shallow aggregate ebb-and-flow system for greenhouse lettuce production. MS thesis. University of Arkansas.

DIY Garden. (n.d). 6 Main hydroponic systems and how they work. https://diygarden.co.uk/hydroponics/hydroponic-systems-and-how-they-work/

EPE USA. (2019). Polyethylene vs Polystyrene: Comparing the sustainability, cost efficiency and protective performance of polyethylene versus polystyrene packaging material. https://epe.global/2019/10/03/polyethylene-vs-polystyrene/

FAO. (2002). *Crops and Drops: Making the Best Use of Water for Agriculture*. Rome: FAO.

Foley J., Ramankutty, N., Brauman, K., Cassidy, E. S., Gerber J. S., Johnston M., …, Zaks D. P. (2011). Solutions for a cultivated planet. *Nature,* 478(7369):337-42. https://doi.org/10.1038/nature10452

Fondriest Environmental, Inc. (2013). “Dissolved Oxygen.” Fundamentals of Environmental Measurements. https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/

Forney, J. M. (2020). Creative strawberry planters. https://www.hgtv.com/outdoors/flowers-and-plants/fruit/13-creative-strawberry-planters-pictures

Franz, E., Visser, A. A., Van Diepeningen, A. D., Klerks, M. M., Termorshuizen, A. J., and van Bruggen. A. H. (2007). Quantification of contamination of lettuce by GFP-expressing

Escherichia coli O157:H7 and Salmonella enteric serovar Typhimurium. *Food Microbiology* 24(1): 106—112. http://europepmc.org/article/med/16943102

Freight Farms. (n.d). The Evolution of the Indoor Vertical Farm. https://www.freightfarms.com/blog/greenery-webinar-recap

Gould, S. (2019). Internal design of a hydroponics greenhouse for Tri Cycle Farms. Undergraduate thesis. University of Arkansas.

Greaves, V. (n.d.). How to regrow green onions from scraps. https://www.allrecipes.com/article/save-money-diy-fresh-green-onions/

Greenhouse Management. (2016). Hydroponics.

https://www.greenhousemag.com/article/hydroponics-provides-major-water-savings/

GreenLivingOffGrid. Hydroponics grow medium: Coco coir. (n.d.). https://greenlivingoffgrid.com/product/hydroponics-grow-medium-coco-coir/

Green and Vibrant. Hydroponic systems: Different types and how they work. (n.d.) https://www.greenandvibrant.com/hydroponic-systems

Halveland, J. (2020). Design of shallow-aero ebb and flow hydroponics and educational outreach for Tri Cycle Farms. Undergraduate thesis. University of Arkansas.

Ito, E., Ikemoto, Y. and Yoshioka, T. (2015). Thermodynamic implications of high Q10 of thermo-TRP channels in living cells. *Biophysics* 1133-38.

Johnson, Larry. (n.d.). Perlite: EZ GRO Garden. https://ezgrogarden.com/growing-mediums/perlite/

Keane, R. (2019). *Applying Ecosystem and Landscape Models in Natural Resource Management*. CRC Press.

KidsGardening. (2017). Classroom hydroponics: KidsGardening indoor lesson plan. https://kidsgardening.org/lesson-plan-classroom-hydroponics/

Ledtonic. (2019). DLI (daily light integral) chart: Understand your plants' PPFD & photoperiod requirements. https://www.ledtonic.com/blogs/guides/dli-daily-light-integral-chart-understand-your-plants-ppfd-photoperiod-requirements

Linney, S. (2017). The Flesch Reading Ease and Flesch-Kincaid Grade Level. https://readable.com/blog/the-flesch-reading-ease-and-flesch-kincaid-grade-level/

NoSoilSolutions. (2014). What is Deep Water Culture (DWC) hydroponics. https://www.nosoilsolutions.com/deep-water-culture-hydroponics/

Off-Grid Gorilla. (2015). Hydroculture & hydroponics. https://offgridgorilla.com/off-grid-systems/food/hydroculture-hydroponics/

Seek an Idea. (2012). Green walls. http://seekanidea.blogspot.com/2012/09/green-walls.html

Simply Hydro. (n.d.). Basic hydroponic systems and how they work. https://www.simplyhydro.com/system/

Storey, A. (2016). How to build a simple hydroponic Dutch bucket system. https://university.upstartfarmers.com/blog/build-simple-hydroponic-dutch-bucket-system

Tasty Seasons. (2018). How to grow green onions from cuttings. https://tastyseasons.com/how-to-grow-green-onions-from-cuttings/

Thunderbolt Kids. (n.d.). Photosynthesis: Grade 6 life and living. http://www.thunderboltkids.co.za/Grade6/01-life-and-living/chapter1.html

uPONICS. (n.d.). Hydroponics growing medium: Which grow media is best. https://uponics.com/hydroponics-growing-medium/

US EPA. (2017). WaterSense: Statistics and facts: https://www.epa.gov/watersense/statistics-and-facts