University of Central Florida

WaterWise Smart Hydroponic System

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(no sponsors currently involved)

1.0 - Executive Summary

This is the final report documentation for the *WaterWise Hydroponic System*. This project is designed and developed in accordance with The University of Central Florida's Computer/Electrical Engineering Senior Design course and the Accreditation Board for Engineering and Technology's (ABET) requirements for accredited engineering programs. The goal of this project to to showcase open-ended design by brainstorming, researching, and creating a project meant to address a current phenomenon.

The focus of this project is a subset of horticulture known as Hydroponics. Horticulture is a subset of agriculture that is focused primarily on growing plants and is an important part of human society that has been around for centuries. From antiquity to modern times, humans have sought to grow plants themselves rather than rely on what grows naturally. Whether the motivation comes from the need for sustainable food sources, medicinal uses, or even the desire for artistic expression, horticulturists have always looked for ways to grow more produce, faster, and in smaller spaces. This pursuit has led to experimentation with many different alternatives to conventional soil-based methodologies. Hydroponics, the subject of this design project, is one of the more recently discovered methods. Due to it's relative infancy, there is a lack of products designed to simplify the method with the intent to allow adoption by general consumers with little or no prior knowledge in horticulture or hydroponics. Our project, the *WaterWise Hydroponic System*, intends to address this phenomenon and bring hydroponics to the general consumer.

To achieve our objective, the specifications of *WaterWise* were designed with mass adoption in mind. First and foremost, *WaterWise* was designed to be small enough for use in housing environments as small as a studio apartment. *WaterWise* is also designed to be a self contained system, providing its own lighting, containment, water-proofing, and structural support. *WaterWise* will also aim help simplify the process of Hydroponic gardening by having a simple LCD panel to allow consumers to see the status of the system in plain English and give various commands. In addition to the on-structure interface, *WaterWise* will also function with a companion application designed for the Android mobile operating system. The companion application will display various information on the status of the Hydroponic system while also providing helpful instruction and notifications.

The *WaterWise Hydroponic System* and its companion application will be developed using an agile development process. This type of development process was selected due to its allowance for the ability to rapidly assess the current state of any one of the many components of the project. We will use this to keep track of the different technologies working in conjunction in real time, switching components, and altering the environment as is necessary to ensure the most consumer friendly design possible within our development time.

2.0 - Project Description

2.1 - Project Motivation and Goals

The decision to design an intelligent hydroponic gardening system is supported by several different motives. One of the main supporting reasons behind this decision is to provide the ability to easily grow and sustain food yielding plants in an otherwise improper indoor or outdoor environment. This system is intended to be located conveniently inside a residential living space, such as an urban city apartment, rental property, or townhome and could also be modified and utilized in expeditions where the ability to grow food with an abundant power source is needed. The consolidated and compact design of the unit is intended to limit the physical space occupied by the main unit and to provide more convenience to users. The system also provides a mobile application that is intended to provide the user with guided, real-time instructions for growing many different species of plants of their choosing. The mobile application is intended to provide an elegantly intuitive design for the user's experience. The robustness of the application is necessary to accommodate a low barrier of entry for the user. Lastly, a few indirect benefits from this system include: the ability to promote consumption of fresh and healthy foods, the plant's production of clean oxygen during indoor use, a reduction in the use of fertilizer and pesticides, and an improvement in conservation awareness.

This project will look to tackle the disadvantages of hydroponics while bringing to the consumer a product that allows them to take all of the benefits from their system. The main goal is to provide the urban and metropolitan-based populous with a way to grow their very own, organic food in the comfort of their home with unprecedented accessibility to their system. Project based goals include the following:

- Construct a compact, durable, and convertible hydroponics system for use in all environments and locations (indoor/outdoor).
- Develop a system that can be used by both entry-level and expert users.
- Provide real-time system monitoring in order to aid the user throughout the growth cycle of their desired produce via a mobile application.
- Create a user friendly experience in both the mobile application as well as the physical interaction with the system.
- Educate and inspire users to continue to foster an interest in hydroponics as a way to grow their very own food, no matter where they live.

2.1.1 - What Is Hydroponics

There are many different ways to go about constructing a hydroponic system including not only various structure types but also different growth techniques, some of which coincide with each other. This section will look to not only define and describe hydroponics as an industry and agricultural technique, but additionally describe popular systems types and structures seen today.

Hydroponics is defined as the process of growing plants in sand, gravel, or liquid, with added nutrients but without soil. The word is directly derived from Greek with “hydro” meaning “water” and “ponos” meaning “labor”, therefore translating into “working water”. Some historians and industry pioneers will sometimes refer to hydroponics going as far back as the Babylonian empire and the hanging gardens but we will stay within recent history and begin with Dr. William Frederick Gericke who coined the term “hydroponics”. While a researcher at the University of California at Berkley, Dr. Gericke was at the forefront of hydroponics research and development. His findings were published in his 1940 book “The Complete Guide to Soilless Gardening” and were a catalyst for the hydroponic industry that we see today. Although other scientists before him had studied and researched water culture, Gericke took the subject to new heights all the while receiving much skepticism from his colleagues and agriculture experts. His book explains every aspect of early hydroponic growth including but not limited to structure, effective nutrient solutions, physical conditions, and many experiments of various plant types and species. Fast forward to present day, hydroponics has been fairly slow moving in comparison to other technologies, but that is beginning to change. Hydroponics is beginning to become a household term and, for some, a lifestyle. From fully operational farms to do-it-yourself users, hydroponics is evolving and innovating with modern technology and a more “food-aware” society. In a 2015-2020 industry forecast report produced by BIS Research, the hydroponics industry is currently seeing unexpected growth with latest numbers for global hydroponics crop value estimated to increase from $18.8 billion in 2014 to $27.29 billion in 2020. That is outperforming the International Monetary Fund’s estimated compound annual growth rate (CAGR) from 2014 of 3.6% by about 3% annually. The North American CAGR between 2015 and 2020 is estimated to be at 9.10% which leads the globe and is spearheaded by the United States. Found in that same report is that the average crop yield for hydroponics farming is ten times that of traditional soil based farming for the same amount of land, an astonishing number that is certainly worth noting. Overall, the future of the industry looks to be trending in the right direction in more ways than one. This is not only good for business but great for the growing concern of how we will adapt to growing metropolitan areas and shrinking rural and fertile areas.

2.1.1.1 – Types of Hydroponic Systems

There are several types of hydroponics systems that are popular among industry giants and do-it-yourself users. These types include drip systems, nutrient film technique, ebb-and-flow, water culture, aeroponics, and wick systems. In this section, we will go into detail of the design and method of each system.

A very commonly used model, a drip system is achieved by simply letting the nutrient solution of the system to drip on the roots of each plant and there is a timer that determines the interval at which the submersed pump wets the base of each plant. There are also two types of drip systems: non-recovery and recovery. In a recovery system, any nutrient solution that may have been pumped in excess is recycled back into the system whereas a non-recovery system does not offer this feature. However, a non-recovery system requires less maintenance due to the consistency in the chemical makeup of the nutrient solution but this also means that a more accurate, and therefore a more costly timer is required.

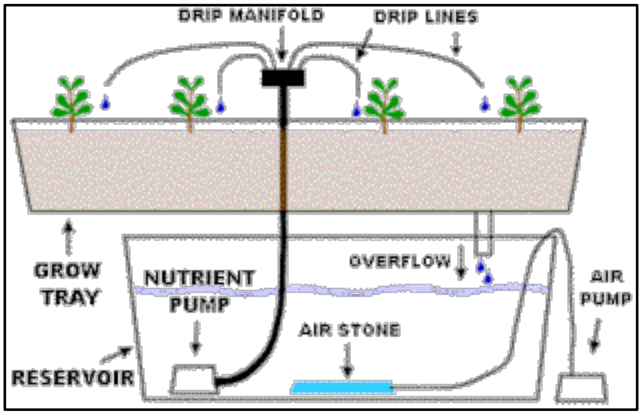


Figure 2.1: Drip Hydroponic System

Better known in the industry as “NFT”, the nutrient film technique is what most people imagine when the word “hydroponics” is discussed. This system consists of your typical reservoir with nutrient solution pumping up to the mouth of a conduit or tubing. The conduit is commonly designed using PVC (polyvinyl chloride) pipe but can be designed in many ways as long as it accomplishes the task of flow as well as holding the plants. The conduit is put at an angle which allows for the nutrient solution to flow at a low level through the system and the excess drain back into the reservoir. A common slope for the conduit to achieve a proper flow rate is about one inch of drop for every thirty or forty inches of conduit. This constant flow of nutrient solution gives the freedom to not rely on a timer in order to feed the plants which can come with extra issues. The roots reach out to the nutrient solution as it flows through the conduit thereby consistently providing the plants with wet roots, with some contribution coming from the humidity inside the conduit. NFT systems are very common for smaller plant species that don’t require a lot of root space because the systems generally use a relatively small conduit in order to allow the plants to quickly get feed in their infancy.

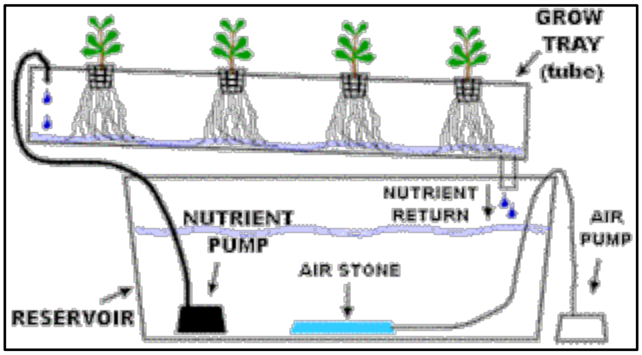


Figure 2.2: NFT Hydroponic System

The ebb-and-flow technique, sometimes known as flood-and-drain, is somewhat similar to the drip system in that it is timer based. At given intervals, the nutrient solution is pumped from the reservoir and temporarily floods the basin the plants are in. Once the solution reaches a certain level, it begins to drain back through an overflow tube as well as the filling tube connected to the submersed pump. These systems are very cost effective and easy to build due to the many ways the structure can be accomplished.

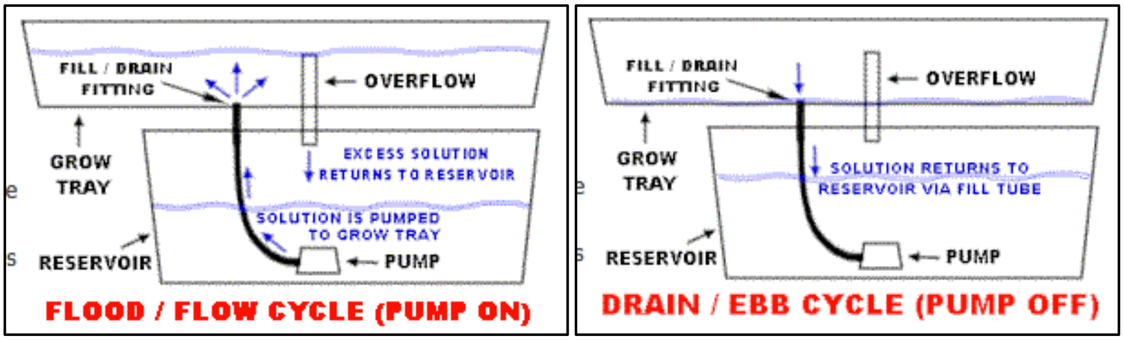


Figure 2.3: EBB-And-Flow Hydroponic System

Water culture systems are non-circulating hydroponic systems which are very simple and easy to build. They consist of a reservoir filled with nutrient solution and an air stone with floating grow beds on top of the water. This method, although very simple, is typically not used for long-term plant growth and is only widely used for specific plant types such as lettuce. Aeration of water culture systems is generally restricted to an air stone inside of the reservoir, but some users venture into surface agitation with falling water. Water culture systems are widely considered very good teaching tools for younger hydroponic users in that it has very little maintenance but great results.

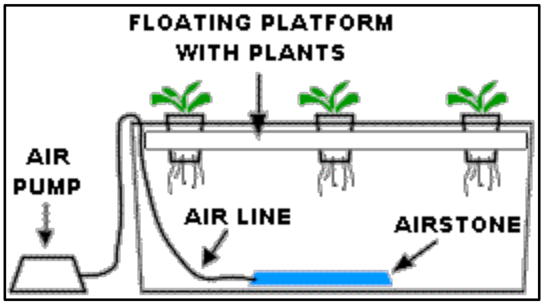


Figure 2.4: Water Culture Hydroponic System

The most technically challenging of all system types, aeroponics is very similar to the previously defined NFT system. In both systems, the plant roots are more exposed to air than water and only allow plants to receive exact amounts of nutrient solution. Aeroponics works by allowing a nutrient pump to send the nutrient solution from a reservoir through a misting system. At the top of each branch from the pump is a misting spray nozzle that coats the roots of each plant in nutrient solution. The major benefit of this method is realized in the maximum exposure each plant consistently has to oxygen. In turn, this allows the plants to grow much more rapidly in comparison to other methods (in most cases). However, the downfalls of this method are found in the technical aspects of the system. For instance, maintaining the misting nozzles from clogging with residue from the nutrient solution and the cost of the system to name a couple.

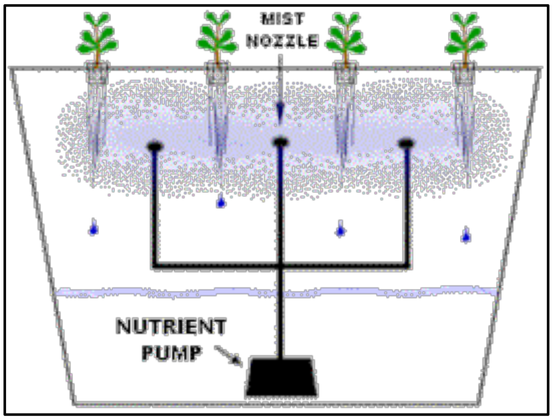


Figure 2.5: Aeroponic System

The wick system is the most basic form of all hydroponic systems. It entails no moving parts and generally no parts requiring electricity. Using a wicking medium, the nutrient solution is forced up to the plants through the porous material and put directly on the roots or into a growing medium. There are many different wick types that are commonly used for these systems and each have their tradeoffs depending on what type of plant species is being grown. Some popular types of wick medium include fibrous rope and rayon rope and popular growing mediums include coconut fiber and vermiculite. The advantages of this system are that it is very simple to make and maintain and great for areas where electricity is not as abundant. The biggest weakness of this system is that the success completely depends on the balance of what the plant needs and how quickly the wick medium can deliver those nutrients. The key to developing a successful wick system is found in finding this balance.

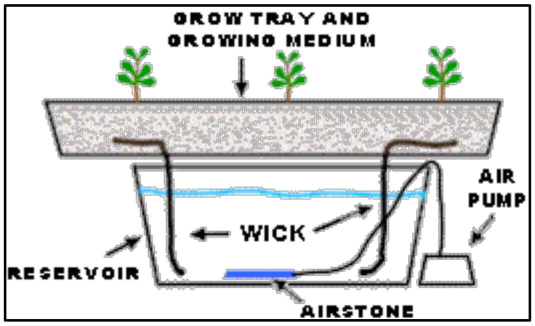


Figure 2.6: Wick System

2.1.1.2 – Hydroponic Structures

While Hydroponics in its current state is predominantly a do-it-yourself practice. There are specific structural designs that have gained a larger popularity amongst horticulturists. During our research for the *WaterWise Hydroponic* system, we took care to examine these most popular structures in order to determine if one could be adapted for our purpose.

The first of these popular structures is most often referred to as the “tower” design. Like its namesake suggests, this design is based on using a tall, thin design as the structure. On the sides of the structure, plants are nested inside of multiple attached “cups” and the reservoir for the water acts as the base of the tower with a submerged pump to move water as well as an air pump to add oxygen to the water.

The water delivery of this type of structure relies on what is commonly referred to as Aeroponics. Aeroponics is a specific method of Hydroponics that seeks to shower plants in a nutrient rich “rain” as opposed to allowing the roots to be submerged in water. With the tower structure, Aeroponics is generally achieved by carrying the nutrient-rich water up the center of the tower, before using a spray nozzle to “shower” the cups with it. See Figure 2.7 and 2.8 for pictures that help illustrate this structure and Aeroponic water delivery. While this structure is effective, ultimately we found that it would not be best for the *WaterWise Hydroponic System*. The specific advantages and disadvantages of this structure that lead to our decision will be discussed later in section 7.0: Project Hardware and Software Design Details.

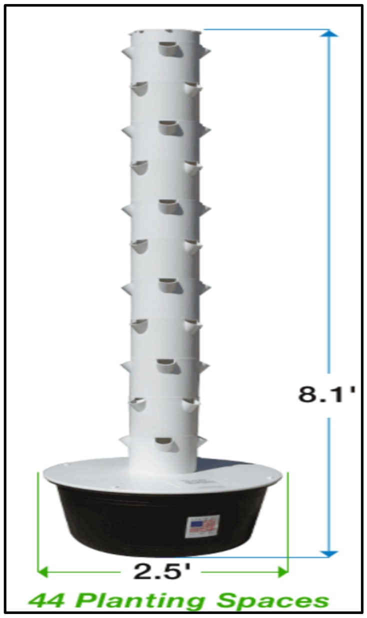


Figure 2.7: The Tower Garden

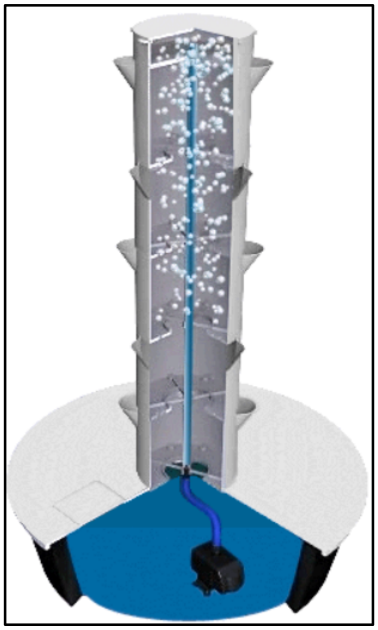


Figure 2.8: Aeroponic System

(permission pending)

We refer to the next hydroponic structure that we found to be popular amongst horticulturists as the “tub” design. We refer to this design as the tub design because it is based on using some kind of large container, such as a storage bin or trash can as the main structure. With this design, the large container is filled with a mixture of water and nutrient solution for plant growth. In addition to the large container, this design utilizes a lid that fits over the top of the container. The lid usually has a series of large, circular, holes cut into it at regular intervals. They are cut in this way so that inside of each of these holes, the horticulturist can place a different cup with a plant nested inside of it. These cups that are used in this process are similar in purpose to the cups from the tower design. However, they differ in that they have small holes throughout similar to netting. This is done so that the roots for each plant may grow outside of the cups and into the tub beneath the lid of the system.

The method of water delivery for this design is much more simple than that of the tower design. Instead of using a pump to transport the water solution and then disperse it to each plant, the cups that hold the plants are seated in such a way that the roots of each plant will remain submerged within the solution. Because there is no need to move any water around, this design has no need for a motorized pump. This design also requires that the tub have an air pump in order to oxidize the solution, this is often accomplished using an “air-stone” which we will discuss in more depth in section 2.1.2.5 - *Water Flow and Oxidation*. See Figure 2.9 for a diagram illustrating this design.

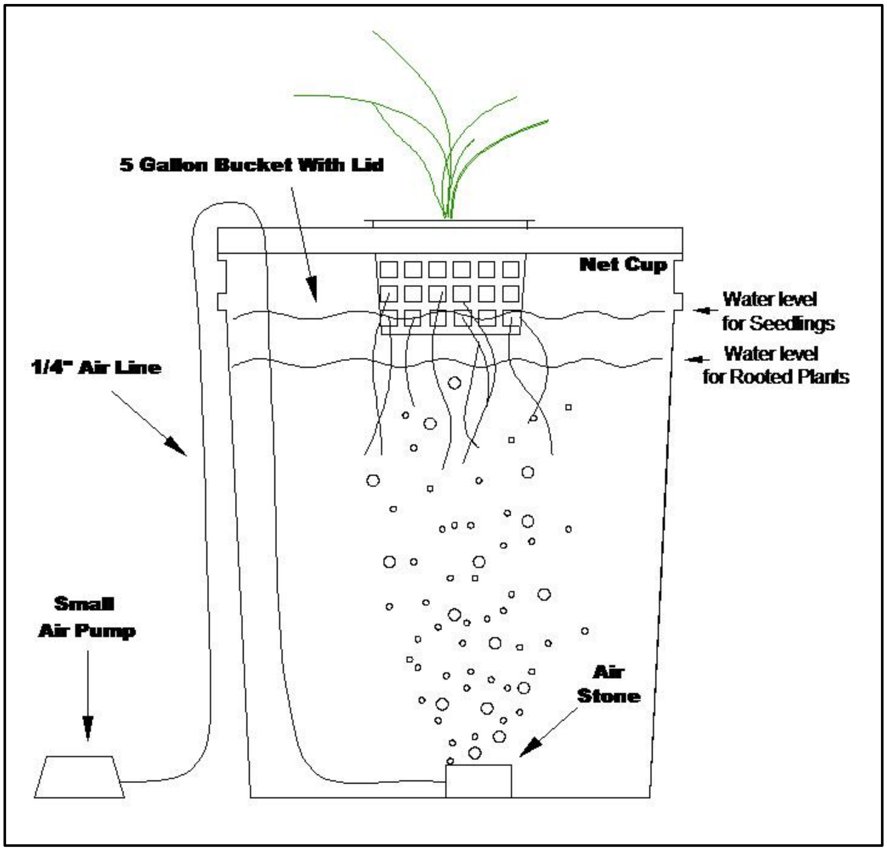


Figure 2.9: Quick and Easy Bubbler System

Lastly, during our research we found many horticulturists using multiple PVC pipes in order to build a hydroponic structure. As such, we refer to this as the “PVC” design. In this design, a large container like the one from the tub design is used to hold a mixture of water and nutrients for plant growth. However, instead of using a lid on this container to hold the plants in the system, large PVC pipes are used. The PVC pipes can then be arranged in any pattern, and use a single or multiple different PVC pipes. Each one of these pipes have several large, circular, holes cut in them, similar to the lids that are used in the tub design. Also similar to the tub design from before, these holes are used to hold “netted” cups with plants nested in them that will allow the roots to remain submerged in the solution. The difference between housing the plants using the PVC pipes as opposed to using the lid is that the piping itself can extend over a variable area, rather than an area the size of the lid.

With this design, a pump is used to assist with delivering the water solution to the plants nested in the cups. Generally, this design only requires a single pump with a small tube to supply solution to the PVC pipe system. This system is able to utilize such a small pump because it is usually implemented in conjunction with a dam structure built into the PVC pipe system. The dam is set up in such a way that a minimum solution level is maintained in the system that is high enough to keep all of the roots for each plant submerged in the solution. Once this level is achieved, the excess solution runs over the dam and flows back into the main reservoir to be recycled through the pump again. See Figure 2.10 for a simple diagram illustrating this design.

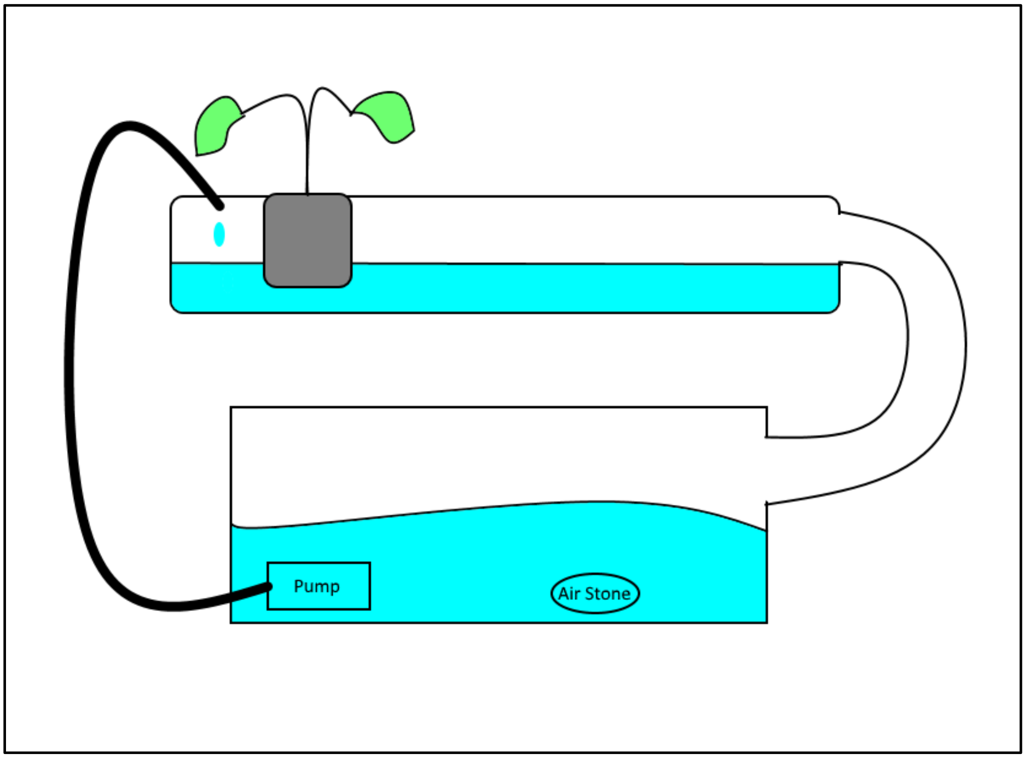


Figure 2.10: PVC Pipe System

2.1.1.3 – Common Nutrients and Plant Types

When considering the nutrients required to grow different types of plants, it is important to realize that each plant variety is unique. As such, each may require a different combination of nutrients, different concentrations of nutrients, or supplied in different stages in the plant's life cycle. However, there are some nutrients that are fundamental to plant growth, meaning that they are found in the requirements of most plants across many varieties. In our research we found that of these nutrients, there are three different categories: macronutrients, secondary macronutrients, and micronutrients. A summary of the different nutrients and an estimation of the range of their presence in a plant is available in Table 2.11.

Macronutrients owe their name to the fact that they are the most fundamental nutrients for plant growth and that they also are absorbed at a higher rate than other nutrients that a specific plant needs. While the exact concentration of each macronutrient necessary for a specific plant may differ from other varieties, or even change during that plant's life cycle, the three macronutrients remain the same. Nitrogen is the first of these nutrients and is arguably the most important of them all. Nitrogen is used to create amino acids, which are necessary for the development of proteins. In addition to amino acids, nitrogen is also used in the creation of enzymes as well as an important component of chlorophyll. When plants are nitrogen deficient, they often suffer poor growth and may even gain a purple color on the stems and on the underside of the leaves.

The next macronutrient is phosphorus, which is almost as important as nitrogen. Phosphorus is often found in the composition of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). While these more than demonstrate the importance of phosphorus in plant growth, phosphorus is also incredibly important for the transfer of energy within a cell. Phosphorus deficiency in a plant can diagnosed by the appearance of an intense either green or red coloration of the leaves. It may also result in plant leaves appearing very denatured, or a purple coloring similar to nitrogen deficiency. However, phosphorus deficiency is often much more difficult to diagnose than nitrogen deficiency, with symptoms appearing only in extreme cases.

The final macronutrient is potassium. Potassium is slightly less important than nitrogen and phosphorus, however, it still plays an instrumental role in healthy leaves and plant growth. Potassium is involved in the creation of carbohydrates and proteins, it also helps to control the moisture within a plant, helping the plant survive drought. Potassium also makes fruits more colorful and improves their shape. Potassium deficiency may lead to wilting, increased damage from drought, and lesser resistance to cold and hot environments.

Secondary macronutrients are the next group of nutrients considered necessary for plant growth. They are required in moderate amounts, less than macronutrients but still more than micronutrients. This category is comprised of just three different nutrients. The first of these three is sulfur, which is primarily used in the creation of chloroplasts. As such, sulfur is also necessary for photosynthesis. Sulfur deficiency is often noticed in newer plant tissues first with its symptoms being stunted growth and the yellowing of a plant's leaves.

The next secondary macronutrient is calcium. Calcium is primarily used to help regulate the transportation of the other nutrients to the plant, help form the cell walls for the plant, and like many of the previous nutrients, is utilized in photosynthesis. Also, similar to some of the other nutrients already discussed, calcium deficiency will result in yellowing of leaves and stunted growth. However, unlike the previous nutrients, the stunted plant growth primarily affects the roots underneath the ground.

The last of this category of secondary macronutrients is magnesium. Magnesium is primarily used in the creation of chlorophyll and in the activations of different enzyme reactions. Magnesium deficiency is evidenced by yellowing and begins in older tissues before translating to newer tissues.

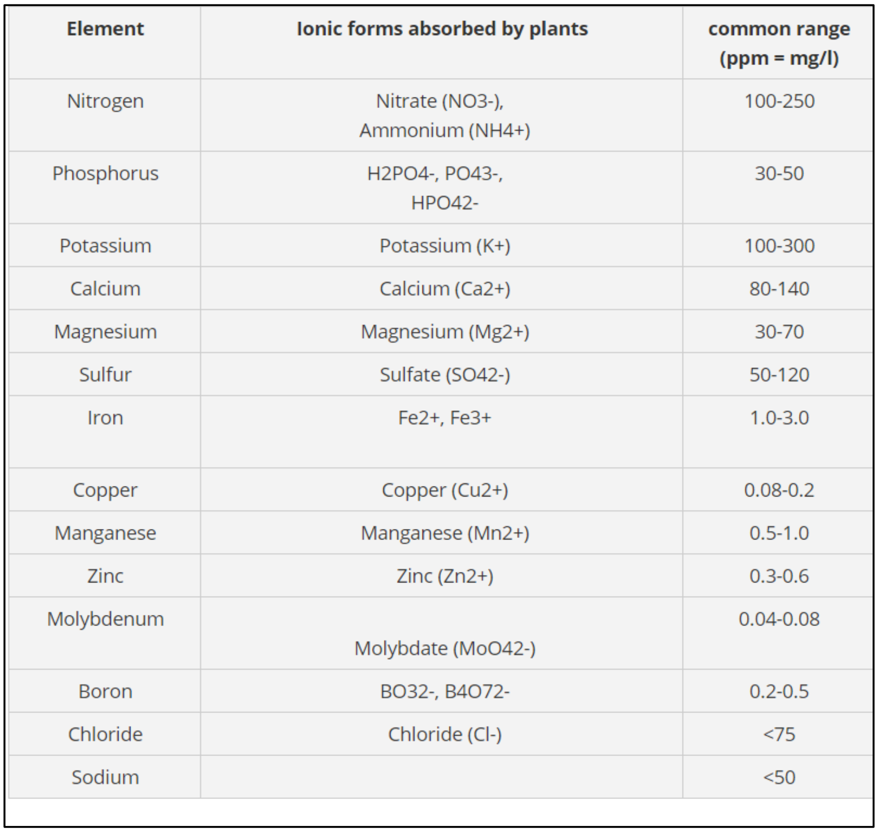
Micronutrients are the final category of the most common plant nutrients. While micronutrients are still necessary for a healthy plant to grow, they are needed in smaller quantities than macronutrients. This category is comprised of eight different nutrients, the first nutrient to be discussed is boron. In combination with calcium, boron helps to create the cell walls within a plant. In addition, boron is utilized in pollen germination and salt absorption. Boron deficiency is one of the most common among the micronutrients and symptoms involve the same traits common to many of the nutrients already discussed such as stunted growth and physical changes.

The next micronutrient we will be discussing is copper which is primarily used in the activation of different enzymes, and is also necessary for photosynthesis. Symptoms of deficiency are similar to many of the symptoms already discussed but are much more difficult to detect.

Like the macronutrient nitrogen, iron is necessary for the formation of chlorophyll, though not structurally, as well as the activation of enzymes. Deficiency will lead to interveinal necrosis, and it also should be noted that iron deficiency can be caused by copper deficiency.

Some final micronutrients and their importance to plant growth include:

- Molybdenum: Creation of amino acids and activation of enzymes.
- Manganese: Creation of chloroplasts.
- Zinc: Utilized in many enzymes and in the transcription of DNA.
- Chlorine: Needed for plant osmosis.
- Sodium: Creation of amino acids.



Element	Ionic forms absorbed by plants	common range (ppm = mg/l)
Nitrogen	Nitrate (NO3-), Ammonium (NH4+)	100-250
Phosphorus	H2PO4-, PO43-, HPO42-	30-50
Potassium	Potassium (K+)	100-300
Calcium	Calcium (Ca2+)	80-140
Magnesium	Magnesium (Mg2+)	30-70
Sulfur	Sulfate (SO42-)	50-120
Iron	Fe2+, Fe3+	1.0-3.0
Copper	Copper (Cu2+)	0.08-0.2
Manganese	Manganese (Mn2+)	0.5-1.0
Zinc	Zinc (Zn2+)	0.3-0.6
Molybdenum	Molybdate (MoO42-)	0.04-0.08
Boron	BO32-, B4O72-	0.2-0.5
Chloride	Chloride (Cl-)	<75
Sodium		<50

Table 2.11: Common Nutrients for Plant Growth

2.1.2 - Hydroponic Considerations

2.1.2.1 – Lighting

Lighting on a hydroponic system is very important due to the fact that plants will struggle to survive in an environment where it is deprived of light. Light is a primary energy source for plants. The definition of photosynthesis according to Dictionary.com is “the complex process by which carbon dioxide, water, and certain inorganic salts are converted into carbohydrates by green plants, algae, and certain bacteria, using energy from the sun and chlorophyll”. However, careful consideration must be paid when choosing grow lights. Plants react to specific colors (wavelengths) in the spectrum and sunlight includes all these colors. Some of these colors are not used, such as green. The color green is reflected instead of absorbed which is why plants foliage appears green to the human eye. Blue and violet light are the most readily absorbed light by the plant to help it grow and produce foliage. Red light is also very important as it helps to manufacture simple plants sugars in mesophyll cells. Luckily for hydroponics, most grow lights are available in red, blue, and both.

There's a wide variety of grow lights but only the best four will be taken into consideration; high pressure sodium (HPS) bulbs, metal halide (MH) bulbs, fluorescent bulbs, and light emitting diodes (LEDs). High pressure sodium bulbs emit from the red and yellow spectrum which is ideal during the blooming period of the plant. Planters will normally switch to these bulbs at the beginning of the flowering stage. Metal halide bulbs, however, emit from the blue spectrum which is excellent for the plant's vegetative stage. These bulbs are designed with spectrum colors that are ideal for plant growth and are used to help young plants grow faster. High pressure sodium and metal halide bulbs are normally used together to obtain a more desired lighting. However, the disadvantages to these two plant light sources are they produce a lot of heat while consuming a great amount of electricity. Fluorescent bulbs are available in a wide range of spectrum and these bulbs are cheap, consume little electricity, and do not produce a lot of heat which makes them ideal as they can be placed close to the plants. Light emitting diodes are becoming more popular by the day. A typical LED has an average rated life of 50,000 hours which is the highest in any man made light source. LEDs can produce the desired spectrum that is ideal for plant growth and some can even change color. This can eliminate the need to change light bulbs at different stages of a plant's life in order to maintain ideal conditions. The downside to LED's are they can be relatively expensive.

When selecting grow lights, it is important to consider the following factors: the budget, enclosure type and size, plant type, and ventilation. Budget is essential when selecting the right kind of light. The best choice for low-budget, small-scale farmers are fluorescent tubes. If there is a bigger budget or a larger amount of land available, then the top pick would be the high intensity discharge (HID) light system. HID lamps have the highest output and work best with larger plants. However, they require their own ventilation system which would add to cooling costs. This could be problematic when trying to regulate the temperature in the grow room. LEDs will work best for long term farmers that are willing to invest greatly in crop production. Even though the installation process is costly, it is more efficient long term. For example, moving from a 350 watt HID system to a 30 watt LED system, then you could potentially save $1,500 to $2,500 on electricity over the lifetime of the LED's.

2.1.2.2 – Temperature

An important factor for hydroponics that we are taking into consideration for our design is the temperature of both the air conditions and water-nutrient solution. This variable is very critical to our design decisions, as maintaining the proper temperature conditions can help to promote the best plant growth conditions. Maintaining the ideal temperatures can help to repel bugs, algae growth, plant disease, and fungus growth. All of these symptoms can be fatal conditions to the life of a typical plant. Our project will stress the significance of temperature conditions to the user of the system. Our sensor measurements will help to provide accurate monitoring of the temperature conditions for the user.

In general, the proper temperature for most plants is about 65-80 degrees Fahrenheit. This range is a broad range and covers most plants. Plant types can be classified into two different classes, warm season crops and cool season crops. It is possible to grow these types of plants together, but in general it is recommended to grow the same type to yield the best results. Warm season plant temperature conditions consist of a daytime temperature range of 70-80 degrees Fahrenheit and a night-time temperature range of 60-70 degrees Fahrenheit. The absolute max for warm season plants is 90 degrees Fahrenheit. Cool season plants have a daytime temperature range of 60-70 degrees Fahrenheit, a night-time temperature range of 50-60 degrees Fahrenheit, and an absolute minimum of 40 degrees Fahrenheit. If the air temperature for a plant is kept to high, then it will go into photorespiration which leads to the destruction of glucose supplies and slows the growth rate. If the air temperature is kept too low, the photosynthesis and respiration process will be suppressed and hinder plant growth and other processes The general "magic temperature" is 77 degrees during the daytime for most plants.

Another important factor to mention is the requirement for variations in temperature indoors just as with regular outdoor conditions. This cycle of temperature during a 24-hour period is crucial to a plant's metabolic process. If a light/heat source for the plants is left running constantly 24/7, it will affect the overall health of the plant and the growth yield will be hindered. Plant's require a cool down phase to promote a healthy metabolic process. Temperature conditions should change by about 10 degrees for about 12 hours during a cool down process.

In addition to the air temperature, the water-nutrient temperature must also be closely monitored and maintained to promote healthy growth conditions. The temperature of the water does have an effect on the nutrient levels of the solution delivered to the root systems. In fact, as the temperature of the solution increases, the solution's ability to retain dissolved oxygen decreases. As mentioned in other sections of this paper, dissolved oxygen is a crucial component to the nutrient solution delivered to the root systems. Also, as the air temperature increases, the plant's respiration rate increases which in turn increases the root system's need for dissolved oxygen. Therefore, as the air temperature increases, the dissolved oxygen levels must be kept high to properly oxygenate the plant. Fully oxygenated water at a temperature of 68 degrees Fahrenheit has been shown to hold about 9 ppm (parts per million) of dissolved oxygen (DO), while water at 86 degrees Fahrenheit will hold about 7.5 ppm of DO. This level of 9 ppm of DO is the ideal level to promote vigorous plant growth.

A system can regulate its temperature conditions through the use of an aquarium heater in cold conditions and an aquarium chiller in warm conditions.

2.1.2.3 - pH Level

Plants are very sensitive to the environment they are grown in and it is vital for them to have a standard pH. Maintaining the pH of plants in a hydroponic system is crucial because if the pH levels deviate too high or too low from the recommended range for a specific plant, it can affect the plant's ability to absorb nutrients causing stunted growth or in the worst case scenario, dying plants. The recommended pH range for plants depends on the following key factors: the type of plant that is present and the nutrients that are to be absorbed.

Plants come in many varieties due to their different genotypes and can differ from the size of their leaves to the taste of their fruits. Owing to these differences, all plants will not thrive under the same conditions and so a range is often selected to accommodate these plants. One example of this is the difference in the recommended pH of pumpkin which is 5.0 compared to broccoli which is around 6. The recommended range of pH is normally between 5.5-6.5. Since most plants thrive under neutral conditions the pH usually stays closer to 7. Table 2.12 shows the most suitable plants for a hydroponic system and their corresponding optimal pH levels.

Type	Plants	Optimal pH
Vegetables	Lettuce	6.0-7.0
	Tomatoes	5.5-7.5
	Radishes	6.0-7.0
	Celery	6.0-7.0
	Cucumbers	5.0-6.0
Fruits	Watermelon	6.0-6.8
	Cantaloupe	6.0-7.5
	Strawberries	5.5-6.5
	Blueberries	4.5-5.5
	Grapes	5.5-7.0
Herbs	Chives	5.0-6.0
	Oregano	6.0-8.0
	Basil	5.5-6.5
	Sage	6.0-6.5
	Rosemary	5.5-6.5

Table 2.12: Common Hydroponic Plant pH Levels

In order to maintain the pH of the water system it is necessary to first be aware of the pH level for the hydroponic system. To do so, the system can be tested using the following methods:

- Liquid kits **-** Uses a pH sensitive dye, which changes in color when you add to a small sample of the nutrient solution and compare to a color chart.
- Disposable strips - Function similarly to the liquid kits; however, it is the least accurate of the three.
- A digital meter is the most expensive option but is more effective and efficient long term once taken care of properly. It is also the simplest and quickest method, which is helpful when you test pH once a day or more. The pH meter can be dipped straight into the nutrient solution and will give the exact pH reading shortly after.

The next phase in maintaining pH is to determine whether you need a pH "level up" or a pH "level down". If the pH is too low (closer to the acidic scale of the pH meter) a pH level up is required to bring it closer to the recommended level. A popular choice for this would be an alkaline substance such as potassium hydroxide. Similarly, if the pH is too high (closer to the alkaline side of the pH scale) a pH level down would be needed to bring it back down to the recommended pH range. A suitable choice for this would be phosphoric acid. Nitric acid is also a popular choice however it is not heavily recommended since it is known to give off toxic fumes when in use. It is important to note that when maintaining pH levels of the nutrient solution, measurements must be a part of the process as this could risk burning out the crops if too much is used or have little to no effect if too little is used.

To ensure proper maintenance of pH level, the following method would be utilized: 1) Measure the required fertilizers then add it to the proposed nutrient solution. This is not an everyday task but when nutrients are being added, ensure that this is the first step since they can severely alter the nutrient solution's pH. 2) Ensure that the air stone is turned on and the water is properly aerated. 3) Test the solution's pH using your chosen method. If using a digital meter, make sure to hold it in the water for at least 3 seconds to get a proper reading. 4) Add chemicals to alter the solution's pH, if necessary. Do not add too much -- go slowly. 5) Re-test pH levels. 6) Repeat step 4 if necessary.

2.1.2.4 - Air (CO_2)

Plants utilize air, more specifically carbon dioxide (CO_2), during the process of photosynthesis combined with water to produce sugars and oxygen used by the plant. The CO_2 levels of the air today reside around 300 ppm. Plants in general benefit from an abundance of CO_2 up to a certain point before too much becomes toxic. Within the practice of hydroponics, CO_2 generators are commonly used to help boost the levels of CO_2 for plant consumption. This practice is largely popular in large scale systems or greenhouse systems where plants are able to consume large amounts of CO_2 in a confined and concentrated area. There are a multitude of ways to generate and regulate CO_2 levels for the purposes of hydroponic growth. Typically, though, the methods of generating CO_2 are costly and in small systems, not worth return on investment.

There are many different methodologies and schedules for the application of enrichment CO_2 for plant growth. Some of the common methods for providing additional CO_2 include: burning hydrocarbon fuels, compressed (bottled) CO_2, dry ice, fermentation, and decomposition of organic matter. In the scope of our design only a small amount of methods are viable, because our system is intended for indoor use, and safety becomes an issue with some of the techniques. The most common technique, burning hydrocarbon fuels, is used by commercial hydroponic greenhouse growers. When a large amount of CO_2 is generated, there is also an additional requirement for proper air circulation and ventilation to properly regulate CO_2 levels. The most common method for indoor garden use is the compressed (bottled) CO_2 technique. This implementation involves the use of timers to schedule the daily CO_2 delivery which helps to regulate the CO_2 levels of the system.

CO_2 delivery scheduling during the plant lifecycle also has additional benefits during specific phases. In the beginning, the two-week seedling phase is an optimal time to provide CO_2 enrichment. Doing so can lead to faster early growth and a higher final crop yield. The transplant stage should not be enriched with CO_2 as the plant is adjusting to new conditions. In the growth stage, the plant can be supplemented with additional CO_2 during light time when the plant is going through photosynthesis. As the plant's growth is finishing up and crop is nearly ready for harvesting, the CO_2 enrichment should be lowered as it is no longer needed once growth is complete.

The benefits received from the additional CO_2 have been shown to be only up to an upper bound of 30% additional growth. The additional benefits are a limiting factor, meaning that the benefits are only received if all other factors in the system are controlled. It is possible to provide too much CO_2 to a plant such that it has negative side effects. When CO_2 levels reach 2000 ppm or above, the plant will begin to decay due to the toxicity of the air conditions. Our design will not incorporate a CO_2 enrichment sub-system, as the benefits for our system do not balance with the higher cost of implementation.

2.1.2.5 - Water Flow and Oxidation

The water flow design for a hydroponic system varies greatly depending on the overall structural design of the system. The different designs require significantly different water flows. For example, an aeroponic system requires a water flow through the use of fine misting sprinkler heads placed near the seedling. In contrast, a nutrient film technique (NFT) system requires an ever constant flow of water flowing at a shallow depth inside the system plumbing. The water flow is essential to the type of hydroponic system that is implemented. The water flow technique chosen helps to determine several significant factors that go into configuring the water flow rate and water level. Being that a hydroponic system's growth success is largely related to the absorption of nutrients through the water flow, the importance of water flow is even more apparent because the plant growth and nutrient absorption are correlated with the water flow efficiency.

In a NFT system, the water and nutrients are constantly flowing throughout the system. The water is pumped to growth tubes, flows down, and exits the tubes at another end. The water is recycled in a main water reservoir where nutrients and oxygen are added again. The rate at which water flows through a NFT system is generally recommended to be about one liter (one quarter gallon) per minute per growth channel. The main feature of NFT is the shallow "film" of water maintained throughout the growth tubes. Generally, the water film for most NFT systems tends to be about 0.1 inches deep. This allows the plant root systems to be constantly absorbing oxygen and nutrient rich water from the film while also having plentiful access to moist air inside the growth tube. Since the quantity of water in the system is rather shallow, the overall volume of the system is able to be lower in comparison to other systems. A lower water level is recommended because it also prevents the water from damming inside the main growth pipes where the root systems can become rather large.

The flow of water and nutrients is generated not only from a main water pump, but also from a gradual slope in the implementation of the piping. Many sources highly recommend this strategy over relying on the water pump alone to control the flow. This sloping of the main growth pipes allows for a finite control of the water flow. It is also beneficial to incorporate a structural design that allows for the ability to adjust the slope of the growth channels. The thinness of the water film is very important and as the root systems grow larger, the channel's slope will require adjustments to maintain the correct water flow rate.

Plant roots also require access to abundant oxygen in addition to the water and nutrient solution. This oxygen is also critical to promote healthy and growing plants. In order to provide this in a hydroponic system, there must be some form of dissolved oxygen (DO) reaching the plant roots. Most NFT systems tend to require very saturated DO levels in order to yield abundant plant growth. The ideal DO level for an NFT system is around 40 ppm. In comparison, the DO levels of tap water tend to be about 5-7 ppm. This super saturation is necessary in a NFT system because the amount of water in contact with roots is kept quite low.

An air stone is the most viable option for substantially increasing the DO level of water in a hydroponic system. An air stone can be easily used to produce bubbles of oxygen in the main water reservoir. Oxygen then diffuses into the water as the bubbles rise up through the water in the reservoir, and therefore saturate the water with oxygen. The size of bubbles that the air stone produces is also an important factor that can lead to an even higher yield of DO. An air stone producing smaller bubbles will yield more bubble surface area against the water than larger bubbles with the same total amount of air. The increase in surface area of air against the water will increase the capacity to raise the DO levels of the water.

2.1.2.6 - Electrical Conductivity

Electrical conductivity (EC) is the ability of a material or solution to conduct electricity. The EC of a hydroponic system is useful because the nutrient ion in the water carries an electrical charge. This electrical charge can be measured using an electrical conductivity meter. The meter uses an electrical current and two electrodes spaced 1 centimeter apart. The meter then shows the amount of electrical current passing between the two electrodes in terms of electrical conductivity. This electric charge can be used to calculate and estimate the amount of nutrients in the water. This is true because as the concentration of the nutrient salts in the solution increases so too does the electrical conductivity. This is a very important aspect to consider in hydroponics when trying to control the nutrient level of the solution. This information is vital as plants thrive under different pH levels and therefore knowing the pH level of the system allows the system to make necessary adjustments to obtain the desired pH level.

However, some limitations stem from the chemical nature of the property being measured. Considering EC is proportional to the amount of salt dissolved in the solution, one would expect that measuring the EC would allow accurate calculation of the amount of nutrient in the solution. This is not true. Even though salts increase the conductivity, each different salt ion has a different specific conductivity and contributes differently to the overall EC. This may result in inaccurate calculations if the solution contains small amounts of an ion that conducts a great deal. The important ions are the ions, which have very large conductivity that helps to determine the pH.

Considering these limitations, the EC should always be measured at a specific pH. EC’s measured at different pH levels; for example, 4 would be completely different to an EC measured at 7 due to the fact that the ions that determine the pH has a very significant effect on the EC value. More importantly, the conductometer should be calibrated at a known conductivity. Failing to meet this requirement would result in meaningless measurements.

With the necessary precautions taken into consideration, the EC will provide information as to whether your solutions have lost nutrients from the growth of the plants or if there has been significant water evaporation, but only if measured at the exact pH levels. It is good practice the measure the EC when it is prepared and at least three other times throughout the day. If the EC rises too high, water should be added to lower it however if the EC drops below 70 percent of the original value then a new solution should be prepared.

2.1.2.7 - Water Pump Configurations

The various types of hydroponic systems require varying water pump configurations. In general, all hydroponic systems incorporate a submersible pump of some size and strength depending on the particular water flow needs. The pump is utilized to deliver the water-nutrient solution from the main reservoir and up to the growing chamber(s) and root zones. Submersible pumps are abundantly available on the market in a wide range of strengths at low cost. It is this low cost factor that has made DIY hydroponic gardening so popular in the recent years. The submersible pumps are simply constructed from mainly an impeller and an electromagnet to spin it and create suction. In any hydroponic system, the pumps and filters need to regularly cleaned to ensure healthy plant growing conditions.

Selecting the strength of the submersible pump for a hydroponic system is based on each individual structure's needs. Things such as head height, system volume, flow rate, and maintained depth are just a few important factors that must be taken into consideration when the strength of a pump is determined. Generally, though, the main factors to determine the strength needed are the head height, system volume, and flow rate. The strength of a pump is determined in gallons per hour (GPH). A pump's GPH and its cost are directly correlated. Depending on the type of system, the minimum pump strength is determined by dividing the system reservoir volume by the amount of time needed to circulate the entire system's volume of water (in hours). This system volume circulation time varies per type of hydroponic system A good rule of thumb is to choose a pump that has at least twice the minimum GPH that a system needs. The flow can then be adjusted by installing restrictive valves off of the main pump outlet to reduce the flow down to the desired level. The main argument for this is that a pump can always be weakened, but never strengthened, so designers should always resort to redundancy.

Head height is the last important factor to consider when determining the minimum pump strength. Head height is defined as the vertical distance between the water line in the reservoir and the system’s delivery outlet. Most pump manufacturers include a head height flow-chart that describes what the GPH rates are for the pump at several different head heights. This piece of information is crucial for establishing the correct flow rate throughout the hydroponic system.

The different system configuration all require different strength pumps to achieve their respective nutrient solution flow rates. For this project, each design configuration is considered to observe the importance of water flow in hydroponic systems. In a flood and drain system, the total volume of all of the growth containers needs to be obtained. The head height for the system and the flooding time need to be determined as well. These three factors typically result in the need for a stronger pump because the flooding time needs to be rather short in this type of system. Drip systems are rather simple in concept but the forms to construct them vary in numerous ways. The same two factors are involved, water volume and head height. The GPH is not as important though, as the system simply soaks the root system enough to last for a period of time, and the control timer can be easily adjusted for accommodations. NFT systems take into consideration the same factors as mentioned before as well as the angle of each tube to determine the flow rate. The pump just needs to be able to keep up with how fast the water is flowing down the angle of the growth channels. Typically, NFT pumps are weaker (and cheaper) because the head height and GPH are kept lower than other systems. Lastly, Aeroponic systems require stronger pumps in direct correlation with the number of sprinkler heads installed. The more sprinkler heads involved, the higher a GPH pump is needed to maintain high psi to achieve an ideal mist of the nutrient solution.

2.1.3 - Gaining Knowledge and Skills

Throughout the design process, our team hopes to gain knowledge and skills related to each of our engineering disciplines. Our project was chosen to allow both electrical engineers and computer engineers to achieve this goal. An automated hydroponic system integrated with web and a mobile application grants each member the opportunity to not only focus on their specialty but also to cross disciplines and contribute to many areas of an overall design. For electrical engineering, some desired skills include, sensor interfacing, PCB design and layout, application of a microcontroller, and overall system integration. For computer engineering, project scope includes web integration, mobile application design, and overall system integration. Besides project scope, there are intangible skills we look to gain as well. Working together in a team to achieve a working product is not only necessary but is an opportunity to grow as engineers. Taking responsibility for action items and delivering to the team desired results is an inevitable future for all of us and senior design is the first step. Accountability, teamwork, integrity, and excellence are some core values we hope to carry throughout this design process in order to deliver a working and innovative design.

2.1.3.1 - Sensor Interfacing

When designing an automated hydroponic system, the goal is to ensure that plants are growing under ideal conditions. To achieve this, a significant amount of sensors must be implemented. All systems (not only automated hydroponic systems) have at least one input device, control unit, and output device. The control unit takes the output from the input device, processes it, then makes a decision as to what the outcome should be. Here we will focus particularly on the input devices which are the sensors.

Sensors can be categorized into two major groups: voltage producing sensors and resistive sensors. Voltage producing sensors generate a voltage that is based on the input. This range of voltage will vary for different sensors. Resistive sensors on the other hand operate like a variable resistor changing the resistance for different inputs. Resistive sensors have a nominal resistance value that is considered to be zero and suggest a range of which can be measure. This information can be found in the datasheet for different sensors as it will vary.

However, regardless of the category it falls under, the sensor must be able to communicate with a microcontroller. Therefore, sensor interfacing is very important. The signal from the sensor must be sent to an interfacing device then to the processing unit. In some cases, the signal must go through some sort of regulating. Interfacing devices are accepting voltages within a certain ranging from 0 to 5 volts. As a result, the signal is passed through a regulating circuit that will take the signal from the sensor (voltage or resistance) and change it to a voltage within the range of 0 to 5 volts. This can be attained by a few simple processes such as: dividing a voltage, converting resistance to voltage, and amplifying a voltage.

Relevant material learned in class permits us to obtain these desired results. Voltage dividing and converting resistance to voltage both use a simple voltage divider circuit. In the voltage divider case, the sensors datasheet will provide specification as to the range of voltage for the output of the sensor. This information can be used to create a voltage divider that will limit the voltage to a max of 5 volts. For example, if the output rating for a given sensor is 0 to 20 voltages, a voltage divider with a ratio of 5/20 can be used. In the resistance to voltage converter, replacing one of the resistors in the voltage divider circuit with the variable resistor sensor will result in a linear resistance to voltage relationship. Some sensors produce very small voltages, and thus require amplification of the output. This can be done by simply using an operational amplifier.

2.1.3.2 - PCB Design and Layout

It is a requirement that a printed circuit boards (PCB) be designed for the hydroponic system being designed. For this reason a significant amount of research was done in order to figure out how to design and layout a PCB correctly. PCBs are a crucial part in electronics today. The PCB design and layout are critical to the success of the product being able to meet its performance requirements or even being able to perform at all. A printed circuit board is a non-conductive substrate laminated with etched copper sheets to produce conductive tracks to allow electrical component to be connected. PCBs can be sided with one layer of copper, double sided with two copper layers, or multiple layers with inner and outer layers of copper. PCBs may contain components such as resisters, capacitors and even active devices embedded within the substrate. The more layers the PCB has the more sophisticated the design that can be implemented. PCBs for intricate hardware such as motherboards may have up to ten layers. Each layer is connected with a plate through hole called a “vias”. These vias connect the components on the different layers to each other.

The first step of designing a PCB is knowing exactly what circuits need to be built. Do all the necessary drawings and calculations and verify that the design is correct. Subsequently a PCB design software will be required. While doing research, a great deal of PCB design software was discovered with Eagle by CadSoft; which is most popular among students. Draw the schematics diagrams into the PCB designing software. Verify everything is connected correctly then prepare the board layout. This is done by transferring the schematic drawing into a printed circuit board within the software. The PCB designing software has tools that do this on its own. Upon doing this and making sure everything is connected correctly and there are no errors shown by the software, the design is now ready to be manufactured. Convert the layout to Gerber files and select an inexpensive PCB manufacture to have your board made.

2.1.3.3 - Microcontroller

Microcontrollers are becoming more and more popular every day and being able to use and program one are very important skills to have. It is a small single integrated circuit containing a processor, programmable output and input peripherals, and memory that can be used as a small computer. They are usually used for sensing input from the real world and controlling devices based on that input. It is good practice to use a microcontroller when designing a simple device that doesn’t require the power of a desktop computer. Microcontrollers have a low power mode where it still and waits for an input such as a button press, processes the input, then goes back into low power mode. This is key as it will help the system to have minimal power consumption. Due to the fact that the hydroponic system will have numerous sensors and motors, we intend to use a microcontroller to interface them. This microcontroller will be an essential component to help maintain ideal conditions for plant growth in our system.

Microcontrollers come in various sizes and levels. Some are large and made up of various components and ports for input and output interactions. These microcontrollers in most cases are ready to use for a specific task right out of the box. Others are small chip-sized that has to be programmed and connected to its own input/output devices to carry out its task. These smaller microcontrollers are normally cheaper since most of the work hasn't been already done for the user. It is our intention to use a small chip-size microcontroller to carry out the functions of our project.

This microcontroller will automatically control the quality of the nutrient solution flowing through the system. This will be achieved by using the input and output pins on the device and read the conditions of the nutrient solution, process the information and make a decision based on the algorithm programmed onto the board, and then send an output to the necessary components. Our course work at the University of Central Florida focused mainly on one specific microcontroller, the Texas Instrument MSP430. However, there are a significant amount of microcontrollers in the industry today that may be utilized for the purposes our project which will be taken into consideration.

2.1.3.4 - System Integration

The project requires interfacing many components together in one cohesive project. One of the biggest components that exemplifies this is the printed circuit board. The UCF curriculum does not provide any working experience with designing printed circuit boards for use in engineering projects. This component is used to interconnect the microcontroller, sensors, Wi-Fi module, and LCD control panel. This requires all of the specifications and protocols to integrate cohesively together. Gaining experience in ensuring components correctly communicate is a valuable skill for any embedded project.

The high level system integration for our project will consist of ensuring the MCU and web server can communicate with the mobile application and database. This involves integrating the high level system components together and ensuring there is cohesive connectivity throughout the system.

The job industry today for embedded technology design requires the ability to verify components can integrate together to form the desired product. This requires experience of working with different technology protocols and specifications. This project creates the ideal opportunity to work with various technologies: such as Arduino sensors, microcontrollers, wireless data modules, and also LCD displays. Our lack of experience in system integration will require us to prototype with our electrical components to ensure that the desired functions can be established with the necessary parts.

2.1.3.5 - Web Integration

This project presents an ideal opportunity to broaden our skills involved with web integration. Jobs in the industry today with radio frequency (RF) communications to web-servers are more prevalent now than before. The internet of things has become a largely popular concept today that is defined as physical devices that are connected to a network that share data can communicate. Our project provides an excellent outlet to acquire some hands on experience in setting up RF communications that forward data to our web server interface. The flow of data measurements from the sensors to the controller and on to the web server will incorporate the use of many different protocols and technologies that we have little to no work experience with. Our core desire, for this project, is to become immersed in the most relevant technologies prior to graduation and working in the industry.

The project will require the implementation of wireless communication technology in order to provide the functionality of remote monitoring from a mobile application. We will explore and research the most current types of communication available to accomplish this. Some of these types will include and are not limited to, Wi-Fi, Bluetooth, ZigBee, and likely several more. These are just a few of the wireless communication technologies that are widely used today. It is our personal interest to gain more knowledge and development experience with these technologies, as the current CpE curriculum at UCF lacks courses that provide practical experience with these technologies.

Web servers are a common middle tier technology that is crucial to the functionality of almost all mobile and web applications. For this reason, we have elected to implement a mobile application that will require a web-server to receive and transmit the raw sensors' measurement data. Many jobs in the market today apply the use of many different types of web server technologies to communicate between mobile/web applications on the front-end and databases on the backend of the system. The two developers and computer engineers have the desire to expand upon our existing low-level knowledge about web-servers. We look to use this project as an opportunity to explore the most modern web server technologies that are in use today. Some these will include and are not limited to, Node.js, Apache, RESTful APIs, and Backend as a Service (BaaS) such as Amazon Web Services.

A last important motive related to web integration and this project is the process of communication between the web-server, mobile application, and database. This experience is very important for a professional's future career in web and mobile application development. The CpE curriculum at UCF seems to lack courses involved with web and mobile application integration. It our own personal interest to explore the various methods that mobile applications can communicate with databases through the use of a mid-layer web server. Our project will require the implementation of a web-server using one of the latest server-side scripting languages. We will investigate the different languages available to accomplish this, and also compare and contrast options to obtain the suitable design for our project. This will require us to analyze the ability to integrate of the server technology with the communication protocols implemented in our main controller. This experience is crucial to web-integration, as there are an abundance of different technologies and protocols. As detail-oriented engineers, we look to gain experience in ensuring the systems cohesiveness is sound throughout all main components of our system.

2.1.3.6 - Mobile Application Design

For the two Computer Engineering (CpE) students working on *WaterWise*, the mobile application design portion of the project is highly beneficial. In general, the Computer Engineering curriculum at UCF is lacking in mobile application development education, as there are no dedicated courses on learning to program for any the major mobile operating systems such as Android or iOS. After coming to this realization, we decided to add a mobile application component to the project so that we could gain valuable knowledge through research and practice.

To achieve this goal, *WaterWise*'s mobile application will be designed for the Android operating system. In order to properly gain experience with Android development, we have spent time researching different unifying features in popular Android applications with an emphasis on UI/UX design and application flow. After examining apps such as Google Hangouts and Twitter, we have determined that there is a very popular UI/UX design approach for Android known as Material Design. Due to its popularity, we decided that the mobile application for *WaterWise* will be developed following this design ethos. Specific details about Material Design, and how it will be applied to the mobile application will be discussed in section *3.3.1 - Material Design*.

In addition to UI/UX design experience through the implementation of Material Design. We also researched different development environments and their popularity within the mobile application development community. This was done in order to ensure that they became comfortable with the most widely used development environment. Our research led to the discovery of Android Studio, an integrated development environment (IDE) created by Google in order to make Android application development as efficient as possible. Given the popularity and usefulness of Android Studio, we have decided that it would be the most beneficial to use this IDE to develop the mobile application for *WaterWise*. The features of the Android Studio IDE will be discussed in more detail in section *3.2.10 - Software Development Environments*.

Continuing, because *WaterWise*'s mobile application will utilize accounts for each user, and a database of plant information to be accessed by the user. We will gain knowledge on integrating server technology with an Android application. After researching different ways to achieve this goal, we came across many different providers of database servers as a service. We discovered that we could use one of these services to build our own database without spending development time creating it from scratch. And because it is far more likely that businesses in the real world use servers like this, we decided to gain experience learning to interface with a provided database server. The research into the database server technology will be discussed in section *3.2.6 - Application Database Server*.

Finally, most Android applications are written in Java. And while Java is covered in the Computer Engineering curriculum, the addition of a mobile application to *WaterWise* will undoubtedly provide excellent practice for implementing real world Java based applications, as opposed to writing Java programs to satisfy assignment requirements.

2.2 – Objectives

The hydroponic system will be very straight-forward and easy to use. Various sensors will be implemented and the information will be display on the platform itself. This information will also be accessible remotely via from a wireless device. It will give real time information about the system and alerts when necessary.

- Sensors- In order to ensure the plants are growing in ideal conditions, a significant amount of sensors would need to be implemented. These sensors include a PH sensor to give real-time information about the PH level of the water flowing through the system and in reservoir. Two (2) electric thermometers to continuously measure and record the temperature of the water flowing through the system and the air surrounding it. A water level sensor will also be implemented to make sure the reservoir doesn't run out of water at any given time.
- Internet Connectivity- The user will be able to interact with the system remotely using a wireless device via a mobile. He/she will be able to check water levels, PH level, both water and surrounding air temperature, air humidity, etc.

- System Control- The system will be equipped with a non-touch display. This display will have four (4) buttons that allows the user to navigate to different menus to see real-time data about the system.
- Hardware- In order to allow the system to operate at its full potential allowing the plants to grow in ideal conditions, a few more hardware will be implemented. Some of these include a pump for the water to continuous flow through the system and not remain stagnant, an air-stone at the bottom of the reservoir to supply the water constantly with oxygen, an on/off power switch to allow the user to shutdown the system safely, a manual control to add nutrients to the reservoir when needed.
- Leak-proof Plumbing- Because of the nature of this project, special precautions must be taken in the designing to ensure its functionality and durability. Careful attention will be paid when putting together plumbing fittings to ensure there are no leaks within the system.
- Minimum Power Consumption- The system will run off of electricity provided by the main grid to the house. Therefore, the system will be design to consume minimum energy. This will ensure the consumer doesn’t experience a noticeable change in their electricity bill.
- Low Cost- Careful consideration will be taken when choosing each component of the system prices, quality, and effectiveness of each component will be reviewed before items are purchased. This will ensure the development of a robust inexpensive system that the average consumer will be able to afford.
- Maximize Space Efficiency- Space efficiency will be a very important aspect in the design of the project. This project is being designed to be used indoors/outdoors. Therefore, this project should be able to fit comfortably within a household and not be cumbersome.

2.3 - Requirements Specifications

The requirements and specifications are an important step for any design, as they help to define the importance of each component of the system. They help to guide the more specific design decisions that will be made for critical parts of each subsystem. These requirements and specifications described below encompass high level details such as physical size of the system and down to the intricate details of the PCB’s wiring. As an example, there are requirements to describe how the growth channels of the *WaterWise* system are setup to properly remain within the overall size constraint. This includes the diameter, length, and number of growth channels channels, as well as the distance between each growth channel to ensure the *WaterWise* system is minimized in space consumption. The remaining requirements and specifications of the *WaterWise* system are described below to ensure that the systems will operate correctly.

2.3.1 – Hardware Requirements

2.3.1.1 - Physical Structure

The structure of the design must first have of a frame made of a strong material to support of the remaining components off of the ground. The frame of the structure should be able to support a heavy amount of weight as the water reservoir and growth channels with fully grown plants will induce a significant load to the structure. The physical structure should include a lower compartment to mount the main water reservoir and nutrient reservoir to the frame. There should be open space at the lower sides of the frame for the plumbing and wiring of the system to run up and down to it's connecting points. The structure should have open space at the top for the growth channels to be mounted along the length of the frame running from one end to the other. The frame and structure should be constructed of durable materials to provide redundant stability for support and waterproofing purposes. We also anticipate constructing dry compartments mounted along the water reservoir to contain the electronic components of the system.

We will strive to build a physical structure that is 2 ft. wide, 3 ft. long, and 3 ft. tall. The lower compartment of the structure will extend the entire width and length of of the structure. This compartment will aim to be about 2 feet in height as well as be enclosed by paneling material to form a cabinet. This cabinet area will hold the essential components of our hydroponic system: the main pump, water reservoir, nutrient reservoir, air stone, and nutrient pump as well as the necessary piping that exiting and entering each end of the reservoir. A majority of the sensors will also be located in this compartment to obtain the necessary water measurements. The controller and interactive control panel will be located along the reservoir in a specially constructed waterproof container.

One of our goals is for the structure to be semi-mobile, under the constraint of the main power cable and an accessible wall power outlet. Our design will incorporate multidirectional spinning wheels to provide some mobility. This simple addition to the design will be provide our desired functionality and achieve the overall goal to ease movement of the system for the user. Figure 2.13 shows a high-level drawing of our initial structural design. The lower compartment will hold our main components. The growth channels will sit above the lower component in the open to receive the lighting and oxygen from the external environment.

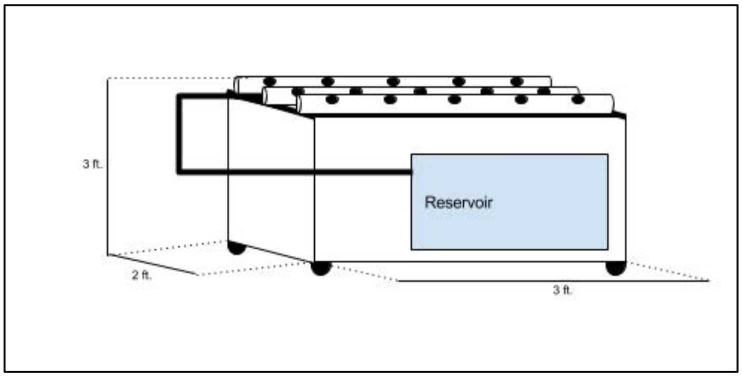


Figure 2.13: Initial Physical Structural Design

2.3.1.2 – Growth Channels

The main feature of a hydroponic system is the apparatus that holds the plants. It is this component that distinguishes the design, and also helps to classify the type of hydroponic system. Our system will include three separate growth channels affixed to the top of the frame and running in parallel down the length of the structure. The diameter of each channel will be about four inches and there will be two middle clearance gaps in between the three pipes at a distance of four inches. This arrangement fits closely inside our width constraint of two feet with a couple extra inches to spare. Each growth channel will be affixed at an adjustable angle with one end slightly higher than the other. This design specification is very significant, as it is a key feature to developing a successful NFT hydroponic system. The three pipes will receive water from the reservoir at one end via plumbing and the water will exit each growth channel and recycled back into the water reservoir via additional plumbing. The growth channels will consist of a number of plant bays evenly spaced to ensure an ideal yield while still maintaining enough space for maximum growth.

2.3.1.3 – Water Solution Pumps

It is important that the plants get a constant supply of food. In order to achieve this, the nutrient solution must flow flowing through the system constantly. Our design incorporates a submersible pump that will be used to keep the nutrient solution flowing. The pump will sit at the bottom of the reservoir where it will steadily pump the solution from the reservoir via water tight tubing to the growth channels where the seedlings and roots of the plants will be located. After flowing over the plant roots, the nutrient solution will then run back down into the reservoir via piping.

The submersible pump will only need to be strong enough to pump the water at a head height of a maximum of four feet. The pump will need to be able to pump at a minimum 45 GPH at a head height of three feet. This rate is ideal to maintain the recommended flow of one-quarter of a gallon per minute per channel. Our design will likely incorporate a pump that is at least 20% stronger than our absolute minimum strength requirement. A redundantly strong pump will then be adjusted with the use of flow release valves near the tubing attachment point to the pump in the reservoir.

2.3.1.4 – Nutrient Delivery Pumps

One of our design goals is to automate the process of adding nutrients. In order to achieve this, the design will incorporate the use of peristaltic pumps to deliver the pure nutrients and pH adjustment into the reservoir. These pumps will not require much strength as the liquid will only flow down into the reservoir from the nutrient hopper. The peristaltic pumps will need to be accurate in the rate of flow. The pumps will need to be able to pump about 100 mL per minute. This accuracy specification is important, as our controlling code that dispenses the nutrient will assume a specific rate the pump will output.

2.3.1.5 – Water Plumbing

In order for the water to reach the growth channels, there will need to be plumbing from the main submersible pump. This tubing will need to be of a specific size to fit properly onto the submersible pump. This is an important specification as it can affect the rate at which the pump operates if the tubing is not securely attached to the lip of the pump. The vertical piping that delivers the water will measure about one to two feet in height. It will be routed up from the pump out of the water reservoir as one main flow pipe. This main flow pipe will diverge into three pipes that will be linked to the higher angled end of the growth channels. This piping and sealant needs to be redundantly strong and sealed in order to achieve the waterproof characteristics of our system.

At the opposite end of the growth channels, there will be drainage pipes connected to the end of each growth channel. These three pipes will converge together and lead back into the main water reservoir. This will help to ensure the nutrient is evenly distributed throughout the solution. This piping can be rather simple in design as all it must accomplish is guiding circulated water back down into the reservoir. The only requirement is that the pipe be thick enough to amply drain the runoff water from the growth channels to ensure there is no backup of water. The same sealant and pipe strength is required for the drainage pipes to ensure the waterproof characteristics of the system.

2.3.1.6 Nutrient Plumbing

The nutrient and pH adjustment chemicals will be delivered via a peristaltic pump from the nutrient reservoir into the main water reservoir. In order to deliver these nutrients, our system will have small tubing connecting the peristaltic pump and traveling into the main water reservoir. These peristaltic pumps are designed with a small tubing attached to the pump. The small tubing that our design will incorporate will need to be flexible in order to bend into the water reservoir. Our tubing design will need to correctly connect to the small tubing on the peristaltic pump. This specification is important to ensure the nutrient delivery occurs correctly. Fortunately, this small tubing is inexpensive, so trial and error is possible to ensure a correct fitting.

2.3.1.7 – pH

When the nutrients and chemicals have been delivered to the main water reservoir, our system will use a pH sensor to obtain measurements. The main controller will use this measurement to determine if the level needs adjusting to get the pH back to the optimum level. In an NFT system, the water is constantly flowing to the plant's root system. Therefore, it is essential that the solution levels are constantly monitored to mitigate the risk of feeding poor quality nutrient solution to the plants' root systems. The ideal pH range for most plants in hydroponic systems is between 5.5 and 6.5. The sensors must be able to provide the measurement data to the controller so that it can be determined whether or not to add nutrients to the water reservoir. After adding pH Up or pH Down, the system should wait some small amount of time for the solution to dissolve before taking another measurement and deciding to further adjust the pH level. Depending on our systems total volume the solution adjustment amount can be determined by the controller depending on the pH reading. It will determine this amount required, and then know how long to run the peristaltic pump to add the correct amount of chemical.

2.3.1.8 – EC

As the system is constantly delivering the water-nutrient solution to the root systems, our design needs to constantly monitor the conditions of the water. The EC sensor will take measurements at the same time as the pH sensor in order to properly analyze the EC level as it varies depending on the pH level. The EC measurement will help determine if the solution of the nutrient ions is too high or too low. The sensor will need to communicate its measurements with the main controller, so that it can be determined if the EC percentage is too low or too high. If it is determined that the level is too low, then the main controller will add more of the required nutrient solution to the water reservoir. If the level is determined to be too high, the controller will not add any nutrients for some time, and may instruct the user to add a specific amount of water to the main reservoir. After the correct action is taken to adjust the EC level, the controller will wait a short amount of time to take another measurement with the EC sensor.

2.3.1.9 – Water Level

Due to the fact that there will be water evaporation within our system, the water level inside the reservoir will be monitored. This will be monitored by having electrical conductors on one side of the reservoir. With the water make connection to the conductor, the circuit would be completed due to the nutrient ions in the solution. At least 2 probes will be used to indicate the min and max levels of the reservoir. If the water level drops below the lower probe, the circuit will be broken and a notification will be sent to the microcontroller. The system will then notify the user that he/she need to add water to the reservoir. As he/she adds more water, when the water reaches the maximum level, a notification will be sent to notify him/her to stop. These probes will be placed at approximately 30% and 70% levels of the reservoir. Based on the known capacity of our reservoir, and the levels of the minimum and maximum levels, the system will also be able to notify the user of the amount of water needed to restore the water reservoir conditions.

2.3.1.10 – Dissolved Oxygen

As the *WaterWise* system is constantly delivering water to the root systems, the dissolved oxygen (DO) level of the water must be constantly monitored to ensure the plants are receiving oxygen rich water. Our system will have a DO sensor to take measurements of the water nutrient solution in the main reservoir after a small amount of time. The sensor will need to be able to communicate its measurement data with the microcontroller. The MCU will then analyze the reading and generate a notification to the user via the Wi-Fi communication and mobile application that the DO level is not optimum, and the air stone needs to be examined. If we are able to implement an air stone with variable power settings, our system could automatically adjust the power supply to the air stone. This would properly help to adjust the DO level to the optimum level. Another option could be having a redundant air stone whose power can be enabled and disabled by the controller. When the DO sensor provided a reading that is too low, then the controller can turn on the second air stone to help raise the DO level. If the DO reading is found to be too high, then the controller can disable both air stones to allow the DO level of the water to fall. When a course of action is taken to adjust the DO level, the controller will wait a short period of time to take another reading to allow time for the DO level to adjust.

2.3.1.11 – Lighting

The WaterWise system will be designed to be able to operate both indoors and outdoors. When it comes to lighting outdoors, the sun provides the entire wavelength spectrum for the plants to get their food through the process of photosynthesis. However, the plants may not be able to get their desired wavelength indoors. For this reason, grow lights will also be implemented. These grow lights will be able to provide the desired red and blue wavelengths that the plants need to grow. The grow lights will also be adjustable in term of being able to position it over the structure. This will help to assist the user in regulating the temperature surrounding the system. The grow lights should also be detachable if the user thinks that it is too cumbersome or if it is not necessary; for example, the system is placed in an outdoor environment. Last but not least the grow lights should consume minimal energy to ensure the user doesn't observe a noticeable change in their electricity bill.

2.3.1.12 – PCB Design

The main purpose of the printed circuit board is to control and distribute power to the main subsystems. It will consist of relays to switch on and off power, and also an LCD panel display and buttons that can be used for direct system interaction. The PCB will be small in size to fit in the constructed dry electronics compartment. The board will receive the data information from all of the different sensors and transmit it via wireless connection. This information will be sent over Wi-Fi to the mobile application where a user will be able to set control parameters. These parameters will be received back via Wi-Fi to the PCB and microcontroller, which will control the relays to create the desired configuration of the system.

2.3.1.13 – Wireless Communications

Our system will require wireless communications functionality for the core subsystems to communicate effectively. This requirement is crucial to achieving our objective of having aspects of automation in our system. Our system will consist of several sensors that will take readings on many different things. Each of these readings needs to be communicated to our back end web server and eventually the data base. This will require the implementation of a wireless data module to transmit this information.

Among the many different modules on the market, all of them have their own specifications and different functions. It is important to compare and contrast each of the different modules choose a cohesive model. This wireless module should be able to connect at least 10 sensors at once. The sensors will provide the readings to the wireless module. The size of each data reading comparatively small from other typical pieces of data. The data rate of the wireless module will not need to be too large as it will only be transmitting about 10 small pieces of data a few times a minute.

The wireless module should be able to interface with our PCB directly. It will need to occupy minimal space on the PCB to leave room for other components. The wireless module will also have some form of antenna that is built in or connected externally. Our design must be also careful to orient the antenna in such a way that avoids electromagnetic interference. The module must also have minimum power consumption. This will help to achieve the low power consumption objective for our design.

It is likely that our module will be a Wi-Fi capable module, as our design will need to be able to connect to the internet to communicate with the server and database. This database will receive the most recent data readings from the sensors. A Wi-Fi module will simplify the system's capability to communicate with a web server. A Wi-Fi module will also provide the range of connectivity that is appropriate for our system.

2.3.1.14 – Control Panel

The system will require a control panel to allow for the user to interact directly with the module. This will allow the user to perform basic actions for the system. The control panel will consist of a simple LCD display with several buttons. The buttons will be able to control power to several different components of the *WaterWise* system. These components are things such as the submersible pump, lighting, main power, and also the nutrient peristaltic pump. This control panel will need to connect directly to the PCB and occupy minimal space to leave room for other relays and wiring of the PCB itself. We will consider many different available panels made by different vendors. Each of these panels has different specification and will require a careful comparison to select the panel that best fits our design.

2.3.2 – Software Requirements

2.3.2.1 – Mobile Application

Our project will require an application for the user to interact with and control the system. The system will include a mobile application to interface with the user. The application will present the most recent data measurements from the sensors. The mobile application will be able to interpret the data from the sensors and alert the user of harmful conditions and of actions being taken by the PCB and MCU to correct the conditions. If the current conditions require the user to take action, then the mobile application will present the necessary instructions to the user in order to restore the system conditions. The mobile application will also allow the user to designate the type of plant the user intends to grow. Based on the user's plant selection, the mobile application will interpret the results and will communicate the necessary settings to the PCB and MCU. These settings will help to automate the process of maintaining nutrient balance for the type of plants being grown.

2.3.2.2 – UI Design

One of the core objectives of our project is to develop a very intuitive user interface for the *WaterWise* mobile application. The mobile application's UI will be developed as closely as possible to the *Material* design principles published by Google. These design principles specify exactly how user interface components should, look, feel, behave and respond to user interaction. The benefits of having a good UI can help to enhance the user's overall experience with the system as a whole. We will strive for the user to be able to simply navigate the application and complete actions without any confusion or difficulty. This requirement will also satisfy personal interest in gaining experience in UI development

2.3.2.3 – Libraries Table

Our project will be using a well defined microcontroller with a respective IDE to allow us to easily develop code for the MCU. We will use XML and an HTTP based server to communicate the sensor data to our database. The main database will use SQL open source technology. All of the APIs and technologies used in the project will be open source. The libraries utilized for this project are listed in Table 2.14.

Library	Function
UART	Serial communication for the MCU and sensors.
Android Studio	Provides all of the defined classes and functions for the Android development environment.
Kinvey	Provides all of the necessary functions to integrate with the Kinvey MBaaS.
Google+	Social media accounts integration functionality.

Table 2.14: Software Libraries Table

3.0 - Project Definition Research

3.1 - Similar Existing Products and Projects

As previously discussed, hydroponics has been growing substantially for the past few years with do-it-yourself (DIY) consumers as well as businesses.

Researching for this project has led to finding many DIY projects that feature very popular methods as well as unconventional integration. In the last few years since Arduino has exploded on the microcontroller scene, there have also been many users that have decided to automate their system using a microcontroller as a hub for data collection and control, especially using an Arduino board. By simply browsing the internet, finding many projects that reflect aspects of what this group has aspired to achieve is very easily accomplished. Two of the larger web contributors to finding similar existing products and projects are YouTube and Instructables.com because of the communities of users who dedicate their time to share their creations. In addition to web resources, there have been many similar senior design projects completed in the recent past. Being able to see what other student groups have done before our group has been invaluable in developing a design that reflects objectives which are more typical for a senior design project.

3.2 - Relevant Research

3.2.1 - Required Conditions for Plant Growth

Required conditions for plant growth in hydroponic systems do not stray away from the general conditions of traditional soil based growth. These necessary conditions include light, water, temperature, oxygen, nutrients, and a support system for the roots. The benefit of using a hydroponic system is that the user is not only able to monitor these conditions but also adapt the system to more ideal conditions. For instance, the temperature at which plants grow best is between 60 and 80 degrees Fahrenheit and with a hydroponic system, this can be completely monitored and controlled to an extent given certain changes to the system e.g. a greenhouse style structure. In this project, tackling the issues of how to monitor and control all or most of the necessary conditions is the key to a successful project.

The oxygen level in a hydroponic system can vary solely based on what type of system is being used. Some systems naturally have more oxygen exposure for the plants than others but in all hydroponic systems, there is a certainly lack of oxygen compared to soil based methods and additional oxygen must be provided. This is generally accomplished by placing an air stone in the reservoir to produce bubbles to carry with the pumped water. In systems such as NFT and aeroponics this is generally not a necessary addition, especially so in aeroponics. As discussed in a previous section, the monitor and control of the system's dissolved oxygen level is an absolute priority in design.

Besides oxygen and water, plants also desire some essential elements as part of their nutrition. The major elements to be considered include nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Some smaller elements such as iron, manganese, boron, zinc, copper, molybdenum, and chlorine are also considered but in what amount is slightly more dependent on what produce is being grown. A successful hydroponics system is completely dependent on determining what plants require what nutrients and what kind of nutrient solution should be delivered in order to achieve proper growth in a timely manner.

3.2.2 - Seed Germination

Germination is the way by which seeds develop into plants. In order for germination to occur certain conditions must first be present or the seeds will remain inactive. Germination of all seeds requires a bare minimum of water, the right temperature and oxygen. While some seeds require darkness others require particular wavelengths of light. Once all the required conditions have been met the water and oxygen are absorbed into the seed's coat. After absorption, the embryo will enlarge, the coat will break open and a root will develop, ensued by a shoot that has leaves and a stem. Some seeds are harder than others and this makes it harder for the water and oxygen to penetrate the coat of the seed. In order to make the taking in of water and oxygen easier, a seed with a hard coat should be soaked or scratched to help break down the coat. Some seeds need other special conditions, such as apple seeds that need to be kept in cold temperatures in addition to the basic necessities, before they can germinate. There are many circumstances under which a seed may not be able to germinate. Dry conditions, over watering, planting the seed too deeply and the seed not receiving enough water are a few reasons why germination might not occur.

A germination station helps to provide optimal conditions for growth. Some of these conditions, such as appropriate heating to arrive at ideal temperatures for germination or proper nutrition, may not be attainable if the seeds are planted directly into the growth medium. Temperatures below 50 degrees Fahrenheit or above 90 degrees Fahrenheit are destructive to germination. In the case of a nutrient film system which we will be designing, the plant has to remain in the germination station until the roots are long enough to reach the nutrient solution on its own. Once the seed has sprouted and the roots are long enough, the plant can be easily transferred and planted into the growing medium of the hydroponic system.

There are many different media to start the germination process in. The media may of inorganic material (not soil) that the roots can grow through so that when they are ready the entire plant and media can be transferred into the system. If an organic material is used such as soil, the organic material will have to be removed from the plants roots before being transferred. This germination process is simple: first moisten the starter material with water and the suggested pH level for the seeds. The temperature should range from 70 to 80 degrees Fahrenheit.

Be sure to monitor the seeds and the germination media everyday adding more germination solution if necessary. Seeds should start to sprout in a couple days, depending on the type of plant. Be sure to cut of thin out the weaker and slow growers. Once the plants have reach a height of about 2 to 3 inches, and the roots are long enough to reach the nutrient solution, then it is ready to be transferred to the main hydroponic system. This process normally takes 1-3 weeks however, tomatoes and peppers may take up to 4 weeks.

3.2.3 - Growth Mediums

Growth medium is used in place of soil in hydroponic systems. Almost any substance that will not easily break down can be used as growing media. This helps with the provision of nutrients to the plants. Solely employing the growth medium and watering the plant with just water is not sufficient for growth. Supplying nutrients is not the purpose of the medium; its function is simply to assist the roots in keeping the plant's weight, holding it upright as well as keeping the roots moist and oxygenated. When choosing a growth medium, there are many things to consider; although, it should be noted that there is no superior type of medium. The type of system being built as well as its design should factor in greatly into the kind of growth medium that is chosen. In order for the medium to sustain growth there a few conditions that need to be met.

In order to attain an optimal growing environment a growth medium must allow for good drainage without condensing, it must also properly distribute oxygen and carbon dioxide, additionally; it should be able to retain moisture and nutrients well and have a neutral pH. Different growth media possess different properties. Some may allow for better drainage than others while others may be more porous and reusable. Growth media can either be man made or organic. Some of the most popular types of medium are expanded clay pellets, water, coconut fiber and rockwool.

There are reusable and non-reusable hydroponic growth mediums. Reusable growth mediums have to be sterilized before being used again. Conversely, non-reusable mediums are meant to be used once and then to be disposed of. If sterilized the medium will lose its shape and structure. However, a medium being non-reusable does not limit it from being a great medium, as some non-reusable growth mediums tend to have great properties. Expanded clay pellets and water are reusable growth mediums. Expanded clay has great drainage properties while still being able to retain lots of nutrients and oxygen, which are both very important for growth. Water is an example of a poor reusable medium because it is unable to hold enough oxygen to sustain plant life. Unless aerated another choice of medium should be used. Coconut fiber, also known as coco fiber, is an excellent choice of a non-reusable medium. Coco fiber protects against harmful bacteria, it enhances the water's absorbing power of potting soil and promotes organic farming. Coco peat or Coir is a natural by product of coconuts. It has a natural pH balance and is useful for up to 5 years. Rockwool is also a very popular non-reusable hydroponic growth medium. It provides exceptional root support, it is sterile, porous and it also holds the air and water that are essential to the roots. It is very likely that rockwool is the most popular and widely used hydroponic growth medium.

Choosing the right type of hydroponic growth media is important if the best growth conditions are desired. There are various choices when it comes to hydroponic growing mediums. There are manmade as well as organic choices, reusable and non-reusable media. Regardless of the medium we choose it is important that it has a neutral pH level, is able to retain air and water and that it drains quickly. The type of system and the way it is designed also factors greatly into the decision making process. Nevertheless, the single most important factor in choosing a medium is knowing the job that needs to be done and understanding what is required to achieve it.

3.2.4 - Microcontrollers and Sensors

One of the first microcontrollers in consideration for our design is the MSP430F6638. This MCU is manufactured by Texas Instruments and is distributed at a relatively low cost. In general, the MSP430 models are renown for their low power characteristics, as they tend to operate in range of 1.8 V to 3.6 V. This MCU is a 16-bit RISC architecture with five different low power modes to help optimize power consumption and extend battery life. The digitally controlled oscillator allows the device to wake up into active mode in 3s. This MCU also features an integrated liquid crystal display (LCD) driver that can control up to 160 segments. It has a clock frequency of 20 MHz, 256 KB of program memory, 18 KB of flash memory, and 74 I/O pins which is far greater than the number of sensors that our design requires. Figure 3.1 shows the pin layout diagram for this MSP430 MCU.

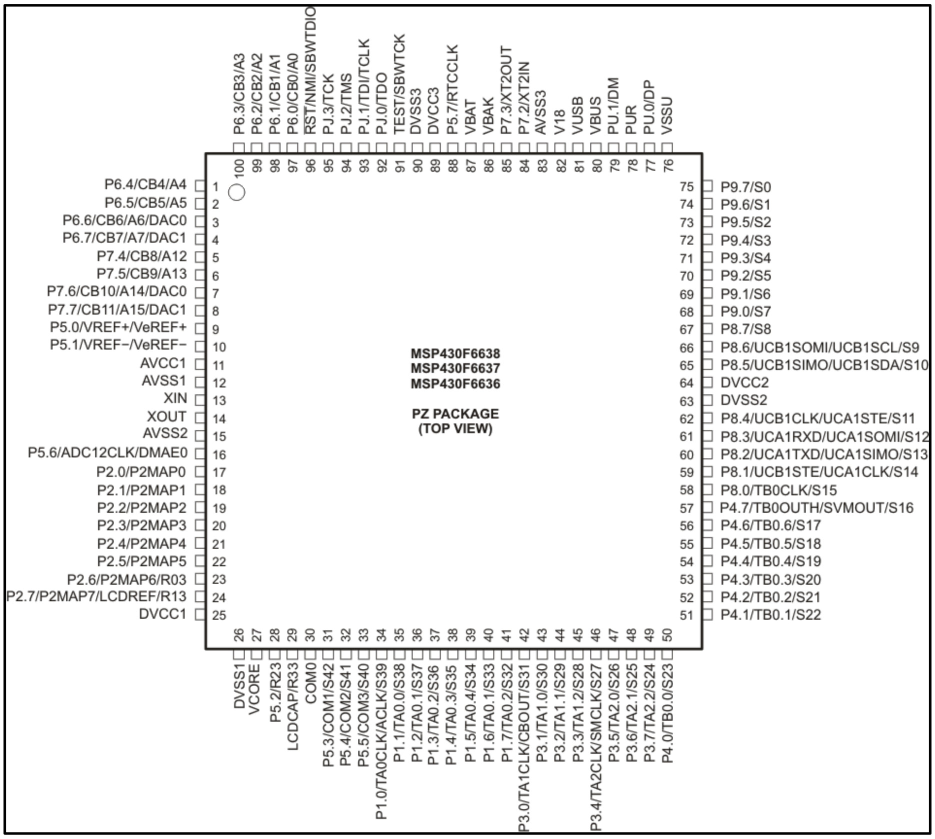


Figure 3.1: MSP430F6638 Pin Layout (Courtesy Texas Instruments)

This microcontroller also includes two universal serial communication interfaces (USCI) for universal asynchronous receiver/transmitter (UART), synchronous serial peripheral interface (SPI), and inter-integrated circuits (I2C). We have previously used the MSP430 in the Embedded Systems course at the University of Central Florida. One disadvantage to this MCU is that it provides no module for Wi-Fi support. Using this MCU will require the use of an external module and program to provide Wi-Fi connectivity. Also it should be noted that in comparison to other IDE's there is a lack of accessible Wi-Fi libraries for C or assembly languages that can interface with the MSP430.

The ATMega328 made by Atmel is a high performance 8-bit AVR RISC based microcontroller with a 32KB flash memory that has read while right capabilities operating at a max frequency of 20 MHz. This microcontroller also has 1KB of electronically erasable programmable read only memory (EEPROM), 23 general purpose I/O lines, an operating voltage range of 1.8 to 5.5 volts which is slightly higher than the MSP430, three flexible timer/counters with compare modes, internal and external interrupts. This device communicates via serial programmable USART, a byte-oriented 2-wire serial interface, and SPI serial port.

The ATmega2560 is another microcontroller made by Atmel that is comparable to the ATmega328. The ATmega2560 operates at a lower frequency of 16MHz when compared to the 20MHz of the ATmega328. In spite of this, the ATMega2560 has a more powerful processor and surpasses the ATmega328 in every other category. The ATMega2560 has 256KB flash memory, 4KB EEPROM, 86 general purpose I/O pins, six flexible timers/counters with compare modes. It also has a JTAG interface for on-chip debugging. Figure 3.2 shows the pin mapping for the ATMega2560.

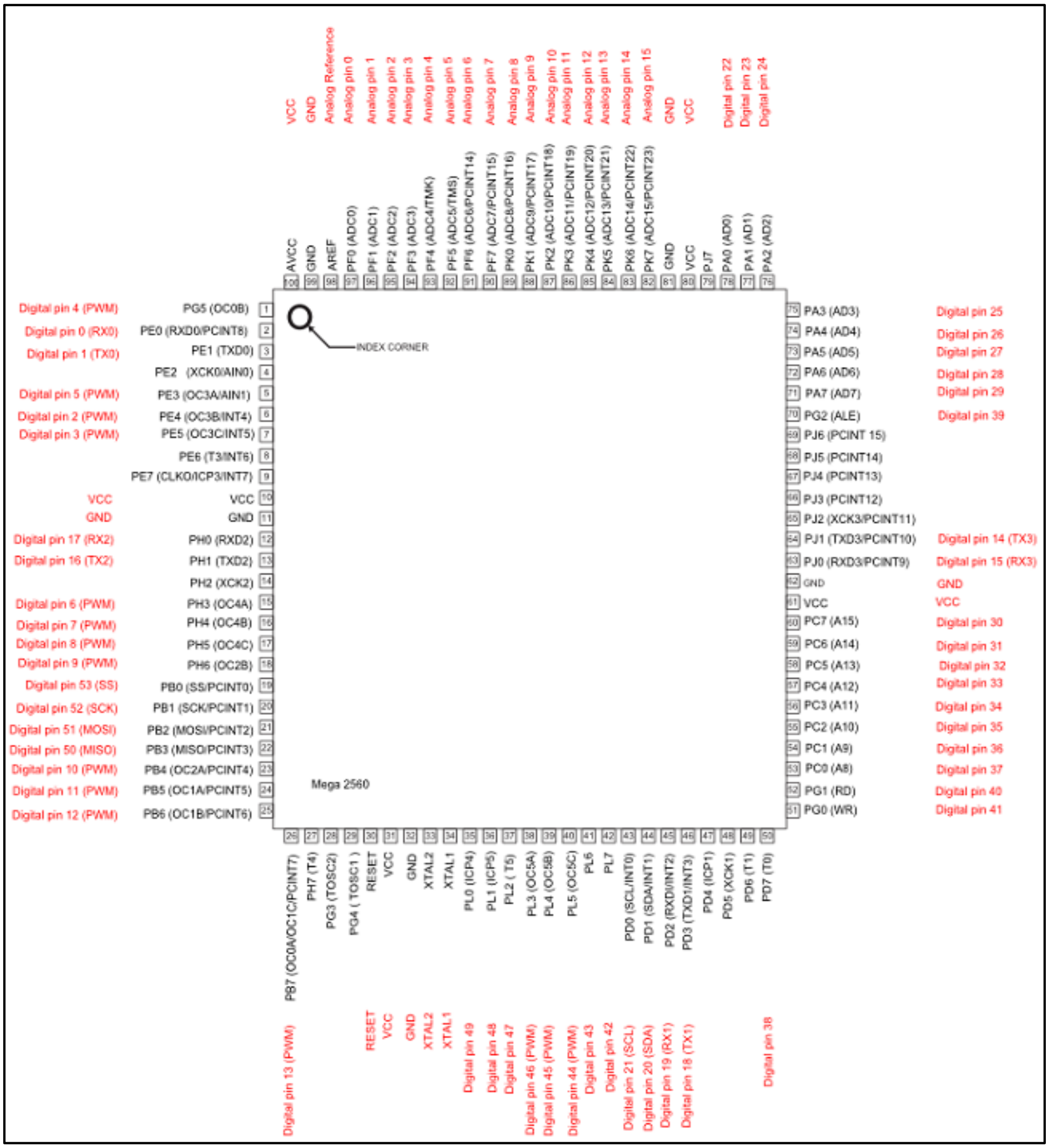


Figure 3.2: ATMega 2560 Pin Mapping (permission pending)

3.2.5 – Environmental Sensors

The automation of our system relies heavily on accurate data measurements of the hydroponic systems' ecosystem parameters. Our system will need to include the following sensors: water pH, water electrical conductivity, water dissolved oxygen (pending cost), water temperature, water level, air temperature/humidity, and air CO2 levels. Each sensor will require a specific configuration circuit to interface with our microcontroller to properly feed analog or digital data to the microcontroller. Each sensor will also require a specific amount of voltage distributed to the sensor to properly allocate power to the module. A good majority of environmental sensors use a type of connection interface called BNC (Bayonet Neill–Concelman). This features a coaxial cable core that provides a quick connect and disconnect mechanism. This connector is quite common on the water sensors, as it can provide relatively good waterproof qualities. Most of the sensors available on the market that are compatible for many microcontrollers. The sensors are generally cheap for most that we intend to implement.

The environmental sensors that we will implement are generally small in size which will implement nicely with our PCB and waterproof objective. The operating voltage for most of the sensors in consideration seems to be in the range of 3V - 5V. Another important parameter that our sensor research discovered was response time. In most sensors in consideration this time tends to be less than 5 seconds, and for some it is guaranteed at a higher time of less than one minute. Our system will not be polling measurements extremely frequently less than one minute, so these response times will be suitable for our system. Another important condition to consider is the operating conditions for each sensor. Both the air and water based sensors have a specified operating temperature, and the air sensors also have an optimal humidity range. Lastly, the measuring range and accuracy of each sensor must be taken into consideration when selecting a final sensor to implement.

It is crucial that we choose the correct sensors based on our microcontroller selection. This is important, because the system's sensors will need to interface with the our implemented microcontroller. Arduino seems to be a great option, because it provides many different libraries that support interfacing with a great amount of environmental sensors. In addition to the availability of libraries, there are large amount of guides and tutorial resources that aid in circuit design to configure each sensor correctly. The availability of additional resources are another factor to consider when selecting sensors to implement, because our project members has no experience working with environmental sensors.

Our research has led to the discovery of several different sensor suppliers. These suppliers include and are not limited to Adafruit, DFRobot, and Arduino.

Between these three entities we will be able to source all of our sensor and meter needs for our system. With each sensor, these suppliers also provide an abundance of necessary documentation needed for our project. These documents include: schematics, layout graphics, datasheets, and even Wiki docs. These will greatly aid our final schematic design as we will be able to easily incorporate these designs with our PCB design upon receiving permission from the supplier and manufacturers.

3.2.6 - Wireless Communications

There are a multitude of ways that a microcontroller can implement wireless communication capability. Each methodology has different requirements and unique characteristics. It is necessary to compare the different options that are applicable to our design requirements and specifications. Some of our design concerns are related to compatibility with our MCU, power requirement, connectivity to web service, module size, and broadcast range.

One of the first technologies considered in our research is ZigBee. This is a relatively new open wireless standard that operates in the unlicensed radio bands 2.5 GHz, 900 MHz, and 868 MHz. It operates using a packet-based radio protocol intended for low-power battery operated devices. It specializes in allowing devices to communicate in a range of network protocols while minimizing power consumption. This main characteristic related to power consumption has made ZigBee popular in the wearable technologies market. It is able to minimize power consumption by operating under a low duty cycle. The technology provides support for multiple network topologies, such as mesh, point to point, or point to multipoint. A downside to ZigBee is that due to its relatively young age, there is limited informational resources about the technology, and to minimize the learning curve with ZigBee to fit the limited timeline of our project would present a difficult challenge.

Another wireless communication technology considered in our research was the use of Bluetooth. This technology also operates on the 2.4 GHz frequency, and is largely used in short distance point to point connections. There are many Bluetooth embedded modules on the market that are compatible with a wide variety of MCUs. There is also an abundance of informational resources to available to decrease the learning curve associated with implementing this technology. One of the main advantages of Bluetooth is its low power consumption characteristic. However, its limited amount of connections adds difficulty in our design of connecting to possibly multiple sessions of our mobile applications. Also, the initial configuration of pairing is an added procedural step that is not always required with ZigBee or Wi-Fi.

The third wireless communication technology considered in our research is Wi-Fi connections. This technology operates in the 2.4GHz band, and is widely used to connect to the internet in many different devices today. It supports medium range connection with multiple node connections at a time. This implementation into our design would require the availability of a preexisting network connected to the internet. There are a wide variety of Wi-Fi modules available on the market that are compatible with multiple different MCUs. A Wi-Fi connection also supports our design's need to communicate with an HTTP server. Most Wi-Fi modules require an initial configuration setting to connect to a network, and will continue to function after this initial configuration is complete. A drawback to implementing a Wi-Fi connection is the additional consumption of power that it incurs. The larger data rate and duty cycle of the wireless modules leads this component to require a greater power supply than ZigBee or Bluetooth. However, our design will source power from a 120V outlet, and additional power consumption from a Wi-Fi module would be relatively small in comparison to the other main components of our design.

3.2.7 - Application Database Server

In order for a mobile application to receive dynamic data content, a server and database are required to fulfill the client-server architecture pattern. The server is used as a middle tier to application which facilitates connectivity to the database for the mobile application. The mobile application will communicate with the web server through HTTP requests. The database in our design will require numerous transactions per hour in order to provide the most up-to-date data readings from the system's sensors. There are many different technology stacks that can be used to implement a solution to this design. Our research has lead to three different solutions: Apache HTTP (LAMP stack), Node.js (MEAN stack), or implementing a mobile backend as a service (MBaaS).

The open source Apache HTTP Server, also known as Apache, is one of the most widely used web server technology around the world. It is part of the LAMP (Linux, Apache, MySQL, PHP/Perl/Python) web services technology stack. An Apache server is very commonly used with the scripting language Hypertext Preprocessor (PHP). Apache is an open source project from the Apache Foundation. It's core power comes from millions of modules that help to extend the server's capability. This is advantageous as it allows a developer to implement a minimalistic version of Apache that provides only the necessary functionalities. Setting up Apache involves downloading the source and scripting language module. The server is stored at an admin level of a computer and the configurations are setup to initialize the server-side language module, host address, and port. Our mobile application will require some type of server-side script to facilitate the connection between the application and the database. The PHP scripting language requires a web server in order to execute. The PHP language is a blocking language, which means that a new thread is created for each server request to a resource. A server has a thread limit to how, which means that using the PHP language could result in the use of many threads and affect performance time to deliver information to our mobile application

Over the past 5 years, one technology stack has quickly become very popular for it's high efficiency and that is Node.js. Node.js is used most frequently in the MEAN technology stack. This stack consists of MongoDB, Express, Angular.js, and Node.js. Node.js is a JavaScript runtime that uses event-driven programming non-blocking I/O model. This main characteristic makes Node.js very lightweight and and efficient as it does not create multiple threads per HTTP request. Node.js has a package system, npm, that contains an extensive collection of different modules that can be used to develop a custom solution for many server implementations. Node.js provides the capability to build an HTTP server that is very lightweight and can handle many simultaneous requests. Node.js is able to execute many commands in parallel which allows it to handle multiple request simultaneously and also reduces its thread usage. Node.js also uses the JSON data format different from a relational data model that SQL uses.

As the mobile application industry has boomed over the past decade, many companies have adopted a business model of providing a mobile backend as a service (MBaaS) for developers to utilize. This service allows mobile developers to quickly eliminate the overhead time required to build a server and database connection to service the mobile application. This allows an app developer to focus more heavily on the user interface and app design. Most service providers offer a lower volume handling free option that any developer can signup to use for their application. Generally, as an application is more successful and requires more request volume to the server, the businesses offer paid plans on request volume. With the recent closure of the open source *Parse* service, one the more popular backend as a services is now *Kinvey*. This service offers extensive features to aid in the development, optimization, and deployment of mobile applications. *Kinvey* also provides support for both iOS and Android applications. It also provides compatibility for both OSX and Windows operating systems.

3.2.8 - Power Systems

The hydroponic system that is desired for this project has varying power needs due to the extensive component requirements of the system and each of these needs must be carefully considered for proper integration of the entire system. The main focus of the power system will be to coincide with the overall system simplicity and give the consumer a simple “plug-and-play” interface. To accomplish this, AC to DC conversion will most certainly required since this project is not featuring a battery source. Designing a hydroponics system with the ability to simply plug into a receptacle in the consumer’s home or growing facility will have to consider three different phases of the system: the submersible pump, PCB, and lighting. Focusing on each phase individually may introduce more parts to the system, but will ultimately mitigate any unnecessary complexity that could come from trying to integrate each part to go to one cord.

In facilities and homes around the United States, a receptacle featuring one hot, one neutral, and one ground terminal is considered fairly typical. Most of these receptacles are rated at 120V/15A or 120V/20A and operate at 60 Hertz. These ratings will be what is referred to as a “receptacle” going forward in this document. One consideration that will be encouraged of the user is that they use ground fault circuit interrupter (GFCI) receptacles in order to combat any encounters with water while using the WaterWise system. A GFCI protected receptacle works by sensing any imbalance in current flow between the receptacle and whatever is connected to it. If it senses a lower current than expected, the breaker will trip in order to prevent whatever is taking current away from the circuit from enduring a potentially fatal electric shock. This is a simple precaution that should be considered when working with other electronics around the WaterWise system or any water-based product. However, this is not a necessary requirement as it is expected that most consumers may not have access to this type of receptacle in the location of choice for their system. It is expected that the user will take all necessary safety precautions when using a non-GFCI receptacle with their WaterWise system.

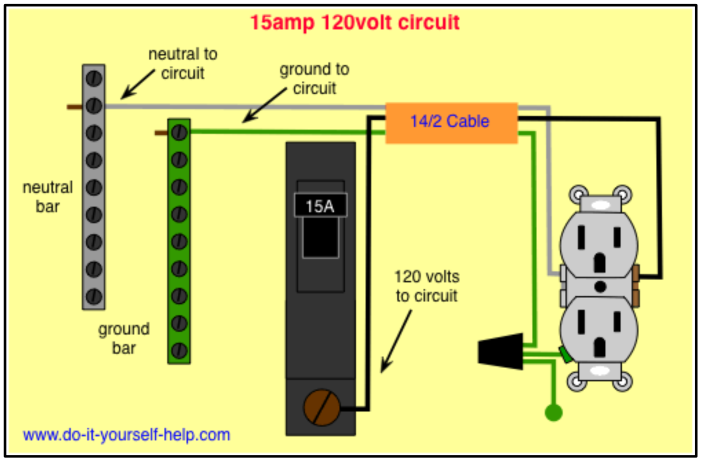


Figure 3.3: Typical Non-GFCI Receptacle Wiring Diagram

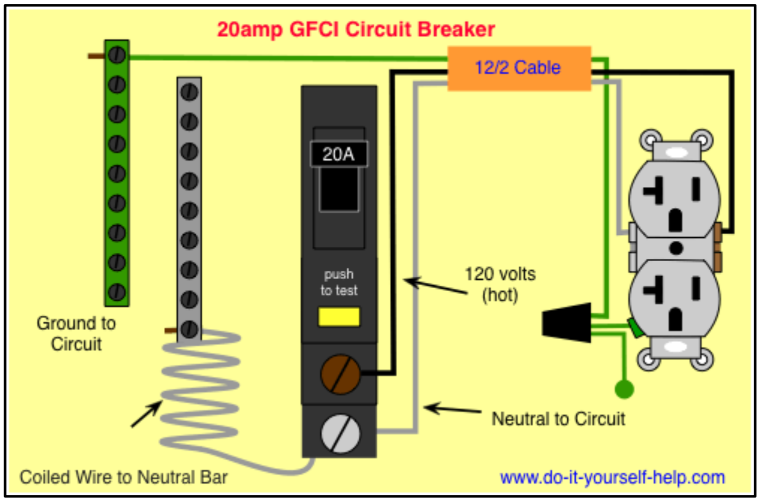


Figure 3.4: Typical GFCI Receptacle Wiring Diagram

A desired submersible pump will achieve its required DC input by an internal AC/DC converter. For this design, the ideal pump will plug directly into the wall and come pre-outfitted with a waterproof cord of considerable length. While it is acknowledged that this will take up an outlet of the receptacle, the ability to have a pump that is completely obsolete of the system is better not only for simplicity but also for any issues that may arise with the pump during its lifetime. If needed, the pump can easily be replaced by the user and not require any extra maintenance with the rest of the system.

For the PCB, it is desired that it is outfitted with a 2.1 millimeter female barrel plug that has its connection via a 9V or 12V DC power adapter that can be plugged directly into a receptacle. Since we will not be operating on battery power, it is necessary to step down and convert our AC signal from the receptacle in order to operate our system. Again, this is keeping in mind the goal of having a simple design that any consumer can use without hassle. In many applications requiring DC voltage from a typical receptacle in the home, a useful range when designing what voltage to send the equipment is 7-20V DC. By using 9-12V for an application in which most parts require 3.3-5V DC, the use of voltage regulators will need to be incorporated on the board. Achieving a harmony between the ratings of the adapter, barrel plug, and voltage regulators will need to be taken into careful consideration in order to operate the PCB and sensors smoothly.

Two separate applications will need to be considered for lighting power distribution. The system will not only feature grow lights for the plants, but also light for the seed germination chamber. Again, the goal will be to utilize any built-in power supply for these lights and coordinating them with a receptacle. However, a consideration that must be made in order to decrease power consumption by these lights will be if they will remain only on a manual switch or if there will be a timer implemented.

3.2.9 - Lighting

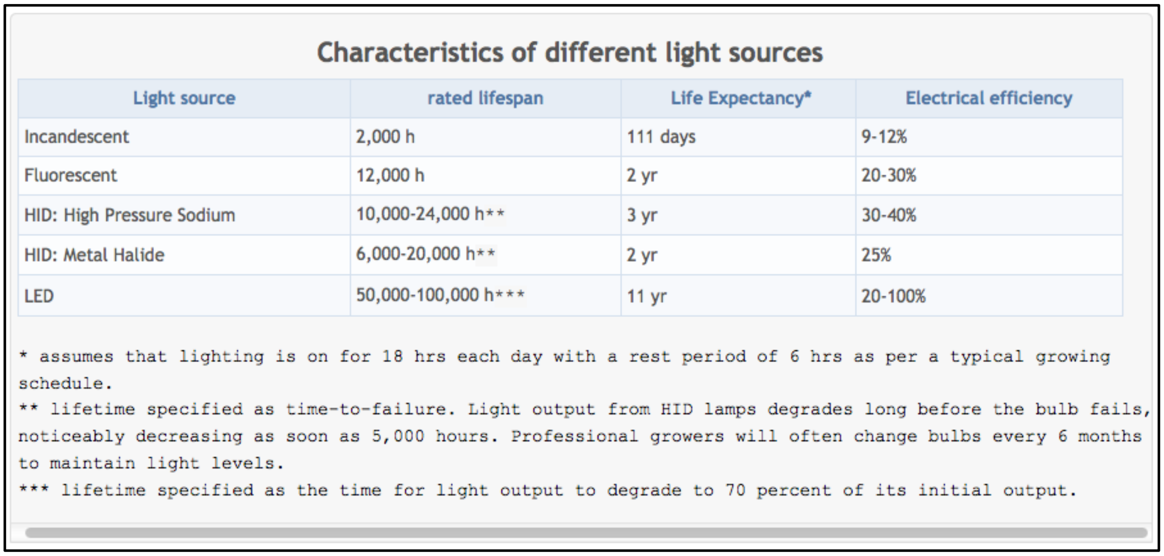
Lighting is a very important aspect to consider when growing plants indoors. Numerous plants do well in indoor conditions under the natural light. However, certain tropical plants and seedlings require a more intense light from a special light source. These special plants and seedlings will have to be supplemented light from a light source with the desired spectrum for growth. To ensure the plants will get the correct type of light, a significant amount of research was carried out. In our research on proper lighting, we gained knowledge on some important factors to consider when growing plants indoors in the presence of good lighting.

The intensity of the light is important as seedlings need bright light in high amounts. Without this plants tend to grow long and bare. However, there are two main ways to overcome this issue. The light intensity can be controlled by adjusting the wattage of the bulbs and/or changing the distance the bulbs are placed from the plants. It is important to find the balance between these two parameters and also to keep in mind the lighting will give off heat as well so it should be a safe distance from the plant.

Another important factor that should be considered is the lengthy of time the plant is exposed to light. The more light a plant receives, the more food it will be able to generate via the process of photosynthesis. Nonetheless, there is a limit to how much food a plant can produce. Plants need a moment of darkness in order to grow. Most vegetables need lighting for about 14 to 16 hours with rest period of approximately 8 to 10 hours.

Last but not least to consider is the color (wavelength) of the lights. As stated before, the color of the light plays a significant role in the plant's life. As previously mentioned, the top four considerations for indoor lighting are: high pressure sodium, metal halide, fluorescent and light emitting diodes bulbs. High pressure sodium bulbs come in different shapes and sizes with a wattage ranging from 35-1000 Watts. They are typically used for outdoor lighting of streets in indoor settings where color rendering isn’t significant which makes it’s a less capable candidate for this project. They discharge white light to stimulate plant and flower growth, however for maximum plant growth the recommended color is blue, violet and red. However, high pressure sodium bulbs are well efficient in terms of lumens per watt (80-140), they are small enough to fit into many fixtures and they have a good bulb life of 24,000. This cuts down on energy bills and replacements. Prices range from 6.00 to 24.50. Indoor farmers and gardeners normally use high pressure sodium bulbs for flowering while metal halide bulbs are utilized for vegetative growth. It is proposed that flower volume and fruit weight increases by at least 20% when high pressure sodium bulbs are used for flowering. Metal halide grow lights however, are ideal for leafy vegetables such as lettuce and herbs. Some growers alternate between the metal halide for vegetative growth and the high pressure sodium bulbs for the flowering cycle. Metal halide bulbs range from 250-1000 Watts with a life span of 6,000- 20,000 hours. The price of these bulbs starts at $12.02 for the 250W bulb to $19.57 for the 1000W.

Fluorescent T-5 grow lights are powerful, quiet and save energy compared to other fluorescent grow lights. These T5 grow lights can be used for any stage of plant growth, from seed starting lights and cloning lights, to vegetative growth lights. Compact fluorescents, also known as CFLs, provide as much light as regular incandescent bulbs while using just one-fourth of the energy. For example, a 15-watt compact fluorescent light bulb yields the same amount of light as a 60-watt incandescent bulb. Compact fluorescent bulbs last about 10,000 hours—10 times longer than incandescent bulbs. Linear fluorescent bulbs are more efficient in terms of energy; however they are not ideal for this project since a small amount of plants would be used. The price ranges for the colored CFL's bulbs are $4.60 for the 60W red light and $3.83 for the $60W blue light. When it comes to purchasing energy-efficient lighting, Light emitting diodes exceed CFLs by a wide margin. LEDs are instant-start with no warmup time required. They are fitting for cold weather, and are considerably sturdier since they are manufactured out of plastic instead of glass. From standard bulbs to fluorescent tubes, LEDs can replicate the same lighting conditions found in fluorescents while lasting longer and using less energy. As an added bonus, all LEDs do not use mercury, a claim that can't be made by fluorescent bulbs. The price for LED grow lights are more expensive compared to other grow lights, however as mentioned before it's efficiency and lifespan far outweighs the rest. For a 17.5W LED bulb, the cost is $19.99 and $100+ for the 150W+. Table 3.5 is a comparison of the different grow lights in terms of lifespan, life expectancy and electrical efficiency.



Characteristics of different light sources

Light source	rated lifespan	Life Expectancy*	Electrical efficiency
Incandescent	2,000 h	111 days	9-12%
Fluorescent	12,000 h	2 yr	20-30%
HID: High Pressure Sodium	10,000-24,000 h**	3 yr	30-40%
HID: Metal Halide	6,000-20,000 h**	2 yr	25%
LED	50,000-100,000 h***	11 yr	20-100%

* assumes that lighting is on for 18 hrs each day with a rest period of 6 hrs as per a typical growing schedule.

** lifetime specified as time-to-failure. Light output from HID lamps degrades long before the bulb fails, noticeably decreasing as soon as 5,000 hours. Professional growers will often change bulbs every 6 months to maintain light levels.

*** lifetime specified as the time for light output to degrade to 70 percent of its initial output.

Figure: 3.5: Light Source Characteristics (permission pending)

3.2.10 - Waterproofing

In our system design, there will be electronic components located near running water, so it is imperative that we include research into proper waterproofing techniques. Our wiring connections will need waterproof coverings as well as waterproof gaskets that can guide wiring into the wet environments. The water sensors that will be purchased are manufactured to be waterproof by nature, but how our design routes these wires is an important factor.

There numerous ways to make waterproof electrical connections. There are also many commercial brands that manufacture different waterproof connection products. These products are typically used in underwater electronics. Our system will require both signal and wire to wire waterproof connectors. These connectors can be purchased for a nominal price in many different configurations. One of the simplest and cheapest solutions is to purchase male and female crimp terminals used to formed the metal to metal connection. Each of these terminals is sealed inside a male and female crimp housing. This housing forms a seal around the wire terminals. Different connection housings have different waterproof ratings. Our design will not require submerging signal connections to our MCU under water at the minimum our wiring connections to the sensors need to be weatherproof to hold out most water.

Our design will require routing of wiring near water sources. Waterproof conduit is commonly used to protect wiring from water, dust, heat and abrasion along the wire's path to connection. The wiring in the system for power and sensors signals should be sealed inside a flexible conduit material that is resalable. Most hardware stores can readily supply conduit in various lengths and diameters to suit many projects' needs. There are also specially designed connection pieces that can securely seal connections of the conduit tubing to the main endpoints at weatherproof electrical boxes. These electrical boxes are commonly used by electricians in home construction. However, it will suit our needs to protect the main electrical components in our system.

Lastly, our design requires the water sensors to be in physical contact with the water source. In order to rout the wires in the water reservoir, our design will need to implement the use of watertight connection seals. These are commonly used in marine boat equipment to run electrical wiring below the deck of a boat. The component consists of a water tight connection that screws together where the wire goes through a material. This is how the wiring can be routed through a hole into the water reservoir and sealed using this connection mechanism to ensure the hole made is water tight. Figure 3.6 shows the overall design of a water tight wire seal used to route through materials. This provides a waterproof wiring mechanism, under the assumption that the housing is attached to the material in a watertight manner. Simple epoxy resins or marine sealants can be used to form a watertight seal around the water reservoir and these wire seals.

Figure 3.6: Watertight Marine Wire Seal

3.2.10 - Software Development Environments

The software for the project will be written in a variety of software integrated development environments (IDE). It is essential to choose an IDE that provides libraries and support for the core components that will require software. The microcontroller of our design will require software to help provide automation aspects to the physical system’s respective sensors and data transmission. Additionally, the mobile application will require the use of a specialized IDE that can provide the necessary libraries to develop all of of the core components in our design. The IDEs in consideration for developing software for our MCU are: Texas Instruments’ Code Composer Studio (CCS), Arduino IDE, and Atmel

Studio 7. The IDEs in consideration for developing the software for the mobile application are: Android Studio, Eclipse, and IntelliJ. Any server side scripts can be simply edited/created in a robust text editor such as Notepad++ or Atom.

Code Composer Studio is an IDE used to support TI's microcontrollers and embedded processors. It is formally used in the Embedded Systems course at UCF. CCS is currently only supported for the Windows and Linux operating systems, which could become an issue for a Mac user without a Linux or Windows virtual machine. The IDE is available for free download and a purchasable premium version from TI's website. The IDE can be used to develop both C and assembly software for the MSP430 family of microcontrollers. The IDE includes a C/C++ compiler, code editor, project build environment and a debugger. CCS uses JTAG to interface with a microcontroller.

The Arduino IDE is an open source software project is widely used in the industry for Arduino based projects. It is available for the Windows, Linux, and Mac operating systems. An Atmel microcontroller can be easily configured to run Arduino code by burning the Arduino bootloader onto the microcontroller. The Arduino language is comprised of a set of C/C++ functions that can be called from the code. All standard C and C++ constructs that are supported by the AVR-g++ compiler. There is a very large amount of useful libraries available to the Arduino IDE that support modules such as Wi-Fi, sensor communication, LCD displays, motors, etc. Overall this IDE stands to be an ideal IDE to us for developing software for the microcontroller.

The mobile application that is coupled with our PCB and microcontroller will require the use of a special IDE. The first IDE in consideration for mobile development is Android Studio. This IDE is available on Windows, Mac OSX, and Linux operating systems which provides ease of development constraints. Android Studio also features a very rich layout editor to provide a smooth UI development process. This additional feature will be quite useful for implementing a UI that follows the *Material* design principles. A number of testing and debugging tools made specifically for Android are also integrated into the IDE. Most importantly, this IDE is now the official IDE for Android platform applications, as opposed to just the Android SDK used in a third party IDE. One of our objectives out of personal interest has been to develop an Android application to gain experience. Because of this design objective we will be using Android Studio to develop our mobile application.

3.2.12 - LCD Panel and Controls

Aside from the Android and web application for the user to control and monitor the system, it is imperative that the user can control the system directly. There are many cases in which the user may not be able to control the system from his or her phone or web application and these need to be taken into careful consideration when growing plants that are so dependent on an optimized system in order to achieve desired results of healthy produce. In order to accomplish this, the incorporation of an LCD screen with control is essential but it is necessary that it is not cumbersome for the user.

There are two routes that can be considered when determining how the LCD screen will operate the control of the system. One is the capacitive touch method which is found on most mobile smartphones and tablets today while the other is the conventional on-board navigational button. For capacitive touch, the screen is the display as well as the control and it detects the user's touch based on the electrical properties of their body. While this is becoming more and more common each day in the consumer electronics industry it is still much more complicated from a design perspective than that of its counterpart, the on-board button control. Not only is it more cumbersome from a design perspective, it is extremely reliant on having a screen that has a great response time and having the sensitivity tuned properly. However, it is not without its pros. Capacitive touch screens have a lot more flexibility in layout in that the designer can cater the controls to what may feel more natural and will take up the least or most amount of space. Generally speaking, the capacitive touch screens are also more attractive.

In lieu of touch screens are the on-board button control screens. By using this method, the designer is certainly more concerned with durability versus looks. Although the buttons may be less attractive, the design avoids touch errors that could cause issues for the consumer when using a touch screen. That is not ideal when the system that is being controlled needs to optimize performance and where a misclick could be very costly. When working with a system that can be messy and includes water, protection from the elements is also important. The benefit of a button controller is that enclosures can be made that do not yield a loss of functionality while also protecting the device. Any time you enclose a touch screen, the screen cannot be properly exposed without a loss of touch functionality.

The goal of the LCD panel and controls on this system will be to give the user an option of not having to use their phone to control and monitor the system. In case of some sort of failure on the software end, there needs to be a failsafe. The LCD panel will display all sensor data and controls will be simple for navigation and selection. Again, because the system features water, there must be measures taken to ensure that our controller is protected. This will most likely be a simple enclosure but there are other casings that would allow for a functional exposure of the controller.

Overall the decision to use capacitive touch versus button controls comes down to how much space you have to work with and how durable you want your controller to be. If the design wants to be sleeker and there is very little space to work with, a capacitive touch screen would be ideal. Otherwise, if you're granted a generous amount of space and require a certain amount of durability, button control may be the best option. In the case of the hydroponic system, either option can be used for a variety of reasons.

3.2.13 - Peristaltic Pumps

Our design will need to implement a small pump to deliver the pure nutrient liquids into the water reservoir. A peristaltic pump is the perfect component to implement in our design to perform this task. The basic principle behind how these pumps work is based on alternating compression and relaxation of the thin flexible tubing. The alternating compression helps to draw contents into the tube, and a roller passes along the length of the tube totally compressing and sealing the tube to create suction and discharge on both sides of the seal. This process forms a strong vacuum in the tube which draws product into the pump. The fluid does not come in contact with any internal parts and is completely contained within a durable hose material.

Most peristaltic pumps are powered by a 12 V DC source, and draw about 300-400mA. They have two terminals for positive and negative connections from a voltage source. The rate of flow through the peristaltic pump can be controlled by varying the current levels into the pump terminals. The flow direction can also be varied by reversing the polarity of the input voltage terminals. Most peristaltic pumps will dispense a true liquid at a rate of 1 milliliter per second. This flow rate is an important factor into programming our PCB to control power to the peristaltic pump. By keeping the flow rate of the pump constant, the PCB will be able to use this value to run the pump and dispense the desired amount of nutrient into the ecosystem with accuracy down to the milliliter. Figure 3.7 shows a typical DC peristaltic pump that will be used in our design to dispense nutrients. Figure 3.8 shows an internal view of how a peristaltic pump is designed. In this figure, the roller can be seen in the middle and how a seal in the tube is formed against the roller and the pump's body.

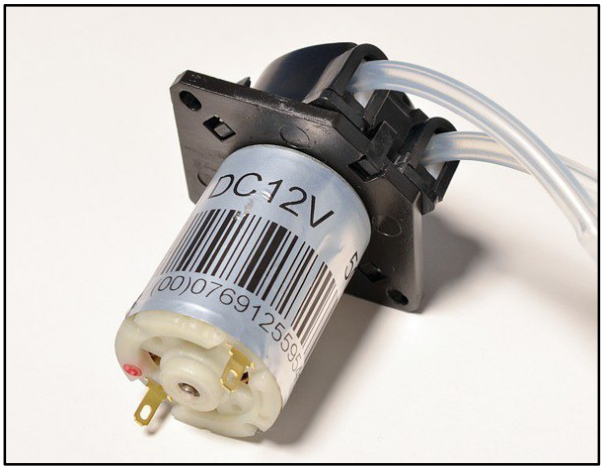


Figure 3.7: DC Peristaltic Pump

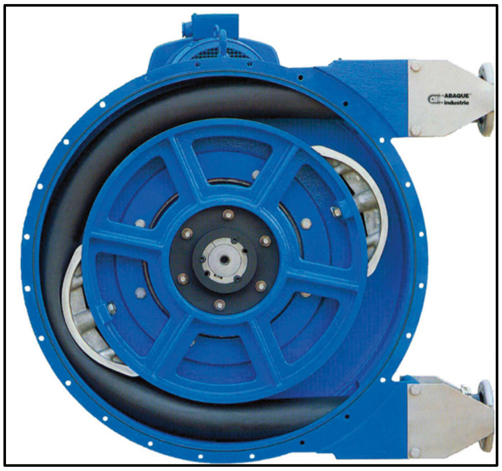


Figure 3.8: Internal Peristaltic Pump

There are a number of open-source example projects that utilize an Arduino SOC and a circuit to power and control a peristaltic pump to run for an accurate amount of time. A timer can be used to run the pump for the desired amount of time to dispense a desired amount of nutrient. It is important to know that the pump must first be calibrated to accurately determine the flow rate. Fortunately, this can be done quite simply by having a microcontroller run the pump for exactly 60 seconds while it is constantly pumping fluid into a measuring beaker. Once the time is complete, the total volume of liquid in the beaker can be divided by 60 seconds to find the flow rate per seconds and minute.

3.3 - Relevant Technologies

3.3.1 - Material Design

Because the mobile application for *WaterWise* will be created for the Android mobile device platform, we researched what mobile applications built for Android looked like. After little research, we came across Google's UI guidelines known as Material Design. These guidelines, while provided by Google, are not mandatory to create an Android application. However, during our research, we found that the Android applications with a reputation for excellent UI design, leaned heavily on these guidelines.

Google's definition of Material Design first begins by explaining the concept of 'material' and the restrictions for it's creation. All Material elements based on the guidelines must exist within a 3D rendering space and have their position described in x, y, and z coordinates. Each material within this space will also be affected by both natural shadows from simulated light sources, and the shadows emitted by other elements within the same screen. Each section of material must also adhere to a thickness guideline stating that each material must be exactly 1 digital pixel (dp) thick. Material must also always be solid, no input events may pass through any material. Figure 3.9 shows a simple visual of material in the 3D environment.

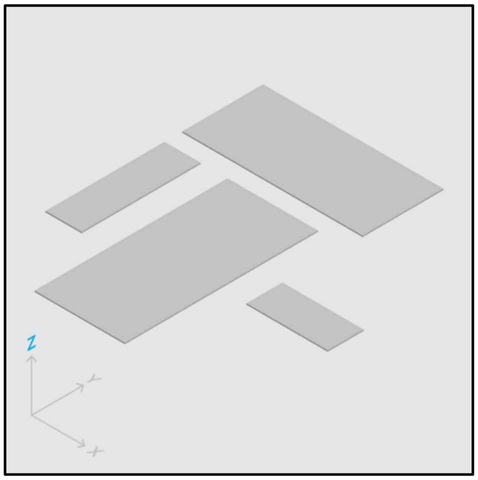


Figure 3.9: Proper Material in 3D environment

The material itself, is the core of Material Design. It does not contain information within itself, but acts as a content delivery system for information. As a delivery system, there are multiple restrictions on its within Material Design. First of which, content is to be displayed as though it were lying on top of the material that is holding it. This means that content cannot add any additional thickness to material, otherwise it would violate the earlier guidelines dictating material be 1 dp thick. Content displayed on material must also be restricted to the bounds of that material. Next, while it is okay to have more than one material in an environment, two different materials cannot overlap or occupy the same space in the 3D plane. This is not to be confused with a material being on top of another material, having different locations on the z-axis. In addition to not overlapping, two materials cannot pass through each other in the environment either. There are many more things that material can and cannot do. Material can for example, go through many different translations, such as: sliding, rising, and sinking. Material can also undergo a long list of transformations as well, such as: changing shape, splitting, merging, and growing, However, material cannot fold or bend.

Another critical component of Material Design is the usage of elevation and shadows between material and other components. This is largely important because it allows for a distinct visual representation of an object's relative position on the z axis of the 3D environment. The basis for this effect is on what Google refers to as the resting elevation of a particular object. An object's resting elevation is the level on the z axis at which the object is created, after any rising or sinking an object is expected to return to this elevation. An object's resting elevation is determined by its position relative to objects below it. This is because each object in the environment must have at least 6 dp of space in between them measured from the surface of the lower object to the surface of the object above it. The immediate concern with elevation and movement, is what to do when an object's rising movement interferes with another object's elevation. For this, Google provides a chart with a simple breakdown of common objects and dp levels. This chart is included in Figure 3.10. The shadows casted by each object go a long way in adding believability to the effect of elevation. Material Design specifies that as dp increases, the size and softness of the shadows cast by that object much also increase. Every object at a given dp must cast the same shadows.

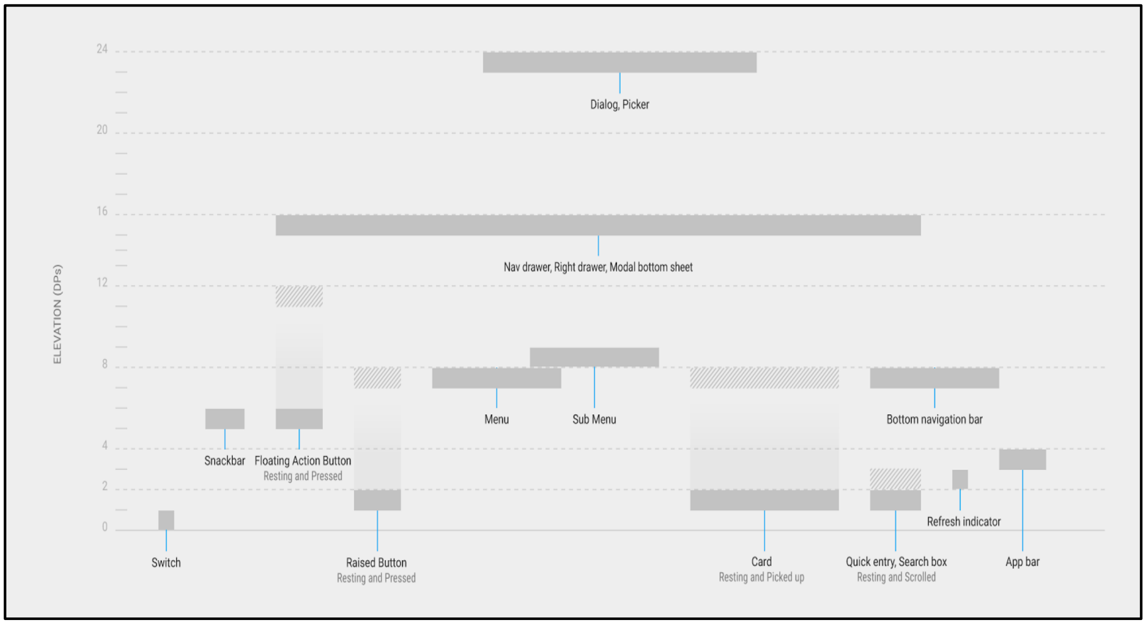
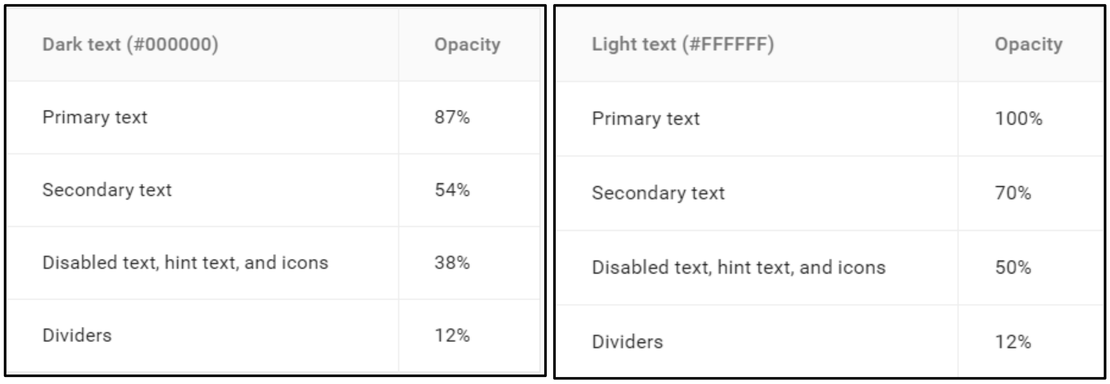


Figure 3.10: Component elevation comparisons

Animation of objects is also very well defined in Material Design. In Material Design, animation is meant to approximate physical reality as much as possible in order to create familiarity for the user. When movement is being implemented, it is accomplished by using acceleration, deceleration, and velocity. Like in reality, objects should never come to a direct stop or immediately reach full speed, every object should show acceleration and deceleration when starting, or coming to a stop on screen. Objects that are heavier and bigger should also move, accelerate, and decelerate, more slowly than other objects. It is also important to use deceleration only when an object will be reaching a stop, as it will draw the user's attention unnecessarily otherwise. Continuing, Material Design also handles animations related to user input. These animations are centered on showcasing the exact point of contact for any touch based events. When the user touches an object, a visual queue should radiate outward from the exact point of contact. When the user touches a movable object, it should be elevated in addition to the visual queue to communicate that the object is active. Lastly, there are some general guidelines for transition animations in Material

Design. These revolve around utilizing three main states: incoming, outgoing, and persistent. Transitions should be made around these three states, emphasizing which is the most important for a certain situation. Also important, is the consideration of timing, incoming elements should be organized in a way to highlight the most important and to direct the user's attention through the group of incoming elements. All transitions should also happen in coordination, preserving organization and limiting user confusion.

Material Design also makes explicit use of vibrant, contrasting color schemes. The main focus is to make color unexpected, and to contrast different elements to display that they have clear distinction in function. Material Design recommends that an application use a color palette with a maximum of 4 colors: a primary color that will be used for most elements, a secondary color to show something related to a primary colored element, and an accent color to be used on points of user interaction such as buttons and links. In addition to color palettes, there are also guidelines for text and background colors. Text should always contrast the background color which should be either light or dark. In order to distinguish between text of varying importance, different text opacity levels should be implemented. Figure 3.11 shows two tables indicating different text opacity levels for dark and light backgrounds.



Dark text (#000000)	Opacity
Primary text	87%
Secondary text	54%
Disabled text, hint text, and icons	38%
Dividers	12%

Light text (#FFFFFF)	Opacity
Primary text	100%
Secondary text	70%
Disabled text, hint text, and icons	50%
Dividers	12%

Figure 3.11: Opacity levels for dark text on light backgrounds and light text on dark backgrounds

There are also guidelines for the creation of text itself in Material Design. All text for English should utilize the font Roboto, which has been optimized by Google for many platforms. For mobile applications, there are specific scales for different text types defined by Google. The scale is: 12sp for captions, 14sp for body 1, body 2, and buttons, 16sp for subheadings, 20sp for titles, 24sp for headlines, and 34sp for the main display. There are also specifications for the space between these different types. There should be 32pt between display and headline, 24pt between headline and subheading 2, 24pt between subheading 2 and subheading 1, 24pt between subheading 1 and body 2, and 20pt between body 2 and body 1, Material Design features another core element similar to material, called paper. Paper is meant to be used as the background of a mobile application, allowing material and other objects to be lain on top of it. There are multiple properties of paper that dictate how it may be used. First any two sheets of paper that are connected there is a seam, any two papers that are connected by a seam must move together. Paper can also partially overlap each other to create a step. In a step, each paper moves independent of each other.

Because Material Design is applied across many different types of devices, there are different recommended application structures for each. For mobile applications, it is recommended that there be a permanent app bar and floating button, an optional bottom bar, and that side menus overlay the other elements when triggered. See Figure 3.12 for a picture detailing the mobile application structure.

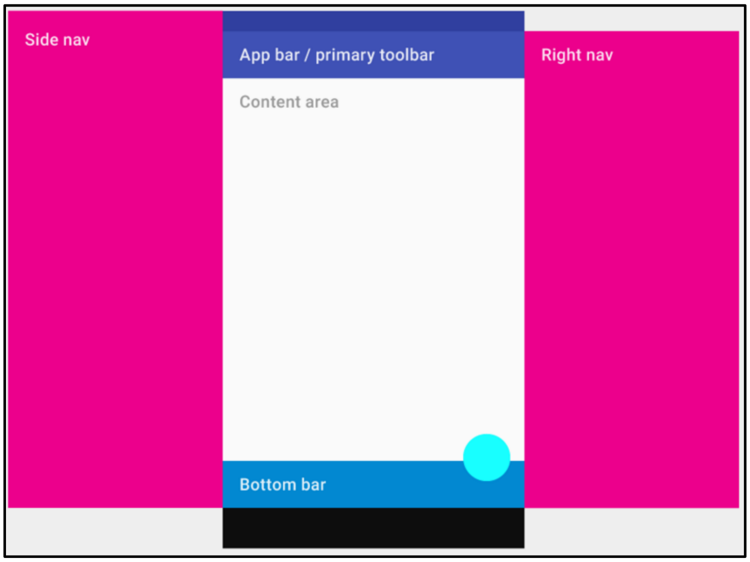


Figure 3.12: Material Design mobile application layout

3.4 - Strategic Components

The *WaterWise* Hydroponic System will incorporate many different features into a single package. In order to bring all of them to reality, it is important that we utilize strategic components in order to simplify our design, or otherwise reduce the workload. While these components are very useful for *WaterWise*, they ultimately can be thought of as non-critical because of the fact that *WaterWise*'s features could still be implemented even if we did not include these components.

3.4.1 - Relay - Controlled Power Strip

Because *WaterWise* supplies nutrient enriched water to the plants, the water within the reservoir will need to be emptied and refilled periodically. For simplicity, we intend to allow the user to stop the system with a button on the LCD so that they may empty it. To do this, a way to stop the pumps in the system using a signal from the microcontroller needed to be designed. However, because the microcontroller cannot supply the power needed to power the pumps, we could not simply wire the pumps to it. We decided to find a way to control the power outlets on a surge protector that we would connect the pumps to. After doing research, we came across a guide to modify a power strip so that the outlets could be controlled using relays that can interface with the microcontroller. By replacing a socket on a power strip with a Grove "Relay Twig" it is possible to run a connection to the microcontroller that will allow us to toggle whether the component connected to this relay receives power. See Figure 3.13 for a schematic depicting multiple relays connected to a single power strip.

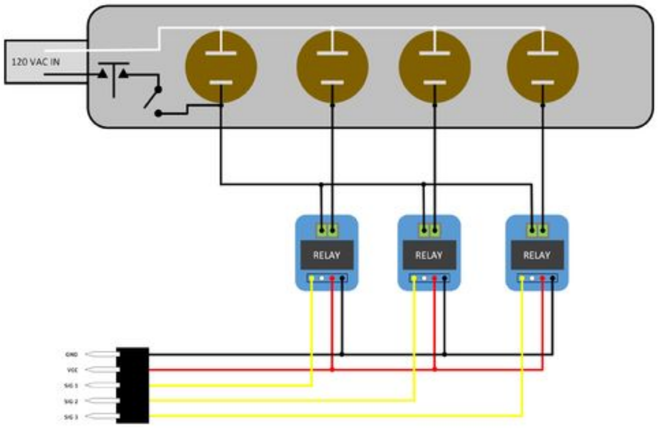


Figure 3.13: Modified power strip

3.4.2 - Water PCB Housing

The final strategic component that will be incorporated into *WaterWise* is a housing for the PCB we will be designing. Because the sensors will be connected to this PCB, it is important that it is sealed in a housing that is waterproof so it can be close to the reservoir. The housing will be similar to the types of housings that can be found protecting different meters outside of houses from the elements. Fortunately, the idea of waterproofing a PCB is common enough that we can buy a premade enclosure and ensure that it is watertight before adding to our system, rather than creating one ourselves.

4.0 - Related Standards

4.1 - Standards

A standard is a publication that is used to establish a norm or requirement for certain procedures and technologies. Generally, these are used to help ensure there is compatibility and uniformity among technologies. Standards are available in documents that entail the specifications for a particular subject. This section of the project document will briefly describe the most significant standards that are in consideration during the design of the *WaterWise* system.

4.1.1 - Wi-Fi (802.11)

The IEEE 802.11 is a set of standards that define medium access control (MAC) and physical layer specifications for configuring wireless local area networks (WLAN). These standards provide specifications for wireless network products adopting the *Wi-Fi* logo. The IEEE organization has defined standards for wireless networks that specify the bandwidth of transmission as well as the supported data rate. Throughout the history of the 802.11 standard the IEEE organization has made several updates that has lead to multiple versions of 802.11 to exist, such as 802.11n or 802.11ac. These updates help to specify the latest changes to the standard. Our project intends to utilize Wi-Fi connectivity and therefore will adopt the 802.11 standard to our project design. The list includes the specifications for the latest 802.11 standard.

- *802.11 (legacy)*: Supported two network data rates of 1 or 2 Mbps. This is currently obsolete today.
- *802.11a*: Supports a maximum network data rate of 54 Mbps and operates using the OFDM transmission scheme with a bandwidth of about 5 GHz.
- *802.11b*: Supports a maximum data rate of 11 Mbps and operates on the 2.4 GHz frequency. This is susceptible to interference from other devices operating on the same bandwidth.
- *802.11g*: Supports a maximum network data rate of 54 Mbps and operates using OFDM with a bandwidth of 2.4 GHz.
- *802.11n*: Supports a maximum network data rate of 600 Mbps and operates on both frequencies of 2.4 GHz and 5 GHz. Added multiple input multiple output antenna support to enable multiple frequency usage.
- *802.11ac*: Includes wider bands in the 5 GHz bandwidth and supports a maximum network data rate of 1300 Mbps on a 5 GHz channel. This amendment also includes 80 MHz channels in the 5 GHz band.

4.1.2 - Main Electricity

Standards for electricity and power supply for mains use varies per country. Due to the location of our design and demo, our project will only consider the US standards for Mains electricity. If the product were to expand into a global market, then the design would require some adaptation to the voltage ratings in other countries. Table 3.15 displays the standards for different plug types in the United States of America.

Plug Type	*Plug Standard*	*Mains Voltage*	*Frequency*
Type A	NEMA 1-15 P	120 V	60 Hz
Type B	NEMA 1-15 P NEMA 5-15 P	120 V	60 Hz

Table 3.15: US Mains Electricity Standards

4.1.3 - CO_2 Air Quality

The levels of CO_2 in our design are an important factor. The amount will help to provide the proper amount of plant growth in our hydroponic system. However, our design must account for the indoor air quality standards for acceptable CO_2 levels. Table 3.16 shows the levels for CO_2 air quality in different environments.

Environment	*Acceptable CO_2 Level*
Normal Outdoor Level	350 - 450 ppm
Acceptable Levels	Less than 600 ppm
Complaints of Stiffness and Odor	600 - 1000 ppm
ASHRAE and OSHA Standards	1000 ppm or less
General Drowsiness	2500 - 5000 ppm
Max Concentration for 8 Hour Work Period	5000 ppm

Table 3.16: Acceptable CO_2 Levels

4.1.4 - Water Quality

WaterWise's design will require the user to add water to the main reservoir. This water could be sourced from a number of different options. It is important to consider the water quality standards in regulations in place to account for the qualities of the water that will be used in the system. These standards considered are sourced from the Environmental Protection Agency's *Water Quality Standards Handbook*.

It is important to note that the handbook states there have not been exact formal criteria specific for agricultural use, but the standards for human use and consumption are more than protective enough for agricultural usage. Table 3.17 shows the regulated levels of contaminants and acceptable water conditions. This table is not a comprehensive list of the EPA's standards, but instead just an excerpt from the original table.

Contaminant	*MCL* (mg/L)*	*Pot. Health Effects*	*Sources of Contaminants*
Turbidity	TT**	Measure of the cloudiness of the water. Higher turbidity is usually associated with higher levels of micro-organisms, viruses, parasites, and bacteria.	Soil Runoff
Bromate	0.01	Increase risk of cancer	Byproduct of water disinfection
Chlorite	1.0	Anemia, nervous system effects	Byproduct of water disinfection
Chlorine	4.0	Eye/nose irritation	Water additive
Chloramines	4.0	Eye/nose irritation	Water additive
Chlorine dioxide	0.8	Anemia, nervous system effects	Water additive
Copper	1.3	TT	Corrosion in plumbing
Lead	.015	TT	Corrosion in plumbing
Fluoride	4.0	Bone Disease	Water additive
Nitrate	10	Infant respiratory problems	Fertilizer runoff
Nitrite	1	Infant respiratory problems	Fertilizer runoff

Table 3.17: Drinking Water Contaminants

** MCL - Maximum Contaminant Level - the level of a contaminant that is allowed in drinking water.*

*** TT - a treatment technique is required to lower the level of the contaminant*

4.2 - Design Impact of Related Standards

Implementing an official standard in a design is very significant step that engineers take when designing a new product. The standards help to ensure that the new product will be compatible with the existing technologies and protocols that are currently in use. This will help to ensure overall functionality of the product, especially if the product is expected to interact with any external technologies. For example, our design is expected to source power from a 120 V 60 Hz US outlet. This expectation requires us, as engineers, to take the proper steps during the design process and account for all major design decisions related to relevant standards. Some of the most critical components in our design that require adopting the use of standards are: Wi-Fi technology, mains electricity for power, air quality, water quality, hydroelectric component safety, fire safety, and also power consumption for energy efficiency.

Our design requires the use of wireless technology to transmit sensor data over the Internet. This will require the use of an embedded wireless module that properly adheres to the latest IEEE 802.11 standard. Our wireless module selection will be carefully examined against the market competitors for adherence to the WLAN standards in place today. This will require that the module provide support for at least up to the 802.11n standard to be properly cohesive with wireless technology today. The wireless standard adherence is necessary because the *WaterWise* system require the ability to connect to the Internet. In order to properly communicate the sensor data with a router on a home network and on further to the Internet, the *WaterWise* system must adhere to the same wireless standards as all other Wi-Fi devices.

The mains electricity standard for the US will be a critical standard that will define the basis of power distribution in the *WaterWise* system. The mains electricity standards will also determine how the power conversion schematic will be configured. Our electrical engineers will be required to account for an AC input voltage of 120 V at a frequency of 60 Hz. This will affect the overall design for power distribution to our main components. The design must ensure that the right amount of power is delivered to the main components of our design; delivering too few or too many volts to components can have adverse effects on the electrical components of our design and will likely cause permanent damage. This standard may very well be the most impactful to our design, because without correct power distribution, our design is guaranteed to fail.

WaterWise is intended to be used mostly indoors, and as such the CO_2 levels of an indoor environment are a factor for growing plants. Plants require CO_2 from the external air during the photosynthesis process to produce sugars. An indoor environment's CO_2 conditions are suitable to sustain normal plant growth, however, in our consideration it is understood that the conditions are not ideal to promote advanced growth rates. There are a limited number of solutions to overcome this in the *WaterWise* design, but those solutions have been researched and have been eliminated from design primarily due to cost effectiveness. In order for plants to achieve a higher growth rate from additional CO_2, all other growth factors must be ideal. Secondly, the additional amount of

CO_2 needed for higher growth rates may affect the levels in a living space which, in extreme cases, could lead to negative human health effects.

The *WaterWise* system design will require its user to fill the water reservoir from a readily available water source. This source, for most users, will be a water faucet that supplies federally and state regulated drinking water. This design decision presents a very significant factor that the design must account for. The sourced water will contain additives that may be harmful to plant conditions, it will be required in the design to provide the proper nutrients to achieve the proper water quality for plant growth. This will require the system to inform the user of the proper nutrients to obtain for their system. There may also be a need for an initial water filtration system when the user is first adding water to the reservoir. This would add another sub-component to the *WaterWise* system and thus presents a large impact to the overall design decisions.

By nature of our design, there is a combination of electric components and flowing water. This unavoidable design characteristic will require our project to abide by standards that exist for water proofing electrical components. The project would be intended to be available to consumers on the market and must provide an electrically safe product that avoids any and all risk of any electrical components getting wet. Our design will be required to incorporate the use of a water tight PCB housing, as well as conduit to seal our wiring from any external elements. We must also ensure that the physical construction of our design incorporates water proof techniques. The water reservoir plumbing and gaskets must have water tight seals. The design will require the use of a marine sealant to ensure any modifications to the reservoir are still watertight.

Another safety standard that our design is impacted by is fire. Our design must utilize the proper wiring safety and power distribution techniques that correctly dissipate any heat. The design is impacted such that all of the wiring must be properly insulated to dissipate any heat from current running through the wires. Another critical heat source in the *WaterWise* design is the lamps that generate light and heat to support plant growth. These lights are intended to generate heat to provide warmth for the plants, however the design must account for heat resistant light enclosures. The enclosure must properly dissipate the heat such that they are not hot on the surface and do not pose any fire safety threats. This design impact is quite significant as the lights will be powered on for most of the day.

The last main design impact that standards will have an influence over is the system's energy efficiency characteristics. This standard is quite impactful to the design as it will influence to configuration of the power dissipation circuit. It will also influence the design to minimize the amount of voltage consumed by the overall design. This holds significance because the system will be running constantly. This characteristic also increases the significance of this design decision. By minimizing the power consumption of the system, this will also minimize the effect on the user's energy cost of using this system.

5.0 - Design Constraints

5.1 - Economic and Time Constraints

5.1.1 - Time Limitations

Our project's design feasibility is limited by a strict time factor. The research and design phase of the project is given a generous amount of time during the Senior Design I semester totaling to 16 weeks. During this time our group has been able to perform ample amounts of research to develop and design the *WaterWise* system. Our design features and functionalities must be limited within reason of our 12-week timeline for the build and test phase during Senior Design II. This constraint has forced our design to refrain from implementing some of the initial ideas that were deemed out of scope for the system. The time limitation has also forced our group to strictly adhere to an intermediate schedule of internal deadlines. This schedule of deadlines has allowed for proper planning to implement the most innovative features in our design.

An important effect on our system that the time limitation will present is the lack of ability to focus on external aesthetic design and to execute a descaling of components. The short amount of time to develop and build a working design of the *WaterWise* system will force our construction of the system to mostly ignore the aesthetic characteristics of the system. The physical structure will make use of suitable and readily available materials, which will lead to the use of cheaper and less specially manufactured parts. If the project were on a longer timeline, then the system would incorporate more specially designed physical structure components to appeal to aesthetics of the design.

Our system's final build during our timeline will likely be similar to that of a large scale project's 4th prototype. Due to the time limitation we will not be able to refine many aspects of our initial designs, whereas in longer large scale projects the design can be refined and prototyped multiple times. During the refinement process, projects typically look to reduce the size of the components to reduce the overall physical footprint. This is especially common today with designs involving any form of technology. Users today tend to prefer a smaller more compact system that is less cumbersome and still yields maximum results. This achievement can only be obtained through the process of scaling design size refinement.

As the progress continues throughout the build phase of the schedule, it will be important for the group to set and track milestones to reach during the 12-week time period. Some of the important milestones include and are not limited to: design and order PCB, order all sensors and parts, construct physical structure, develop code for mobile application, develop code for embedded microcontroller, and integrate system sensors and communications. Through the use of milestones and timeline projections, our group will be able to manage the time constraint as effectively as possible. These projections have also been used to determine the scope of feasibility for the amount of work required to finish a working system. Our group is aware that in order to meet the short deadline, we will be required to invest many hours per day towards the construction, development, and testing of the system.

5.1.2 - Project Budgeting Summary

Another important limiting constraint for our project is the overall budget to build the system. At the current time, we do not have any financial aid from sponsors, so the total cost to acquire materials and build the system is to be covered by the four group members. As with any project, cost is always a limiting factor, and as our project is funded by college students, the budget has even more significance. Throughout the design process of the project, it is crucial for us to compare the available options on the market, and select the most cost effective component to implement in our design. Some strategies to determine the cost effectiveness include: examining product reviews, considering component design importance, and evaluation component performance metrics versus the total cost. The strategies as well as many others will be utilized during the process of building the bill of materials (BOM).

While researching for parts and components, the most important argument in consideration is the cost against the performance. For example, we could design a system that implements sensors for many different water measurements and eventually need to design a multilayer PCB. This would require a great amount of cost for a circuit board house to fabricate and mount components as we do not have access to the proper tools to fabricate on our own. Many key electrical components in our system are opportunities to consider the significance and absolute requirements of each component. Some considerations include: utilizing different materials for construction, choosing to implement sub-components of an existing readily available product, selecting a cheaper off-brand component over a top-brand component, or even modifying the system design of a sub-component to reduce cost and design/build time for other important aspects of the system.

Each of the aforementioned considerations are crucial to enhancing the overall design of the system, and also reducing the monetary and time costs. One example of cost reduction in our design involved the layout of our PCB. We decided that moving some of the relays off of the PCB and integrated into a power strip would help to reduce the overall cost of the PCB. We will be able to obtain our own relays and correctly wire them for a lower cost than opting to have a PCB manufacturer do so. Another example of cost reductions in our design is evident in a sensor design decision. Dissolved oxygen level had been researched and determined to be a relatively important measurement to obtain with our sensor array. However, after product research we found that most DO sensors cost an upwards of 200 USD. Our group carefully evaluated the marginal benefits of the DO sensor compared to the cost, and concluded that the sensor should not be purchased. A key determining factor for this decision was the high risk of electrically damaging the sensor during the build and test phase. Lastly, some other major cost savings decisions included: electing to employ the use of an MBaaS to serve as the backend of our mobile application, deciding which hydroponic items to substitute with “common items”, and choosing to implement cheaper PVC plumbing as growth channels rather than specialized hydroponic growth channels.

5.1.3 - Consumer Economic Constraint

Throughout the development and design of this project, one of the main constraints is the economic ability of our target consumers. We are striving to develop a product that a market consumer would be both willing and financially able to purchase this product after commercial development. In order to make the product financially affordable for a broad amount of buyers, our group must strive to minimize the production costs. By reducing the production cost, the product could be sold on the market at a more competitive price, and furthermore help to reduce a consumer’s initial cost for the system. The most efficient way to satisfy this constraint is to develop and build our system at a total cost under our projected budget.

In addition to reducing the initial cost to obtain the system, this constraint also requires our design to adopt strategies that reduce the associated operating and maintenance costs of the *WaterWise* system. The main operating costs of the system include energy consumption and water consumption. Through the process of iterative design factor consideration, our group is able to develop strategies to reduce both of these operating costs. One example, is designing the system to automate the process of powering on and off the main LED lights. This will help to avoid the potential occurrence where the user may forget to turn the lights off and draw more power than needed. Another example to reduce this cost is our selection of low power rated electrical components. For example, our lighting selection of LEDs consumes much less power than the alternative HID or Halide lighting modules. The PCB design will also be designed to effectively minimize the amount of power consumed throughout the main circuit components. In addition to power, we are also striving to minimize the water consumption of the system. This required a fair amount of research into the configurations of hydroponics and water evaporation. Through our research, we were able to determine that maximizing the seals for all water routing and storing components will achieve the lowest water consumption possible. This strategy will involve ensuring the seals of each plumbing component are thoroughly water tight. Secondly this strategy will also require a water reservoir lid that includes a locking mechanism forming a watertight seal. By following these strategies our system will effectively reduce the two main operating costs.

One of the last few associated costs to reduce is the maintenance cost. By nature of the general design, a hydroponic system does require cleaning maintenance of the water reservoir. This is to ensure that a healthy water ecosystem free of bacteria, fungi, and dangerous micro-organisms is maintained. This cost comes in the form of time and effort required of the user, and to minimize this cost, we are striving to build a physical design that adds ease to this process. For example, our design of an opening cabinet helps to allow the user to easily access the submersible pump and water reservoir for cleaning and maintenance. The cabinet is simple to open and provides an opening wide enough to remove components to clean them externally from the system. Another example is the configuration of the nutrient reservoirs that will require refilling by the user. The reservoirs will be mounted externally from the cabinet so that the user may remove the opening mechanism and add the proper nutrients to each reservoir. Both of these strategies will greatly improve the overall costs of maintenance for the *WaterWise* system.

5.2 - Environmental, Social, and Political Constraints

5.2.1 - Political Contraband

The current laws in the United States ban the production of any illegal or banned substances. Some of these laws vary from state to state, but the for the majority these aforementioned rules. Through our research, we discovered that hydroponic systems have have been used to grow the illegal substance producing cannabis plant in states that have legalized the substance. We have realized the importance to stress the intended use of the *WaterWise* system, and produce warnings that the system should not be used to produce or grow any illegal or banned substances.

The development of our project is intended to be used to grow crops to supplement the user’s food sources. It is not the intention of the designers for the system to be used to grow anything other than food source crops. There are some ways that the project design has incorporated the awareness for illegal growing of cannabis. It has been considered to include warning messages within the mobile application. This would help to avoid association of the *WaterWise* system with any illegal activity. It is in our best interest to consider these constraints to avoid any potential legal situations against the designers.

The only situations where the system could be used to grow cannabis plants would be within the states that have legally allowed the growth of the plant for medical purposes. This requires that the user have the proper registrations and licenses to do so within the bounds of the law. Unfortunately, many people choose not to obey the law, and the *WaterWise* system would risk be used for illegal purposes. If the product were to be commercially sold to consumers, it would be in the best interest to record the buyer's state of residence and also require them to sign an agreement not to abuse the system by conducting illegal activity. This would help to further prevent any illegal use of the system, and also avoid promoting any illegal activity.

It should be clearly stated that our group does not condone the participation in any illegal activities, especially those related to our project. This project is not intended to be used for any illegal or banned activities such as growing any illegal substances. The main intended use of the project is to grow food source crops and other plants only. For example, it is intended to test the *WaterWise* system with some form of leafing crop like lettuce plants. Lettuce and other similar types of plants are of intended use for our project.

If the design limitations allowed for it, the system could include a water chemical analysis sensor to attempt to detect any specific chemicals that are produced by the growing crops. If a cannabis related chemical was detected, the design could incorporate some type of kill switch to prevent any illegal activity occurring from the use of the *WaterWise* system. The system could also utilize its internet connection to determine its geographical location, and reference that to a database of laws for specific plants. If the plant is illegal for the current location of the system, a cut off signal could be issued. This would force the user to prohibit any illegal growing in the *WaterWise* system. However, due to the other time and budget constraints, we will not be able to implement any preventative feature that disallow illegal activity.

5.2.2 - Social - Aesthetics and Data Protection

With regards to the mobile application for *WaterWise*, there are two major social constraints that we will have an effect on the overall design. The first is the aesthetics of an application. This is because technology is becoming so widespread that you can find an application for nearly anything, there is a tendency for applications that are aesthetically pleasing and easy to use to be preferred over others even if they offer less functionality. This is even more pronounced for a mobile application, most likely because mobile applications are meant to provide more streamlined application functionality to allow you to do more frequent tasks faster. With this in mind, we have decided to scale back on the idea of including as much functionality as possible, in order to ensure the best UI design possible.

The second major social constraint for the mobile application for *WaterWise* is data protection. Because we live in an increasingly digital age, there are many malicious uses for the personal data of people. Whether it is spam advertisement, identity theft, or even phishing scams, there is always a risk of someone misusing your data. In response to this, the mobile application for *WaterWise* will utilize a service for all of the data that we will store for the user. This was decided based on the difficulty of creating our own encryption. In addition to the added peace of mind knowing that the security is handled by a bigger organization with much more experience in the field, the server technology we are utilizing also has its own policies and guarantees for data security to protect the user that will apply to users using their service through our application.

5.3 - Health and Safety

5.3.1 - Bacteria, Mold, and Pest Control

Important aspects when health concerns come into play, especially with food growth, include but are not limited to mold prevention and pest control. Since the *WaterWise* is an indoor-use product preventative measures must be taken into consideration when designing the system. What sensors may be needed? What information can be delivered to the eventual user to encourage that preventative measures are taken? These are important questions that should be addressed in a general manner due to the fact that users will be in different climates and conditions and must adapt to what they know is best for their system in their own environment.

When growing any plant-life, there is a potential for mold to form on the subject organism. Mold is a type of fungus that decomposes dead, organic material (cellulose, hemicellulose, and lignin), comes in many different forms, and is generally caused by the presence of a high relative humidity in the area of the plants. Any relative humidity above 60% is generally considered high for plant life and should be monitored and mitigated in order to control any fungal growth on the produce. It is also important that the produce does not come in contact with any walls. As the *WaterWise* is a system intended for indoor use, this is a consideration to take when evaluating where to place the system in the consumer's home. Luckily in hydroponics systems, seldom are there cases where mold grows within the reservoir or the rest of the structural components of the system. However, cases of plant mold are about as common as would be found with traditional growing techniques. Additionally, the concern of having an unhealthy amount of mold for human exposure is generally not considered but if that is the case, the system would best be replaced if too much mold is present to remove from the pipe interiors with a mild bleach scrubbing or other light mold treatments including flushing the lines with hydrogen peroxide. For plants, there are other healthy treatments for use during growth that the consumer could use such as a garden sulfur solution to spray small amounts of mold on the plants. However, the best method to mitigate the development of mold is prevention. Prevention techniques include the monitoring of the relative humidity around the plants and occasional checks of the system components for any signs of development. Another method in the case that the consumer places their *WaterWise* in a tight space would be to use a dehumidifier in the area. Again, monitoring will be needed in order to determine if this is needed.

Another concern regarding plant growth are pests. The goal of this system is to not have to use any sort of pesticides on the plants so that the user is growing truly fresh produce. A key component to preventing pests is simply keeping the grow area clean. Seeing that the system is designed for smaller spaces, it is imperative that no daily messes interact with the *WaterWise* and that the system itself is also occasionally cleaned. This cleaning also includes ridding the system of any dead or dying produce or leaves. This is where pests are generally most abundant. Similarly, to mold, humidity control is also important to prevent pests and must be considered.

What has been discovered is that similar concerns when dealing with mold and pests alike are cleanliness and humidity. When designing and placing the system, humidity is a consideration that must be taken seriously by both the designer and the user in order to foster an environment for healthy plants. For the sake of the user, system maintenance and monitoring are both items that should be stressed by the designer, particularly as information provided in their control application.

5.3.2 - Water and Electrical Components

When developing a system that encompasses the use of many electrical components around water, it is important that understanding the potentially dangerous relationship of electricity and water and how crucial it is for the sake of user safety when working with the *WaterWise*. In order to achieve this, routing and enclosures for wires as well as enclosures for the LCD control panel, PCB, sensors and miscellaneous electrical components must be implemented. In the case that a leak or spillage occurs, it must be ensured that the system is not compromised by the interaction of water and electrical components. In design, a strategy for wiring and component placement must be developed in order to avoid or, at the very least, mitigate the potential issue. In doing so, there will be a tradeoff of space versus functionality as well as appearance versus functionality. When adding enclosures to the system and aiming to keep the desired dimensions of the *WaterWise,* being aware of where the enclosures are placed and their desired functionality of what is being enclosed can be tricky. For example, you want to place the LCD control panel enclosure in an accessible manner where it is user friendly but you may lose the ability to achieve a desired appearance of the system. In addition, by adding another component to the system, the available space is limited for the next elements that need to populate the given dimensions. There are many different situations that will arise in design for these enclosures and wiring but the idea is to achieve a balance of appearance, spatial awareness, and functionality while also keeping the system safe from being compromised by an unwanted interaction with water.

5.4 - Manufacturability and Sustainability Constraints

When designing the *WaterWise*, the collaboration of many parts of a greater system is important to keep in mind when approaching the design of each separate subsystem. Manufacturing a fully integrated system and having all of the subsystems line up in perfect harmony at the final product comes with its challenges, but it is the best way to ensure that troubleshooting the fully integrated system as well as continued design are easily achieved. If the design were to require that the *WaterWise*, was treated and manufactured all as one system, any issues that may develop could potentially much harder to diagnose and properly fix because there are so many components all being integrated at once. This is not a smart design method in that small mistakes can be much costlier not only with time but with money as well. This is why each subsystem should be manufactured individually and given their own desired specifications. By treating each subsystem as its own “project”, so to speak, better testing can be done and better design data extrapolated in order to make sure each part is working to the desired specifications before full system integration. When full system integration is finally ready to be obtained, meaning all subsystems meet their desired specifications, the hope will be for flawless integration. However, if problems do arise from the collaboration, they can be more easily diagnosed and treated based on the subsystem data collected and then adapted to match the full system specifications. Along with manufacturing constraints due to proper design, testing, and implementation methods, there are also material constraints that are put on the system due to not only physical ability to realize the design, but also why certain materials are not desired.

A few overall structural material constraints are given by weight, strength, and physical manipulation. These three constraints will dictate exactly how the final system is realized for the desired appearance and functionality of the project. There are many materials that this project could choose from, but with economic constraints the list can be easily narrowed down to materials that are readily available for design. This list can also be reduced by taking away materials that are very niche and must be manufactured in a manner that requires an expert in order to fabricate a useful product. For example, a material such as steel would not be suited for a project of this size, subject, or budget. Steel is not physically manipulated easily without proper tools and it is very heavy. However, it is extremely durable and strong. A steel *WaterWise* system could definitely take a beating but this is not a concern of the project. Going with lighter materials that are easily physically manipulated by readily available tools is definitely more desirable, but there must be a balance found in the strength of the material used. For instance, a hydroponic system could easily be made out of a rigid insulation material but any sort of physical harm dealt to the system could be fatal. This is where manufacturability and sustainability meet and trade offs occur.

For a sustainable system, not only does strength of a material come into play but also its ability to withstand time and the elements it is exposed to is an important factor when choosing a material to use for manufacturing. Throughout research of hydroponic systems, it would seem that the best options for a sustainable structure are PVC or an equivalent of PVC as well as wood. These materials are not only durable and light but they are easily manipulated to realize many appearances and functionality specifications. In the case of *WaterWise*, the structure will be designed for indoor use but both PVC and wood are very sustainable even outdoors. Also, since the environment that is being created is completely reliant on the constant flow of water through many parts of the system, treated wood is readily available and is a perfect candidate to achieve a sense of waterproofing while being able to easily manipulate the design to our desired specifications and appearance.

5.5 - Software Constraints

While building the software for the mobile application and microcontrollers in the *WaterWise* design, our group must take into consideration several constraints related to the software. In relation to the mobile application, the app itself must be limited in size, because we do not want to occupy too much memory on a user's phone. The mobile application will also require the use of a permission based system to properly identify users and their systems. Furthermore, the permissioning strategy will likely incorporate some form of password, and therefore will also require encrypted data transmissions over the Internet. Another constraint that we are considering is the possibility to leave opportunities for advertising within the mobile application. This could prove to be profitable if the design were to gain popularity. The mobile application will also be constrained by the Android platform for the first development of our project. Other platforms could be explored later on.

The mobile application should be limited to a relatively small size. We have considered to keeping the application size minimized. This will help to reduce the cumbersome process to actually download the app, as well as the application's data footprint on the user's phone. Overall, users will avoid applications that are cumbersome in overall size, as this extra size normally requires a Wi-Fi connection to download and takes up valuable disk storage space on the device. With this constraint in mind, we will strive to minimize the total size of the application, by limiting the use of large resource files in the application i.e. high resolution images or videos.

The first development of the mobile application for the *WaterWise* system will be on the Android platform. This constraint has been assumed by project group out of interest to gain development experience with the Android platform. This will limit the amount of consumers that could readily use the *WaterWise* system, however, in a later development, the iOS platform could also be explored and an app could also be developed for Apple's Appstore.

The software written for the microcontrollers must also accommodate several constraints. One of the first, and most obvious, constraints is the type of IDE and language that the software must be written in. Our project group has selected an Atmel microcontroller and will need to write the code for the MCU in the Arduino IDE using Arduino's language. There are more constraints to keep in mind when actually developing the software for the MCU. For example, the code size of the microcontroller code must be reduced as the RAM space on the microcontroller is very limited. Another example is the amount of memory used by variables in the microcontroller's software. The memory space for the microcontroller, like the RAM, is also very limited, and the developers must be cautious not to utilize too much memory in the programs.

Lastly, the microcontroller will be using a wireless module to connect to the internet. The software for this module deals with very sensitive network data like the SSID and password. Our design recognizes the importance of this data and its desired privacy. We will strive to implement some form of security on the password and SSID data that is communicated from the microcontroller over the internet in the home network to the main router gateway.

6.0 - Hardware and Software Design Summary

6.1 - Initial Design

The final structural design of the *WaterWise Hydroponic System* differs significantly from our initial design concepts. A comparison between the two designs can be seen in Figure 6.1 and 6.2. In contrast with the structural design, there has not been much change with the original design of the mobile application. This is due to the fact that *WaterWise*'s mobile application was designed with Material Design principles in mind from the beginning. Figure 6.3 shows a simple prototype design for the mobile application.

To begin, the original design for *WaterWise* utilized a cube design. This design is open with two rows of PVC tubing running between four posts, the PVC pipes held multiple plants within netted pots. The four posts were also used to support the lighting for the hydroponic system. The base of this structure also functions as the main reservoir for the system, housing the water, pumps, and sensors. Also, the design included an LCD with buttons for user interaction, which was to be mounted on the outside of one of the support posts.

While we initially considered using this design, further research showed that there we too many flaws in this design leading to more difficulties. First, with the PVC pipes running along the perimeter of the structure, it would be complicated to run the water from the reservoir through each plant. Secondly, because there were two rows of PVC running with one on top of the other with the light mounted above them, the lower pipe would suffer a reduction in light received, stunting growth. Thirdly, this design does not leave enough space for the routing of different internal components necessary to *WaterWise*'s functionality. For example, we would need to run tubing from multiple pumps up the posts to the PVC pipes while also reserving space in the posts to run the LCD wires and the wires for the lights. This design also does not account for a separate chamber to hold nutrient solution, nor does it allow for seed germination within the system.

In order to correct the flaws, found in the original structural design of *WaterWise*, we decided to create a new structure all together. The new design overcomes the issue of transferring the water through the PVC by using a longer, single set of PVC pipes arranged in 3 rows next to each other. The set of PVC pipes is then tilted slightly to make use of gravity when transporting the water through the pipe. With regards to the issue of lighting, the new design incorporates the rows of PVC next to each other instead of on top of each other, this way each row should receive the same amount of light as the others. In order to overcome the issue of not having enough space for components, the new design implements a more cabinet-like structure where there is ample space for components to remain within the cabinet, hidden from the consumer's eyes.

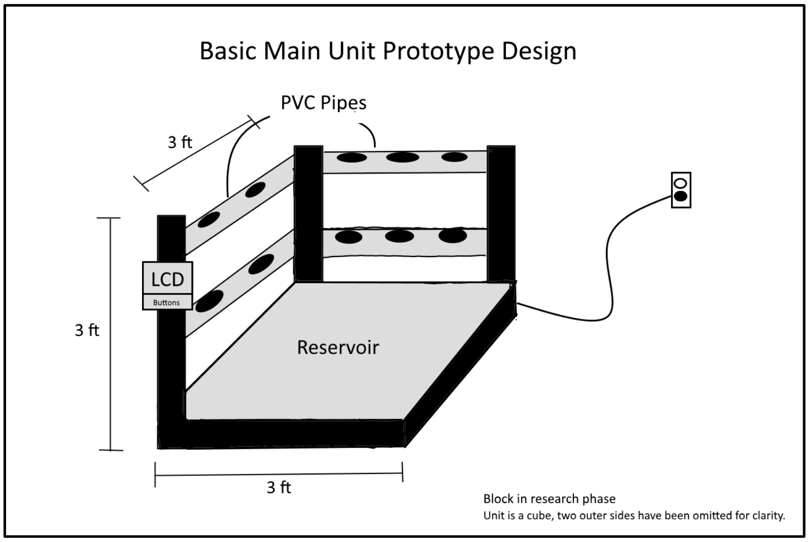


Figure 6.1: Initial Prototype Structural Design

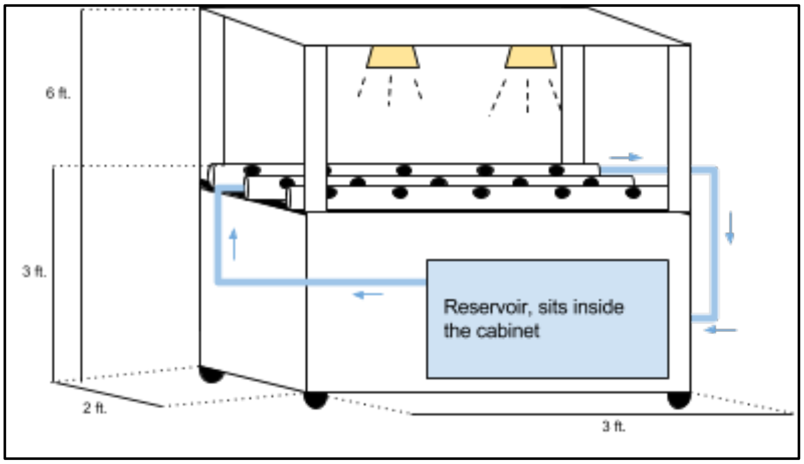


Figure 6.2: Prototype Structural Post-Design

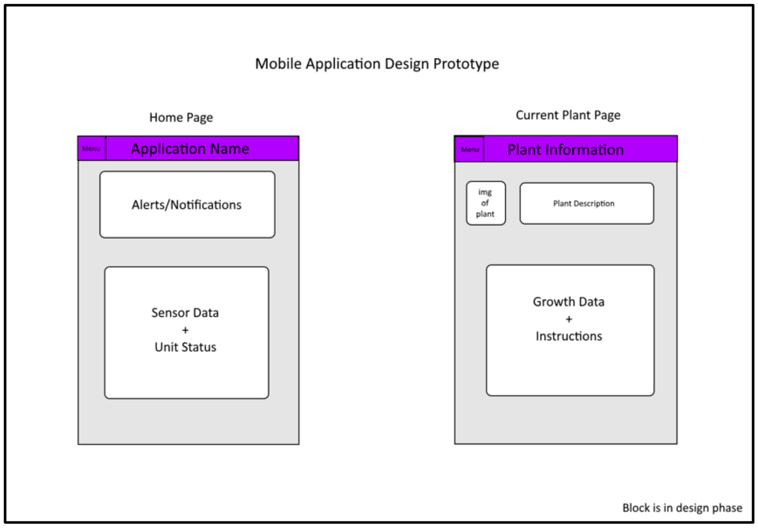


Figure 6.3: Initial Mobile Application Design

6.2 - Hydroponic Subsystems

6.2.1 - Physical Structure

The *WaterWise* Hydroponic system structure will stand 6 feet tall, 3 feet long and a width of 2 feet giving it a space consumption of about 36 cubic feet. The structure will be down sizable to half its size by removing the overhead lighting structure if it is not needed. The structure will have 4 wheels on its base making it easy to move around. At the top of the system will be two grow LED lights to supply the plants with the necessary wavelength for their photosynthesis process. These lights will be approximately 3 feet above the growth channels in order to reduce the effects of the heat on the plants that the lights will give off.

6.2.2 - Reservoir

The reservoir will sit at the bottom of the entire system serving as the stabilizer preventing the system from tipping over since majority of the weight will be at the bottom. The reservoir will hold a minimum of 20 gallons of nutrient solution that will be continuously be pumped through the system. It will also house numerous sensors that will monitor the state of the nutrient solution flowing thought the system.

6.2.3 - Plant Channel

PVC piping will be used for the plant channels. There will be 3 lengths of 4 inch PVC piping running lengthways across the system. Each pipe will have 4 holes with net cups for the plants to be placed in allowing a total of 12 plants to be grown at the same time. These pipes will be 3-4 inches apart to allow for adequate space for the plants to grow as they mature. The plant channels will have a slight slant in order to allow the water to flow through the channels back down into the reservoir without any buildup or overflow.

6.3 - Electronic Subsystems

6.3.1 - Main Pump

The *WaterWise* Hydroponic System will be designed to be a nutrient film system. The reservoir will sit directly under the growth channels with the nutrient solution being pumped up to the growth channel where it will flow over the plants roots and back down into the reservoir. The plants will need a constant flow of nutrient solution over their roots and for this reason the main pump chosen must be able to handle the job. The pump will have to be able to achieve a minimum head-height (the height at which a pump can raise water up) of 3 feet which will be the height of the entire system. The pump also has to be submersible and be able to handle continuous use. It must also be able to pump one quarter of a gallon per hour. The pump chosen for this job should be able to meet these necessary requirements easily.

6.3.2 - Nutrient and pH Pumps

Three smaller pumps will be used to keep the solutions' pH and nutrients at their desired levels. Two pumps will be used for the pH up and pH down solutions and another for the hydroponic nutrients. These pumps will have a more precise caliber compared to the main pump and will have a controlled pump rate at a milliliter accuracy. For example, if the system required 9.5ml of the nutrient solution the main pump would deliver around 10ml while the smaller pumps would accurately deliver 9.5ml of the nutrient solution. This is a necessary requirement as it will be easier for the system to maintain its desired pH level. Peristaltic pumps are the best option to achieve this. As displayed in Figure 6.4, these pumps use a mechanism where the fluid is enclosed within a flexible tube within a circular casing. A rotor with a few rollers attached to its circumference compresses the flex tube as it rotates and therefore pushes the liquid through the system. These pumps operate at 12 volts drawing a maximum current of about 400mA. The life span for these pumps is estimated at approximately 30,000 hrs. Since these pumps won't be running continuously they should last very long.

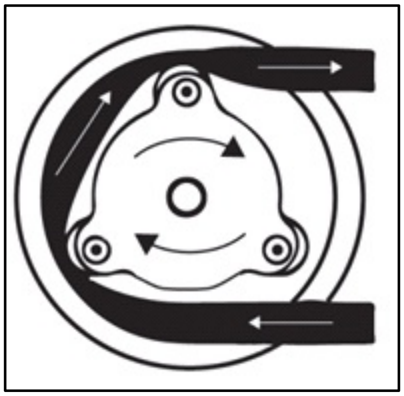


Figure 6.4: Peristaltic Pump Internals

6.3.3 - Sensors

It is our goal to design the *WaterWise* Hydroponic system to operate under ideal conditions at all time. To achieve this, we will implement various sensors. A pH level sensor will test the pH of water solution in the system constantly. Based on the information obtained from this sensor, the microcontroller will either turn on the pH up peristaltic pump if the systems' pH is too low or the pH down peristaltic pump if the systems' pH is too high. If the pH of the system is within range, then nothing will be done. The system will also need an Electrical conductivity (EC) sensor that will help to determine the nutrient concentration of the system. This is important as the nutrient solution needs to remain at a desired level (varies with different plants) for ideal plant growth. If the nutrient level falls too low, the microcontroller will turn on the peristaltic pump that controls the nutrient solution.

6.3.4 - Water Level

The nutrient solution level will also need to be monitored for the system to operate smoothly. The nutrient solution level in the reservoir will fall overtime due to plant consumption and evaporation. This has to be monitored as it may be difficult for the system to maintain its pH level. When the level falls too low, 1ml of the pH up, pH down, and nutrient mixture will have a much more significant effect of the solution flowing through the system. The system will be designed to operate within a reasonable range. Due to the fact that we won't be connected the system to a main water supple, the system needs to be able to alert the user if the water level falls too low. This will be done by having a water level sensor in the reservoir.

6.3.5 - Temperature Sensors

The *WaterWise* will have two temperature sensors for data recording purposes only. These temperature sensors will be place inside the reservoir to record the temperature of the nutrient solution flowing through the system and the other on the outside the record the temperature of the air surrounding the system. Temperature sensors are fairly popular and can be found easily, however, the temperature sensor for the reservoir needs to meet the requirement of being waterproof. Figure 6.5 shows a simple waterproof temperature sensor that can be interfaced with Arduino.

Figure 6.5: Waterproof Temperature Sensor

6.4 - Description of Hardware Block Diagrams

The component block diagram below gives an idea of the interconnections of the entire *WaterWise* Hydroponic system. Notice some components are standalone components, meaning there is no interconnection represented on the diagram as they do not need to communicate with the microcontroller. Other components are controlled by the microcontroller or they supply information to the microcontroller. Each item plays an important role in the smooth operation of the *WaterWise* system and will be further discussed in order to get a full understanding of how it is all incorporated.

To start the explanation off it is best to begin with the power supply. An AC (alternating current) to DC (direct current) converter will be used to convert the 120 – 130 voltage at a frequency of 60 Hz from the wall outlet to a DC voltage of 12 volts. This 12 volt will be used to power our printed circuit board with the microcontroller, debugger and wireless transceiver. The microcontroller needs a voltage of 5 volts and will therefore require voltage regulators to step the voltage down to the desired 5 volts that will be needed to power the microcontroller. A linear regulator will be used to step the voltages down to the desired 5 volt. Also in our design there will be a power strip with three relays to control our peristaltic pumps and lights. We thought it would be best to isolate these high powered components from our micro-controller which will be the brain the *WaterWise* Hydroponic system. This power strip design is essential to power the high voltage components in our system rather than having these components being powered directly from our printed circuit board as they require a minimum voltage of 12 volts.

As mentioned before, the printed circuit board will be powered by a 12-volt AC to DC power adapter. These 12 volts will be used to supply power to various components connected to the printed circuit board (PCB). Components such as the temperature sensors and water level sensor require small voltages in the range 3.5 to 5.5 volts. These sensors will be interfaced directly from the PCB. However, components that require larger power consumption will be interfaced via relays located in our power strip. For example, dedicated pins on the printed circuit board will be used to send a signal to the relays that will then close or open the circuit to allow our peristaltic pumps to turn on and off. On our PCB there will also be a display and buttons to control and check parameters within the system such as the current pH level of the solution flowing through the system. This design was incorporated into the system to make it more user friendly and easy to use. The PCB will also have a wireless transceiver that will allow the user to connect to the system wirelessly. Due to this feature, anyone that is using the system will be able to set the desired parameters or observe the system data over a period of time via the mobile application.

Sensors are vital components in the *WaterWise* Hydroponic system. They provide the system and the user with well needed information on how the conditions of the *WaterWise* Hydroponic system is operating. Some sensors provide information that will be used for data logging purposes only. The system itself will not use this information to make any adjustments on its own whatsoever. The temperature sensors for example will monitor the temperature of the air surrounding the system as well as the temperature of the nutrient solution flowing through the system. Since the *WaterWise* system will not be enclosed, these is no way for the system to adjust the surrounding temperature. However, the user can make a decision as to whether or not he/she will adjust the temperature of their house or the environment it will be placed in. Although the user can manipulate the surrounding temperature after reviewing the logged information the system would not make any adjustments in response to the information.

Other sensors provide information that will directly affect the operations of the *WaterWise* Hydroponic system. The pH sensor for example will tell the system the current pH level of the nutrient solution flowing through the system. The system will then compare it to the set range for the plant being grown and make necessary adjustments on its own if needed by either turning on the pH up or pH down peristaltic pump. pH is the measurement of hydrogen ion concentration and based on this measured value the system will determine how long to turn on the corresponding peristaltic pump to regain the desired pH level. Similarly, the electrical conductivity (EC) sensor will test the electrical conductivity of the solution flowing through the system. This information gives an idea of how much nutrients are in the solution flowing through the system and makes a decision on whether to add more nutrients or not. The light sensor will detect the intensity of the light hitting the structure and plants. Based on this intensity level, the system will make a decision as to whether the plants need more light to maintain ideal conditions for plant growth. If the plants need more light, the system will turn on the LED lights to the appropriate intensity. It is our goal to have the system operating as close to the sunlight conditions of an average day.

Some components will be running consistently such as the main pump in the reservoir. This pump will only be turned off if the user needs to clean the system or he/she is replacing the nutrient solution. In trying to make the *WaterWise* Hydroponic system as user friendly and simple to use as possible, we thought it would be best to allow the user to turn off the main pump from within the system instead of having to unplug its power wire since most of the pumps we've seen doesn't come with a power switch. The air stone is another component that should be running continuously and will be able to be turn off from within the software itself rather than hardware.

In the process of making the *WaterWise* system more user friendly, a wireless router would be used to communicate with the system. This is a very important aspect in making the system more user friendly since the user won't have to be in the exact location to observe the conditions under which the system is running. For example, the user can have the system in their basement and still be able to communicate with it while stationed in any location of their house providing that the wireless connection is strong enough. The wireless router would be powered by the power supply. This would be used as a means to connect to the *WaterWise* system wirelessly instead of having to go to the actual system to examine how the system is doing. The user will have full access to the operations of the system and will be able to make adjustment to the parameters of the system.

In the block diagram, there are some components that have no interconnections with the microcontroller. The microcontroller does not need to communicate with these components as they are the actual hardware components that make up the physical structure of the *WaterWise* Hydroponic system. These components were important to mention as they play a vital part in our system. Many of the components mentioned above will be placed within these physical structures. The reservoir for example will house the temperature sensor that monitors the temperature of the solution flowing through the system. The pH sensor along with the EC sensor will also be located in the reservoir to give accurate readings on the state of the nutrient solution. The air stone that will oxygenate the nutrient solution will also have to be placed in the reservoir.

6.5 - Component-Level Block Diagram

The component level block diagram can be seen in Figure 6.6. This block diagram shows the principal parts of the *WaterWise* hydroponic system and their interconnections.

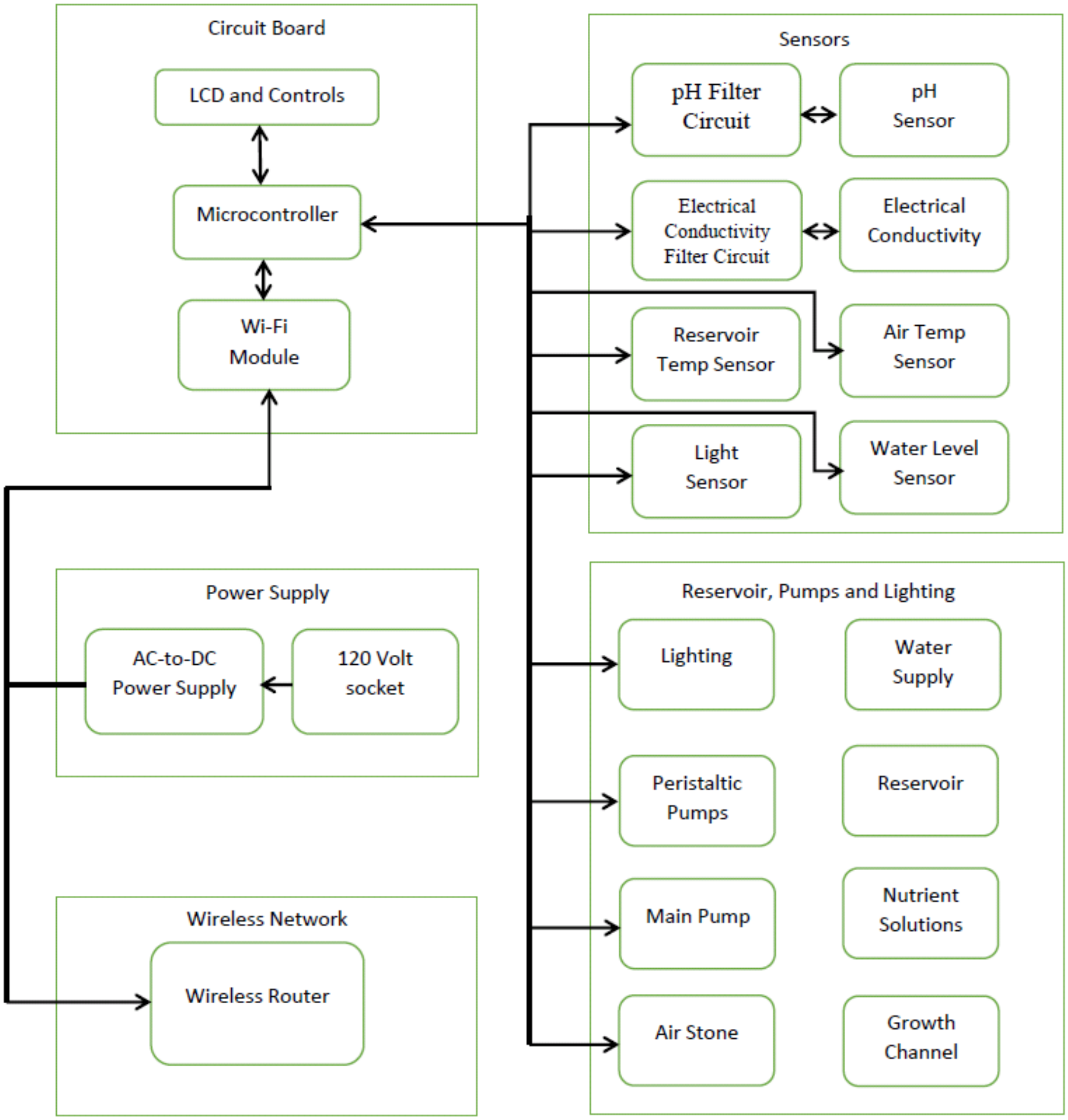


Figure 6.6: Component level block diagram

6.6 - Description of Software Block Diagram

The software block diagrams in section *6.6 Software Block Diagrams* contain a block diagram showing the overall system, a block diagram showing the mobile application's flow of control, and a block diagram showing the flow of control for the LCD program running on the MCU. Each of these diagrams helps to detail the critical actions that our system performs.

The first diagram shown in *Figure 6.7 Software Block Diagram*, begins with the Sensor readings performing measurements of the conditions based on a timer from the MCU. The data from each sensor is communicated back the MCU, which the microcontroller will use in a number of different actions. As the MCU program analyzes the measurements, it may generate alerts to the mobile application for particular conditions that are not within the correct ranges. If the MCU finds that the pH measurements or the EC measurements are incorrect, then it will determine how much nutrient level is required to restore the system and signal power on the corresponding peristaltic pump for a certain amount of time to add the correct amount of chemicals. The MCU will also communicate the data readings via the Wi-Fi module. The Wi-Fi module allows the device to connect to a wireless network and then set up its own server to communicate data to the mobile application via the Internet connection.

The main MCU is also connected to an LCD with interface buttons that allows the user to directly control the system. The button interface allows the user to select power control options of components or the entire system. The MCU controls the LCD output based on the input signals from the directly connected directional and select buttons. The MCU program will determine the user's selection and thus distribute the respective control signals to the power relay array to turn on/off the respective components selected by the user. The MCU will also be able to receive system control signals from the Wi-Fi module via the mobile application. The mobile application will also communicate with a MBaaS service with a database of user account information and plant information.

The second block diagram in *Figure 6.8 Mobile Application Flow Block Diagram* displays the high level flow of the *WaterWise* mobile application. The application will begin with a home welcoming screen that provides the options to sign up with the system using a Google+ account or another email address, and it also allows users to sign in to the application. After signing in, the application will display a digitally created top down view of the *WaterWise* system. This view will show what the user has currently growing in the bays of the system and represents the plant's growth based on a timeline representation. This view will include a floating action button that will provide ability to control the physical *WaterWise* system. Throughout the application's views a slide in menu option is available with the options for Help, Account information, Sensor readings, and Plant information. The Help and Account information will provide general static information to the user. The sensor view will display a table of the most recent sensor readings from the connected *WaterWise* system along with a timestamp of the updated readings. The Plant information view will provide users with a view of different plants and relevant information including the growing cycle and timeline. This view will also provide a forward action button that will bring up the ability to search for different plants to view information about and repopulate the main plant information view with the selected plant's information from the database.

Lastly, the third block diagram is shown in *Figure 6.9 LCD Flow Block diagram*, which shows the flow of control throughout the lightweight LCD interface. The

LCD will be put to sleep when not in use and can be woken up by an input received from the select button. The main menu will provide options to step into the power control menu or the sensor readings, or put the system to sleep. This menu will behave in a character select carousel formation, in that the user will use the up/down directional buttons to highlight an option of the view and the left/right directional buttons to view the next pair of options in the menu The power control menu will provide option to turn power on/off of lighting, air-stone, submersible pump, or the entire system. The Sensor Readings menu will display the sensor type and the current reading, and the user can select left/right to view all of the different readings. At the end of each pair of menu options will be an option to go back up to the previous menu.

6.7 - Software Block Diagram

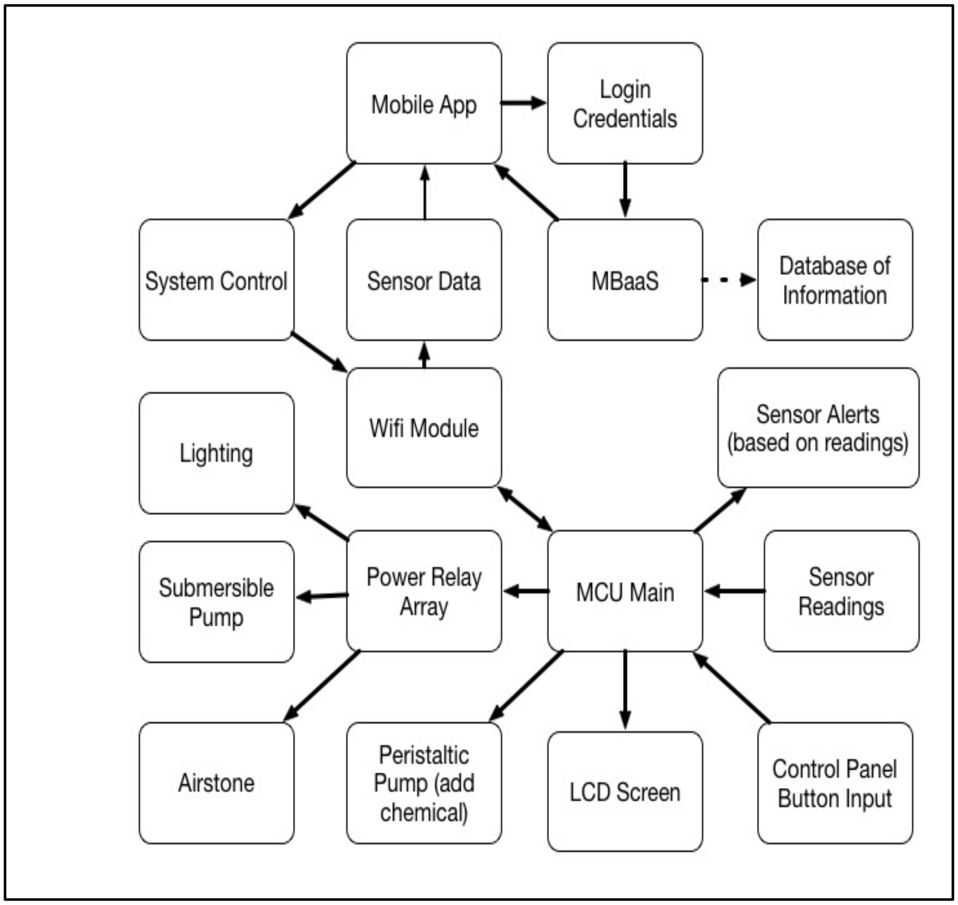


Figure 6.7: Software Block Diagram

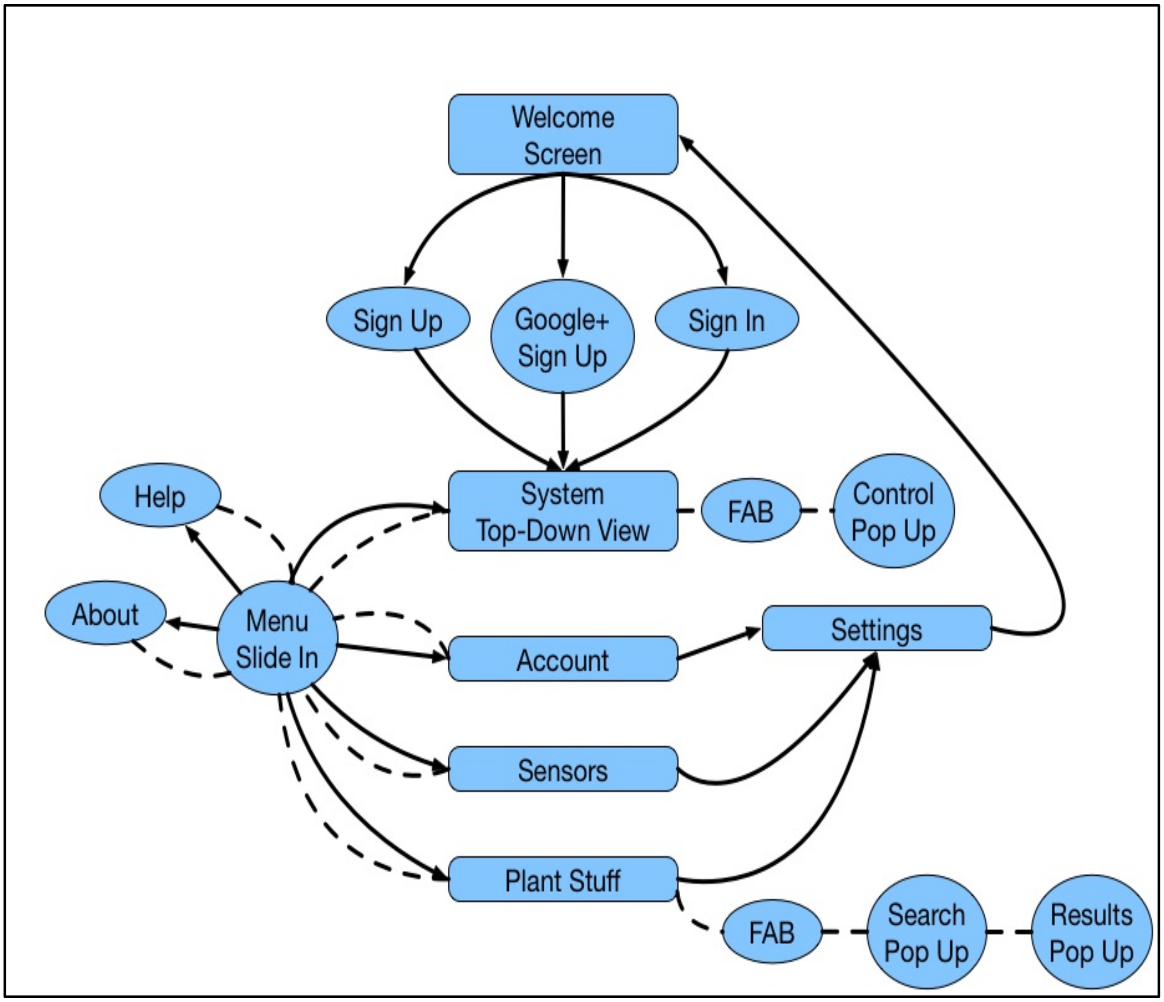


Figure 6.8: Mobile Application Flow Block Diagram

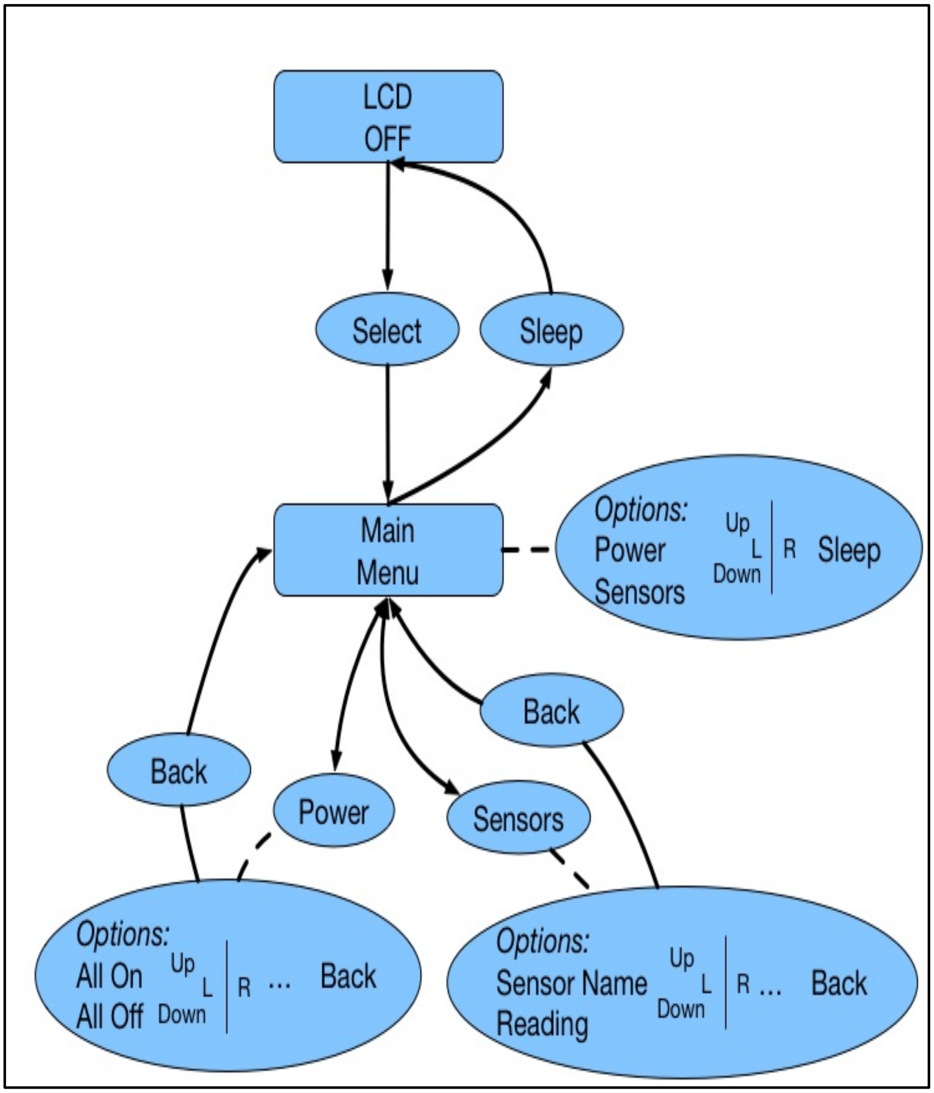


Figure 6.9: LCD Flow Block Diagram

6.8 - Motivation

6.8.1 - Software Motivation

6.8.1.1 - Microcontroller Software Motivation

Section *3.0 - Research Related to Project Definition* discussed some of the different microcontrollers and combined IDEs associated with those microcontrollers. After conducting this research, our design decision has concluded to utilize the Arduino IDE in conjunction with our hardware design decision of the Atmega2560. Our research discovered the availability of many open source libraries supporting sensors as well as Wi-Fi connectivity for the Arduino boards. This abundance of libraries was one of the deciding factors to select this MCU and associated software IDE. We also discovered an ideal LCD and button interface that is made to function cohesively with an Atmel microcontroller. This LCD is also extensively supported in the available Arduino libraries. Ultimately, the decision of the Arduino IDE was simple as it provides a large amount of additional functionality support that we require for our system design.

The design of the program for the MCU and LCD is based on simplicity and functionality. The controlling software for the MCU will be written to utilize low power modes of the MCU to avoid consuming too much power during normal operation. The program will utilize interrupts for controlling the LCD interface for the user. The menu design on the LCD will be created to maximize intuitiveness and simplicity. Since the overall focus of the design is on the mobile application interface and not the LCD interface, our software design for this portion will be kept simple to reduce development time.

6.8.1.2 - Mobile Application Software Motivation

In section *3.0 - Research Related to Project Definition* we discussed some of the results of our research into the different options for designing the mobile application for *WaterWise*. We discussed server technologies, IDEs, and UI/UX design. In this section we will discuss the choices we've made and why we felt they were appropriate for our mobile application.

While researching different server technologies that we could incorporate for the mobile application, we came across multiple server technologies such as: Apache, Node.js, Parse, and Kinvey. After consideration of all of them, we ultimately decided to use the Kinvey server technology to implement the necessary database backend. We chose Kinvey primarily because of its availability as a service to be utilized by our mobile application as opposed to a language in which we create and host our own database. While this is a property that Kinvey also shares with Parse, our research found that the Parse service is actually approaching a shutdown that would interfere with our mobile application's use of the database. Furthermore, the free version of Kinvey will provide us with enough space, and a large enough query limit to satisfy our mobile application's requirements, helping to cut the overall budget of the project.

Choosing the most optimal IDE to use for the creation of the mobile application was fairly simple. While it is possible to create an android application in any IDE that supports Java and XML, as shown in section *3.2.10 - Software Development Environments*, a short amount of research revealed the existence of the Android Studio IDE created by Google. After considering the options, we chose the Android studio IDE for a few key reasons. First of all while most IDEs allow for us to write Java and XML within the same environment, since Android Studio is design for the creation of Android applications much of the initial set up with file directories and necessary files is done automatically. Secondly, Android Studio allows for the creation of the XML files used for the application to be done using a GUI rather than simply writing the XML code by hand. This speeds up the development time and also gives a quick glance at what the resulting code will look like when running on a phone. Lastly, Android Studio also includes full Android virtualization which will allow us to simulate and test our app on the fly with a very short amount of time spent on setting up the testing environment.

For the UI/UX design of the mobile application we considered a few different variables. For starters, since we new the application would be created for the Android mobile operating system, we felt that it was a top priority to ensure that the application looked similar to other Android applications in order to build a sense of harmony that ultimately builds user satisfaction. While researching the common features in many different popular Android applications, we came across Google's own documentation of design guidelines for its own Android applications known as Material Design. After reviewing the guidelines and discussing them in section *3.3.1 - Material Design*, we decided that our mobile application would benefit from it. While we primarily decided on Material Design due to its popularity with users, we also felt that a cleaner, more simple user interface would suit the mobile application for *WaterWise* due to the fact that it is designed to be a companion to a larger system rather than a standalone product in and of itself. In addition to that, we recognized that our consumers may vary drastically considering the goal of the system is to be easily adoptable by a large audience. This greatly contributed to the decision to use Material Design due to its well designed usability standards.

6.8.2 - Hardware Motivation

The WaterWise system was designed to be a self-automated, strong, and user friendly hydroponic system keeping the user in mind. For these reason, careful considerations were taken when choosing each hardware component that makes up the entire system.

Keeping the user in mind, we debated long and hard over how the user would interact directly with the system. Ultimately we came to the decision to use a simple non touch display with a few buttons over using a touch sensitive screen. Touch screens can be rather expensive and even then, they are clumsy to use. There are even cases where the screen becomes non-responsive if the digitizer goes bad.

It goes without say that almost all of our sensors needed to be waterproof with the exceptions of the light intensity sensor and temperature and humidity sensor. Even though these sensors will not be submerged in water at no point in time, we will coat them will a water proof spray just to be on the safe side since water will be flowing the system constantly. The white LED lights that will be used in the germination station will be waterproof since they will be so close to the reservoir that holds the solution mixture for the system.

It is also our objective to make the system leak-free. To achieve this, a hard plastic reservoir will be used. PVC will be used to get the water from the reservoir to the plants and also for the plant channels. Waterproof fittings will be used to reduce the chance of leaks in our connections. The only opening to the solution in the system while in operation would be via the holes in the plant channel where the plants would be placed. This design will help to reduce the chances of water leaks in our system.

7.0 - Project Hardware & Software Design Details

7.1 - Structural Design

The structure of the *WaterWise* system is the result of many different mockup prototypes and our core objectives. The structural design had to include the hydroponic considerations as well as physical mechanics to build an overall stable structure. The design will consist of a rectangular rolling structure that has a main lower compartment that comprises of the entire lower half of the structure. The lower compartment is open on all four sides for ease of access to the user as well as to allow for visual monitoring of the system. It will be about 3 ft. long, 2 ft. wide, and 3 ft. tall and have a few shelves catered to what items will sit on them such as the air pump and peristaltic pumps. Each corner of the compartment will have 360-degree swiveling casters mounted under the structure. At each of the narrower sides of the cabinet there will be large openings located at the upper half of the side panel. These openings will serve purpose to route the main pipes of the water pumping subsystem. The structure will also have a 2 ft. by 3 ft. rectangular flat roof-like structure mounted 3 ft. high above lower compartment. The platform will be held up above the lower structure by 4 posts, one at each corner, mounted to the top of the lower compartment and attached to the platform. This platform will be used to mount the grow light above the lower cabinet structure where the grow tubes will be located.

The entire physical structure will be constructed entirely from lumber materials. The frame itself will be mostly constructed from two-by-fours while the floor of the canopy and lower compartment as well as the shelves will be made of half-inch thick plywood. Additionally, the canopy roof will be one sheet of plywood and will feature the grow light as previously stated.

The initial design for the structure featured a cabinet in the lower compartment. However, after going through the build process, the team decided that it would be more of a hindrance to access the subsystem components inside the lower compartment. Figure 7.1 shows an accurately scaled CAD model of the originally intended physical structure for the *WaterWise* system as well as the final realization of the product.

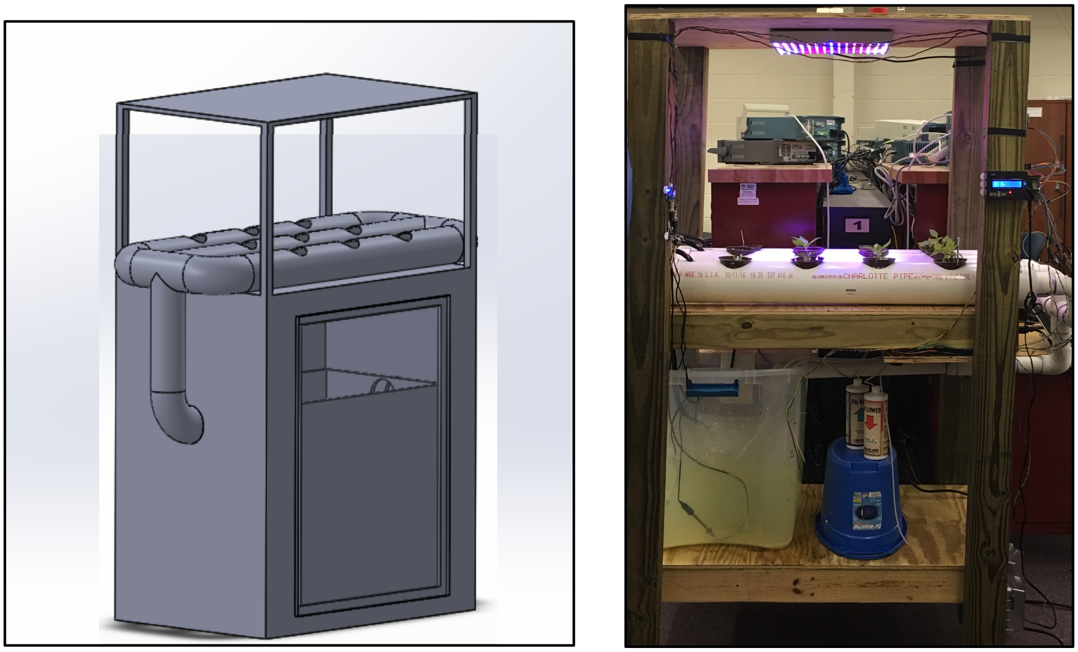


Figure 7.1: WaterWise Physical Structure CAD Model

7.2 - Hardware Design

The design of the PCB hardware will be done in direct reference to an Arduino, more specifically the ATMega2560 development board. The reason being is that it contains a great model interface for the MCU we will be specifying on the PCB. Of course, there will be some design decisions made with the open source design in order to keep the amount of components minimized. This is done by eliminating those components that are not necessary for this project and it is also essential to keep cost down when the board is created. In addition to what the model of our PCB will be, it is desired that the finished design is submitted in a professional manner. Routing the wiring on the PCB will be organized and in adherence to routing guidelines. There will be silkscreen labels for user clarity of what is on the board and their locations. The hardware design of this board is to make it a fully functional and efficient design that is neatly compiled and easily read.

In conjunction with the PCB will be the sensor interface subsystem. This subsystem will consist of a multitude of components and it is ideal that minimal space is taken by the subsystem. Luckily, the majority of components will be assigned to the reservoir and therefore will not take much space elsewhere in the system. For the sensors that are not reserved to the PCB, wiring of the system is desired to be in a workmanlike manner and does not take away from the aesthetics of the system. In addition to minimizing space in the system, the on-board sensor interface must comply with the desire to minimize the size of the final PCB design. Only components necessary to interface with the sensors will remain for this portion of the PCB design.

The power supply on the board will be specified to be a 2.1 mm barrel jack that connects to a 12V DC adapter and goes directly to a receptacle. This removes any hardware design required for a battery supply enclosure to coincide with the PCB. This helps in keeping the size of our PCB on a small scale. This is favorable since our PCB will be placed in a PCB waterproof container. Figures 7.2 and 7.3 show an initial schematic of our intended PCB.

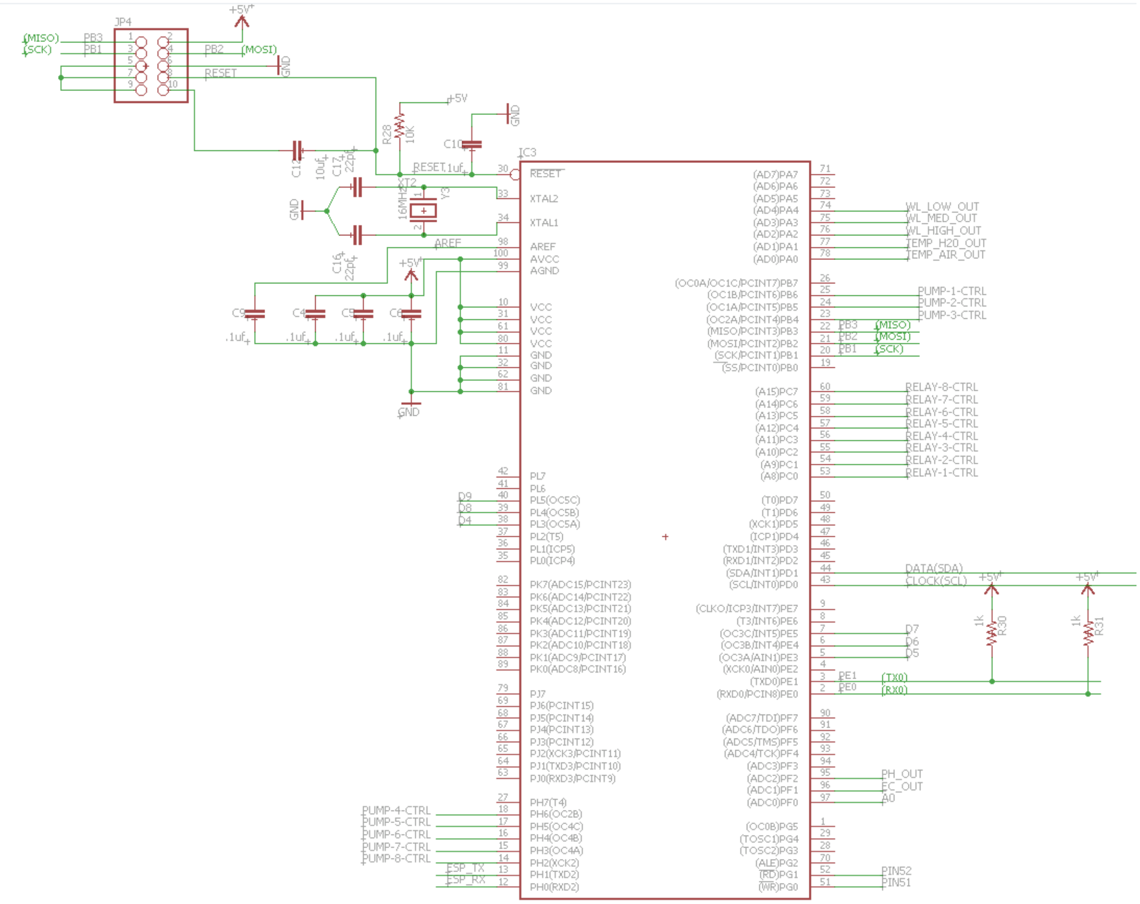


Figure 7.2: Schematic Layout of Microcontroller

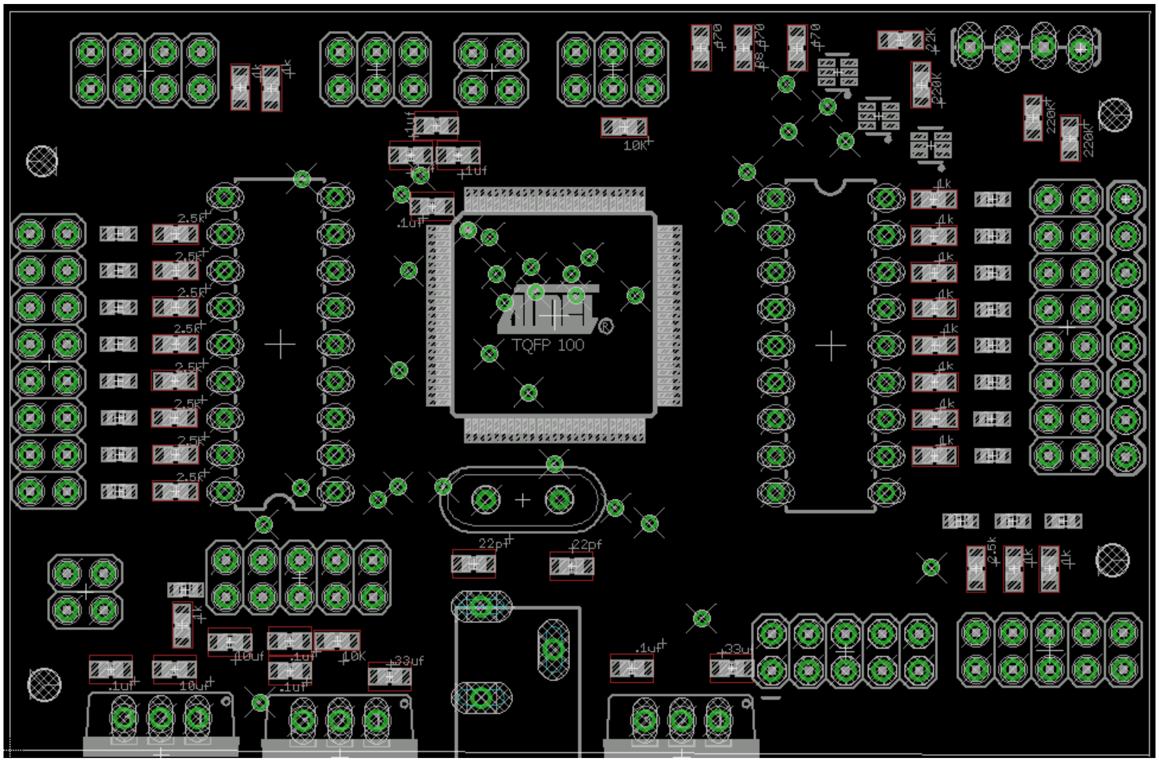


Figure 7.3: Final Board Layout

7.3 - Master Parts List

Table 7.4 contains all of the different parts that will be used in each subsystem of the *WaterWise* section. This table also includes some specific part numbers and descriptions for the significant parts in our design, so that a manufacturer will be able to locate and obtain all of the necessary parts. Each part listed in the table is also accounted for in the final bill of materials section of this document.

Subsystem	Parts & Materials	Part No. or Description
Physical Structure	Lumber/Plywood	Obtained from local hardware store
	PVC pipes	Obtained from local hardware store
	Screws, Hinges, other related hardware	Obtained from local hardware store
	Wires, Conduit, Tubing, Solder	Obtained from local hardware store
	Wheels	5 in. Polyurethane Heavy Duty Swivel Caster (330lb load rated)
	PVC Cement, Glue, Tape, Marine Sealant	Obtained from local hardware store
	Marine Through-Hole Adapters, Rubber Gaskets	Ancor Watertight Wire Seals Mfg # 765012 - ¾”
Strategic Components	MCU	ATmega2560AU
	Power Strip	Receptacles, gang boxes, conduit
	Darlington Driver	8 Channel utilized with relays.
	Solid State Relay	Grove Twig Relays
	Wifi Module	ESP8266 Wifi Module
	LCD Control Panel	AdaFruit 772 LCD Shield Kit, 16x2 Blue/White Display Arduino
	AC-DC Power Converter	12V DC 2A 2.1mm CAT# PS-12275
	PCB Components	Resistors, Capacitors, OpAmps
	PCB Housing	Watertight PCB Housing
	Air Pump / Air Stone	EcoPlus 728355 6.5W/ 8 in. Disk
	Water Pump	Submersible, <200 GPH with flow control adapter.

Table 7.4: Master Parts List (Part 1 of 2)

	Main Reservoir	25 Gallon Plastic Container
	Peristaltic Pumps (4)	12V DC Peristaltic Pumps
	LED Grow Lights	450 LED Quad Band
	Plant Trays	Plastic Net Pots Trays
Sensors	pH Sensor	Analog pH Meter Kit SEN0161
	EC Sensor	Analog EC Meter Kit DFR0300
	Water Level Sensor	Multi Probing Design
	Air Temperature & Humidity Sensor	Adafruit DHT11
Miscellaneous	Nutrients	Maxigro Hydroponic Nutrients
	Growth Medium	Expanded Rockwool & Clay Pellets

Table 7.5: Master Parts List (Part 2 of 2)

7.4 - Component Details

7.4.1 - Sensors

7.4.1.1 - pH Sensor

The WaterWise Hydroponic system requires a pH sensor that can be submersible for extended period of time. This sensor must also be able to work in temperature ranging from 15 to 40 degrees Celsius. It must also be lower powered since the WaterWise system is design to be power efficient. The pH level is a very important part of the system for this reason we require a minimum accuracy of ±0.1. Last but not least, this sensor must be able to detect pH levels from 0 to 14.

The pH sensor that will be used in our WaterWise Hydroponic system is the DFRobot Analog pH Meter kit. This kit meets the requirements needed to be implemented in our system. The sensor’s module is rated at 5 volts which can be supplied by our PCB. It can read pH values of 0 to 12. Temperature ranges is 0 to 60 Degrees Celsius which falls between the expected ranges of operation of our system. The accuracy is ±0.1 at room temperature (25°C). This device has a response time of less than one minute which is sufficient since the device will be reading continuously. The sensor also needs to be submersible. These are the minimum requirements we were looking for in a pH sensor to implement in our design.

The pH sensor will be interface via an intermediate circuit that will be connected to an analog pin out our PCB / microcontroller. This pin will be programmed specifically to recognize input from the pH sensor and determine the pH level of the system based on the voltage readings detected. These readings will then be compared with the preset values. If the value is falls within range, then no action will be taken. However, it the readings falls out of range, the corresponding peristaltic pumps will be activated to get the pH level within the corresponding range. Figure 7.6 shows a schematic layout of the intermediate circuit that will be used to send information from the probe to our PCB.

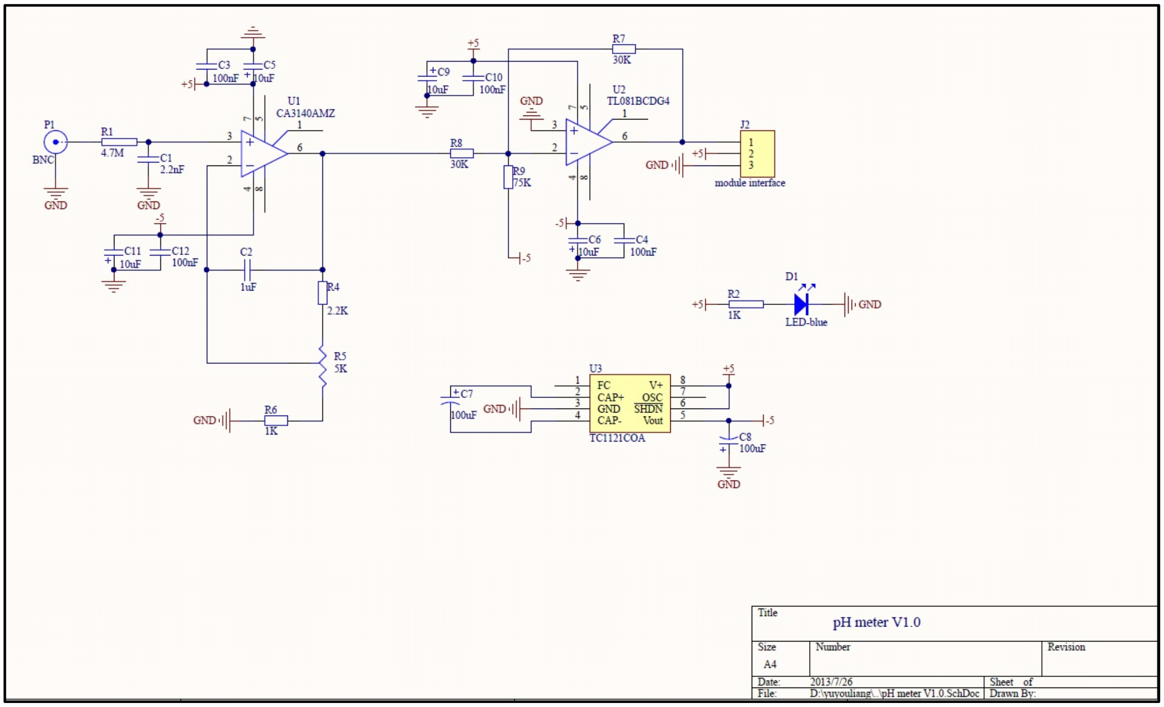


Figure 7.6: pH sensor schematic

7.4.1.2 - Electrical Conductivity Sensor

The electrical conductivity (EC) sensor that will be used is the Analog EC Meter DFR0300 from dfrobot.com. As discussed previously, the EC sensor is used to measure the salinity of the nutrient solution in order to give feedback on water quality and if desired nutrient solution specifications are met. Does more water need to be added to dilute the nutrient solution or more nutrient solution added to ensure proper growth of the plants? This is the question that the EC sensor will answer for the user.

The sensor consists of the electrode as well as a BNC connection PCB that will need to be incorporated with the main PCB in order to get the readings from the probe. It is also important to note that this is a laboratory probe and requires cleaning after use. The readings that will need to be interpreted from the probe will be presented as a conductivity value in terms of ms/cm. In order to properly track what the nutrient solution requires, a nominal value must be determined. If the new reading is less than 70% of the nominal value, more nutrient solution will be required. If there is more conductivity than the nominal value, more water should be supplied. Table 7.7 shows the specifications of the EC probe. Figure 7.8 shows the details of the EC electrode.

Operating Voltage	+5.00 V
PCB Size	45 x 32 mm (1.77 x 1.26 in.)
Measuring Range	1 ms/cm - 20 ms/cm
Operating Temperature	5 - 40 °C
Cable Length	60 cm (23.62 in.)

Table 7.7: Probe Specifications

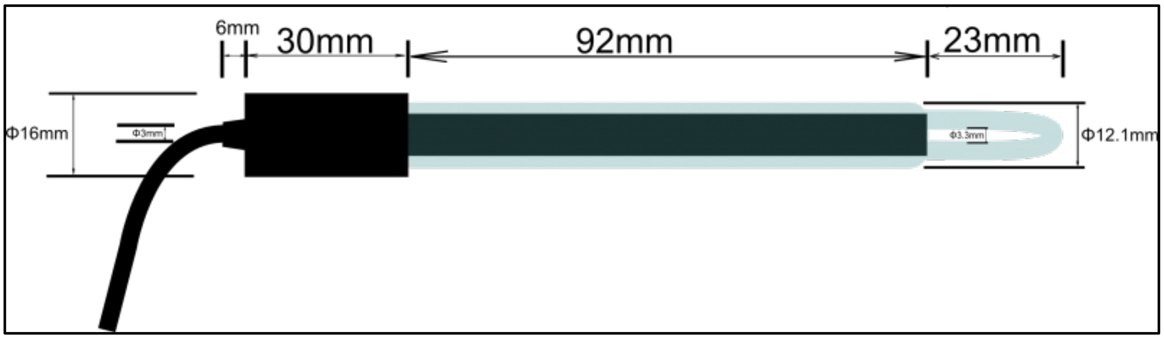


Figure 7.8: Electrode Details

7.4.1.3 - Light Intensity

Being able to read-in the intensity of light will be very important for our seed germination station. This way, we can minimize growth time and maximize plant growth in that same period. In order to do so, a digital light sensor will return data in terms of lux and a determined value will be required to be met. This value will change depending on what is being grown and therefore the amount of power delivered to the light may need to be changed but this consideration will not be discussed further in this section.

The sensor that will be specified is the BH1750 digital light sensor that can be found on dfrobot.com and other suppliers. This sensor features a built-in ADC in order to directly supply a digital signal. Another feature of this board is that the on-board lux meter supplies a measurement explicitly in terms of lux, allowing the avoidance of any calculation efforts that could make the sensor data be displayed not as accurately as desired. Figure 7.9 shows the schematic of the light intensity sensor. Figure 7.10 shows the board layout of the light intensity sensor. Table 7.11 lists the specifications of the light intensity sensor.

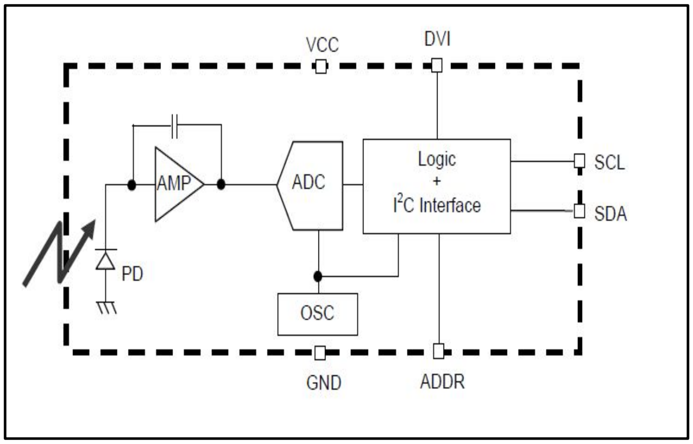


Figure 7.9: Sensor Schematic

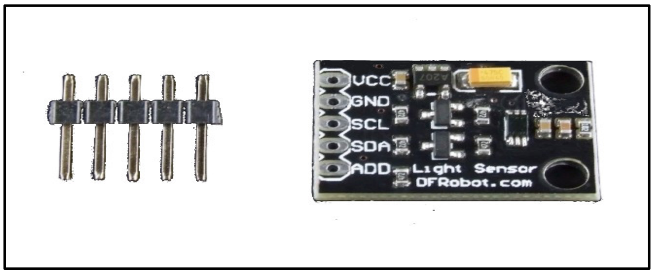


Figure 7.10: Sensor Board Layout

Power Supply Voltage	3 - 5V DC
Interface	I2C
Detectable Range	1 - 65535 lux
Small Measurement Variation	± 20%
Size	21 mm x 16 mm x 3.3 mm

Table 7.11: Sensor Specifications

7.4.1.4 - Temperature and Humidity

After extensive searching, we were able to find a very low cost, easily implemented, all-in-one air temperature and humidity sensor. The Adafruit DHT11 is a four pin digital temperature and humidity sensor that features the usage of a capacitive humidity sensor and a thermistor to give the current conditions in the surrounding area. Of course, being very low cost, there are a couple of drawbacks of the sensor but none that this project is too concerned with. These drawbacks relate to the ability to extrapolate data in real time from the sensor, as this model does not have such capability. The DHT11 requires very careful timing and can only give data once about every two seconds. Since our system isn't completely reliant on immediate temperature data, this is not a big deal and something we are willing to sacrifice in order to save money. Table 7.12 lists the specifications of the temperature/humidity sensor. Figure 7.13 shows the details of the temperature and humidity sensor.

Power and I/O	3 - 5 V
Maximum Current Use	2.5 mA (while requesting data)
Humidity Range	20% - 80% (with 5% accuracy)
Temperature Range	0 -50 °C (with ±2°C accuracy)
Maximum Sampling Rate	1 Hz
Body Size	15.5 mm x 12 mm x 5.5 mm

Table 7.12: Sensor Specifications

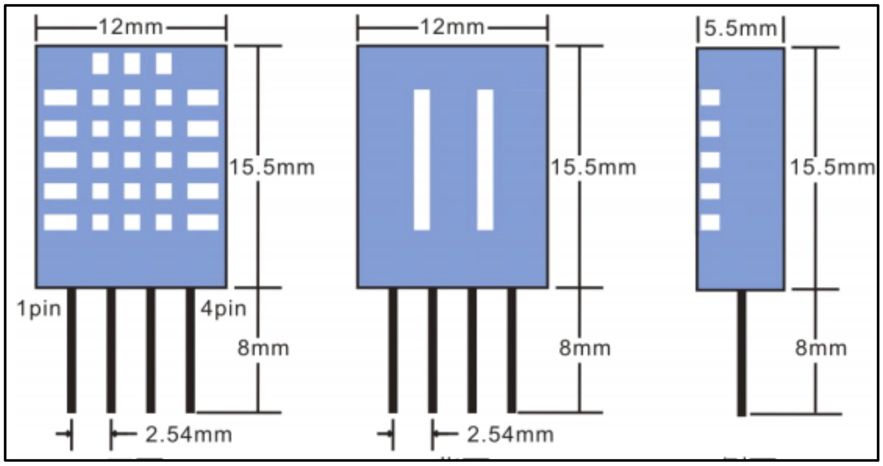


Figure 7.13: Sensor Details

7.4.1.5 - Reservoir Water Level

The water level sensor for the reservoir will be constructed using a simple circuit involving multiple jumper wires, resistors and transistors on a breakout board and having the PCB read-in the data. The circuit involves one 22kΩ, three 220kΩ, and three 470Ω resistors as well as three jumper wires and three NPN transistors. The sensor is realized by taking three jumper wires and assigning each of them a level (low, medium, high) that they will be in charge of detecting.

For example, if the water is touching the bottom two probes and not the top, the system will recognize that it is at a medium level. The jumper wires do this by detecting if there is any contact with the electrical presence that exists in the water. If, for some reason, the water dips below the middle probe and is now only in contact with the first, the system will know that the water level is low. By reading in this data, the values given from the system will display on the *WaterWise's* LCD control panel, notifying the user that there is either a sufficient amount of water or that too much has been lost and needs to be added. Figure 7.14 shows a schematic for the water level circuit.

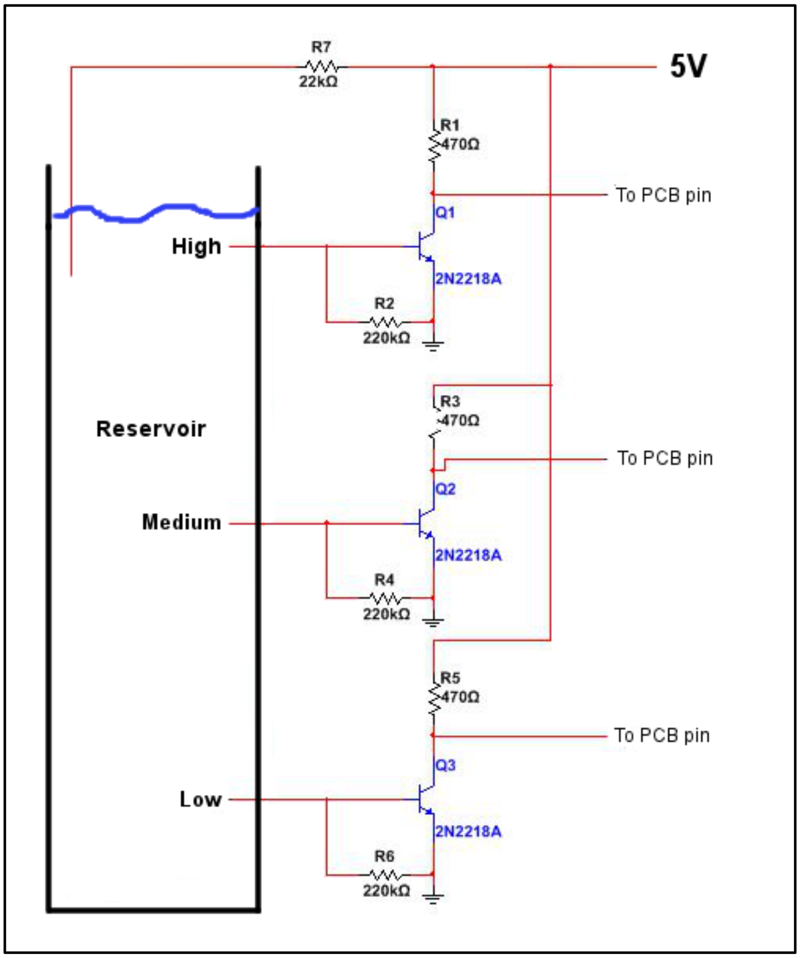


Figure 7.14: Circuit Schematic

7.4.2 - Power

Since the *WaterWise* does not feature batteries, many components will be needed in order to make up the power distribution subsystem but user friendliness will most certainly be achieved. Each component that is electrically connected will need a 120V, 60Hz receptacle to be plugged into. This will be accomplished by creating a power strip that will extend any nearby receptacle that the user will choose. The power strip must be created by using mountable gang boxes, conduit, NEMA rated coverings, three duplex receptacles and a basic switch. Most power strips were discovered to use a brass bus for power distribution, making them much more difficult to repurpose than to build a power strip from scratch. For those systems such as the water pump that can be directly connected to the power strip, internal AC to DC conversion will occur and therefore there is no requirement to have any special plugs for them. However, it is a design specification that must be taken into consideration for those components.

For the PCB, a 2.1mm barrel jack will be used to receive supplied power from the receptacle. It is required that a 12V DC 2A power supply with a 2.1mm coaxial male plug be supplied in order to achieve the desired input voltage for the PCB. This power supply satisfies the previously defined typical desired range of 7-20V for this type of application and will feature a functional cord that is 5' in length in order to allow the user to place their *WaterWise* in any position and orientation in their home. On and extending from the PCB will be many sensors and other various electronics. These components will require small voltages in a typical range 3.3 - 5V which is simply given straight from the PCB. After the PCB receives the 12V signal in the 2.1mm jack, the voltage is immediately regulated to this range in order to allow the PCB to be equipped with a proper voltage that can be used throughout the board and for these extending pieces of equipment.

7.4.3 - Lighting

Lighting requirements that will be implemented in the system are strictly for the benefit of stronger plant growth, not ambient light. The light will be placed above the system. As described previously, the light on top will require a light that is good for already germinated plants. The light will also need to be close enough to the plants such that they receive the proper balance of time under the lights and with the lights off. This is why a model must be chosen that can be mounted to the underside of the canopy and have enough of a light footprint to yield proper coverage for all of the plants.

The model chosen is a 225 LED square panel featuring wavelengths of red, blue, orange, and white light and is manufactured by Yescom. The use of LED lighting not only aligns with our goal of making a sustainable and efficient system, but also decreases heat given off by the use of lighting. Generally speaking, any time light fixtures are introduced to a compact system such as *WaterWise*, heat can become a major issue. However, by using LEDs as grow lights, little to no effect will be noticeable after installation. This fixture was specifically chosen because of its efficient nature as well as the ability to produce wavelengths of light that plants crave. The breakdown of how many LEDs of each wavelength and their respective intensities is shown in Table 7.15, Figure 7.16, and Figure 7.17.

Color	Wavelength	Intensity	Number of LEDs
Red	660 nm	7.3 lux	77
Blue	450 nm	4.8 lux	47
Orange	630 nm	7.1 lux	77
White	n/a	7.5 lux	24

Table 7.15: LED Color Specifications

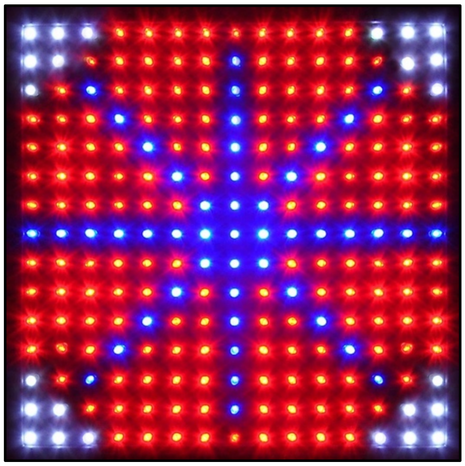


Figure 7.16: LED Layout

Figure 7.17: Grow Light by Yescom Image

As seen, the fixture has a fair balance of each light type, keeping in mind that wavelengths of red are very important to bring up plants from a very small level. Blue light is important for after the plants are thriving as it is not as intense and white light is always a good supplement for growth. However, wavelength of light is not the only important constraint placed on grow lights. It is always important to understand exactly what the system needs in order to decide where the grow light needs to be placed in relation to the plants. This LED panel light has a coverage of 6.5 square feet but elevation is what will come into play, especially when the system is reliant on suspending the fixture. The manufacturer recommends that this light is placed 1-4 feet from the produce in order to ensure proper coverage. Determining which distance is necessary is dependent upon where the plants are at in their growth cycle and is therefore determined by the user. From a design perspective, it is important to ensure that the need for adjustment can be met by the structural configuration of the system. Table 7.18 lists the main grow light specifications.

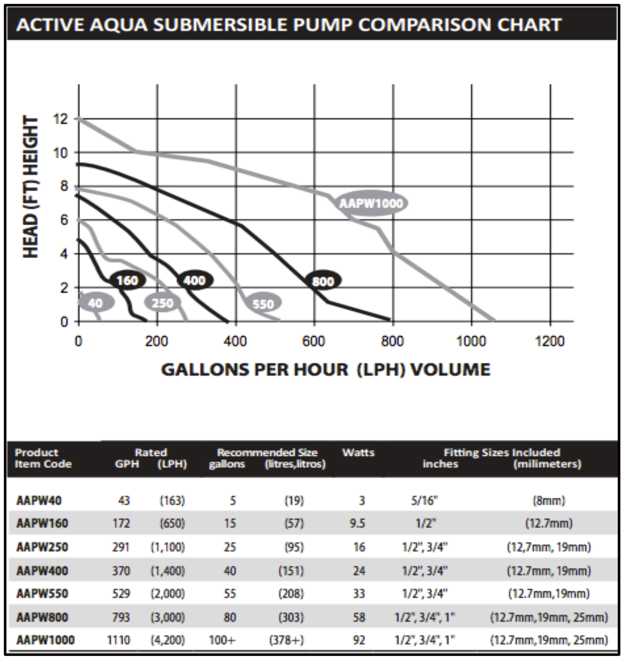
Total Intensity	1514 lux
LEDs Diameter	5 mm
Power Supply	80-265V AC, 14W, standard plug
Output Voltage	37V
Dimensions	12 in. x 12 in. x 1.5 in.

Table 7.18: Main Grow Light Specifications

7.4.4 - Pumps

The most crucial component to our system, other than the PCB, is the submersible water pump located within the main water reservoir. This pump is critically responsible for to keeping the water continuously flowing in our NFT hydroponic system. It is responsible for delivering the essential nutrients to the plants located above in the growth tubes. It is essential for the submersible pump to cycle the system's contents once every two hours, and more specifically for an NFT system, one quarter of a gallon per minute per growth tube. This rate must also be compounded with pushing the water at this rate up a head height distance to the growth tubes. This factor of head height is a crucial in selecting the right submersible pump with the required GPH at certain head heights. Our system's design requires a pump to deliver contents at a head height of about 3 ft. and at a rate of 45 GPH at a minimum.

As discussed in section *3.2 Relevant Research*, our submersible pump will much more pumping capability than our minimum requirement. This is appropriate, because it is always possible to decrease the output flow of a pump, and it is never possible to increase the strength of a submersible pump. With this consideration, we intend to incorporate the Active Aqua Submersible Pump with a flow rate of 250 GPH. This model includes many additional features that are beneficial to the needs of our design. The pump includes a built in flow regulator valve that can reach a minimum of 87 GPH at a head height of zero feet. The pump also includes many different size of adapter fittings that will simplify connecting our pipes to the pump's output port. The manufacturer of the pump also includes a very details owner's manual with an exact chart showing the flow rates at different head heights. This pump is also oil free and environmentally safe, making it an even more optimum selection for our design. Figure 7.21 shows the different flow rates for the 250 GPH model at head heights ranging from six feet to zero feet.



Product Item Code	Rated GPH	(LPH)	Recommended Size gallons	(litres,litros)	Watts	Fitting Sizes Included inches	(milimeters)
AAPW40	43	(163)	5	(19)	3	5/16"	(8mm)
AAPW160	172	(650)	15	(57)	9.5	1/2"	(12.7mm)
AAPW250	291	(1,100)	25	(95)	16	1/2", 3/4"	(12,7mm, 19mm)
AAPW400	370	(1,400)	40	(151)	24	1/2", 3/4"	(12.7mm, 19mm)
AAPW550	529	(2,000)	55	(208)	33	1/2", 3/4"	(12.7mm,19mm)
AAPW800	793	(3,000)	80	(303)	58	1/2", 3/4", 1"	(12.7mm,19mm, 25mm)
AAPW1000	1110	(4,200)	100+	(378+)	92	1/2", 3/4", 1"	(12.7mm,19mm, 25mm)

Figure 7.21: Active Aqua Flow Rate Head Height Chart

This pump model will work perfectly for our system, as it is recommended by the manufacturer for the exact main reservoir size that our design uses. It's power consumption is relatively low in comparison to other components of our design. Also, the price of the pump is considerably low in comparison to our overall system cost. The Figure 7.22 AAPW250 Internal Physical Breakdown shows the complete physical design of the submersible pump. The flow control knob mechanism is shown as well as the multiple sizes of tube fittings. This diagram is also useful to include in an owner's manual for breakdown during required cleaning and maintenance of the pump.

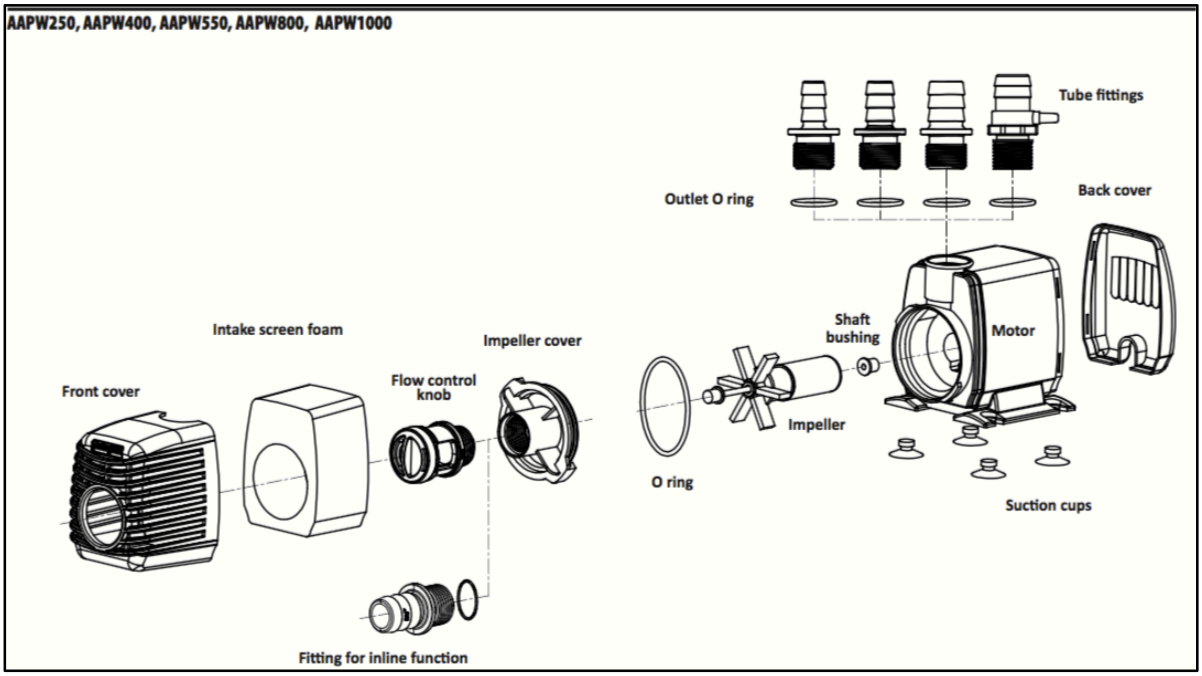


Figure 7.22: AAPW250 Internal Physical Breakdown

7.4.5 - LCD and Controls

In section *3.2.12 - LCD Panel and Controls* we discussed the different types of LCD panels and control layouts that we could utilize for *WaterWise's* main structure. As we discussed, the main focus behind including an LCD with controls is to allow the system to provide full functionality even if the user cannot utilize the mobile application. After research, we determined that utilizing a display with capacitive touch would not be the best choice for our system. This was due to budget constraints and the fact that anything less than the best capacitive display will result in a frustrating experience for the user due to inaccuracy.

It is for those reasons that we decided to utilize an LCD display with buttons to allow simple menu navigation and interaction. While this format is not the most visually pleasing, we determined that the greater reliability and ease of use would provide a better user experience. After reaching this conclusion, we then deliberated on whether to select a high end display with low end external buttons, or to design around a simple display with integrated buttons. The high end display might look better, but would ultimately add a lot of cost to the project. Additionally, using a display with integrated buttons would cut down on errors and simplify the design process for it. In the end, we decided a simpler display with integrated buttons would be a better choice for *WaterWise*.

The simple LCD with integrated buttons we ended up choosing was the Adafruit 772 Blue & White Shield Kit with Keypad. This is a two row by 16-character LCD display attached to a PCB with 6 buttons. It is a 2.1” x 3.2” board that is compatible with any ‘classic’ Arduino board. The Adafruit 772 also cuts down the the pins required to control the LCD and buttons significantly. If we were to use the LCD in this kit as a standalone LCD, we would need a total of 7 pins from our board to be able to control it. With this kit, we are able to control the LCD and the 6 extra buttons using only two I2C pins. This will undoubtedly save us development time since we have so many sensors and relays that will need to connect to our board as well. Figure 7.23 shows a picture of the Adafruit 772 16x2 Display Shield Kit.

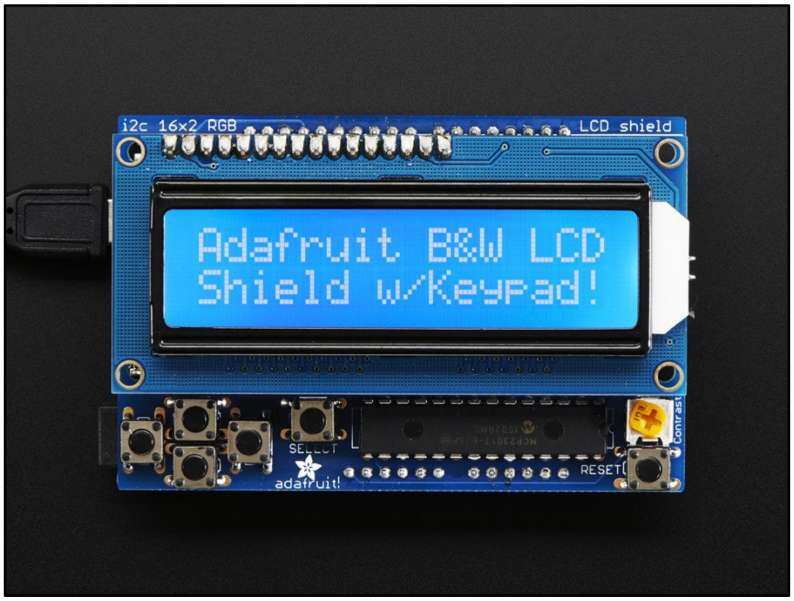


Figure 7.23: Adafruit 772 16x2 Display Shield Kit

7.4.7 - Wi-Fi Module

In section *3.2 - Relevant Research* we discussed the proper forms of wireless communication, and for the *WaterWise* system, we have decided to opt for Wi-Fi communication. More specifically our design will implement the ESP8266 Wi-Fi module. This module is a SOC that provides full TCP/IP stack support that can provide most MCUs with Wi-Fi capability. The module is capable of communicating on the 802.11b/g/n standards. This module has 4 main pins, a Tx, Rx, GND, and 3V pin that can be connected to a PCB. The ESP8266 module has an operating voltage of 3.3V. The module requires two hardware serial pins to communicate with an MCU (Rx & Tx). The recommended baud rate for serial communication with an ATmega2560 is 9600, but will function at other rates so long as the ESP8266 and MCU match. The module can be programmed using serial connections to properly configure the network credentials. The module can also be set to ‘server mode’ to allow for wireless configuration over via the server hosted by the module itself. Figure 7.24 shows the schematic layout of the ESP8266 wireless module. The 4 key pins to note in the schematic are VDD33, GND, UTXD, and URXD.

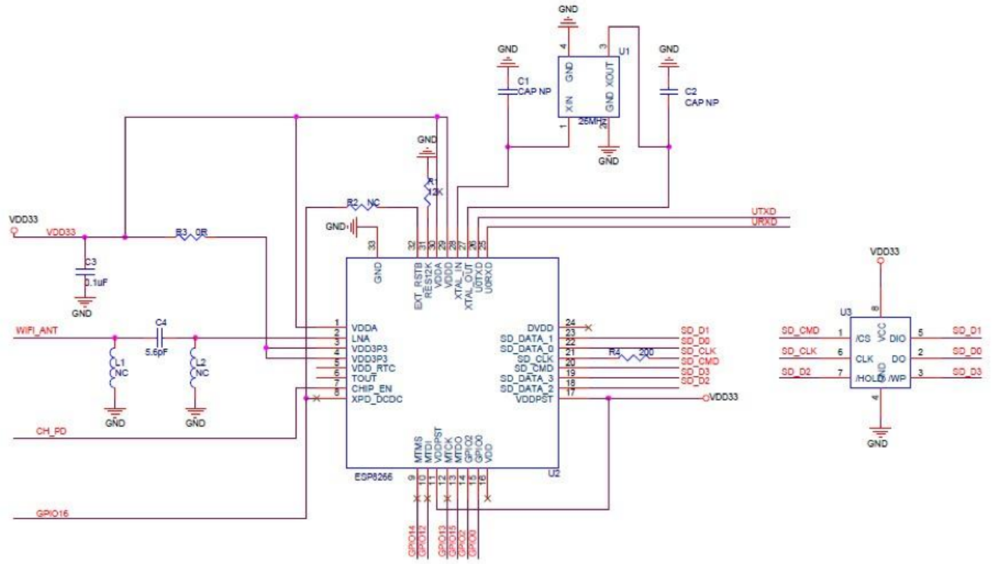


Figure 7.24: ESP8266 Schematic

7.5 - Software Design

7.5.1 - Embedded Software

The embedded software we will be designing for *WaterWise* will be focused on creating a simple user friendly interface for interacting with the main unit without using the mobile application. The user will interact with this interface using the LCD unit that is mounted on the outside of the cabinet of the main structure. The LCD that we are using comes with five buttons that we can program for our use. In order to facilitate ease of use, we have decided to implement the menu in such a way that the left and right will change the page that is displayed on the LCD screen, and the up and down buttons will choose between the two options currently displayed on the screen. Figure 7.25 summarizes the layout of each menu.

From screen off, pressing the select button will wake the screen to the main menu. The first page will contain two options: power, and sensors. The power option will take the user to the power menu, and the sensor option will take the user to the sensor menu. The second page will contain an option to turn off the screen, returning to the LCD off state.

The power menu will contain several pages to allow the user to toggle power to all of the elements in the main unit, this will enable disassembly, cleaning, or even storage. For each page in this menu, the up button will enable an element, while the down button will disable the element. We decided on this design so that the user will not need to remember the state of any given component, which is important because some elements cannot be seen outside of the system. The first page will allow the user to toggle the entire system, with the following pages being dedicated to a specific component. The last page in this menu will allow the user to return to the main menu.

The sensors menu will contain pages for each of the sensors. In this menu, the up and down buttons will be disabled because there is no selection available to the user. This is because the top row will show the sensor name, and the bottom row will show the current reading from that sensor. The last page will allow the user to return to the main menu.

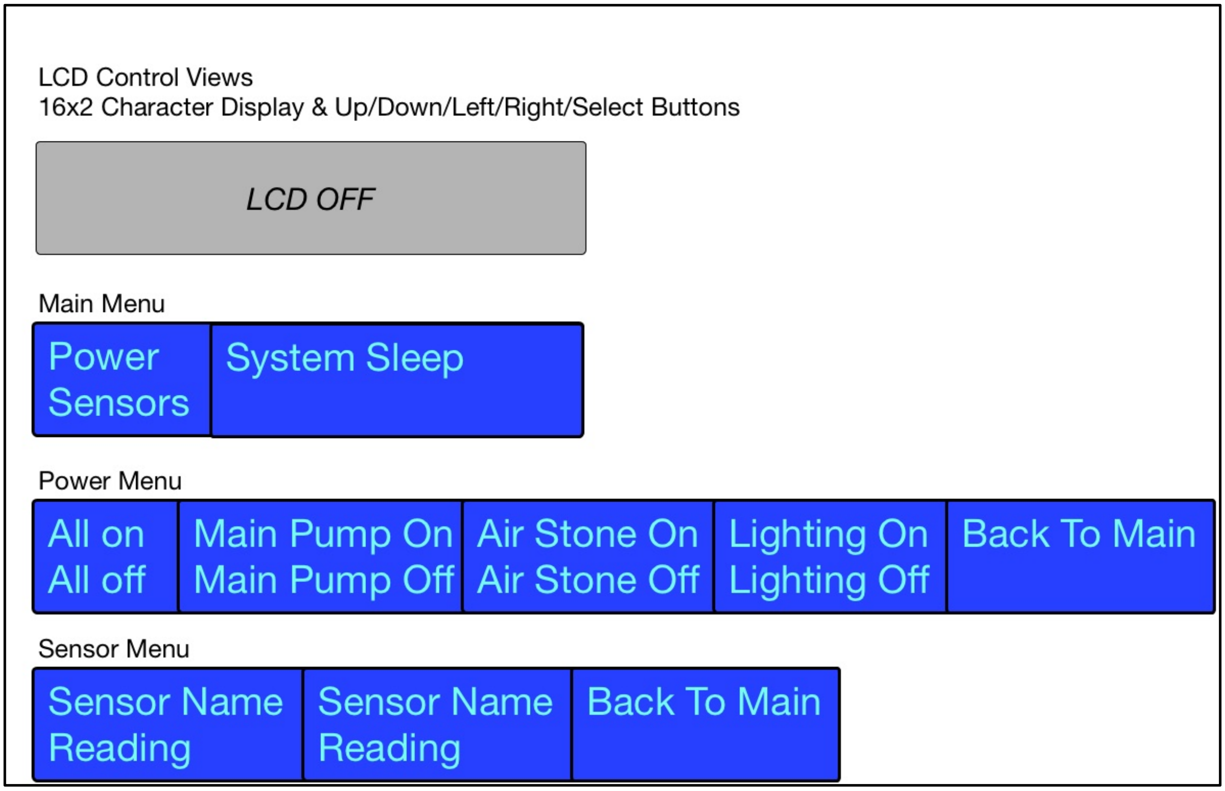


Figure 7.25: LCD Control Screen Views

7.5.2 - Mobile Application Software

The mobile application for *WaterWise* was designed with simplicity in mind. In accordance with this goal, we sought to minimize the number different views or ‘pages’ in the application. The application includes six different views in total, they are: the welcome view, system view, account view, help view, about view, and the plant plan view. In addition to the six views, the application will include pop up windows, a settings icon, and a slide in menu accessible from the top left. All views except the welcome view will have an app bar at the top with the menu icon. For each view that has a menu icon, pressing the icon will trigger a sliding menu that will allow the user to jump to any specific view, with the exception of the settings view. In addition to the description of these views below, Figure 7.26 will also have a representation of how these views should be formatted.

The welcome view will be the first view that user sees, it allows for the user to connect to the database we are implementing. It will include two text fields for email and password, and three buttons. The first button is the sign in button and if the credentials are correct, it will lead the user to the system view. The second button is the sign up button, when pressed it will lead the user to the account view. Finally, the third button is the google plus button and will lead the user to the account view.

The account view contains an update button, and three text fields. The first text field is for the user to update their email address; it will show the current email in the text field before any text has been entered. The second text field is for the user to update their password; unlike the previous text field it will show “(Unchanged)” by default. The final text field will be used to update the key-code for the user’s specific system, it will show the current key-code by default. The account view does not redirect the user when the update button has been pressed, instead it will popup a confirmation dialog. From there, the user can either press the settings icon to go to the settings view, or use the menu icon to change views.

The system view is the main view of the application; it contains a top-down picture of the system that has been selected by the user through the key-code. This picture will be a generic image of the product provided by us, with labelling next to the plant slots showing the name of the plant variety that was selected by the user in the plant plan view.
Beneath that picture will be a similar picture of the germination chamber in the cabinet beneath the main unit. It will also have labelling showing the name of the selected plant for germination.

The plant plan view will allow the user to browse the plants we have available in our database. Information on each plant such as its uses, characteristics, and growth patterns will be available. Additionally, the user will be able to mark the current plant that they’re looking at as the plant in the main unit, or the seeds in the germination chamber. This view will have a picture of the currently selected plant, the description from our database, and a floating action button. The floating action button will allow the user to mark the plant, or search for a different plant. When search is selected, a popup will appear with a text field for search terms, a cancel button, and a search button. When search is selected, a popup list will appear with a list of results that can be tapped to be returned as the selected plant ion the plant plan view.

The sensor view will have a simple table showing information from each sensor, formatted in a way that is digestible for the user. The table will have separate columns for the sensor name, the time of the most recent reading, and the value of that reading. This view will also implement the drag to refresh mechanic that is very common in Android applications.

Lastly, the settings view will allow the user to toggle a few settings within the application. It will have check boxes next to headings that describe which feature will be toggled, such as notifications. In addition to these toggles, it will include a drop down menu to select text size in order to make the application more accessible. Finally, the settings view will also include a logout button that will return the user to the welcome view.

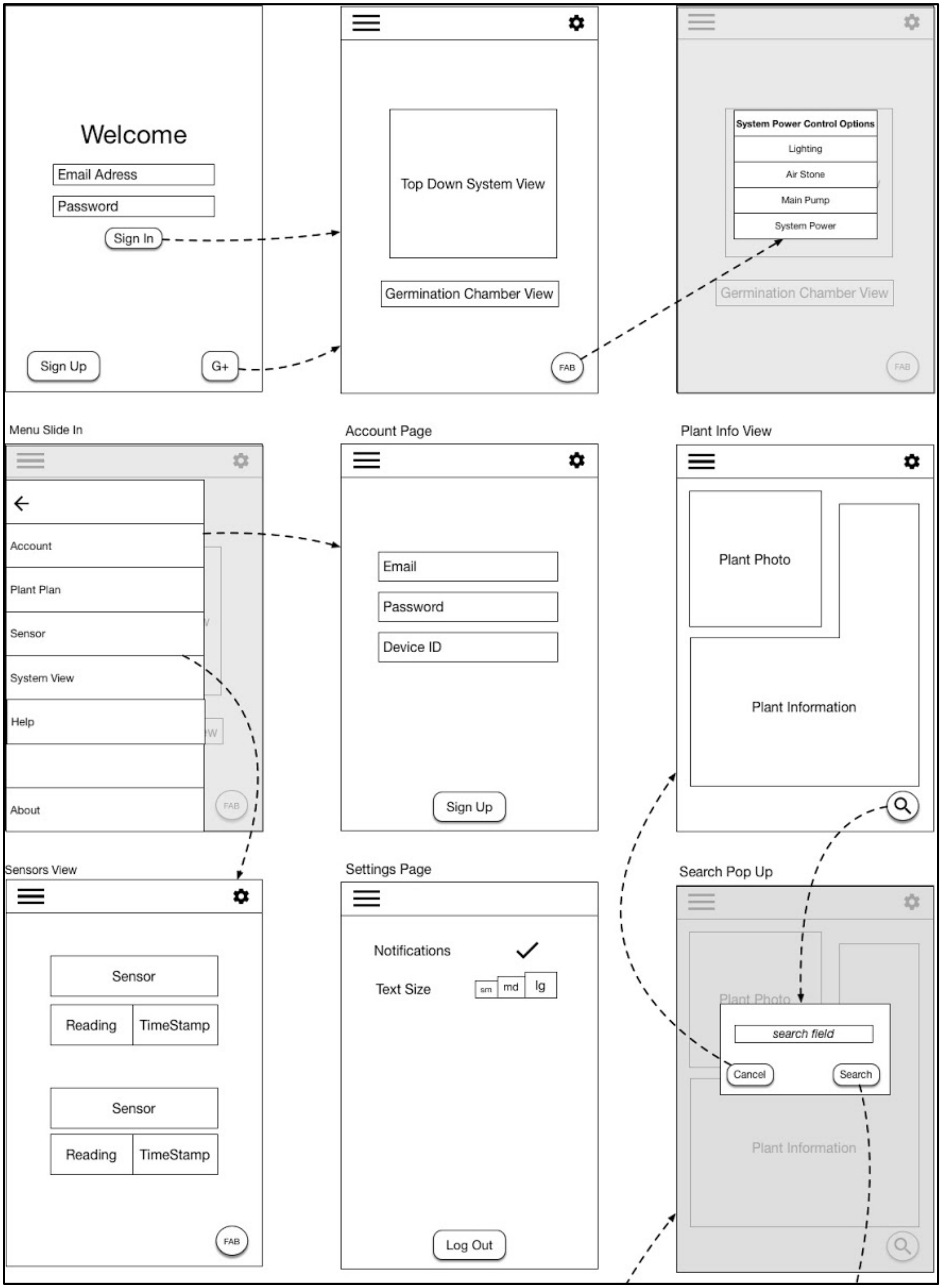


Figure 7.26: Mobile Application Screen Flow Diagram (Part 1 of 2)

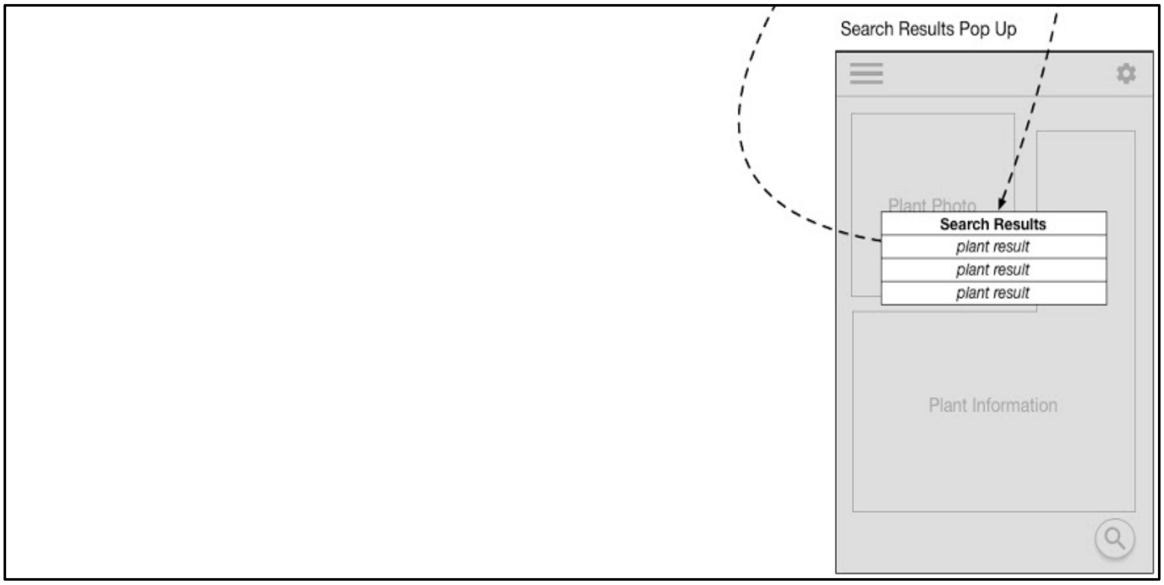


Figure 7.27: Mobile Application Screen Flow Diagram (Part 2 of 2)

7.5.2.1 - Software Class Descriptions

The code for the Android application will have a class hierarchy that involved some simple Object Oriented (OO) design pattern, as well as some encapsulation principles to wrap provide simple data objects. We will develop the Android application using the Java programming language, which is very suitable for our intended use of OO design patterns. The UI for the mobile application will be defined in a package of XML files, with each XML file defining each of the unique views for the application. A main XML file will also be included to instantiate a reference to each of the sub-hierarchical XML classes. As mentioned in section *3.2.11 Software IDE*, we will be utilizing the latest version of Android Studio which will include the use of the latest Android SDK. Our software design will incorporate many of the predefined classes, especially for most of the UI components. For example, each label, text input field, button, menu, pop-up, will require the code to import the predefined classes from the Android SDK.

Our main class structure that we will use will have only a couple of hierarchical classes and interfaces defined. We intend to incorporate the Factory Method OO design pattern in our Java class structure. The first main class will be a User class used to refer to the current user that is utilizing the system. This class will help to encapsulate all of the relevant pieces of data about a user in a simple object that can be easily created or destroyed. This User class will also include the methods for logging in, logging out, mutator methods to get and set the different attributes of the User object. Some of the attributes that will be included with a User are, email, status, and a list of device IDs that are owned by that user. Another encapsulation object will be created for a Plant. The Plant object will have attributes for the plant name, plant information paragraphs, plant growth cycle, plant photo, and plant nutrient requirements, planted status, growth status. A Plant class will have mutator methods, methods to update the growth timeline, and methods to provide the plant summary to the information view. Another encapsulating Sensor object will be developed to represent each sensor of the system and its latest reading. The Sensor object will have class attributes for the sensor name, latest sensor readings, and the timestamp of the latest reading. There will be mutator methods, and methods to retrieve the latest sensor reading. The last encapsulation object will be the System object to represent a model of the physical system and what plant is currently growing in the system. This class will have attributes to for the current plant growing, plant life cycle status, nutrient levels, and the physical device ID.

The Factory Method OO design pattern will be utilized for the UI View classes for each unique view. We intend to develop an overarching View interface that provides definitions for all of the different attributes and behaviors required by all of the different views. Then each unique view class will implement to hierarchal interface and implement only the attributes and behaviors as needed. Each of the unique View classes will also import the necessary UI element classes from the Android SDK. The unique sub View classes will have attributes for the view name, UI elements, and references to capture any possible user input from that view. One key method that will be developed in the View interface is a doMove method that will be used by each implementing class to pass data objects between the different view objects. This method can be overloaded by each unique view class as needed to pass different amounts of parameters. Through this use of OO design patterns, our UI will be able to function correctly while also keeping a simplistic code design.

7.5.2.2 - UI Design

In section *3.3.1 - Material Design* we discussed the Material Design guidelines we would be following for the mobile application for *WaterWise*. Within that section, we also discussed the necessity for a carefully chosen color palette. The color scheme for *WaterWise*'s mobile application consists of a primary color and an accent color with the standard colors for text and backgrounds, we used a Material Design color palette generator in order to generate the different forms of these colors that we need. For the primary color, we chose a green color with a hex value of #4CAF50. For the accent color we chose a pink color that would contrast well with the green, its hex value is #FF4081. Figure 7.28 shows the color palette we have chose and a previous of what these colors will look like together in Material Design.

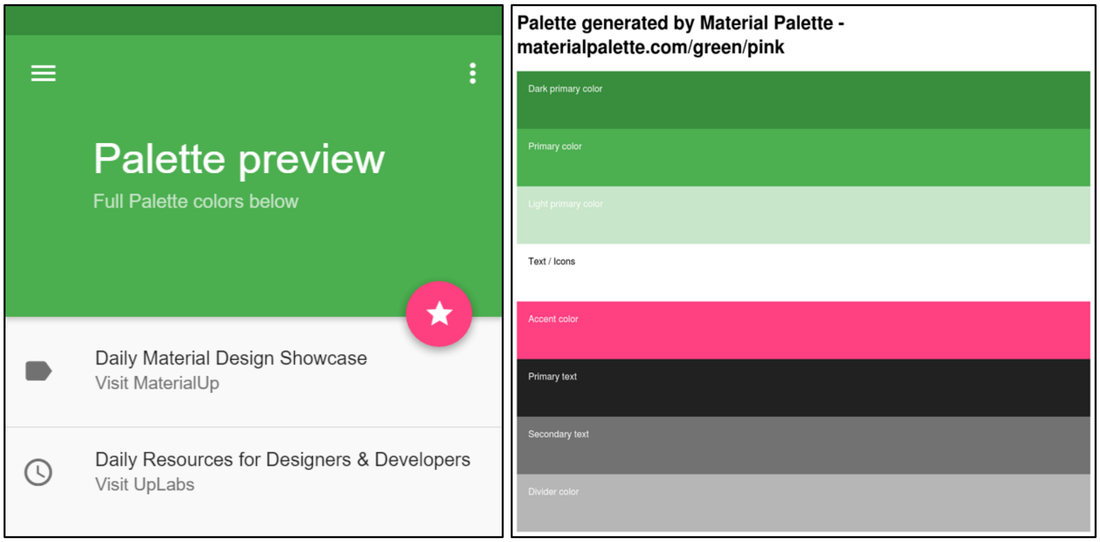


Figure 7.28: WaterWise Color Palette

7.5.2.3 - API Implementation

The mobile application for *WaterWise* will make use of a few different third-party services in order to create greater functionality. In order to incorporate a third-party service into an Android application, the usage of APIs is very common. API stands for application program interface and allows you to take a small portion of an application or service and interface with it from another application. Because our mobile application will be using Kinvey's server technology as a MbaaS, there is an API that we will have to make use of in order to access it. In addition to this API, we will also have to implement another API to allow the user to log into our mobile application using a Google Plus account.

The API for using Kinvey with an Android application has a straightforward implementation. In order for it to be properly integrated with any android application it must satisfy certain requirements. The Android application must be designed to only support Android SDK versions 9 and newer. The application must also import the Kinvey library in its main activity. Lastly, the library must be included as a dependency in the Gradle Script for that application. Once the application meets these requirements, the application must initialize a client using the client.builder() method within the Kinvey library.

The API necessary to allow the user to log into the mobile application using their Google Plus account is a little more complicated than the Kinvey API. In order to make it work, we first have to include the Google Play Services SDK in the project for the application in Android Studio. We then have to generate a configuration file so that we can unpack what we need from the SDK to include in our application. Once the SDK is included, we can then use methods defined in the Kinvey API to connect the Google Plus account to the user account.

7.6 - Software Back-end Design

7.6.1 - Database

Our Mobile application will require the use of a database on the “backend” of our application’s design. As discussed in section *3.2.7 Application Database*, we explored the different options to provide a database to serve our mobile application. For our design, we intend to utilize a Mobile Backend as a Service (MBaaS). The service we will utilize is called *Kinvey*. They provide a free level of service for small development applications that provides a limit of up to 1000 active user per month, 1 admin account, and up to 30 GB in data storage. These provisions will be more than enough for the development and testing of our mobile applications. As the system may be later marketed to consumers, Kinvey does provide an easy upgrade process to provide a higher level of service for an application.

Kinvey’s data management platform follows an entity relationship (ER) data model. The entities define the different tables that make up the entire database. Relationships are used to define behaviors between entities. For example, in our design, a User entity may have multiple WaterWise system entities they manage from the application. This relationship could be captured in a separate table that stores the user’s ID and the different system IDs as entries in the relationship database. In the Android language, the Kinvey API allows entities to be created by simply defining a new class for each entity that extends the GenericJson class from the package com.google.api.client.json.GenericJson. This will allow us to create the entities needed for our database such as User, Plant, and System. Each of these tables will have unique columns to store the necessary information for each data entry in the table.

In their API, Kinvey provides a simple predefined user entity with all of the methods and attributes that our mobile application will require. The Kinvey service also provides a simple integration functionality for users to login with their social media accounts. This be used in our application to allow Google+™ users to login with their credentials registered on their Google+™ account. The User class is already predefined in the GenericJson class, and it automatically provides all of the metadata fields needed for our application (first name, last name, email, username, and password). A signup method is included with this User class which takes in all of the user input from the application and creates a new User table entry populated from the data provided. There are also provided methods for logging in and logging out, which does account for data encryption processes for sensitive credential data. As an additional “bonus” feature to our design, Kinvey also provides a simple API method to provide email verification functionality during the signup process. When the user completes the signup process, the method *sendEmailVerification()*, can send an email with a confirmation link to the user, using the email address that the user has provided.

The Plant entities will all be defined in the database by the administrative developers of the system. These entities will be modeled after the Plant class definition to store all of the information about a wide variety of plants. We intend to source the information manually from hydroponic plant growth information resources from the internet. Kinvey's data management platform does allow a system administrator to manually import data entries to the applications Kinvey database. This Plants table will store medium quality image files for each plant, and Kinvey does provide simple file storage mechanisms especially for image files. Querying in Kinvey is also very straightforward to retrieve the necessary data for our mobile application, i.e. plant information, photos, and growth cycle.

Our database will also have an entity class to store the information about the different systems in use. The System entity will have fields for the device id and other relevant information from the System class structure discussed in section *7.5.2.1 - Software Classes*. This data will be easily referenced and updated with Kinvey's querying methods and relational table management. Figure 7.29 shows the ER model for our application's database.

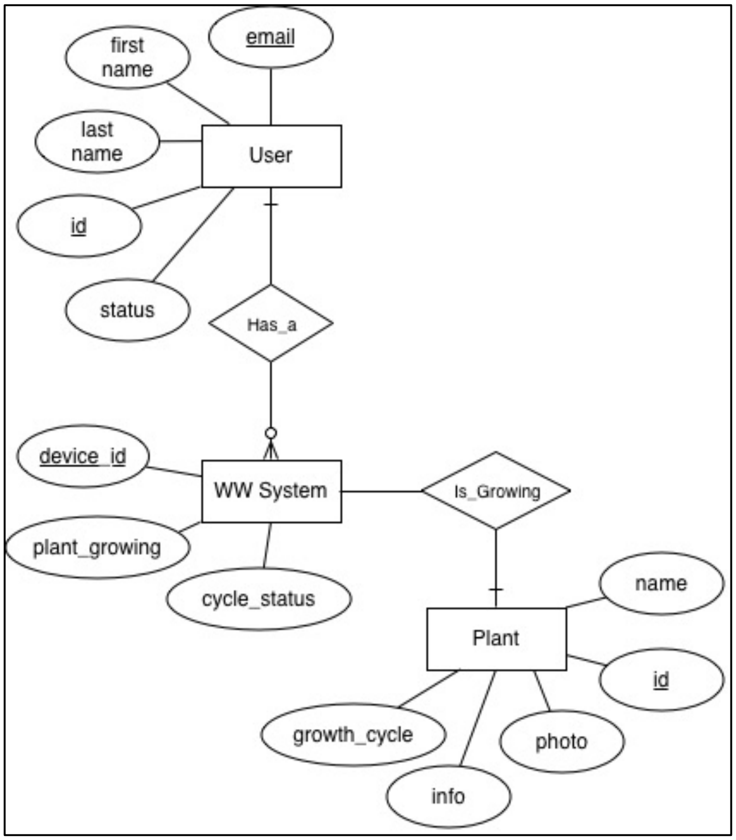


Figure 7.29: WaterWise Entity-Relationship Data Model

7.6.2 - Web Server

A core feature of the *WaterWise Hydroponic System* is to enable the user to interact with the system using an Android device. In order to accomplish this, we decided to use Wi-Fi between the mobile application and the main PCB. To add wireless connectivity to our PCB, we have decided to use the ESP8266 Wi-Fi module. This Wi-Fi module is capable of communicating with another device over Wi-Fi with the stipulation that it and the other device are connected to the same wireless network. The wifi module does this by hosting its own web server while either acting as a wireless access point for other devices or connecting to another access point.

For use in *WaterWise*, we will program the module to first act as an access point for other devices to connect to. While in this mode, the user will be able to connect their device to the access point and navigate to an IP address where they will be able to set the name of the wireless network they would like to connect the system to, and the password for that network. After this step is completed, the wifi module will again put up a server, however this time the server will be on the wireless network the user has specified. With this server, the mobile application will be able to connect with and communicate to the wifi module when the user requests interaction with the system.

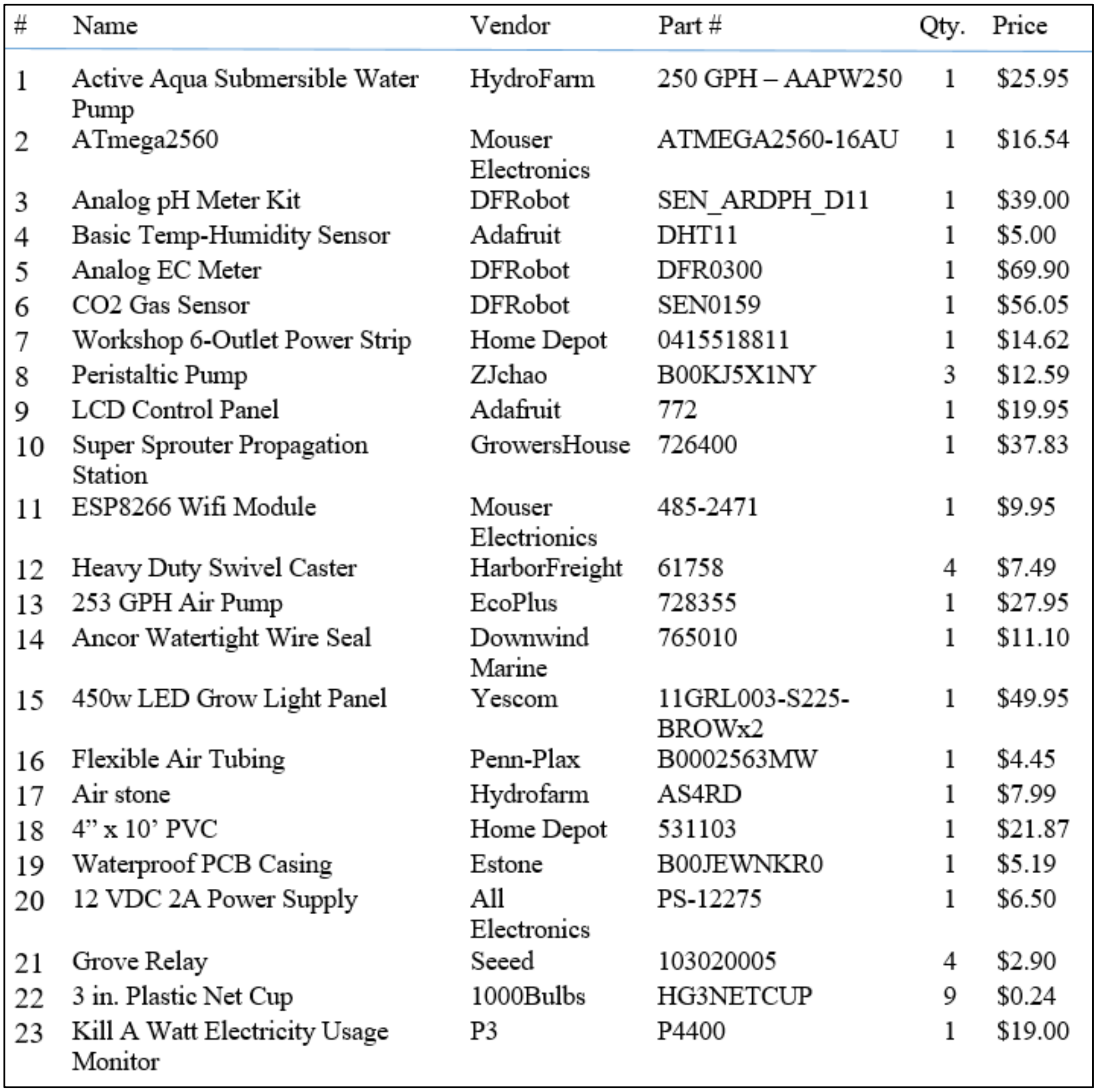
7.6.3 - Data Security

As discussed in section *3.2 Relevant Research*, our design must take into consideration the sensitive data that will be handled by the software systems. Namely for the *WaterWise* system these data pieces will be any user information and any private network credentials that the wireless module on the PCB uses to connect to the local private network. The need for this was also discussed in section *4.0 Standards*, in that any sensitive data related to the user of the system must be protected throughout the system so that it does not become viewable to any unintended parties. The user information will only be handled by the mobile application and the Kinvey MBaaS database. The Kinvey API does provide support for data encryption when passing data between the database and the application. Kinvey provides their ‘crypto’ extension for the Android library which allows a developer to apply encryption to user credentials, files and also offline file storage while stored on disk. The implementation uses AES encryption with Cipher-Block Chaining and PKCS5Padding. The file encryption and decryption is accomplished by applying a cipher to the IO streams. Static methods of the *Crypto* class can be used when reading or writing encrypted files.

While our design calls for data security, it is somewhat out of scope for the senior design project as the built prototype will only be used in a controlled development environment. It is also limited to implement as our selected MBaaS, Kinvey, only provides their encryption extension with the paid service agreements in their Business and Enterprise Editions of the software. This will not be an option to implement in our project as we will only be using Kinvey's Development level of service.

8.0 - Project Prototype Construction and Coding

8.1 - Parts Acquisition and Bill of Materials



#	Name	Vendor	Part #	Qty.	Price
1	Active Aqua Submersible Water Pump	HydroFarm	250 GPH – AAPW250	1	$25.95
2	ATmega2560	Mouser Electronics	ATMEGA2560-16AU	1	$16.54
3	Analog pH Meter Kit	DFRobot	SEN_ARDPH_D11	1	$39.00
4	Basic Temp-Humidity Sensor	Adafruit	DHT11	1	$5.00
5	Analog EC Meter	DFRobot	DFR0300	1	$69.90
6	CO2 Gas Sensor	DFRobot	SEN0159	1	$56.05
7	Workshop 6-Outlet Power Strip	Home Depot	0415518811	1	$14.62
8	Peristaltic Pump	ZJchao	B00KJ5X1NY	3	$12.59
9	LCD Control Panel	Adafruit	772	1	$19.95
10	Super Sprouter Propagation Station	GrowersHouse	726400	1	$37.83
11	ESP8266 Wifi Module	Mouser Electronics	485-2471	1	$9.95
12	Heavy Duty Swivel Caster	HarborFreight	61758	4	$7.49
13	253 GPH Air Pump	EcoPlus	728355	1	$27.95
14	Ancor Watertight Wire Seal	Downwind Marine	765010	1	$11.10
15	450w LED Grow Light Panel	Yescom	11GRL003-S225-BROWx2	1	$49.95
16	Flexible Air Tubing	Penn-Plax	B0002563MW	1	$4.45
17	Air stone	Hydrofarm	AS4RD	1	$7.99
18	4" x 10' PVC	Home Depot	531103	1	$21.87
19	Waterproof PCB Casing	Estone	B00JEWNKR0	1	$5.19
20	12 VDC 2A Power Supply	All Electronics	PS-12275	1	$6.50
21	Grove Relay	Seeed	103020005	4	$2.90
22	3 in. Plastic Net Cup	1000Bulbs	HG3NETCUP	9	$0.24
23	Kill A Watt Electricity Usage Monitor	P3	P4400	1	$19.00

Table 8.1: Bill of Materials

Total Cost: 530.28

8.2 - PCB Vendor and Assembly

After attending an educational seminar for EAGLE software, we have decided to download the free version of CadSoft EAGLE PCB design software. This free piece of software includes all of the necessary libraries and components that will enable us to complete our own PCB design. This software enables you to generate the schematic and respective board design files. Lastly, this software provides the ability to quickly generate the Gerber files that PCB vendors can utilize to manufacture, print, and mount our PCB and components.

We conducted some research on different PCB manufacturing services available on the market. Some of the important factors we considered in our research included pricing, turnaround time, and US based manufacturing. The turnaround time is very important for the build phase of our project, because we will need to obtain the board quickly and have enough time for prototyping and testing our design. Vendors that offer US based manufacturing typically have a shorter turnaround time, as there is less impact from shipping time in comparison to manufacturers that are based in China.

One manufacturer that stood out from the rest is 4PCB.com or known as Advanced Circuits. This company offers a deal of any two-layer PCB special for $33. Some of the specifications of the deal include a minimum quantity of 4 boards and a max size of 60 sq. in., and a lead time of 5 days. This company also offers a student discount program that allows students to order $33 boards with no minimum quantity. Additional features included by this company are: free PCB layout software, free PCB file check, and multilayer design discounts. Lastly, Advanced Circuits also provides sponsorships for collegiate engineering projects and competitions, and we intend to inquire about sponsorships from them.

9.0 - Project Prototype Testing

9.1 - Testing Environment

The construction of the physical structure for the *WaterWise* system will take place in the garage in the residence of Joseph Bender. This workbench environment will provide all the necessary space and tools to construct the system. We will construct the physical system at this location and perform any physical structure testing. We will require a semi indoor environment that is conducive for constructing lumber materials and working with flowing water. This environment will provide power the necessary access to power outlets and access to water. This location will also provide an ideal environment to store the system during construction and testing.

Testing the physical structure will require a period of time to begin growing plants without the electrical sensors and interface. This will require the construction of the system to be completed in a short amount of time at the beginning of the build phase of the project. By the end of week three, we should be completing the final stages of building the physical structure. Our initial testing of the physical structure will consist testing the main plumbing features of the design. Once these features are complete, we will connect the plumbing with PVC cement to finalize the construction of the main plumbing. After this phase, we will then complete the construction of the final structure. This phase will include mounting the lights and platform, as well as the outer paneling of the lower cabinet, and mount the cabinet doors.

We will be concurrently building and testing our electrical components in the UCF senior design lab. We will utilize all of the power supply, signal testing, and breadboards provided by the design lab in addition to our own electrical testing materials. We will also utilize our own small sealed pitcher of water to properly test all of the liquid sensors in the lab. This environment will be ideal for testing all of the electrical interfaces and sensors without having to physically integrate these components with the physical structure and risk any damage to the sensors or PCB. The main electrical testing equipment that we will require are: power supply, oscilloscope, multimeter, breadboard, wiring, resistors and capacitors, transistors, wiring, and schematic simulation tools.

9.2 - Structural Testing

The physical hydroponic system will require many different aspects of structural testing. We need to ensure that the structural components are constructed properly together in order to provide a safe, functional, and sustainable system. Our structural testing aspects will include water leak testing, physical load testing, functional movement testing, stability testing, material strength and durability testing, and electrical waterproof strategy testing. The culmination of all the aforementioned test strategies will provide a wholesome suite of test cases to ensure the functionality of our design.

The construction of the structural frame of lumber material will be one of the first build phases in our plan. Upon completion of this phase, we will conduct unit testing on this frame structure to ensure it can support an abundance of loading of at least twice the intended design load. This step is strategically important as the continuance of the build phases without conducting these unit test could lead to design failure and damage of other design components. The next strategic build phase is the plumbing design for our NFT hydroponic system. Before we cement the PVC piping in place, we will conduct testing with active water flows using a running water hose to ensure our physical orientation of the plumbing creates the desired water flow. Once we have confirmed that the PVC layout is correct, then we will apply the PVC cement to permanently connect the pipes together. After the PVC cement and water sealant has dried, we will then conduct more water flow testing to ensure there are absolutely no water leaks anywhere in the system plumbing. Once the waterproof quality testing is passed, then we can proceed with integrating the water reservoir and submersible pump into the plumbing of the system. This stage will then require water flow testing and calibration by adjusting the flow control valve of the submersible pump. After we have properly integrated and tested the submersible pump, we can then proceed with completing the remainder of the physical lumber construction.

The last functional step will be to ensure the overall complete structure is stable and movable. Ensuring this design quality will require tests to push the wheeled structure across multiple types of typical indoor floor surfaces. The level of friction between the wheels and the floor surfaces should be relatively low to allow a user to easily move the structure. The wheels' locking mechanism should properly hold the entire structure in position without slipping. Stability testing of the structure will require a series of forces applied at different angles of application to ensure the structure is not vulnerable to tipping over or a wobbling structure effect. The system needs to be stable enough as to not disturb the internal hydroponic system to avoid any water displacement from the main reservoir into the external environment.

When going through the structural testing of the fully assembled system, controlling the water level inside the growth channels was important in order to ensure that the nutrient solution was reaching the grow cups. This accomplished by a tedious and patient method of adjusting the flow rate to be even going to each channel and then adjusting the ball valve on the return manifold. Once the system had reached equilibrium, it was important to keep careful watch of any leaks in the system. Initially, there was a leak in the ball valve connection; however, applying Teflon tape to the connection quickly mitigated the leak and then we proceeded to continue the same process to find system equilibrium.

9.3 - Power Testing

In order to test the system's power consumption and efficiency, each component that uses power will be individually tested prior to a full system evaluation. The idea for testing each component separately is to ensure that the power supply, power consumption, and voltage values specified by the manufacturer are correct and will properly integrate with the rest of the system according to the overall design. For the small components, testing will require the use of lab

equipment such as a power supply and multimeter to ensure the values are at least very similar, understanding that testing conditions will not be perfect.
From testing each component to see if they met their design specifications, most of the sensors and small components tested to be accurate. However, one surprising discovery was that the peristaltic pumps pulled a much higher current than what they were rated for.

9.4 - Hardware-Software Integration

To ensure that the hardware and software are integrating according to our design, we must test that the readings are being correctly displayed on both the LCD panel and the app. For the LCD panel, the button control must be functioning in order to scroll through the display and will need to be tested in conjunction with the sensor data readings. If the button control is not functioning, we will not be able to retrieve all of the system data directly from the LCD panel. If it is functioning, by scrolling through the display we can check that the sensor readings that are showing on the display accurately match the readings on the computer. The same will be said for what is displayed on the Android application.

In addition to ensuring that the sensor readings are accurate, the LCD panel controls must also be tested. As described in the design section, the LCD panel will also be able to control power to certain components of the system. In order to confirm that these functions are working, testing will be accomplished by quickly turning each component off and back on, as some components can not be left off for very long while the system is running. The Android app will also have similar capabilities that need to be tested, such as pump control.

9.5 - Software Test Environment

The environment we will be using to test the mobile application for *WaterWise* will be provided by Android Studio. As we discussed earlier in section *3.2.11 - Software Development Environments*, Android Studio is the most popular IDE for Android application development. This is largely due to the fact that Android Studio has its own mobile device emulator to allow testing of a mobile application during development. The emulator will also allow us to test the application's UI and spacing on many different Android devices that can be loaded through profiles. We will primarily rely on this Android emulation for unit testing of our mobile application through all stages of development.

For larger, less frequent testing we will be utilizing Android Studio's ability to push an application directly to an Android device connected through USB. This may take longer than testing using the emulator, however it will allow us to perform more real world tests on an actual physical device. The Android device we will be using as the test device will be a Motorola XT1095 Cell Phone running

Android 6.0.1 Marshmallow. The device is also rooted to allow additional log generation and stability testing.

9.6 - Software Specific Testing

WaterWise utilizes three separate software systems that need to be tested individually. The first system that needs to be tested is the web page that will allow the user to connect the system to their wireless network. We will test this software component by first verifying that the wireless module properly sets itself in wireless access point mode. From there, we were verify that we are able to connect to the access point, and then navigate to the web page being hosted by the module. Next, we will test our ability to connect the module to multiple different wireless access points by providing the SSID and password for them though the web page. Finally, we will connect other devices to the same wireless access point as the wireless module and verify that we are able to use it to transfer data to the microcontroller.

The next system we will test is the mobile application for *WaterWise.* It will be tested in two phases. First, we will use the two software testing environments described in section *9.5 - Software Test Environment* to test for stability issues within the application. This will involve, but is not limited to: simulating random user input, checking hardware back button functionality to ensure no disruptions in application flows, and ensuring compatibility with Android multitasking. After ensuring that the mobile application is stable, we will move on to system integration testing. Here, we will insure that the mobile application is able to communicate properly with the *WaterWise* system. We will test sensor readings and different controls.

Once we have verified the functionality of those two systems, we will move on to testing the actual Kinvey database we will be using for this application. The testing will ensure that the device can connect with the database properly. We will utilize Kinvey's own query tracking capabilities to make sure that each query comes through as expected, and that the database is altered in the appropriate way. We will check the ability to create a new account on the database and the ability to change the account details that we will allow you to change on the account page. In addition to checking queries, we will ensure that the plant database that we will build and update for use with *WaterWise* can be interacted with properly. We will test our ability to log into Kinvey's database management software and update the database on the fly. We will also test to make sure that all of the information necessary for each plant is transferred properly to the mobile application.

10.0 - Administrative Content

10.1 - Milestones Discussion

This section of the document is dedicated to examining the overall objectives of the project that the group has completed or will complete in the later stages of the project. A milestone not limited to simply completing a tangible portion of the project, but rather overcoming a significant challenge experienced or foreseen in the project. For example, a major milestone could be overcoming a first-time experience at finalizing a PCB design. Another example could also be locating and solving a hidden bug in a piece of software during the testing phase. Milestones throughout the project will be both planned and unplanned, however we have done our best to plan accordingly based on our technical experience levels.

A few of the biggest milestones that we have already completed during the project are related to accomplishing major design decisions for the *WaterWise* system. This process involved a collaborative debate process to properly analyze each design decision carefully. For example, the *WaterWise* system infrastructure design was a point of major deliberation. We spent many discussions on several different aspects of how the physical structure of the design should be built based on other major design constraints. One clear example of a milestone in design was determining how the power to major sub-components of the system should be controlled i.e. submersible pump and lighting. After much research and deliberation, we were able to finalize our decision to avoid designing our own high power distribution circuit, and opt to implement a simpler relay-controlled power strip component. Another major design milestone involved where on the physical structure should the PCB and LCD control panel be mounted in order to accommodate the connection between the two components. This was big milestone in our design process as it affected the fundamental design of our physical structure. Throughout the design process we encountered many other significant milestones similar to the aforementioned examples. Through accomplishing these milestones, we achieved a well thought-out design for our system.

One of the most recent milestones that we are currently working to achieve is finalizing the design of our PCB. Currently we have the component requirements defined, including the amount of analog input pins required for all of the environmental sensors, output pins to drive signals to the relays of the power strip, and output pins to drive power to the peristaltic pumps array. Our lack of experience in PCB design has made it quite challenging to achieve this milestone. We have worked diligently to absorb as much information as possible to aid us in the design process. We have the base PCB design obtained from the open-source hardware provided by the company, Arduino. This resource has greatly advanced our progress to completing this milestone. As of now, the remaining steps to complete this milestone are as follows: identify and remove unnecessary components from Arduino open source schematic, insert the correct components in the PCB schematic design to accommodate our I/O requirements, and submit the Gerber files to a PCB manufacturer to receive our final PCB to implement. This is the most important milestone of the entire project, as it is one the key requirements for our design, and it is the most challenging milestone given our lack of experience.

Another major milestone for our project is acquiring all of the major parts required to build our designed system. This is a crucial milestone to complete as the structure cannot be built and tested without all of necessary parts. We are currently in the process of acquiring all of the parts required in our BOM discussed in section 8.0. This requires tracking the shipments and scheduling our build phases around when the necessary parts are received in stock. Fully completing this milestone will allow us to achieve our future milestones during the build phase.

As we enter the build and test phase of our project our initial major milestone will be to construct the hydroponic system and begin to successfully grow plants. This milestone can be broken down into a series of smaller milestones, such as constructing the system infrastructure and building the hydroponic plumbing system. Once the hydroponic system is complete we can begin to manually grow plants in the system to ensure that we in fact have a functioning hydroponic structure to automate with our electrical interface. The convenient nature of our project is that the two entities, hydroponic structure and electrical components, can be built and tested completely separate from each other and also concurrently. Once both of these milestones are complete, we can then move on to complete a later milestone of properly integrating the two systems according to our design. In accomplishing this final milestone, we should achieve our overall goal to develop an automated hydroponic system.

We have planned out a general schedule for our build and test phase to account for future milestones and possible challenges that may arise. We have also completed an abundant amount of research in our documentation to help reduce the likeliness of challenges arising in the future.

10.2 - Budget and Finance Discussion

The expected cost of this project according to the bill of materials was $530.28. It was fully expected that we would encounter cost overruns in certain areas due to adaptations in design and other unforeseen circumstances. Accordingly, the team decided to budget approximately $700 in order to assure we were prepared for any cost overruns. Companies that included the Home Depot, local hydroponic companies, and companies that the group members have personal connections with were sought after for third party funding. However, these attempts were unsuccessful and the WaterWise was fully self-funded.

The final cost to build the system was $756.21 and after an analysis of the final bill of materials, it was discovered that the most expensive portion of this project is the PCB interface and sensors while the least expensive is the structural components. This doesn't come as a surprise considering the extent of the interface and sensor components and as for the structural components, there is a good reason why hydroponics can easily be picked up as a hobby if the desire to grow plants exists. Without the electrical components of this system, the hydroponic components and structure are relatively inexpensive and there is a physical return on investment in the form of produce.

10.3 - Conclusion

The goal of the *WaterWise Hydroponic System* was to bring the agriculture practice known as Hydroponics to regular consumers with the lowest barrier of entry possible. While there are currently systems available to allow for consumers to create their own Hydroponic systems, they are almost always either require a lot of research and do-it-yourself ability, or are very expensive. It is our hope that our design will surpass competitor offerings through its use of: wireless connectivity, user-centric mobile application design, and system information and control delivered through a simple LCD screen with buttons.

We also believe that the knowledge gained through the research described in section *3.0 - Research related to Project Definition* and the designs discussed in sections *6.0 - Design Summary of Hardware and Software*, will not only satisfy the ABET requirements for graduating with a degree in Engineering, but give us valuable insight into what it is like to be an Engineer.

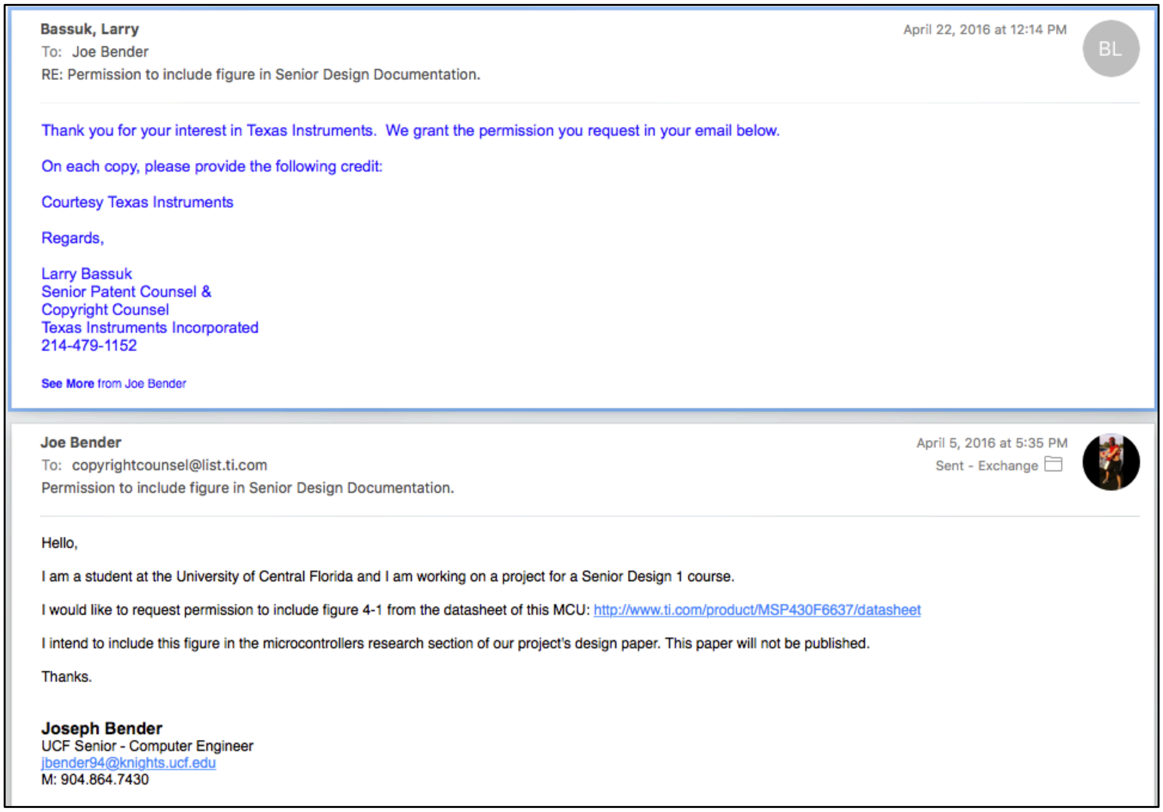
After completion of the project, the WaterWise proved to be a success and was a great learning experience for the entire team. The research presented in this paper prepared the team very well, and made the transition to the build phase very smooth in all aspects of the project. The project achieved its goal of bringing a common home project to the 21st century with innovative automation and monitoring and we believe that it would inspire more people to grow their green thumb.

Appendix A - References

1. "ABET." *Accreditation Board for Engineering and Technology*. N.p., n.d. Web. Feb. 2016.
2. "Basic Hydroponic Systems and How They Work." *Simply Hydroponics*. N.p., 2008. Web. 2016.
3. "Facts About Future Growing'sAeroponic Tower Garden® Technology." *Facts about the Tower Garden®*. N.p., n.d. Web. 26 Apr. 2016.
4. "Free System Plans." *Simply Hydroponics*. N.p., 2008. Web. Feb. 2016.
5. Gericke, W. F. *The Complete Guide to Soilless Gardening*. New York: Prentice-Hall, 1946. N. pag. Print.
6. "Getting Started." *Android Guide*. Kinvey, n.d. Web. Feb. 2016.
7. "Grove - Relay." *Www.epictinker.com*. N.p., n.d. Web. Mar. 2016.
8. "Growers House." *Super Sprouter Propagation Station W/ 7 in Dome*. N.p., n.d. Web. Mar. 2016.
9. "Growth in the Hydroponics Food Industry Set to Outpace Global Markets by 80%." *Growth in the Hydroponics Food Industry Set to Outpace Global Markets by 80%*. Manifest Mind, LLC, 21 Jan. 2014. Web. Feb. 2016.
10. "Hydroponic N.F.T. Systems." *Hydroponic N.F.T. Systems*. Home Hydro Systems, n.d. Web. Feb. 2016.
11. "Hydroponic Nutrient Solutions." *Hydroponic Nutrient Solutions*. N.p., n.d. Web. Mar. 2016.
12. "IEEE 802.11." Wikipedia. Wikimedia Foundation, n.d. Web. 26 Apr. 2016.
13. "Individual or Startup with Less than 25 Employees." *Backend as a Service Pricing*. N.p., n.d. Web. Mar. 2016.
14. "Just 4 Growers: Global Garden Community." Hydroponics-Dealing with High Temperatures. N.p., n.d. Web. 26 Apr. 2016.
15. "Just 4 Growers: Global Garden Community." NFT: A Beginner's Quick Start Guide. N.p., n.d. Web. 26 Apr. 2016.
16. "Introduction - Material Design - Google Design Guidelines." *Google Design Guidelines*. Google, Inc., n.d. Web. Mar. 2016.
17. Kevin. "Learn to Grow Food at Home." *Epic Gardening Learn Hydroponics Urban Gardening and Aquaponics Hydroponic Nutrients Guide Comments*. N.p., Feb. 2016. Web. Mar. 2016.
18. Laun, KD. "Relay-Controlled Power Strip." *Instructables.com*. N.p., n.d. Web. Mar. 2016.
19. "LED Grow Lights: The Facts." *LED Grow Lights - Indoor Gardening with LED Grow Lights*. N.p., n.d. Web. Mar. 2016.
20. Nari. "Touch Sensors vs. Mechanical Buttons." *Community.silabs.com*. Silicon Labs, 16 Oct. 2014. Web. Mar. 2016.
21. "Plant Nutrition." *Wikipedia*. Wikimedia Foundation, n.d. Web. Mar. 2016.

22. "Quick and Easy Bubbler System." *Simply Hydroponics*. N.p., 2008. Web. Feb. 2016.
23. "Research and Markets: Hydroponics Market by Crops (Tomato, Lettuce, Cucumber, Pepper, Marijuana & Others): A Global Insight Through 2015 to 2020 with Special Focus on the U.S. & India Market." *Reuters.com*. Research and Markets, 30 Mar. 2015. Web. Feb. 2016.
24. Schmidt, James C., John M. Gerber, and J. W. Courter. "Requirements for Plant Growth." *Requirements for Plant Growth*. N.p., n.d. Web. Mar. 2016.
25. "Sizing a Pump for Your Hydroponic Systems." What Size Pump Do I Need for My Hydroponic System? N.p., n.d. Web. 26 Apr. 2016.
26. "Start Integrating Google Sign-In into Your Android App." *Google Developers*. N.p., 2 Feb. 2016. Web. Mar. 2016.
27. Turner, Bambi. "How Hydroponics Works." *HowStuffWorks*. N.p., 20 Oct. 2008. Web. Feb. 2016.

Appendix B - Permissions



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Hello,

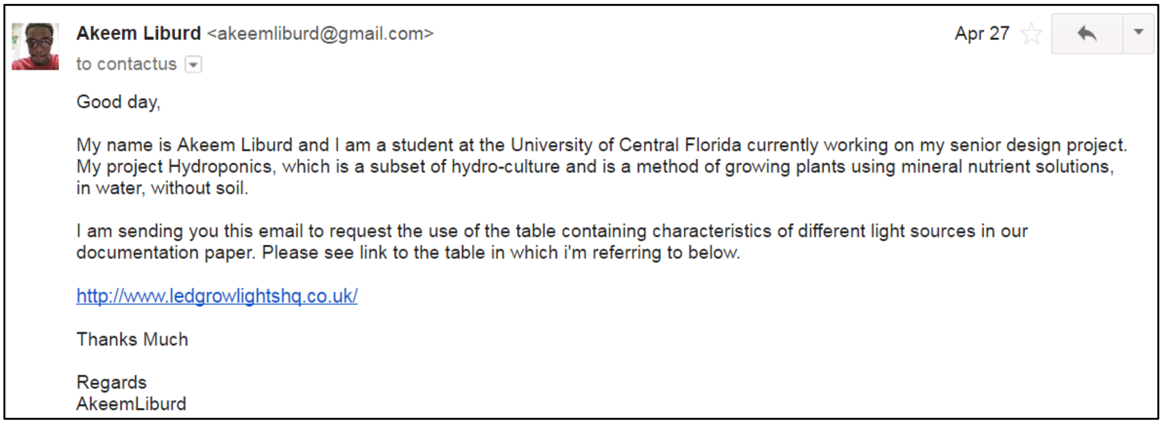
I am a student at the University of Central Florida and I am working on a project for a Senior Design 1 course.

I would like to request permission to include figure 4-1 from the datasheet of this MCU: http://www.ti.com/product/MSP430F6637/datasheet

I intend to include this figure in the microcontrollers research section of our project's design paper. This paper will not be published.

Thanks.

Joseph Bender
UCF Senior - Computer Engineer
jbender94@knights.ucf.edu
M: 904.864.7430



Akeem Liburd <akeemliburd@gmail.com> Apr 27

to contactus

Good day,

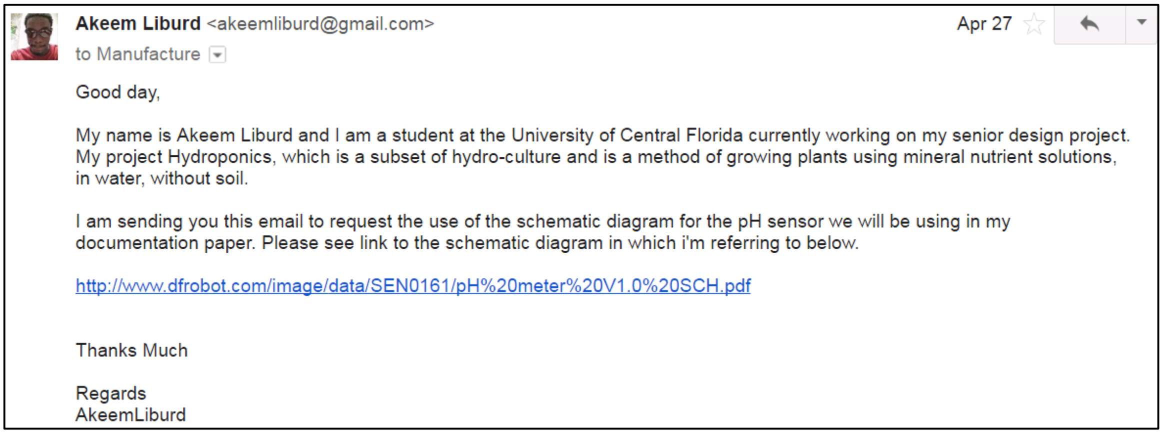
My name is Akeem Liburd and I am a student at the University of Central Florida currently working on my senior design project. My project Hydroponics, which is a subset of hydro-culture and is a method of growing plants using mineral nutrient solutions, in water, without soil.

I am sending you this email to request the use of the table containing characteristics of different light sources in our documentation paper. Please see link to the table in which i'm referring to below.

http://www.ledgrowlightshq.co.uk/

Thanks Much

Regards
AkeemLiburd



Akeem Liburd <akeemliburd@gmail.com> Apr 27

to Manufacture

Good day,

My name is Akeem Liburd and I am a student at the University of Central Florida currently working on my senior design project. My project Hydroponics, which is a subset of hydro-culture and is a method of growing plants using mineral nutrient solutions, in water, without soil.

I am sending you this email to request the use of the schematic diagram for the pH sensor we will be using in my documentation paper. Please see link to the schematic diagram in which i'm referring to below.

http://www.dfrobot.com/image/data/SEN0161/pH%20meter%20V1.0%20SCH.pdf

Thanks Much

Regards
AkeemLiburd