Testing Protocols, Safety Plan, and Plan for Stakeholder Feedback

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Team Name: Science with Style

Section U

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1.1 Problem Definition

Our goal is to empower English and Spanish speaking Wheat Ridge residents over 65 years in age who live in food desert regions and rely on food stamps to utilize a self-sustaining plant growing system. The majority of the system will come pre-packaged for safe installation and use and will partially utilize materials that can be easily sourced in the Wheat Ridge neighborhood. The net cost will be neutral or better after a two years of harvest and will include features that consider the potential physical limitations of our target stakeholders.

1.2 System Description

The following sketches illustrate our design. Section 1.2.1 explains each of the subsystems and their purpose as well as the key functionalities that must be tested.

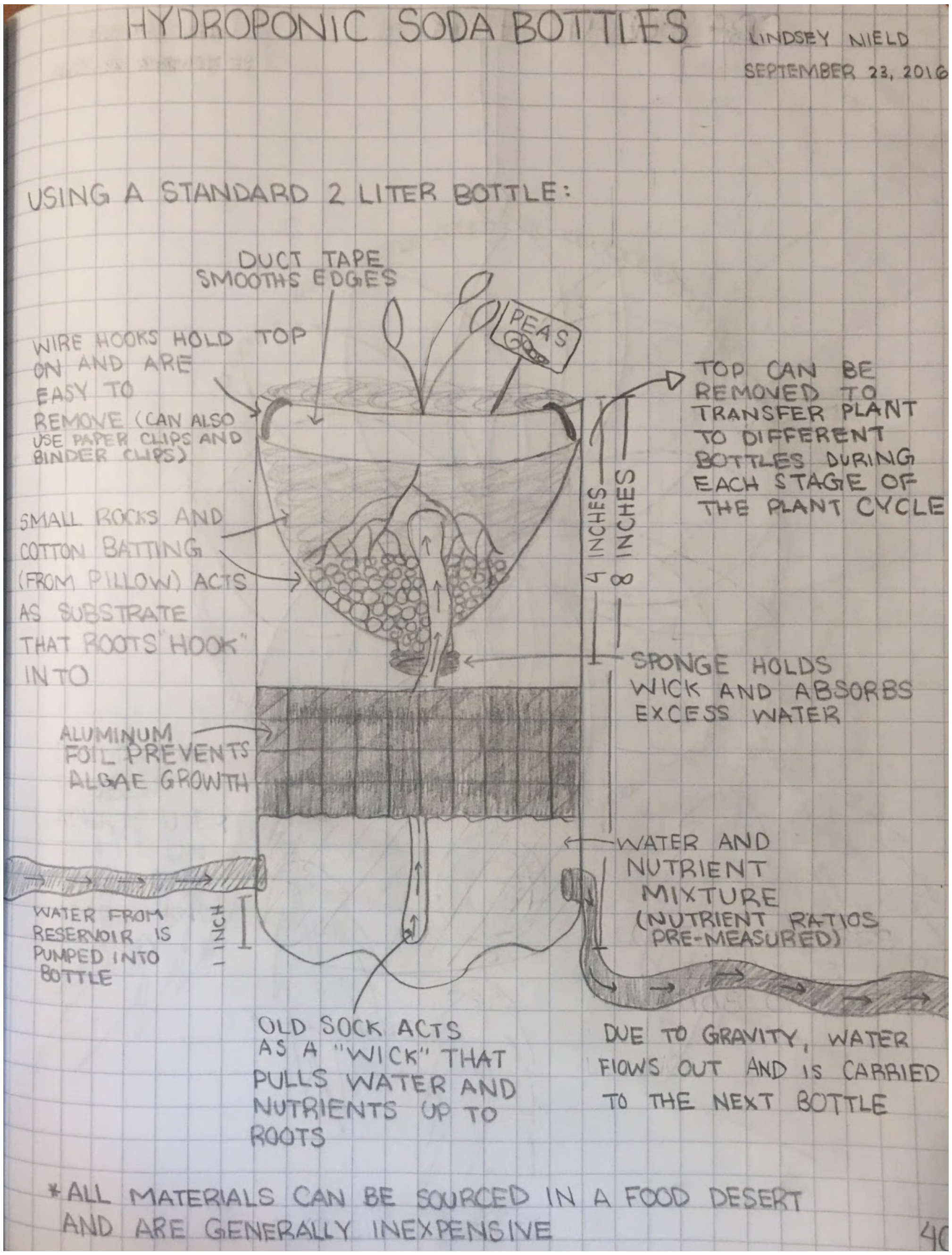

Figure 1. Diagram of Hydroponic Bottle System

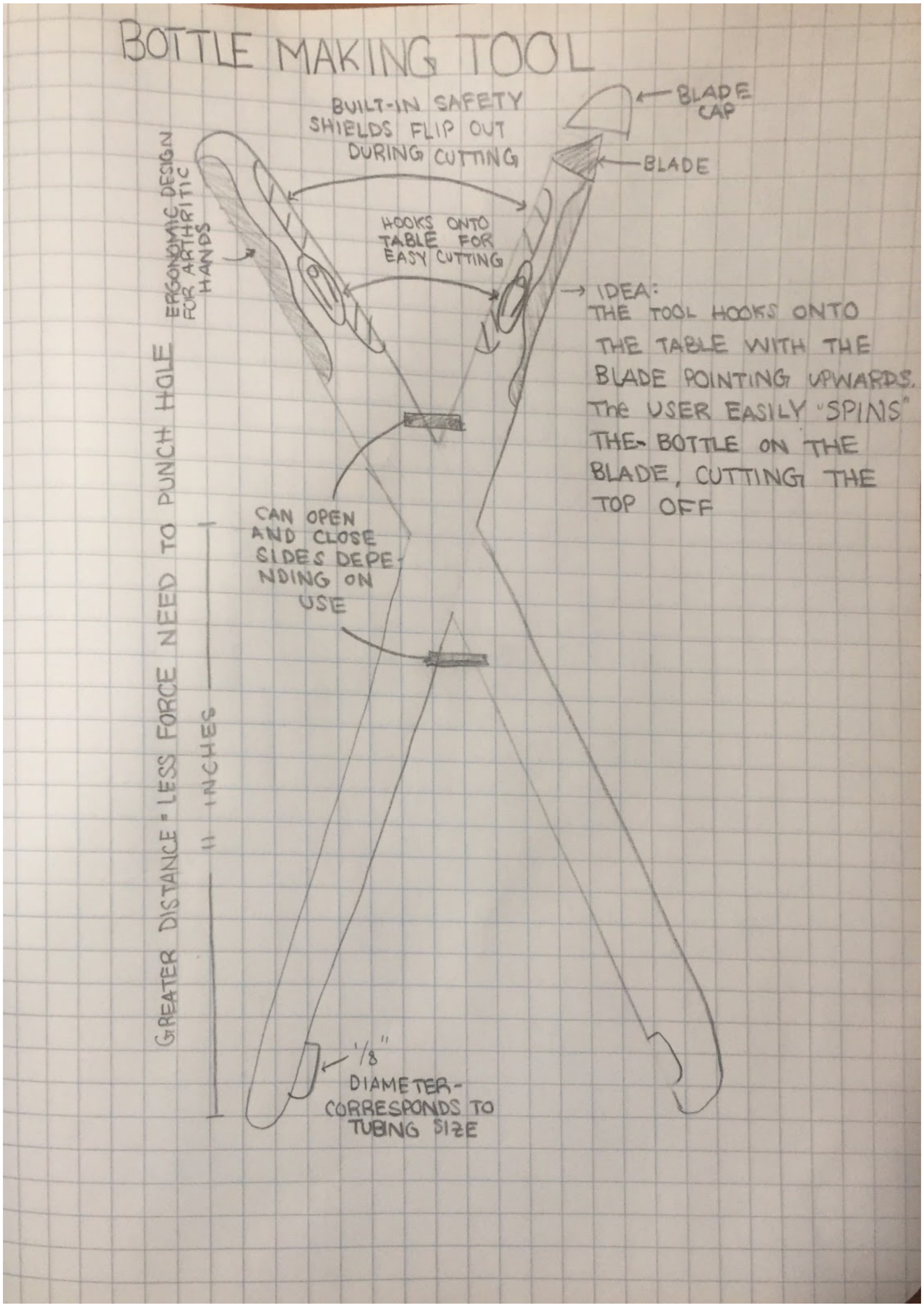

Figure 2. Diagram of Tool Used To Make Soda Bottle System.

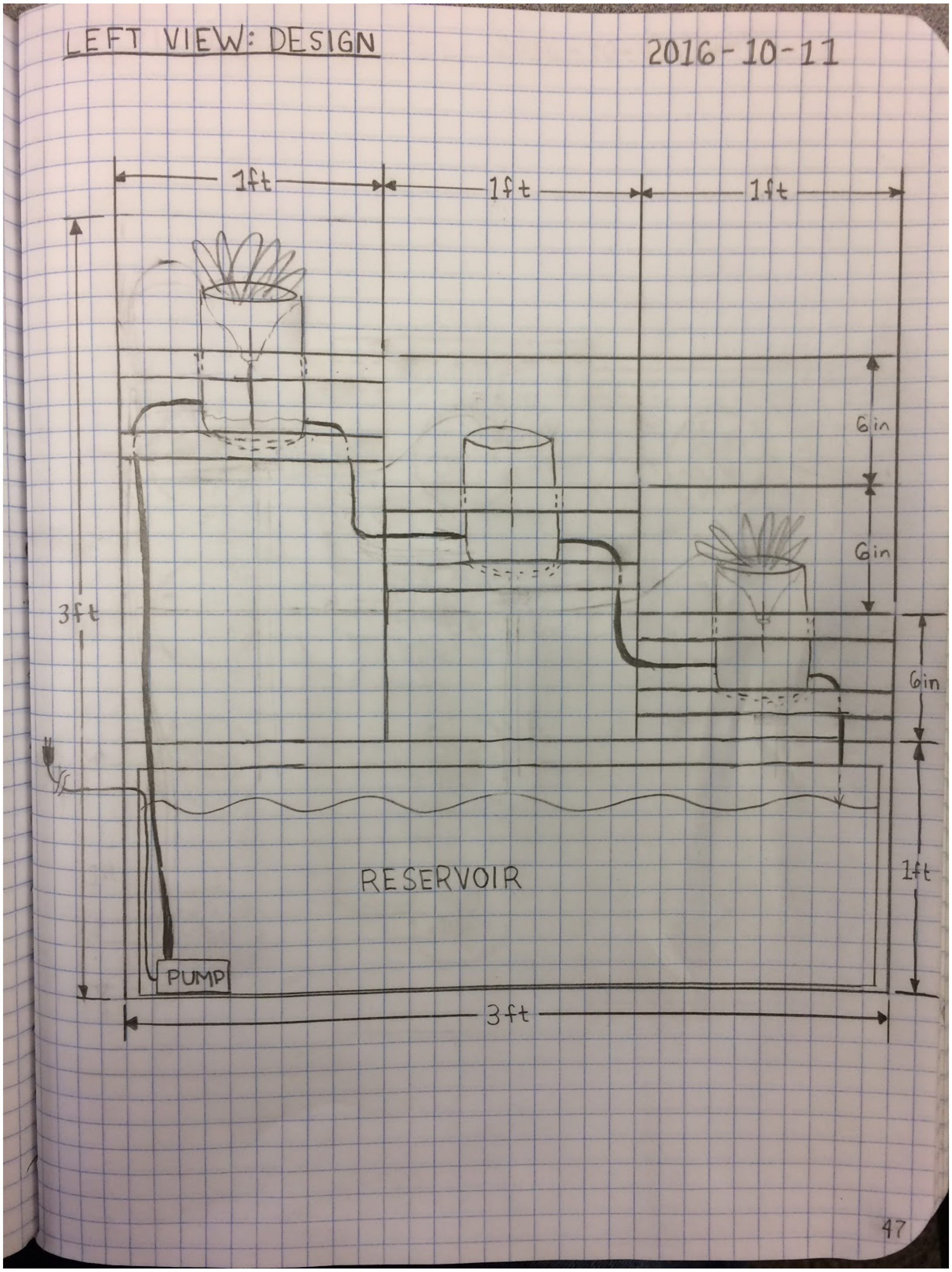

Figure 3. Side View of Water Circulation System

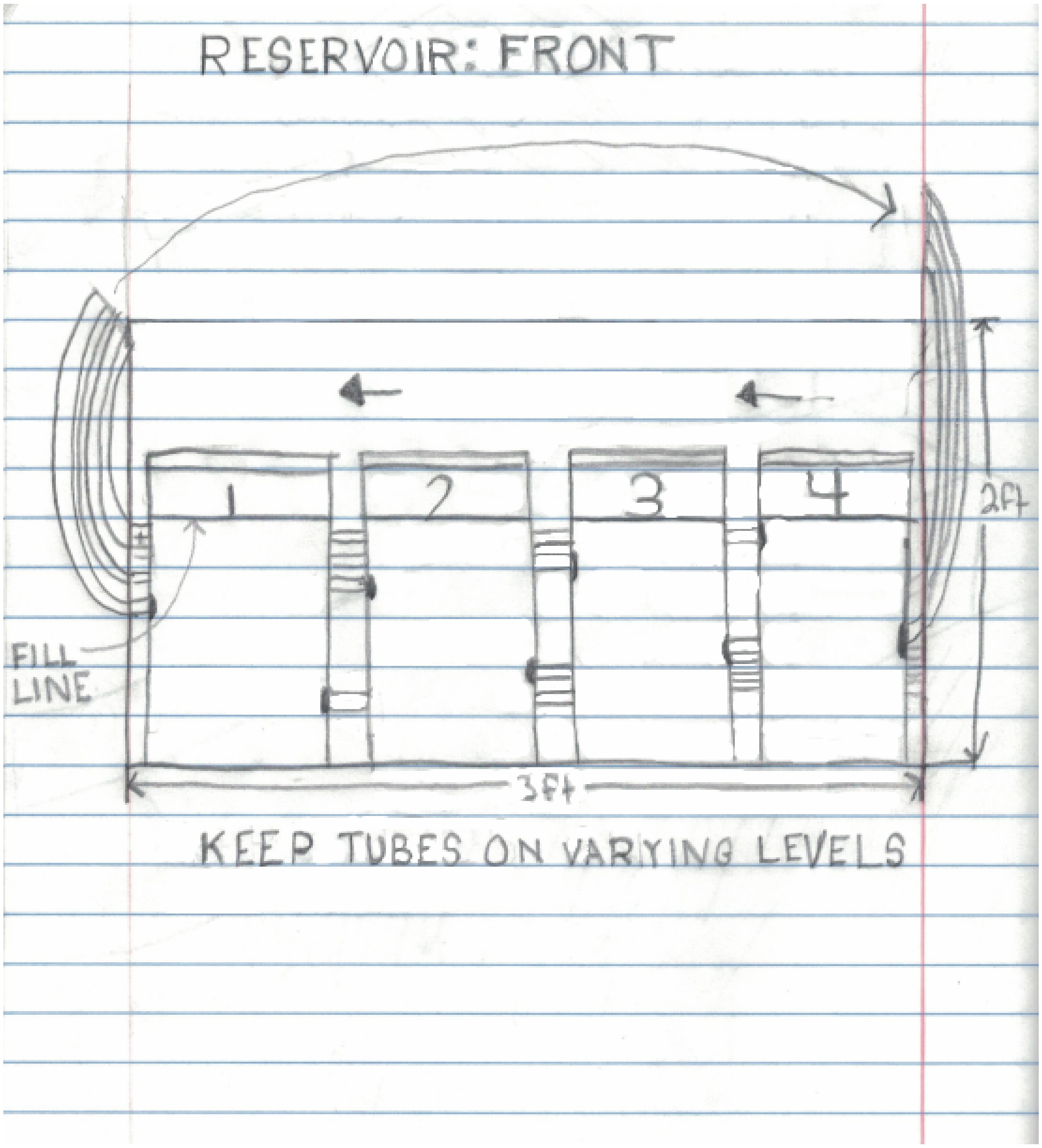

Figure 4. Front View of the Reservoirs

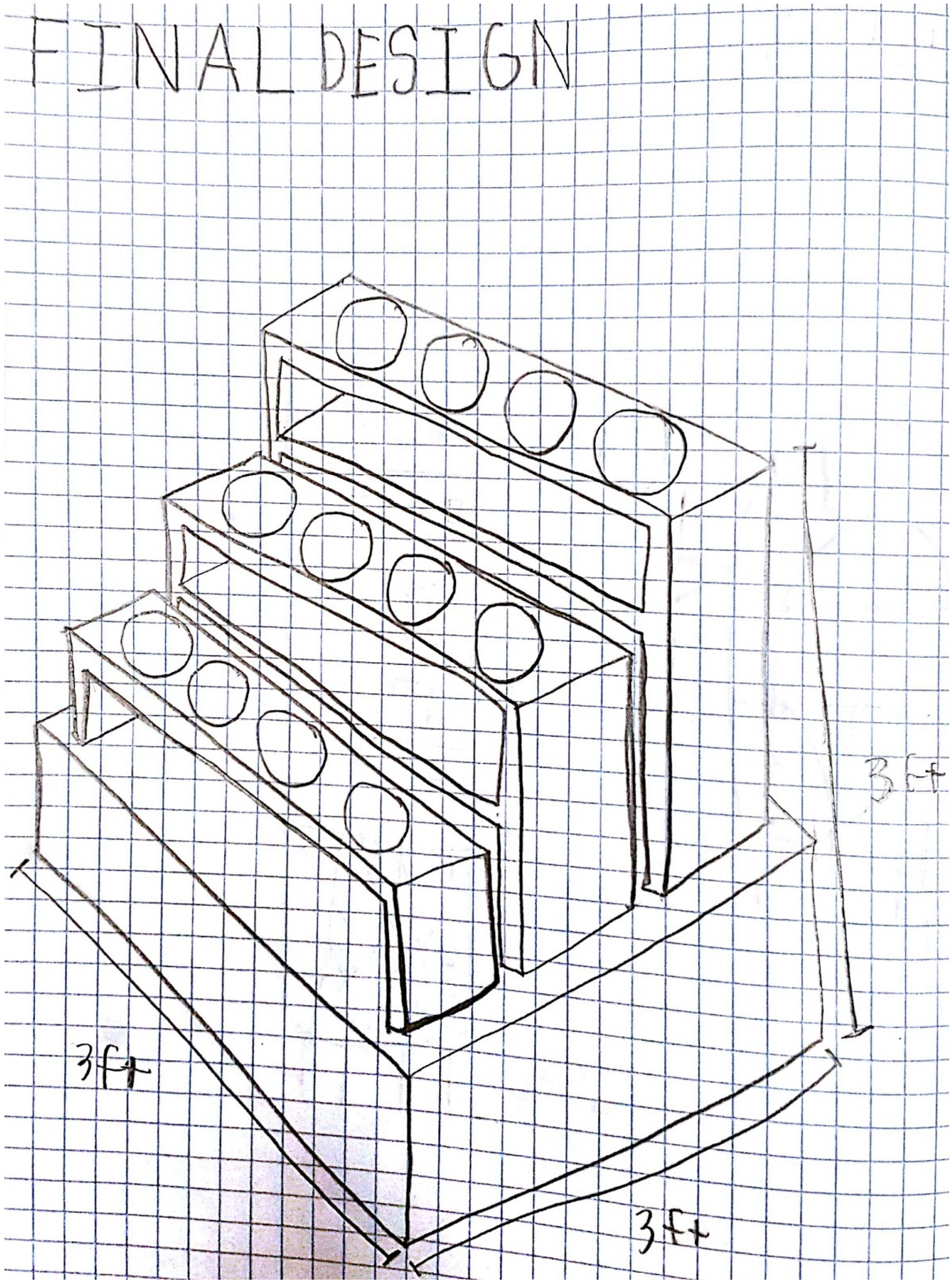

Figure 5. Isometric View of Structure

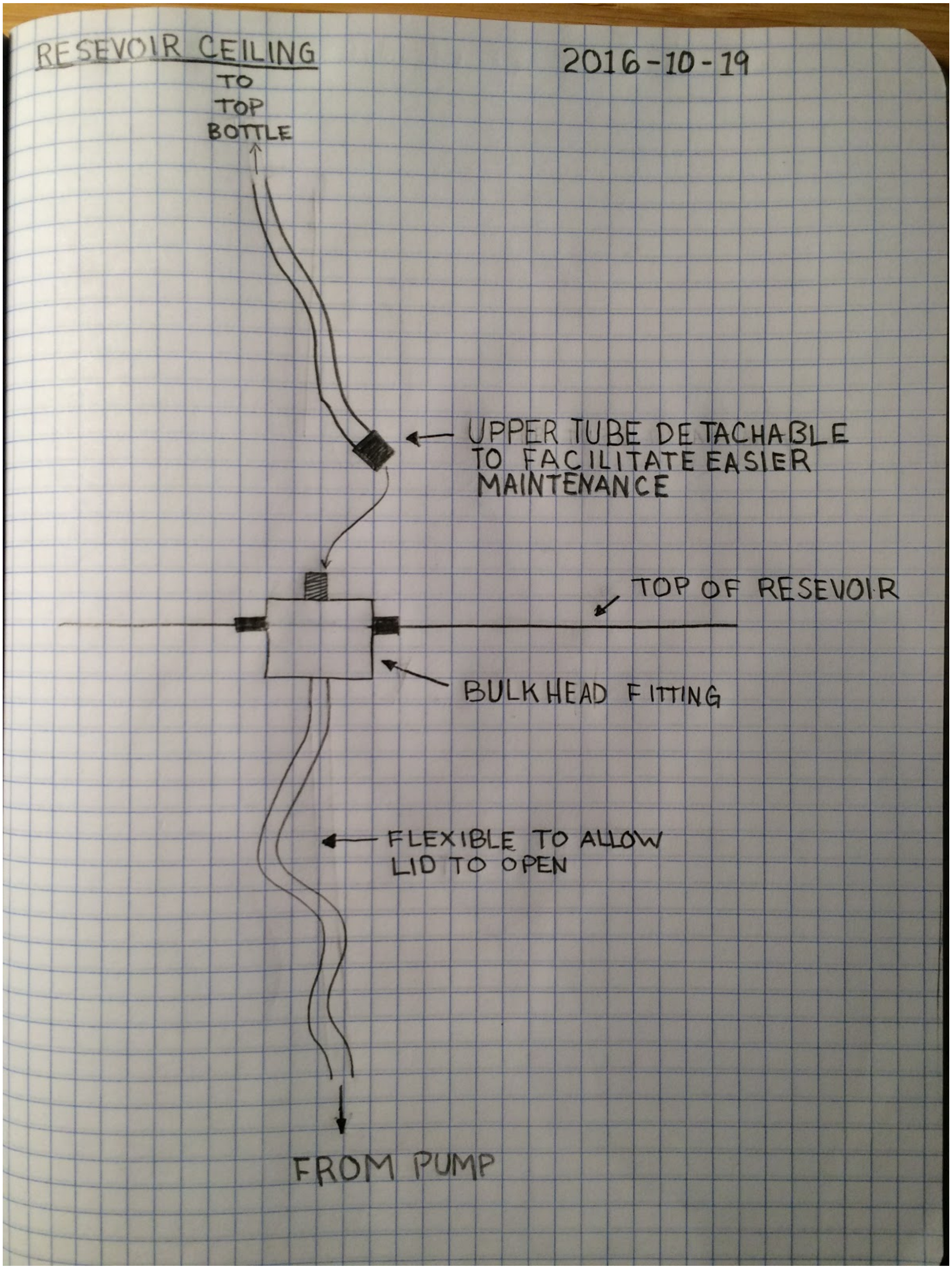

Figure 6. Reservoir Ceiling Tube Connections

1.2.1 Subsystems:

Hydroponic Soda Bottles: The soda bottles are the site of plant growth. The plants are rooted in the non-soil substrate, and a wick at the bottom of the bottle carries water and nutrients to the plant. The bottles are a part of the automated watering subsystem, which brings water and nutrients to each of the bottles. The stakeholder is expected to construct the bottles themselves using a specialized tool that we provide as well as materials that they can find around their house or in their food desert.

Nutrient Subsystem: This subsystem will provide nutrients to the plants based on their stage in the growing cycle. It will keep the plants healthy and promote growth in order to yield an abundant crop.

Structure: This subsystem will house the hydroponic bottles, reservoir, and water delivery. The structure is made up of a three step compactable design with a water storage as a base. This will allow for a lightweight design that is compatible and made from cost-effective and accessible materials.

Water Delivery: The water delivery subsystem transports water and nutrients from the reservoir to the soda bottles. Additionally, this subsystem cycles the water through three different bottles to ensure that the water does not become stagnant.

Reservoir: The reservoir holds the water and the nutrients. The reservoir can be easily accessed and refilled without much trouble for the stakeholder. The reservoir is equipped with a pump and timer in order to have an automated system in which the stakeholder can have minimal interaction in case they forget about it.

Components of the subsystems that require testing and/or validation:

- Pump: Does the pump pump the correct amount of water to maintain the water cycle?
- Weight of structure: Will the stakeholder be able to lift it?
- Instructions: Can the stakeholder understand them?
- Nutrients distribution: Are the nutrients distributed correctly, and are they in the proper amounts?
- Structure weight supported: Is the structure stable? Does the reservoir support it?
- Ease of use: Will the stakeholder be able to operate it?
- Bottle making tool: Does the tool make it easier for the stakeholder to construct the bottles?
- Compatibility: Do the subsystems work together in harmony?

1.3 Testing Protocol: Bottles

1.3.1 Hypotheses

The hydroponic soda bottle subsystem functions as the prime growing mechanism for our overall system. The automated watering subsystem pumps water and nutrients into the bottom of the bottles, and this water-nutrient mixture is carried to the plant by a makeshift wick that controls the amount of water and nutrients that are delivered to the plant. The plant resides in the top half of the bottle, which is filled with gravel and cotton batting that function as a substrate that the plant's roots can "hook" into. The bottles are expected to contribute to solving our overall system by being the site of plant growth and development. They are the intermediate between the water-nutrient subsystem and the plant as well as the environment where the plants will grow.

For the soda bottle subsystem to be successful, it would have to be compatible with the watering system. The correct amount of water (which is dependent upon the amount of water required by the individual plants) would need to be pumped into the "initial" bottle so that the water can continuously flow into the next bottle while still maintaining a proper water level in all the bottles. If this subsystem is working properly, a healthy plant (correct color and size depending on plant type) should grow. If the subsystem is not working properly, then the plant would either not get enough water or get too much water, causing stunted plant growth or plant death. In addition, a successful bottle subsystem would also have no visible algae growth, and the stakeholder (Wheat Ridge residents over 65 years of age) would have to be able to successfully make at least twelve soda bottle systems when given a specialized tool (see Figure 2). Due to the design of the bottle, a successful subsystem would have to ensure that the tops of the bottles can hold a minimum of 64 ounces of material for at least three months without falling into the body of the bottle.

1.3.2 Test Plan

1.3.2.1 Watering Subsystem (will also need research-based validation)

One of the most critical parts of the soda bottle subsystem is its ability to function with the watering system. We must ensure that the two work together in such a way that the plant gets the right amount of water and nutrients and that the bottles contain an appropriate amount of water at all times. To test this, we would need to carry out the following procedure:

1. Acquire a pump, 3 2L soda bottles, an exacto knife, ⅛" tubing, a reservoir containing water, sharpie, and a three step structural system (a basic shelving system also works).
2. Prepare the soda bottles by cutting two ⅛" diameter holes on each side of the bottle, one inch above the bottom of the bottle.
3. Set up the bottles so that one bottle is on each level of the step structural system.

4. Using tubing and the holes that were just cut and connect the “top” bottle to the “mid-level” bottle, the “mid-level” bottle to the “bottom” bottle, and the “bottom” bottle to the reservoir.
5. Set up the pump system so that water is pumped from the reservoir to the “top” bottle, thus creating a water cycling system.
6. Draw a “fill” line on each bottle three inches above the bottom of the bottle.
7. Using a guess-and-check system, adjust the pump so that the water reaches the fill line on all three bottles, and consistently stays at the fill line.
8. Record the rate at which water is being pumped to reach this ideal level.
9. Repeat this procedure several times to ensure that the pump rate is consistent and the water is cycling through the system with no blockage.

1.3.2.2 Algae Growth

To prevent algae growth, we would need to perform several rounds of testing using different light blocking materials. Algae appear when light is reflected through nutrient-rich water; thus, we will have to wrap the bottoms of our bottles in an opaque material that can easily be sourced in a food desert, such as aluminum foil [1]. To test that this strategy inhibits algae growth, we will perform the following test:

1. Acquire eight 2L plastic soda bottles, an exacto knife or specialized tool, water, plant nutrients (FloraGro, FloraMicro, FloraBloom), and aluminum foil.
2. For all eight soda bottles, use the exacto knife or specialized tool to cut off the top four inches of the bottle. Save these pieces.
3. Separate the eight bottles into four groups of two, each group corresponding to one of the plant nutrient mixtures that our system will use.
4. For the first group of bottles, mix 0.25 tsp of each nutrient with 2L of water and pour 1L of this mixture into each bottle.
5. For the second group of bottles, mix 2 tsp of FloraGro, 1 tsp of FloraMicro, and 0.5 tsp of FloraBloom with 2L of water and pour 1L of this mixture into each bottle.
6. For the third group of bottles, mix 1 tsp of each nutrient with 2L of water and pour 1L of this mixture into each bottles.
7. For the fourth group of bottles, mix 0.5 tsp of FloraGro, 1 tsp of FloraMicro, and 1.5 tsp of FloraBloom with 2L of water and pour 1L of this mixture into each bottle.
8. Wrap aluminum foil around one bottle in each of the four groups. The covered bottle is our experimental bottle and the uncovered bottle is our control.
9. Place the “tops” that were cut off in step 2 upside down in each bottle (see Figure 1).
10. Place all eight bottles in an area where they are exposed to direct sunlight (such as a window). Let them sit for a minimum of two weeks to an upwards of three months.

11. Once the testing period is over, check the bottles for algae growth. Algae can be green, red, brown, or black and is often fuzzy in texture [1]. Compare the experimental bottle with the control bottle and note any differences in algae growth.
    a. The goal is to have no visible algae growth in the experimental bottles.
12. Repeat procedure several times for more accurate results.

1.3.2.3 Stakeholder Ability

The cost of our system is dependent upon our stakeholder's ability to make the soda bottle systems using inexpensive, readily-available materials. To ensure that our stakeholder will be able to accomplish this using our specialized tool, and that our tool is safe and functional, we should perform the following test:

1. Acquire a variety of people aged 65 and up who accurately represent our stakeholder population.
2. Provide each person with a 2L soda bottle, specialized tool, scissors, sock, sponge, gravel, duct tape, and instructions (in English and Spanish) on how to build the bottle.
3. Observe as each person attempts to build their bottle. Note any difficulties that they seem to have, suggestions or complaints that they make, and their overall feelings before, during, and after making a bottle. Take note of the functionality and safety of the tool.
4. After an hour, count the number of people who were able to successfully make a bottle and those who were not. Take note of each individual's demographics (gender, age, primary language, etc.).
5. Calculate the "stakeholder success rate" by dividing the number of people who successfully made a bottle by the total number of people who attempted and multiplying by 100%.
    a. Ideally, we would want this calculation to be 100%.
6. Determine if any particular group (men, women, those over 80, those under 70, etc.) had any specific and/or common issue that would need to be addressed.
7. Using your observations and any suggestions that you garnered, adjust the bottle design or tool design as seems necessary.
8. Repeat this experiment again using your new adjustments.

1.3.2.4 Bottle Stability

The tops of the bottles will have to be able to support a minimum of 64 ounces of material (gravel, cotton batting, sponge, wick, and the plant itself) for an upwards of three months without falling into the body of the bottle. While the tops will be rotated to new bottles every few weeks so they can get the correct nutrient mixture, it is still crucial that the tops do not fall down for an extended amount of time. To test this, we should perform the following steps:

1. Acquire four 2L bottles, an exacto knife or specialized tool, duct tape, wire hooks, paper clips, binder clips, a scale, and some sort of substrate (gravel, marbles, beans, etc.).
2. Prepare the soda bottles by using the exacto knife or specialized tool to cut the top four inches off of each of the bottles.
3. Line the cut edges on both the bottle body and the part that was just cut off with duct tape.
4. Turn the cut pieces upside down and place them in the soda bottle body (see Figure 1).
5. On one of the bottles, attach the top to the body using three wire hooks.
6. One another bottle, attach the top to the body using three paper clips.
7. On the third bottle, attach the top to the body using three binder clips.
8. In all four bottles, fill the tops with 64 ounces of your chosen substrate.
9. Let the bottles sit for two to three weeks. If the top of one bottle falls into the body, note when this occurs.
10. Once the testing period is over, note which system worked the best (i.e. which top stayed up the longest).
11. Repeat this experiment several times for more accurate results. You can also adjust the number of hooks and clips that you use to determine which combination provides the best stability.

1.3.3 Required Equipment and Materials

The materials needed for these experiments are:

- 2L soda bottles
- Specialized tools
- Scissors
- Water
- Nutrients (FloraGro, FloraMicro, FloraBloom)
- Socks
- Sponges
- Scale
- Gravel
- Substrate (rocks, marbles, beans, etc.)
- Aluminum foil
- Stakeholders (people aged 65+)
- Duct tape
- Bottle building instructions
- Wire hooks
- Paper clips
- Binder clips
- Scale
- Pump
- Reservoir
- Sharpie Marker
- Three Step Structural System

1.3.4 Testing Phases

1.3.4.1 Phase 1[1]

Our first phase of testing will focus on stakeholder feasibility; in this phase, we may have to adjust our design significantly, and thus it is critical that it gets done first. We will need to test if the stakeholder is able to construct these bottles easily and quickly, using the stakeholder ability test outlined above. We will need to make all the changes necessary to the design if our stakeholder struggles to create the bottles. This phase of testing should be complete by 2 November 2016 and may take up to a week.

1.3.4.2 Phase 2

Once the first phase of testing is done and we have our design finalized, we will need to get more specific with our testing. We need to ensure that the bottle subsystem is compatible with the structural subsystem and watering subsystem by testing them together. At this stage, we must ensure that all measurements are correct and that the water can cycle seamlessly through the system. This will need to be accomplished by 12 November 2016 and may take up to a week to accomplish.

1.3.4.3 Phase 3

Once it is established that the bottles are compatible with the rest of the system, we will work on perfecting the bottle design. We will need to run our algae test and our bottle stability test to verify the longevity of the subsystem and make small tweaks if necessary. Finally, we will again ensure that the bottle functions with the rest of the system and verify that it functions properly (the correct amount of water-nutrient mixture is being pulled up to the plant bed), so that, theoretically, a plant can successfully mature in the system. This final phase will take up to two weeks and needs to be complete by 20 November 2016.

1.3.5 ALTERNATIVE to above for critical components needing research validation

Since we are unable to actually grow food, there are several critical components of the soda bottle subsystem that we cannot physically test. For example, in regards to the water system, we can test that it is getting around the correct amount of water-nutrient mixture, but since we cannot actually grow a plant given our time constraints, we would not be able to know for sure that the right amount is being delivered to the plant. Instead, we must research how much water each plant (lettuce, spinach, and snow peas) needs during each stage of its plant cycle, and then use that to calculate how much water per hour/day/week needs to be pumped

[1] For all subsystems, phase 1 testing must be complete prior to the submission of the subsystem report. We will continue to perform other phases of testing leading up to the final report and presentation.

into each bottle. This would also provide us with the water flow rate setting for each of our pumps. We would also need to research how far apart each plant (and thus each bottle) would have to be from each other so they can grow properly. We would then have to incorporate this information into the structure to ensure that the bottles are placed a correct distance apart.

1.4 Testing Protocols: Nutrients

1.4.1 Hypotheses

The nutrients subsystem has two components: 1) detailed instructions on how to properly add nutrients to their vegetation at each growing stage and 2) pre-measured nutrient containers. This subsystem will take up a small section of overall space to hold the pre measured nutrient containers. The instructions will be on the side of the structure so that they are easy to see and available whenever needed. They will include information about what the user should look for to ensure proper plant growth and will explain how to determine if the plant is over nourished or undernourished and provide a guide on the proper steps to take in order to solve the situation.

Successful instructions will provide the steps our stakeholders must follow to grow the plants. These instructions must be easy to understand and follow so that our stakeholders do not require assistance or need to ask questions. For the information about proper plant growth to be successful, the pictures and description must must accurately portray the appearance of a supersaturated and undersaturated plant with a clear guide on how to alter the nutrient regimen. The stakeholder will be able to identify when the plant needs a change in nutrition and will be able to perform the necessary steps to modify the nutrient amounts. If the nutrients subsystem is successful, the plants will grow according to their expected growing stages and the appearance and length of each stage will be relatively uniform. The stakeholder will only have to monitor the plants once a week for less than 15 minutes. A successful nutrient subsystem will cost under $20.00 per growing cycle (approximately 3 months) and the amounts provided must be sufficient to sustain the plants' growth.

1.4.2 Test Plan

1.4.2.1 Instruction Clarity: Normal Operation

To ensure that our instructions are clear, we need to test them with potential stakeholders. The following steps will be performed:

1. Create a rough prototype including the instructions, pre-measured packets and a water reservoir (this water reservoir does not need to be the same as the one utilized in the final design).
2. Provide the pre-prepared prototype to 10 random potential stakeholders and observe their ability to effectively follow the intended steps.
3. Provide a questionnaire with feedback in order to refine the instructions.
4. Repeat this test with fluent Spanish speakers in order to test that the Spanish instructions are clear as well.

1.4.2.2 Instruction Clarity: Troubleshooting

In the case that the plants do not grow exactly as expected, we must test the accuracy and abilities of the troubleshooting instructions. The following steps will be performed to do this test:

1. We will show 10 random potential stakeholders pictures of 3 supersaturated plants, 3 undersaturated plants, and 3 perfectly healthy plants.
2. Include the instructions for troubleshooting nutrients with the plants along with a table asking the test participant to label the health of the plant (i.e. is it supersaturated, etc.) with a column for how the user should proceed in adding nutrients.
3. Rate their accuracy in assessing the plants' health and their following steps to fix the problem. Based on their responses, refine the instructions and/or descriptions to make the guide easier to understand.

1.4.2.3 Maintenence Time

In order to mitigate the risk of the nutrient subsystem becoming a burden to the stakeholder and taking too much time, the following steps must be performed:

1. Provide ten random potential stakeholders with pictures of 11 plants, the instructions, the remeasured nutrients, and a water reservoir.
2. Time how long it takes each person to assess what nutrients each plant needs, what growing stage they are in, and provide the nutrients accordingly.
3. If the user takes less than 15 minutes to complete all their tasks, the subsystem is successful because it allows the stakeholder to spend minimal amount of time per week maintaining their plants while living their busy life.

1.4.2.4 Nutrient Cost

The cost of nutrients is a key component that must be tests. To test the nutrients cost, the following steps will be followed:

1. Take twelve possible stakeholders and divide them into four groups of three.
2. Members of Group 1 will each grow the provided seedling in growing stage 1. Members of Group 2 will will each grow the provided plant in growing stage 2. Members of Group 3 will grow the given plant in growing stage three. Finally, members of Group 4 will each grow the provided plant in growing stage four. The plants will be provided all at once, each at the start of their respective growing stage necessary for each group.
3. Each participant will measure the amount of nutrients used and at the end add up the total value of nutrients. This will provide data points for nutrients that take into account plants becoming supersaturated or unsaturated which alters the theoretical nutrient regimen determined by our research. Additionally, this data will help estimate the accuracy of the estimated growing length

4. Using this data, take an average of the amount of nutrients used at each stage and aggregate them to find the estimated amount of nutrients required by one plant for a single growing season.
5. Take this amount and divide it by the amount purchased in bulk and multiply by the cost of the bulk nutrients.
6. If the total is under $20/growing cycle, the nutrients subsystem is cost-effective.
7. This test will also provide more information on how much nutrients to include with food production system when selling the product.

1.4.3 Required Equipment and Materials

- Access to a multitude of stakeholders, some of whom are fluent in Spanish (Table 2 has contact information for a few potential stakeholders)
- Twelve copies of the instructions with troubleshooting guide
- A reservoir similar to the one in the final product
- 10 pre-measured nutrient packets
- A questionnaire asking the test participant which parts of the instructions were clear, which portions were unclear, and what they were unsure about as the followed the instructions
- 3 photos of each plant, one showing a supersaturated plant, one showing an undersaturated plant, and another showing a healthy plant
- 10 copies of a questionnaire asking user to label a variety of plants as supersaturated, unsaturated, or healthy and a questions about the steps they would take to mitigate the nutrient imbalance
- 11 pictures of spinach at various growing stages
- A timer
- Twelve pre-made hydroponics bottles
- Three spinach seeds
- Three spinach plants about to start the second growing stage
- Three spinach plants about to start the third growing stage
- Three spinach plants about to start the fourth growing stage
- Bulk supplies of nutrients
- Document to record amount of nutrients used

1.4.4 Testing Phases

1.4.4.1 Phase 1

Informally and randomly finding 10 people willing to read through the instructions and answers questions about it. This needs to be done first as every test after this relies on a clear and final draft of the instructions. This should take 5 days by doing 2 people a day. After every day, the test subjects answers will be read and evaluated in order to refine the instructions for the best final product possible. This will be done by 2 November 2016.

1.4.4.2 Phase 2

Again this is an informal testing phase in which 10 people are evaluate the troubleshooting guide coupled with the instructions for clarity, accuracy, and level of ease to comprehend. We will test two subjects a day for 5 days and refine the guide at the end of each day in order to receive new feedback on each draft. This will be completed by 11 November 2016.

1.4.4.3 Phase 3

This will be an intermediate testing phase in which a more finalized product is presented for testing and the data is quantitative making it semi formal. In this phase, if the product fails, there must be refinement to the nutrition subsystem as a whole. This phase however can be done all in one day as this is a pass or fail phase in which the product will not be slightly altered based on a few subjects trial. Instead, we will take the average time from all of the subjects and if the majority passed the product is a success while if most of the subjects fail the product will need a new design. This test will be done on 12 November 2016.

1.4.4.4 Phase 4

This is longest and most crucial testing phase. Since we can test everyone at once this phase should last about 3 weeks based on research of the expected length of the longest growing stage. This will be a finality of the nutrition subsystem as a whole providing a formal test for the subjects. Given that the subjects average using the expected amount of nutrients, the subsystem is a success and ready to be put in the food production system. This test will begin 6 November 2016 and end by 27 November 2016 with some test participants finishing before others due to the varying lengths of each growing stage. This test can be done simultaneously with the others because they focus on the amount of nutrients and will be able to ask questions as they go about the instructions. They will also provide even more feedback on the clarity of the instructions.

1.4.5 ALTERNATIVE to above for critical components needing research validation

In the nutrient system, every value for the amount of nutrients necessary per gallon of water must be measured with extreme accuracy. The following procedure should be followed to determine these amounts:

1. Research the amount of nutrition required for hydroponics system per gallon for each growing stage.
2. Research the length of each growing stage. This information will be used to give the user a guide for how long to expect each plant to take to mature into a fully grown crop.

3. Look up the appearance of spinach, lettuce, and green peas that are supersaturated and undersaturated and how to alter the nutrition regimen accordingly.
4. Research the frequency at which the stakeholder will need to add nutrients for maximum efficiency.

1.5 Testing Protocol: Water Delivery

1.5.1 Hypotheses

The water delivery subsystem is the sole mechanism for transporting nutrients and water from the reservoir to the soda bottles. This is critical to the overall system because if water and nutrients cannot be delivered to the bottles, the plants cannot grow and thus no food can be produced. The water delivery subsystem is comprised of four separate water circulation systems, one for each nutrient stage. This will help facilitate our modular design. Each circulation system corresponds to a single column of bottles and distributes water to each bottle in the column (see Figure 3). Because we are using a wicking mechanism to transport water and nutrients from the bottom of the bottle to the plant, the circulation system does not have to run continuously. Therefore, the pumps will be on a timer which will let water run for a few minutes every hour.

A successful water delivery subsystem will successfully interface with both the reservoir and the bottles without any issues. For those interfaces to be successful, all connections must be watertight. The water delivery subsystem must also deliver the correct amount of water to each bottle. Additionally, these interfaces must be simple enough that our stakeholders can setup and configure them without issues.

1.5.2 Test Plan

The water delivery subsystem has many points of failure, all of which are critical. Because of this, it is important that the possible failure points of the subsystem are tested. Below are the procedures for testing each interface.

1.5.2.1 Pump Head Height

The pump must be able to raise the water from the bottom of the reservoir to the level of the top bottle. It is critical that the pump can do this because if it cannot, none of the plants will receive the necessary nutrients and water. To test the head height, follow these steps:

1. Acquire a pump and place it in a water container (for this test, it is not necessary to use the actual reservoir).
2. Connect ⅛" diameter tubing to the pump (this is the same type of tubing that will be used in the final product).
3. Ensure that the pump can push water three feet up through the tubing.
4. If the pump does not have the necessary head to raise the water up to three feet, determine the maximum height that it can pump by gradually reducing the height until the pump can force the water out of the tubing. Find another pump that has a greater head and repeat this test until a satisfactory pump is found.

5. If the pump can push the water up three feet, then the pump is sufficient for our purposes and this test is successful.

1.5.2.2 Transfer Through Reservoir Ceiling

The water from the reservoir must be pumped out through the ceiling of the reservoir to the top bottle. This transfer point must be watertight because if it leaks, the top plants will not receive the required water. Figure 6 shows the mechanism that will be used to transfer the water from the tube inside the reservoir to the tube that goes to the top bottle. The following steps explain how this transfer should be tested. (Note that in the final product, the pump will not run for 12 hours straight, however this test attempts to evaluate the performance of the connection in an extreme case).

1. Acquire a pump similar to the one that will be placed in the final reservoirs and a lid similar to the one that will be used to cover the final reservoirs (see Section 1.6).
2. Install bulkhead fitting into the reservoir lid and attach the tubing in the same way that it will be installed on the final system. The tube that would go to the top bottle can be redirected back down to the reservoir.
3. Run the pump for a 12 hour period, checking it every hour to see if there are any leaks.
4. If a leak occurs inside the reservoir, determine the amount of water that is being leaked, identify the source of the leak and attempt to mitigate the issue. Though these leaks will not damage anything outside of the system, they will affect the amount of water being pumped to the upper bottle.
5. If a leak occurs outside of the reservoir, identify the source of the leaks and attempt to mitigate the issue.
6. If no leaks occur, the test is successful.

1.5.2.3 Connections on Bottle

Tubing will carry water from the reservoir to the upper bottle. Similar tubing will drain water from the top bottle to the lower bottles in the column. The connections between the tubes and the bottles must be tested to ensure that no leakage occurs. Follow these steps to test the aforementioned connections:

1. Acquire three soda bottles with their tops cut off similar to the ones we will use in our final product.
2. For each bottle, create a hole on each side of the bottle 1” above the bottom of the bottle using the bottle construction tool as shown in Figure 2.
3. Connect bulkhead fittings into the holes and connect the tubing to these fittings.
4. Set up a reservoir and pump (for this test, it is not necessary to use the actual reservoir)
5. Set up a stair step prototype to hold the three bottle prototypes.
6. Connect the tube from the pump to the first bottle.
7. Connect the output tube from the first bottle to the second bottle.

8. Connect the bottles together in this manner, with the last bottle draining back into the reservoir.
9. Circulate the water for 12 hours, checking each our for leaks.
10. If leaks occur, identify the source and attempt to mitigate the issue.
11. If no leaks occur, the test is successful.

1.5.2.4 Water Flow Rate

We must determine an appropriate water flow rate to ensure that 1) the plants always have sufficient water and nutrients and 2) the pump operates for a minimal time to reduce power consumption. To determine the correct water flow, the following steps will be performed.

1. Set up a reservoir, pump, tubing, and stair step prototype with soda bottles. (This is the same setup as used in 1.5.2.3.)
2. Fill the bottles with water up to the overflow bulkhead.
3. Measure the amount of water in each bottle.
4. Redirect the water from the last bottle to a different reservoir.
5. Run the pump for five minutes and measure the amount of water in the other reservoir.
6. Adjust the amount of time to run the pump until the water in the reservoir is twice the amount of water in each bottle from Step 3. This will ensure that the plants get new water every hour during normal operation.

1.5.3 Required Equipment and Materials

- (1) Pump
- (1) Reservoir with lid
- (7+) Bulkhead fittings
- (10’+) ⅛” tubing
- (3) Finished bottle prototypes
- (1) Stair step structure prototype
- (1) Timer
- (1) Meterstick

1.5.4 Testing Phases

1.5.4.1 Phase 1

Our first phase will focus on the pump head (see Section 1.5.2.1) and the interface between the top of the reservoir and the tubing (see Section 1.5.2.2). It is critical that the pump can raise the water to the top bottle and it is also critical that the connection through the top of the reservoir does not leak. The assembly required to perform these tests could take up to one weeks, but the actual testing should take no more than two days. This phase of testing should be complete by 2 November 2016.

1.5.4.2 Phase 2

In this phase, a single column of bottles will be assembled. Only one will be assembled to help simplify testing and identify potential issues before building all four circulation systems. At this stage, the most important test is the bottle connection test (see Section 1.5.2.3). The assembly required to perform these tests could take one week, and the actual testing could take up to two days. Thus, this phase of testing should be complete by 10 November 2016.

1.5.4.3 Phase 3

The primary goal of Phase 3 is to determine the amount of time the pump needs to be running every hour. Thus, performing the water flow rate test outlined in Section 1.5.2.4 is critical for this phase. There is very little assembly required for this test, so it can be completed in two days. Because of possible complications, however, this phase of testing should be complete by 17 November 2016.

1.5.5 ALTERNATIVE to above for critical components needing research validation

Although we are unable to grow food, we have to determine if the water flow is sufficient to supply the necessary nutrients and water to the plants. The answer to this question will be largely dependent on research performed for the Nutrients subsystem (see Section 1.4.5) and for the Soda Bottle subsystem. If the plants will be consuming more water than we are pumping, we will have to either increase the amount of time that the pump is operating or increase the frequency that the pump operates. Section 1.5.2.4 outlines the procedure to follow in order to find the optimal combination of pump time and frequency. Once the optimal combination is determined, we will need to incorporate our findings into our final timer design.

1.6 Testing Protocols: Reservoir

1.6.1 Hypotheses

The reservoir subsystem is expected to contribute to solving the overall problem in many ways. It will be compact to align with our modular design and it will be lightweight to appeal to our stakeholders as they will find it more desirable to not have a heavy component. The reservoir subsystem will also demonstrate a degree of automation allowing our stakeholders to set the system up without having to worry about daily maintenance such as adding water. Additionally, as shown in Figure 4, the water is cycled back into the reservoir. This arrangement will allow the water to be reused, further reducing the amount of maintenance required on the part of the stakeholder.

A successful reservoir system would be able to hold enough water that it will not run out of water for a reasonable time. A successful reservoir system would also demonstrate automation proving that the reservoir can be left alone without risk of plant death due to lack of water. Ultimately, success can be determined by how much the stakeholder likes the prototype. If they find the weight and design appealing to their needs, then it will be proven successful.

1.6.2 Test Plan

To test, plug the pump in and see how much water being pushed through the tubes. If there is an unequal distribution of water, that may kill plants and empty the reservoir faster than intended.

1. Ensure the parts of the reservoir are attached properly (pump on the inner side, tubing going out from the pump to the output, the output coming back to the input on the reservoir).
2. Fill the reservoir to the fill line.
3. Plug in the pump to check the flow of water.
    a. If the pump does not seem to be working, ensure it is horizontal to the water.
    b. If it still does not work, check tubing.
    c. If all fails, faulty pump.
4. Ensure the water is flowing at a steady rate that will not overflow the bottles.
5. Adjust the valve as so needed to adjust the rate if the flow is too high.
6. Set timer on the reservoir to automatically water each plant.
7. Wait to ensure timer is working, and bottles have equal distribution of water.
8. Check the water level in the reservoir to ensure the water does not fall past the minimum line in a speedy manner.

    a. If the water level is dropping too fast, either set the timer to water at a longer interval or lower the output via valve.
9. Check for any leaks from the reservoir, and if so, shut the valve and unplug the pump and wait for any remaining water from the tubes to flow back into the reservoir.

This procedure will test the outflow of the reservoir. Additionally it will demonstrate that the automation system works and that, once started, all that the stakeholder is required do is fill the water back up periodically. It is critical that the water level of the reservoir does not drop too quickly as our stakeholders may forget to refill it, thus causing problems if it needs to be refilled everyday.

1.6.3 Required Equipment and Materials

1. Reservoir that will be used in the final design
2. Pump
3. ⅛” tubing
4. Hydroponic bottle
5. The structure to ensure overall design functions properly

The reservoir itself does not require all of these materials, however to ensure the reservoir works according to our design. It is critical to have all of our prototyped pieces together to ensure that the components interface properly with one another.

1.6.4 Testing Phases

1.6.4.1 Phase 1

Run the subsystem incomplete to ensure that the pump and reservoir are working together properly with adequate output. This will let us know if our subsystem has any leaks right off the get go, and showcase the very basic idea of our design. This will take a few hours as it is just setting up the overall system. This will be done by 2 November 2016.

1.6.4.2 Phase 2

Add the ⅛” tubes to our main tube to see how much water gets distributed to the different bottles. This will let us monitor how much water is being drained per hour to each plant, based on the 5 minutes per hour of watering. This will take at least 4 hours of testing to get multiple runs to make sure the watering subsystem remains consistent. This test will be done by 20 November 2016.

1.6.4.3 Phase 3

Attach the tubes into the bottles on different shelves and let the subsystem run by itself. This test ensures that our design is working as intended. We will need to monitor the water level of the reservoir heavily to make sure that it does not drop too fast, and ensure that there are no conflicts with tubing and other pieces. This test should take about 6 hours, as it is letting the subsystem run by itself to ensure it works properly. This will be done by 23 November 2016.

1.6.4.4 Phase 4

Attach every tube to the different bottles at different heights and let the entire system function without human interaction. We will monitor the water levels of the reservoirs to see if any are being drained too quickly, and make sure that the automation is successful. This will take the longest period of time, up to 1-2 weeks, and will ensure that our reservoir holds enough water and will not be drained too quickly for each of the bottles. This will be done by 30 November 2016.

1.6.5 ALTERNATIVE to above for critical components needing research validation

We need to research what reservoirs are viable options for our subsystem. We need to ensure that the stakeholders' needs are accounted for in our reservoir choice. It must be lightweight and modular as that is a crucial part of our design. Additionally, we need to research if certain plastics or containers have ill effects on our plants or if certain reservoirs are more effective than others (i.e. rounded corners versus a box). Research must also be performed to find a cost effective reservoir. After this research, we will be able to test the reservoir as described above.

1.7 Testing Protocols: Structure

1.7.1 Hypotheses

The structural subsystem will be used to hold all components of the hydroponic growing system in a compact, lightweight, sturdy, and cost-effective manner. Our design seeks to accomplish this my using a three step compactable design that integrates with the water reservoir. This will allow the users to easily store and transport the system. Additionally, the structure will be made out of plywood. We chose this material because it is cost-effective and strong. Finally, the compactable design allows for individual movement of each piece of the system, allowing our stakeholders to move it around easily. By combining the three step design with plywood, we have allowed a compact system made from cost-effective materials to meet our weight and stability requirements.

A successful structural system will be lightweight, compactable, and cost-effective to produce. If we had the time and technical ability, we would make a lightweight metal or plastic that was very stable and had a large degree of compactibility, and we would want this to be at the smallest cost to produce this good possible. Because we are unable to manufacture such a material, we needed to find a suitable alternative. Our criteria for this material is that it must cost less that $40.00 to produce the final full scale product, it must be able to support the weight of the hydroponic water bottles and water without becoming unstable, and it must weigh under 30 lbs per piece. We have decided to use plywood since is a very cost-effective, strong, durable, and abundant material. The biggest problem with using plywood is that it is heavy. This is compensated for via our 3 step design. Since our structure can be moved in multiple pieces, no one piece should be to heavy for our stakeholders.

1.7.2 Test Plan

The following is a procedure that we will use to test the stability of the structure:

1. Acquire full scale prototype.
2. Place on solid level ground.
3. Place approximately 25 lbs on top of shelf .
4. Wiggle shelfs to see if they are likely to tip.
5. If a shelf tips over or breaks or if the shelf fails. Reconsider materials design or construction process.
6. If the shelf passes repeat steps 2-4 for all sizes.
7. Processed to weight testing.
8. Take the entire prototyped system and ensure that the total weight does not exceed 65 lbs.
9. Weight each individual piece of the system to ensure no single piece exceeds 30 lbs.
10. Processed to compatibility testing.
11. Assemble the structure in compact form.
12. Make sure that all components fit nicely in the area of no less than 1” × 3” × 3”.

1.7.3 Required Equipment and Materials

The materials needed for this experiment are:

- (1) Full scale three step structural system
- (1) 25 lbs weight
- (1) Scale

1.7.4 Testing Phases

1.7.4.1 Phase 1

This phase consists of a few informal tests. We will do quick wiggle test by wiggling the prototype to see if the structure is sturdy. Also, we will quickly test the weight of the prototype by lifting the prototype to determine if the weight is appropriate for our stakeholders. This is to be completed by 2 November 2016.

1.7.4.2 Phase 2

Phase two consists of semi-formal tests. These tests are designed to push the prototype to its limits. We will find the maximum weight that the structure can support. This will involve stacking weight on the structure until it collapses. This is to be completed by 17 November 2016.

1.7.4.3 Phase 3

The last phase consists of formal tests. We will follow the instructions above to precisely evaluate if the strength, weight, and compactibility are up to our standards. This is to be completed by 27 November 2016.

1.7.5 ALTERNATIVE to above for critical components needing research validation

We will research different types of woods, metals, and plastics to determine if there is a better alternative. Being as strong, cost-effective, and lightweight as possible is very pivotal to our design. We will look to find which of these materials is the most cost-effective for their weight, then compare them to one another the find the best option for our project.

1.8 Safety Plan: Risk Identification and Mitigation Plan

Because of the complex nature of our system, there are many risks which must be mitigated. The next sections describe the identified risks and how we intend to mitigate them.

1.8.1 General Risks

- **Stakeholder Incompetence**
  - **Assembly:** Although we have strived to design a simple solution, our stakeholders might have difficulties assembling the structure.
  - **Nutrients:** The instructions on how to add nutrients may be difficult to follow and understanding when to alter the nutrient regimen based on plant appearance may be difficult.
  - **Bottle Assembly:** The stakeholder may struggle to construct the bottle systems.
  - **Weight:** The system may weigh more than our stakeholders can lift.
- **Language Barrier:** Some of our stakeholders may not be English-speaking (Wheat Ridge is 23.8% Hispanic) and thus would not understand instructions written in English [2].
- **Cost:** The cost of the system and the parts needed to maintain it may exceed the amount of money the stakeholder would be able to contribute to the system.

1.8.2 Structural Risks

- **Stability:** If the structure is not stable, it could fall over and possibly harm our stakeholder or damage nearby objects.
- **Spacing:** If the bottles are too close together, plant growth may be stunted.

1.8.3 Nutrient Risks

- **Incorrect Nutrients:** The stakeholder could add improper nutrient amounts or they could fail to move the plants to the the next growing stage.
- **Nutrient Shortage:** After the season is over, the stakeholder will be out of nutrients and require more in order to grow the next cycle of plants.
- **Light:** Spinach, lettuce, and snow peas require minimal light and thus if they are outside they could get too much light.
- **Plants Do Not Grow:** If the plants do not grow, the stakeholder will not be able to harvest vegetables and thus will not benefit from our system.
- **Plant Maturation Timing Discrepancies:** Sometimes plants will take different lengths of time to grow and mature to the next growing stage.

1.8.4 Reservoir Risks

- **Water Fill:** Filling the reservoir may be cumbersome and be messy and the stakeholder may underfill or overfill the reservoir.
- **Leakage:** Fittings on the reservoir for the tubes may leak if they are not properly attached or if they become loose.
- **Water Contamination:** If the reservoir gets bugs or incorrect nutrients in it, then the plants may not grow properly, or even die.
- **Accessibility:** The reservoir is located on the bottom of the shelf which may make it hard to access, especially since there are 4 different reservoirs.
- **Bacterial Growth (Algae):** Algae could grow on the surface of the water which could lead to further contamination and cause an unhealthy plant and undesirable results.
- **Weight:** The reservoirs will be heavy and moving them while full will be hard to do for some stakeholders.
- **Structural Integrity:** The fittings may become loose or the reservoir could break. It is also possible that the structure itself could break due to the weight of the 4 reservoirs.
- **Cleaning:** As accessibility and weight may be a factor, cleaning the reservoirs then will be difficult, especially since a reservoir may need to be deconstructed in order to be cleaned.

1.8.5 Water Delivery Mechanism Risks

- **Pump Failure:** Because the pumps have moving parts, it is possible that the pump could break or malfunction.
- **Power Loss:** Since the pump requires power from an outlet, if the power fails, the pumps will stop operating.
- **Leakage:** There are three points where leakage could occur: 1) the connection from the reservoir to the watering system, 2) the tubing itself, 3) the connections from the tubing to the bottles.
- **Flow rate:** If the water does not flow at a fast enough rate, the plants may consume the water in each bottle before it can be replenished. If it is too fast, the pump will be running unnecessarily and there is a greater chance of leakage.
- **Water Cycle:** If a tube becomes clogged or some other factor prevents the water from flowing properly, the plants water and nutrients will not be distributed which will lead to plant death.

1.8.6 Bottle Risks

- **Top of Bottle Falling In:** The top of the soda bottle subsystem can sometimes fall into the body of the bottle.

- **Amount of Water Administered to the Plant:** The plant may be given too much or too little water, leading to stunted growth or plant death.
- **Bacterial Growth:** The bottle subsystem provides a prime breeding ground for algae growth.

1.8.7 Analysis

After determining the possible risks, we used the Risk Matrix in Figure 7 to determine the magnitude of the of each item described in Sections 1.8.1 to 1.8.6 and placed the results into Table 1. Table 1 also contains a plan to mitigate each risk.

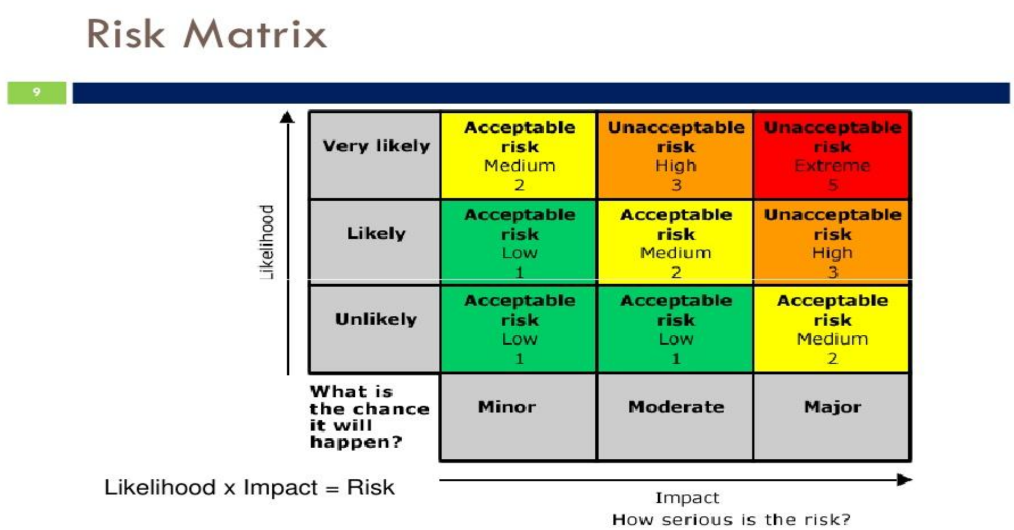

Figure 7: Risk Matrix

Table 1: Risk Register on Testing

Risk	Likelihood	Impact	Magnitude	Mitigation Plan
Stakeholder Incompetence	**Very Likely**	**Major**	**5**	**See Below**
Structural Assembly	Very Likely	Major	5	We will provide a very detailed and easy to understand instruction packet with the system. These instructions will utilize pictures,

				color-coding, and text in multiple languages to be accessible to all of our stakeholders. We will also including a hotline that our consumers may call to receive assistance for their specific problems.
Nutrients	Likely	Minor	1	Our nutrient instructions will be easy to understand to ensure that all the plants get proper nutrients for their individual stages of growth. We will also color-code our nutrients so that they correspond to our reservoir subsystem colors.
Bottle Assembly	Likely	Major	3	We will include an easy to use bottle assembly tool so that the stakeholders can make the hydroponic water bottles without risk of injuring themselves.
Structural Weight	Likely	Major	3	Our design allows for each piece of the structure to be carried separately, enabling the stakeholders to move the structure even with their physical limitations.
Language Barrier	Likely	Moderate	2	Our instructions will be multilingual and rely on illustrations and color-coding to ensure that all of our potential stakeholders can use the instructions.
Cost	Likely	Major	3	We have strategically selected our materials and structure as to minimize the cost of the system. We will also provide a minimal cost maintenance plan for the stakeholder. This “membership” system will deliver new nutrients and seeds to the stakeholder every three months.
Stability	Likely	Major	3	The reservoir stabilizes the structure, preventing it from falling over.

Pump Failure	Unlikely	Moderate	1	Our design also allows for manual watering.
Incorrect Nutrients	Unlikely	Minor	1	The nutrients will come pre-measured and color-coded to minimize the risk of incorrect nutrient ratios.
Water Contamination	Unlikely	Moderate	1	Our water tanks will be made of quality plastic. This will make punctures less likely. Also, we will have the water tanks in their own drawer under the the hydroponic bottles, therefore reducing the amount of light that reaches these tanks to almost zero. This will ensure that there is little to no contamination in these tanks.
Flow rate	Unlikely	Moderate	1	Our tubing will be the appropriate sizes to ensure the correct flow rates to each plant. We will calculate the flow rate to ensure that the pump is pumping at an ideal rate to optimize the water cycling.
Leakage	Unlikely	Moderate	1	The tubing will be high quality, ensuring that the tubes won't break.
Bacterial Growth	Very Likely	Moderate	3	We will use tinfoil around the hydroponic water bottles to reduce the sunlight entering the area and therefore decreasing the bacterial growth. The tubing we use will also be opaque to discourage the growth of algae.
Nutrient Shortage	Likely	Moderate	2	Included in the price is a nutrient "membership" so that new pre-measured nutrients are delivered to the stakeholder every three months, ensuring that they do not run out.
Plants Do Not Grow	Unlikely	Moderate	1	Planting multiple seeds in each bottle increases the chances of germination.

Power Loss	Likely	Minor/ Moderate	1.5	While it depends on the duration of the power-loss, there will still be water in the bottles and the bottles can be manually filled if the blackout is prolonged.
Top of Bottle Falling In	Very Likely	Minor	2	We will use clips to ensure that the top does not fall into the bottom of the bottle.
Spacing Issues	Likely	Moderate	2	Our design is made to ensure that there will be extra space for plants to grow.
Light	Likely	Moderate	2	We have chosen plants that prefer to be grown in partial shade. Thus, the plants do not need constant light to grow making a window an ideal light source.
Water Cycle	Unlikely	Moderate	1	Our gravitation water flow system will allow the water to circulate.
Plant Maturation	Likely	Major	3	The many “spots” in our structure ensures that the user can move plants around to other open spots temporarily in case a plant matures too fast or too slow.
Fill Reservoir	Likely	Minor	1	The reservoirs will contain a fill line to ensure that all the containers have the correct amount of water.
Water Fill (Reservoir Access)	Unlikely	Moderate	1	The base of our structure will contain a door that will allow quick access to the water reservoirs. Instead of carrying the reservoirs, the user can use a pitcher to easily fill them.
Water Amount	Unlikely	Minor	1	The size of the tubes used, the specs. on the water pumps, and the size of the tanks will dictate how much water the plants receive.
Weight of Reservoir	Likely	Moderate	4	Instead of moving the reservoirs to fill them, the user can fill the reservoir using a pitcher or water

				bottle.
Cleaning Reservoir	Likely	Moderate	3	Easier access to the reservoirs will allow for easy cleaning. Efforts to reduce bacterial growth will lengthen the time in between cleanings.
Structural Integrity of Reservoir	Unlikely	Moderate	2	We will test different reservoirs to see which holds water and fittings the best.

1.9 Plan for Stakeholder Feedback

1.9.1 Demonstrations for Mentor

During or after every Tuesday class, we will give a quick verbal status update to Professor Kousman describing the progress on our subsystem testing. During or after every Thursday class, we will give a slightly longer demonstration to Professor Kousman showing him the actual subsystems and the progress made in testing them.

1.9.2 Plan for Interviewing Stakeholders

As explained above, much of our testing, especially in Phase 1, requires stakeholder engagement. Table 2 is a list of stakeholders who will be able to give us feedback on our design.

Table 2: Communication Plan for Stakeholder Feedback

Stakeholder/Type	Name, Contact Info	Due Date	Person Responsible
85 Year Old Woman	Norma Dwyer, dwyer931@gmail.com	Nov. 3, 2016	Lindsey Nield
65 Year Old Woman	Judy Dwyer, judydwyersmith@comcast.net	Nov. 3, 2016	Lindsey Nield
73 Year Old Woman	Sherrie Brink, 720-309-7777	Nov. 3, 2016	Cooper Cordero
60 Year Old Man	Dwight Peters, 281-650-0876	Nov. 3, 2016	Lilli Peters
63 Year Old Woman	Lisa Peters, 281-650-0875	Nov. 3, 2016	Lilli Peters
Christopher House Retirement Center	No Contact Identified, 303-421-2272	Nov. 3, 2016	Sumner Evans
Mountain Vista Senior Living Community	No Contact Identified, 303-421-4161	Nov. 3, 2016	Cade Nash
Wheat Ridge Senior Resource Center	No Contact Identified, 303-238-8151	Nov. 3, 2016	Lindsey Nield
68 Year Old Woman Living in Senior Living	Carolynne Gibson, 281-253-8696	Nov. 3, 2016	Lilli Peters

2 References

[1] “Algae Information,” in *Washington State Department of Ecology*. [Online]. Available: http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/AlgaeInformation.html. Accessed: Oct. 19, 2016

[2] "Community profile," in City of Wheat Ridge, 2013. [Online]. Available: http://www.ci.wheatridge.co.us/272/Community-Profile. Accessed: Oct. 1, 2016.