5-2019

Feasibility of Custom Aquaponics for Home Use

Jesse Blanchard
University of Arkansas, Fayetteville

Feasibility of Custom Aquaponics for Home Use

Jesse Blanchard

April 2019

University of Arkansas

Contents Page

Overview and Research Goals

Growing in popularity, aquaponic gardens are closed loop systems that take advantage of the nitrogen cycle to create a clean, nutrient-rich environment for fish and plants, both of which can be served fresh as high-quality food. But is an interconnected series of tanks and grow-beds too complex a project for families that want to produce their own table ready fruits, vegetables and fish at home? My research shows that while there are opportunities for homeowners to adopt and manage their own aquaponic system, limiting factors in terms of high infrastructure and on-going operational costs may put the owner at an economic loss in the first few years of operation. Furthermore, aquaponic systems rely on more technical skills than traditional farming and require background knowledge in basic chemistry, biology, nutrition, construction and plumbing. Despite these barriers, the aquaponic system detailed throughout this research produced over $700 worth of product as well as other intangible benefits including a better understanding of natural systems, operational experience with aquatic species with crop management and the enjoyment of a new and exciting hobby.

Aquaponics is not a new concept and consists of a wide variety of unique designs and varied information available on the internet. This content includes detailed information on large scale commercial systems as well as small scale hobby systems – the focus of my research. YouTube channels, hobbyist forums, researcher accounts, aqua-consultants and aquaponic businesses all offer designs and practices that claim to be optimized for the best possible growth for plants and fish. On the commercial side of things there are operations such as Ouroboros Farms in Half Moon Bay, California use a 30,000-gallon fishery and rows upon rows of crops to support an onsite diner and shop while offering tours and classes for those interested in learning about aquaponics. Alongside their fresh products, Ouroboros Farms also offers their own small scale systems for individual home use at varying sizes to meet the needs of varying clients (OuroborosFarms, 2019). Similarly, home hobbyist Shawn Paul and his team with MorningStarMission.org have designed and constructed an educational small scale systems out of Intermediate Bulk Container (IBC) totes to teach others the basics of aquaponics while benefiting from harvestable crops at home. Both promote highly efficient systems at varying sizes offering versatile growing methods in what they believe to be the best systems. Although each interchangeable variable in system design brings its own strengths and weaknesses, there is very limited formal research into aquaponic systems as a whole and even less on small scale aquaponic systems.

Most aquaponic systems are designed and constructed by hobbyists who enjoy producing their own food at home. Without investing thousands of dollars for specialized classes, Do It Yourself (DIY) designs make up most of the available opportunities for the average operator. When searching aquaponic systems online, many of the systems shown are small scale hobbyist designs composed of IBC totes, Styrofoam rafts, and 55 gallon drums. Popular YouTube channels including "The School of Aquaponics," "OutdoorLife," "Home Farm Ideas," "GrowingYourGreens," "Shawn Paul" and "Rob Bob's Aquaponics & Backyard Farm'' make up a majority of the top viewed aquaponic videos for their explanations and guides for small scale aquaponic systems at a low cost. For this reason, much of the research done in this investigation focuses on affordable options DIY style in order to make home systems more readily attainable for all skill levels. This replaces expensive tanks with water troughs and pond liners, bead filters with 55 gallon barrels as swirl filters and pH balanced grow media with pea gravel and expanded clay.

Feasibility of Custom Aquaponics for Home Use

The primary goal of this research is to access the feasibility of implementing and operating small scale aquaponic systems in a home setting to serve as a means of producing high quality fresh produce and fish protein to supplement similar store-bought products. Factors such as system cost, skill level and management requirements will be addressed alongside customizable, educational and sustainable aspects of aquaponic systems to determine whether home aquaponic systems are a feasible option for the home grower. To elaborate, feasibility in this research will refer to both economic costs relative to costs of the system. Outlined in this short investigation of aquaponic systems is a brief history of aquaponic systems and how they derive from aquaculture and hydroponics, detailed explanations of how the systems work, personal accounts from operating a system, management requirements, benefits of owning a system, opportunities for growth, and a conclusion on whether adoption of home aquaponics is feasible. Custom designs and results from a personal home system will be included throughout for a clearer understanding of the innerworkings of an operational aquaponic system encased in a greenhouse setting.

Section 1. Literature Review

Introduction and Background of Aquaponics

When evaluating aquaponic systems in their efficiency of production and wide variety of products available, it is important to first understand that "aquaponics is the cultivation of fish and plants together in a constructed, re-circulating ecosystem utilizing natural bacterial cycles to convert fish wastes to plant nutrients" (Sawyer, 2010, para. 4). Similar production methods including aquaculture and hydroponics focus solely on producing either fish or plants, but not both simultaneously. Aquaculture and hydroponic methods both have advantages and disadvantages, but aquaponic systems capitalize on the strengths of each to create a highly effective system that produces fibrous crops and quality fish protein in a single system requiring less maintenance while generating more product. This section explains the three methods of production in order to narrow in on small scale aquaponic systems as opposed to traditional aquaculture, hydroponics and large scale aquaponics for a better means of production at a home level.

Aquaculture.

Traditionally, aquaculture takes one species of fish and stocks them at a high density for grow-out production which is common around the world including freshwater and saltwater varieties of fish in both warm tropical areas and cooler polar waters (AgMRC, 2018). Many operations produce their own fry (juvenile fish) with selective breeding of mature brood stock fish and transfer them from tank to tank as they put on size and require more space or different diets and water parameters. With populations increasing and natural fish stocks declining, "global [aquaculture] production of farmed fish has grown from very little to approximately one-half of all fish eaten today" over a thirty year period (Lockwood, 2013, pp. 50-52).There are many varieties of aquaculture operations ranging from low tech freshwater ponds and massive sea cages to high tech indoor recirculation systems with instruments to measure and make changes to nearly any parameter to optimize growth rates (Arizona, n.d.). Regardless of which route is taken, there are a few requirements and issues present in aquaculture such as: species oriented requirements; adequate nutrition; waste management; continuous supply of fresh water; dissolved oxygen for survivability; and most importantly, maintaining clean water quality with an acceptable chemical balance between pH, ammonia, nitrites/nitrates, phosphates and other dissolved minerals or hardness of the water (WQA, 2019). While some fish species are more forgiving to failures in these requirements, each must be closely monitored and adjusted to minimize stress to the animals and in turn promote quick growth.

Unfortunately, there are a variety of common issues in relation to size and cost with modern aquaculture practices. Many of the issues listed can be resolved, but there are many more that can be addressed but not resolved under current methods. One major issue comes in the cost of operation. Up front infrastructure costs for a large scale aquaculture operation are extremely high when factoring in the costs of massive out tanks, proper temperature and lighting, all the small additions of oxygen lines and other such fail safes, and the fish themselves being relatively expensive to purchase, medicate and transport. Regarded as leaders in aquaculture practices in 2014, Bell Aquaculture in Albany Indiana faced bankruptcy in 2016 when faced with extreme debt and lawsuits (Slabaugh, 2017). From time spent personally working at Bell, it can be said that their infrastructure was top of the line and production of yellow perch, hybrid bass, rainbow trout and Coho salmon was unmatched in relation to the acreage of the operation. Complete with four warehouse sized buildings housing a fish hatchery, massive 70,000 gallon grow out tanks, filters over thirty feet tall, research and development sectors a small scale feed mill and a weak customer base for their products, it is not surprising that "the Bell Aquaculture fish farm went bankrupt and] has been sold for $14 million to a biotech company focused on building better fish" (Slabaugh, 2017, para. 1).

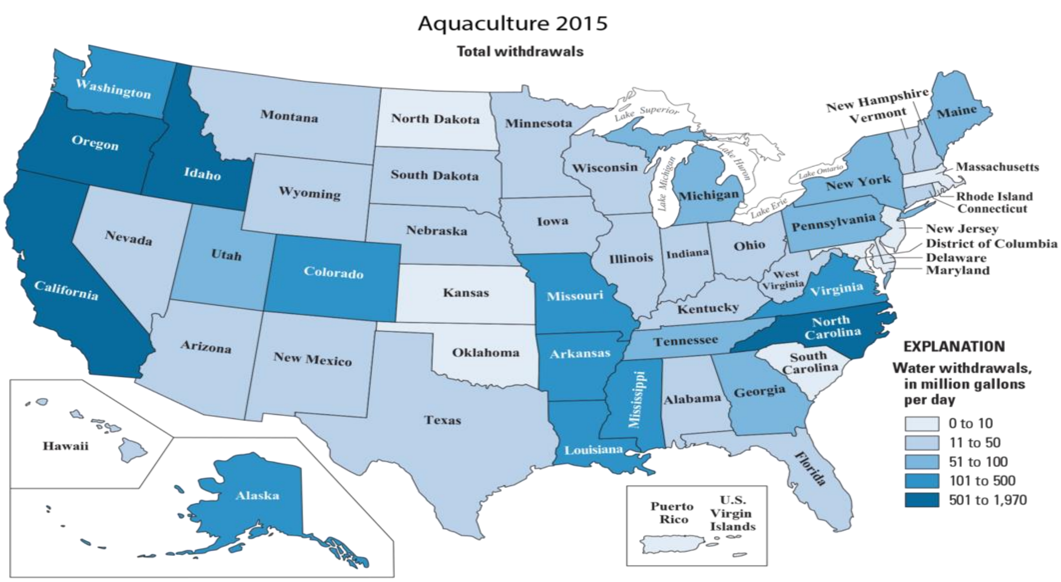


Figure 1. Aquaculture Water use from well withdraws in 2015. Figure created by the United States Geological Survey (USGS, 2015).

These fixed costs create an initial high entry barrier before factoring in the operational cost of moving and filtering hundreds of thousands of gallons of water on a daily basis (figure 1). While water is cheap in most areas, and even cheaper on its own well system, the cost of pumping water through a system with adequate flow requires a tremendous amount of energy (Troell, Tyedmers, Kautsky, & Ronnback, 2004). Pair this with the need to filter waste out of the water before recirculating it back to the fish and daily operational costs of producing fish requires the producer to either lapse in quality by cutting costs in operation or charge a premium for the product. The latter is often chosen due to cheap tilapia importing (Castiglione, 2018).

Fillets have taken preference among consumers as seen in a U.S. Census in 2012 where whole fish imported was approximately 64,979,792lbs and fresh/frozen fillets was estimated to be 347,236,566lbs (Brown Jr., Brown, & Rubio, 2013). Tilapia fillet imports have continued to grow as imports from China and Taiwan alone were estimated to be 192,870,000lbs in 2018 (Castiglione, 2018). This amount with a current price seen in Walmart of $2.88/lb. for fresh tilapia fillets and the target price point drops lower than the average producer can compete against without adding additional value (Walmart, 2019).

One method often used for capturing cost from the expensive filtration of these systems is to remove a majority of the waste water and sell it as a high grade fertilizer that is already in a mostly liquid state. Products such as *Alaska Fish Fertilizer* can be purchased at The Home Depot for $20 per gallon (TheHomeDepot, 2019). This organic substance provides more than adequate micronutrients that can be added in place of many synthetic fertilizers. The issue here is that filtering all these micronutrients out of the water would require many stage filtration systems that could not be feasibly achieved at a profit. Because of this, after the solids have been filtered out of the water column, the remaining nutrient rich water is often discharged into retention ponds where it slowly leeches into surrounding area and works its way into other water sources that are not accustomed to the high levels of available nutrients (Rees, 2014). While not inherently toxic to the environment, these nutrient levels can cause massive algae blooms and create dead zones in local water sources. This is not only an issue with high tech recirculation systems but is also apparent in outdoor ponds and sea cages where very little to none of the waste is collected to be filtered (Mckinnon, et al., 2008). Therefore, it is important that aquaculture operations closely monitor their waste production while trying to maximize fish production.

Hydroponics.

On the fiber side of production, we have the practice of hydroponics. Unlike aquaculture that specializes in protein production, hydroponics is defined as “the method of growing plants in water to which special chemicals are added, rather than growing them in earth” (Cambridge, n.d., n.p.).

What separates hydroponics from traditional farming is that water and a hard substrate is used instead of soil to transmit nutrients to the plants. With a recirculation of water in a closed loop, these systems create a continuous flow of water full of readily available nutrients for the plants to absorb through their roots and produce clean and high quality fruits and vegetables. These nutrients are generally added to the system as a concentrated liquid such as *Jobe’s Liquid Hydroponic Starter Plant Food Fertilizer* which can be purchased for $20 per 32 oz. liquid container at The Home Depot (TheHomeDepot, 2019). “Jobe’s Hydroponic Plant Foods were created to deliver balanced nutrition to hydroponic systems… [that] enhances the growth process of established plants and encourages strong stems and overall healthy plants for enhanced finishing” (Jobescompany, 2019, n.p.).

Most hydroponic systems are set up in a greenhouse environment to eliminate issues with pests and temperature fluctuations which removes the need for pesticides while conserving water and space as opposed to traditional production in the soil (Baptista, 2014). Seeds are grown tightly packed together in plastic net pots or sponges to conserve space before being moved to larger spaces to reach maturity. Because the plants are grown in movable media it is easy to transition them to their new grow-out location which often consists of a similar structure with more space between plants. Interconnected racking systems of PVC pipes or Styrofoam rafts are the most common types of grow beds because of the ability to move the media pots around while still allowing the roots to be fully submerged where they can receive all the nutrients they require.

Aquaponics.

Dating back to the Aztecs, the combination of fish and crops creates a symbiotic symphony of growth between waste producer, waste converter, and waste absorber with its own built in filtration system for rapid production of both fish and fresh produce. While there may not have been a way for the ancients to measure and conclude exactly how the process worked at the time, it was clear that the addition of animal waste to crops caused an increase in production. Aztecs devised *chinampas*, or what is now regarded as the first use of an aquaponic system that doubled as a means of waste treatment. Raised sediment islands rowed with crops were flooded in order provide the crops a constant water and nutrient supply while allowing navigation via canoe for an easy harvest of rapidly growing fruits and vegetables. “The canals surrounding the *chinampa* plots formed an illusion that these agricultural lands were floating on water, hence its misattribution as ‘floating gardens’” (Dhwty, 2014, para. 3).

Through much experimentation throughout the world, namely through word of mouth amongst hobbyist in Australia, aquaponics made tentative leaps in efficient production without much attention from the outside world until Dr. James Rakocy, considered to be the father of modern aquaponics, started releasing his research and results from his thirty year development project of tilapia production in aquaponic systems at the University of the Virgin Islands (UVI). While explaining his initial system designs and scalability with Dr. Wilson Lennard on their stories for The Aquaponics Doctors, Dr. Rakocy said “My research team first built a model aquaponic system out of three- and one-half oil barrels, a production method that has recently become popular. It produced 100 lbs (45 kg) of food in 4.5 months" (Rakocy J. , 2012). With this initial success, the team scaled up their system through multiple production trials before the final commercial system was established. This system contained four fish tanks rated at 2,060 gallons and six hydroponic tanks that held 1,320 gallons each. With four fish tanks the system could contain a constant supply of fish waste while being able to harvest fish at a staggered rate from one tank at a time. (Rakocy J. , 2012).

Making monumental leaps in production size from any previous hobbyist, Dr. Rakocy and his team at UVI created the first high volume commercial scale aquaponic system that many consider a starting point for designing their own systems due to the successes that this system design carried with it. The option for a more sustainable food production method became available, and hobbyists went to work designing their own unique systems to try to capture the most innovative properties that allow the operator to produce more, be more cost efficient and bring its own special aesthetic appeal. Many have "best" practices and special techniques that make their system better than their competitors and acquaintances.

Alongside these new technologies for production, fish products are becoming more acceptable amongst consumers. Tilapia are at the head of this trend because of their palatable taste and "a diversified production base and market base, which makes their sector [of production] more robust" (Tveteras, 2013, pp. 10-11). When designing an aquaponic system, many choose tilapia as a beginner fish because of their high tolerances to varied water parameters and temperatures, explosive growth rates and their popular 'non-fishy' flavor. Of aquatic species available in aquaponics, tilapia bring another very important strength as well: high stocking density. While results vary depending on tank sizing, generally "a stocking density of 0.25-0.33 lbs. of fish per every gallon of water" creates a stable environment for maintaining healthy fish (Pentair, 2016, p. 36). For these reasons, tilapia will be the main focus of this research.

How It Works: The Nitrogen Cycle

Combining three types of organisms in one closed system, aquaponics takes advantage of symbiotic relationships between waste producing fish, waste converting bacteria and nutrient absorbing plants. Through the chemical process known as the nitrogen cycle, aquaponic systems undergo the constant cycling of nutrients to create a healthy environment for all three organisms to thrive and be harvested from. Listed in this section are the three primary drivers and benefactors of the nitrogen cycle in order as seen in Diagram 1.

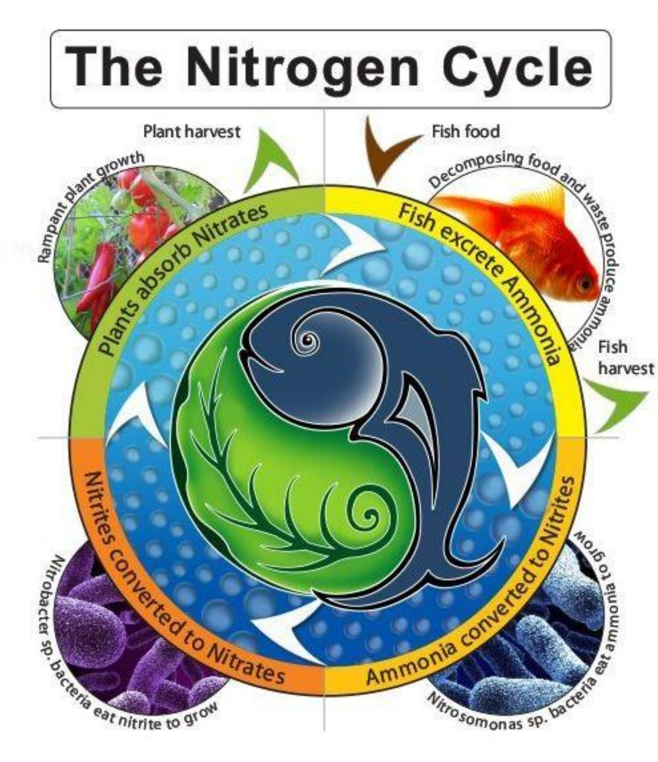


Diagram 1. The Nitrogen Cycle beginning top right with fish food being introduced to and cycling through clockwise until plant harvest top left. Diagram created by Backyard Aquaponics (Aquaponics, 2012).

Fish.

Simply put, aquaponics is the process of growing fresh fish along with table ready fruits and vegetables in a closed loop nutrient cycle that starts with the fish. Aquatic species produce high amounts of ammonia as they convert food into waste at a rate that is directly proportional to the species and amount of food available. For this case we will be discussing Blue Nile Tilapia (*Oreochromis Niloticus*) which is a popular aquaponic fish due to its high tolerance to poor water quality and its rapid growth rate. While ammonia production rate is highly variable in relation to fish health, initial water parameters, and type of feed they are receiving, "the ammonia production rate is estimated to be 10 grams/100 pounds of fish/day [for tilapia]" (Rakocy J. E., 1989, n.p.). Blue tilapia can grow up to about three pounds which would translate to one hundred adults producing about 30 grams of ammonia per day in the system. Ammonia is toxic to aquatic species and tilapia begin to die at ammonia concentrations around 2 mg/liter (expressed as NH3-N) and nitrite levels of 5 mg/liter (Rakocy J. E., 1989). Because of this, ammonia and nitrites in an aquaponic system require regular measurements, and interventions such as water changes (replacing dirty water with fresh water) need to be available for quick execution. This will ensure healthy fish.

Bacterium.

One method for keeping the ammonia levels in check would be to continuously add fresh water while expelling the waste water, but this costly solution is not needed because of the smallest, but most important organism in the system: nitrifying bacteria. Completed in two steps, the nitrification process converts ammonia into nitrites (No2) aerobically with *Nitrosomonas sp.* bacteria and then to nitrates (No3) through *Nitrobacter sp.* bacteria to be absorbed by the plants in the system. “Nitrite is a less poisonous compound for the fish compared to ammonia but is still of no use for the plants” (Fu, para. 9). After the second conversion, the nitrate is readily accessible to plants as a good source of nutrient. The good thing is, fish can tolerate a much higher level of nitrate compared to nitrite or ammonia. The bacteria grow on nearly any surface submerged in the water and can often be seen as a light milky film on dark surfaces. The initial conversion of ammonia to nitrites is an aerobic process; the bacteria do require adequate oxygen levels in the water. This is rarely an issue due to the fish already receiving oxygen through diffusing stones. With an abundance of ammonia and oxygen the bacteria can establish itself within one week of filling the system with water and only days to adapt to higher levels of ammonia. “The cycling period takes about 2 weeks to a month normally, however this is greatly affected by your external environments. In colder countries, this tends to be slower and faster on the other hand in warmer geographical locations. That’s why it’s always easier to cycle your system during summer times” (Fu, para. 11). As the fish grow and produce more waste from increased food consumption, the bacteria in the system grows with the fish to keep the water at a healthy balance.

Plants.

Rounding off the nitrogen cycle in this system are the fruit and vegetable plants grown by absorbing nutrients directly from the water. Of the many nutrients plants require for healthy growth, nitrates are the main staple for growth followed by phosphates and potassium. Nitrates are naturally readily available from the fish waste and are rapidly taken up by the plants to round off the nitrogen cycle in the system and complete the water cleaning process for the fish. While this concludes the nitrogen cycle in the system, it doesn’t provide the plants with an adequate supply of phosphates or potassium so these nutrients must enter the system another way. “Most aquaponic systems shoot for phosphate concentrations between 10 and 20 ppm for light feeders (vegetative crops) and between 20 and 40 ppm for heavy feeders (tomatoes, cucumbers, etc.)" (Storey, The Most Important Things to Know About Phosphorus, 2017). Luckily most fresh water suppliers, both well and city water, provide phosphates around 10-12 ppm to sustain systems with weekly water refills. Proof of this added nutrient is clearly shown when first setting up a system as algae blooms *nearly always* afflict juvenile systems (Gab, 2015).

While there are many methods for removing the algae involving chemicals, simply covering the tank to reduce light exposure while refraining from adding more feed to the system can cut down the algae population within a day or two. By adding a couple of common Plecostomus from a local fish store and the algae will no longer be an issue. Referred to as the most common aquarium fish, the common Plecostomus (Pleco) is a species of armored catfish that is often seen in aquariums as a 'suckerfish' or algae cleaner. It is important to note that these armored catfish are believed to only eat algae but "unfortunately, nothing could be further from the truth, and this belief leads to many underfed and malnourished plecos. They are actually omnivores, and eat plant material, algae, insects and small crustaceans in the wild" (Brand, 2014, para. 10). When paired with a fish receiving a high protein feed such as tilapia, the common pleco will thrive in the aquaponic system and may even out-grow the other fish to a maximum length of two feet (Brand, 2014).

Section 2. Materials and Methods

Greenhouse System Design

In this section, I will explain some common designs and methods of construction that were selected and adjusted for use in the greenhouse system. The primary goal of the greenhouse system in the first year of operation was to serve as a base level for measuring water quality, temperatures and growth rates between the Blue Nile Tilapia and plants in order to later rotate out inefficient or difficult pieces. For this reason, each component of the greenhouse system was placed separately in removable sections connected by PVC pipes and rubber airline tubing. These sections can be broken up into- one lined 600 gallon in ground sump, two separate Rubbermaid water troughs rated at 300 gallons and 100 gallons for fish tanks, one 8 foot by 3 foot Styrofoam raft grow bed, one overhead frame of 2 inch PVC pipe for continuous flow and lastly, two separate box frames housing three bell siphons in half 55 gallon barrels.

Currently, the plan is to break operation into two phases. Phase one for testing and acquiring a feel for operating an aquaponic system. The second phase focuses on optimizing the system for low cost and low maintenance operation in order to further simplify system management and produce higher yields. Phase two begins when water temperatures reach a consistent 72 degrees Fahrenheit without the need for any additional heating during the latter half of spring 2019. Phase one is covered in this section while phase two is mentioned in future plans and covers potential improvements that have not been settled on at this time.

General flow starts in the sump through a 560 gallon per hour (GPH) pump into the bell siphons before draining into the 300 gallon tank where the flow is split. One pump rated at 330 GPH pushes water seven feet up and through the gradually sloping 2 inch PVC pipe and drains into the 100 gallon fish tank where it overflows through a fish guard and back into the sump. This completes one of the two loops. Because the 300 gallon tank receives water from the 560 GPH pump faster than the 330 GPH pump, the water drains out of a fish guard and into the Styrofoam raft system where it overflows a standpipe and returns to the sump. This completes the second loop and ensures that the system will continue flowing if one side is closed off for maintenance.

Sump Tank.

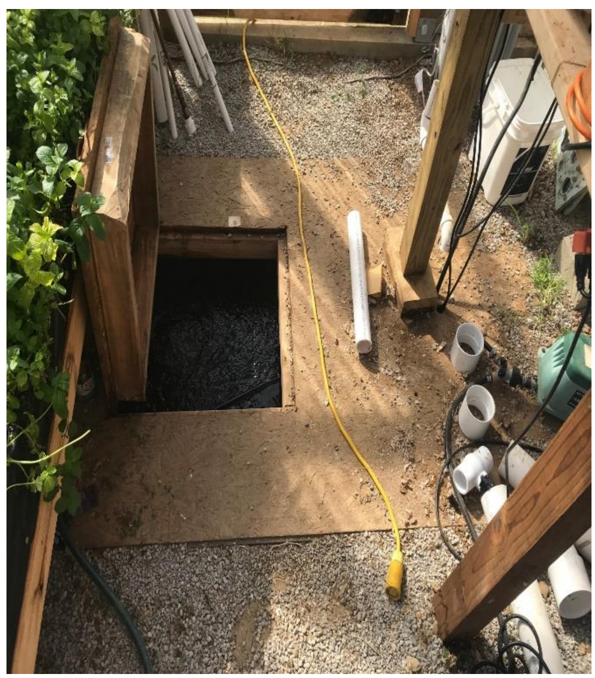


Figure 2. Left to right, initial frame being set on sump tank for fit to complete and covered sump tank with openable hatch. Photo source from Jesse Blanchard.

Sump Tank Materials:

- 1 – 12’x16’ nylon mesh pond liner
- 4 – 4”x4”x8’ treated lumber boards
- 1 – 2”x4”x8’ treated lumber board
- 1 – 4’x8’ sheet of OSB
- 2 – small hinges
- Screws
- Optional: string or handle

Serving as the lowest point in the greenhouse system, the sump tank (Figure 2) can be described as a six by four foot square hole that slopes down to a depth of three and a half feet and lined with a nylon mesh pond liner. While this hole could have been dug by hand, the use of a tractor with a six-foot wide bucket saved hours of digging. Once the surrounding dirt work and concrete footing were put in place, a simple frame of treated 4x4 lumber was placed on top of the sump hole with four support beams crossing the hole on the short edge (two more than visible in Figure 2). After ensuring a supportive fit around the edges to be sure the frame cannot fall into the hole, it was removed, and the nylon liner was placed inside the sump and lightly covered with dirt on the edges to hold in place while creases were taken out. The frame was put back in place before filling in the outer edges with dirt to hold everything in place. Next, one sheet of 8’x4’ OSB paneling was placed and squared on top of the frame while I traced out the supports on the OSB from inside the sump. A small panel was then cut between the lines to be trimmed and replaced later as a trapdoor to view into the sump. For further support, 2"x4" lumber was cut and framed along the bottom of the opening and secured overhanging the OSB by 1/4" on three sides to support the trapdoor from the bottom. Lastly, small hinges were used to secure the trapdoor lid to the frame before drilling a small hole and running a piece of twine through to serve as a handle. With this, the sump was ready to be filled.

Fish Tanks.

Figure 3. Rubbermaid 300-gallon water trough with PVC framed Styrofoam/wire lid and two timed feeders for growing out tilapia. Photo source from Jesse Blanchard.

Figure 4. Rubbermaid 100-gallon water trough with Styrofoam rafts to serve as a juvenile fish tank. Photo source from Jesse Blanchard.

Fish Tank(s) Materials:

- 1 – Rubbermaid Water Trough at 300 gallons
- 1 – Rubbermaid Water Trough at 100 gallons
- 1 – 1 1/2"x 8' PVC pipe
- 1 – 1 1/2" PVC corner
- 1 – 1 1/2" PVC cap
- PVC glue
- Silicone glue
- Drill bit for holes

For housing the tilapia for the greenhouse system, I had two Rubbermaid water troughs rated at one hundred and three hundred gallons available for use after some minor leak repair. After the patches dried, the tanks were placed at their required height and became the first above ground addition to the greenhouse. Near the top of the three hundred gallon, or grow-out tank, a hole large enough to silicone in a 1 1/2” PVC pipe was cut to serve as an overflow drain. To ensure no juvenile fish were able to exit the tank at this location, an elbow and cap were attached and angled down into the tank with small holes to still allow continuous water flow. This addition was not attached to the tank until after the raft grow-bed was constructed and placed to ensure the correct height was determined to ensure proper drainage. Water from the flood/drain beds periodically drains into the tank as each bell siphon activates and pulls water out of the grow-bed and into the grow-out tank. A simple PVC frame with Styrofoam and netting wire was added to provide the fish with shade on sunny days while ensuring no jumpers could escape (Figure 3).

Also present in the grow-out tank is a six inch airstone for aeration and a water pump rated at 340 gph to push water up the back wall and through the PVC planter run across the ceiling. While this pump is not able to produce nearly 340 gph due to the seven-foot head height, it moves enough water to provide nourishment to the elevated crops above and receive extra aeration when dropping into the one hundred gallon fish. Similar to the grow-out tank, the one hundred gallon, or juvenile tank, received the same drainage system with the only difference being that it drained directly into the in-ground sump tank. Because this tank is aerated from the falling water no airstone was added but two small Styrofoam rafts were placed into the tank to account for low flow rate and accumulation of excess nutrients (Figure 4).

Grow Beds and Media.

Aquaponic systems follow a similar method as hydroponics in terms of plant production as both are devoid of soil and rely on water to transport nutrients to the crops. In most cases soil is replaced with media such as gravel, expanded clay, lava rock, tumbled glass, and recycled plastic to act as a support structure for plant roots. This media also doubles as a biological filter that collects solid waste to act as a high grade fertilizer. There are primarily three common designs for aquaponic grow beds: raft, flood/drain and continuous flow.

Raft systems are generally used for plants that do not require extensive root systems to support a tall stalk and are the preferred option for many producers of leafy greens. As seen in Figure 5, these cheap and easy to construct rafts are most commonly made of Styrofoam sheets with plastic net pots that hang down into the water to house the plants. Water underneath the pots need to only be four to six inches deep to allow roots enough room to hang and draw up nutrients. Oxygen for bacterial health is optional in this design if the bed receives a continuous flow of nutrient rich water but can be added to promote overall oxygen saturation of the aquaponic system if desired. Rafts can also be used as a starting area for new seeds to be later transplanted as the plants mature and can be placed directly after the fish tank to serve as an easily cleanable solids collector via hanging roots. This is the most popular choice amongst producers due to low maintenance and high yield qualities.

Figure 5. Lined 8’x3’ Box Raft Planter for starting seeds and growing out leafy greens. Squash, mint, basil, rosemary, tomatoes, cucumbers, broccoli and watermelon seedlings visible. Photo source from Jesse Blanchard.

Styrofoam Raft Materials:

- 1 – 8’x10’ Pond Liner
- 3 – 4’x8’ Styrofoam Boards
- 2 – 4’x8’ Sheets of Plywood
- 2 – 4”x4”x8’ Wooden Boards
- 4 – 2”x6”x8’ Wooden Boards
- 1 – 2”x4”x8’ Wooden Board
- 1 – 2” PVC Pipe at 4’
- 1 – Male 2” PVC Adaptor
- 1 – Female 2” PVC Adaptor
- Screws

- Silicone Sealant
- Staples

This simple raft system is simple and can be started by creating a wooden frame of 2x6s that is near 4'x8'x6" with two additional support 2"x4"s running across the bottom of the frame spaced evenly to divide the tank into three sections. The 2"x6"s for this should be 'on end' which means that the 2" sides are facing up and down. This creates more strength in the frame and will prevent later warping due to water weight. Next, cut the plywood to fit the in the bottom of the 2"x6" frame and on top of the 2"x4"s. This will serve as the base to hold the liner. To save time later, cut the 4x4s to the desired height and place on the bottom of the frame flush with the plywood for extra support. One in each corner and at the 2"x4"s will ensure lasting strength. Once this is done the liner can be placed inside the frame and cut around the edges before being stapled on along the top or outside of the frame to hold in place. Once set, the drain pipe can be put in place by cutting a hole in the liner and plywood to match the 2" PVC male adaptor before connecting the two on either side of the frame with silicone to ensure no leaks occur. The 2" PVC standpipe on top should come up about 4.5-5 inches from the bottom of the frame to give at least one inch of space from the maximum water line. The 2" PVC pipe going below the frame can be cut to a desirable length for drainage. Lastly, the Styrofoam sheets can be cut to fit inside the lined frame so that they fit loosely near the top. Holes to place plastic net pots can be added for desired plant growth density.

On the more complicated side of things, the option for a flood/drain can be utilized as a large biofilter that slowly fills with water before rapidly draining. To achieve this unique flow a bell siphon (Figures 5 and 6) is used to keep water levels below a certain height and doubling as an oxygenator by pulling water and air through the media and down the standpipe. Acting as a rapid accelerator, the bell siphon pulls water through the holes in the bottom of the bell and up over the standpipe in a pressurized suction action- hence the name. Holes are cut at the base of the bell to establish a minimum water level that breaks the suction when the water drops below the holes and allows air into the system. A secondary cover with smaller holes is often utilized in order to separate the media from the bell to prevent blockage and reduced water flow.

Constructing a bell siphon is simple and cheap when using a readily available and sturdy material like PVC pipe. Sizing varies for amount of water needed to drain, but for this example the common half drum design adapted from Spaceman Spiff's "Make a Bell Siphon" tutorial on *Instructables* was chosen to fit inside the greenhouse system (Spiff, 2014).

Figure 6. Six half 55gallon drums filled with pea gravel and expanded clay with bell siphons to rapidly drain water from media. Squash, tomatoes, watermelon and jalapeno peppers visible. Photo source from Jesse Blanchard.

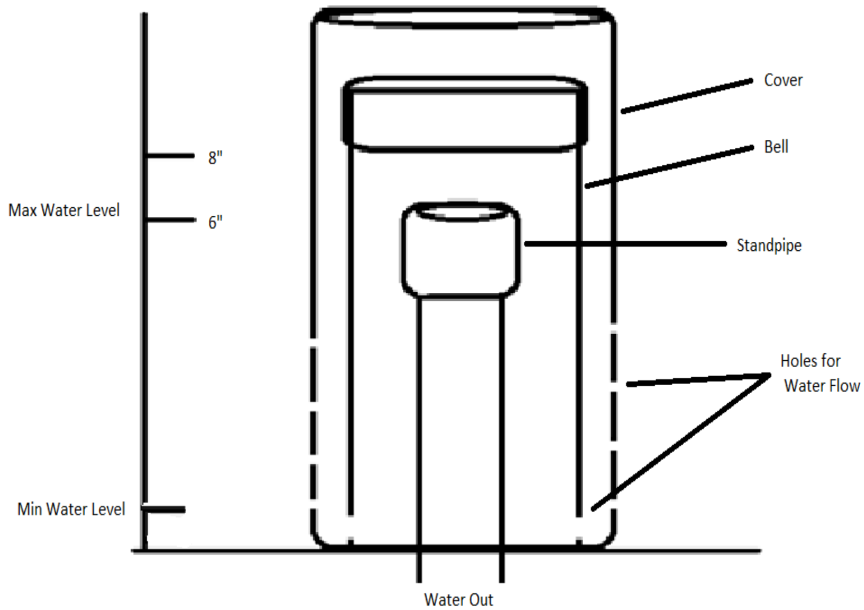


Figure 7. Cross Section of a Bell Siphon housed in Figure 6. Figure created by Jesse Blanchard.

Bell Siphon Materials:

Standpipe

- 2 – 3/4" PVC pipe at 8" and 6" long
- 1 – 3/4" to 1" bell adaptor
- 1 – 3/4" threaded to slip male adaptor
- 1 – 3/4" threaded to slip female adaptor
- 2 – #18 O-rings
- 1 – 3/4" elbow

Bell Dome

- 1 – 1 1/2" PVC pipe at 10" long
- 1 – 1 1/2" PVC cap

Cover

- 1 – 2" PVC pipe at 12" long

- 1 – 2” PVC cap (optional but recommended)

Recommended

- PVC Glue
- 12-15” String

Begin by matching the male adaptor with an appropriately sized drill bit so that the adaptor will fit snugly with an O-ring threaded on both sides of the barrel once the hole is cut. Slip the two pieces of 3/4” pipe into the top and bottom of the adaptors with the 6” on top and the 8” on bottom with the elbow attached. Finish the standpipe by attaching the bell to the top. If this project is desired long term, then use appropriate glue to protect against leaks. Next, cut holes at the desired minimum water level in the 1 1/2” pipe (recommended at 0.5-1”) and attach the cap to the other end to complete the bell. This should be approximately two inches taller than the standpipe. For easy future maintenance, tie the string to the top of the bell for easy removal if needed. Finally, drill an abundance of small holes in the cover pipe at various levels both above and at minimum water level and loosely attach the cap on the top as this is mainly to keep debris out and does not require a tight fit. Then simply place the bell over the standpipe and then the cover over the bell and the bell siphon is complete.

The final type of grow bed used in this system is the continuous flow method using the same plastic net pots placed in a two inch PVC pipe filled with pea gravel (Figure 7, page 54). This style of planter provides the plants with a constant flow of nutrient rich water to create a new filtration system between fish tanks to ensure the receiving end gets a cleaner water supply.

Figure 8. Rectangle shaped 2” PVC with gravel filled plastic net pots continuous flow system. Juvenile cucumber plants visible. Photo source from Jesse Blanchard.

3” PVC Continuous Flow Materials:

- PVC glue
- 2 – 3” PVC pipes at 10-12ft
- 1 – 3” PVC pipe at 8ft
- 3 – 3” PVC elbows
- 1 – 3” PVC T joint
- 1 – 3” to 1” PVC adaptor
- 1 – 2” PVC pipe at 8ft
- 1 – 2” PVC ball valve
- 2 – 2” PVC Elbow

Begin this design by cutting the 8’x3” pipe into two 3ft sections before laying out the 3” PVC pipes, elbows and T joint into a large rectangle with the T joint exiting as a continuation of a 3ft side. Make sure everything fits together well and then glue this frame together as it needs to be solid before continuing. Once dry, cut the desired number of holes sized at the plastic net pots to be placed in upon completion as well as a small hole to serve as a water inlet. Continue by placing the frame in position overhead before continuing. Once this is done, add approximately one foot of leftover 3” pipe to the T joint and cap it with the 3” to 2” adaptor. From here attach a small section of 2” pipe to both ends of the ball valve (facing down for later convenience) and attach to the adaptor in the previous step. From here add a 2” elbow and add the desired length of 2” PVC pipe dropping down towards the next tank before adding one final elbow and small section of 2” PVC pipe horizontally over the tank. For added oxygen diffusion into the water, cut holes or slits into the bottom side of this final pipe to allow water to drain from many locations. Adjust positioning as needed and glue all remaining joints together before adding the net pots and filling with water. I recommend closing the ball valve about halfway to ensure proper root saturation.

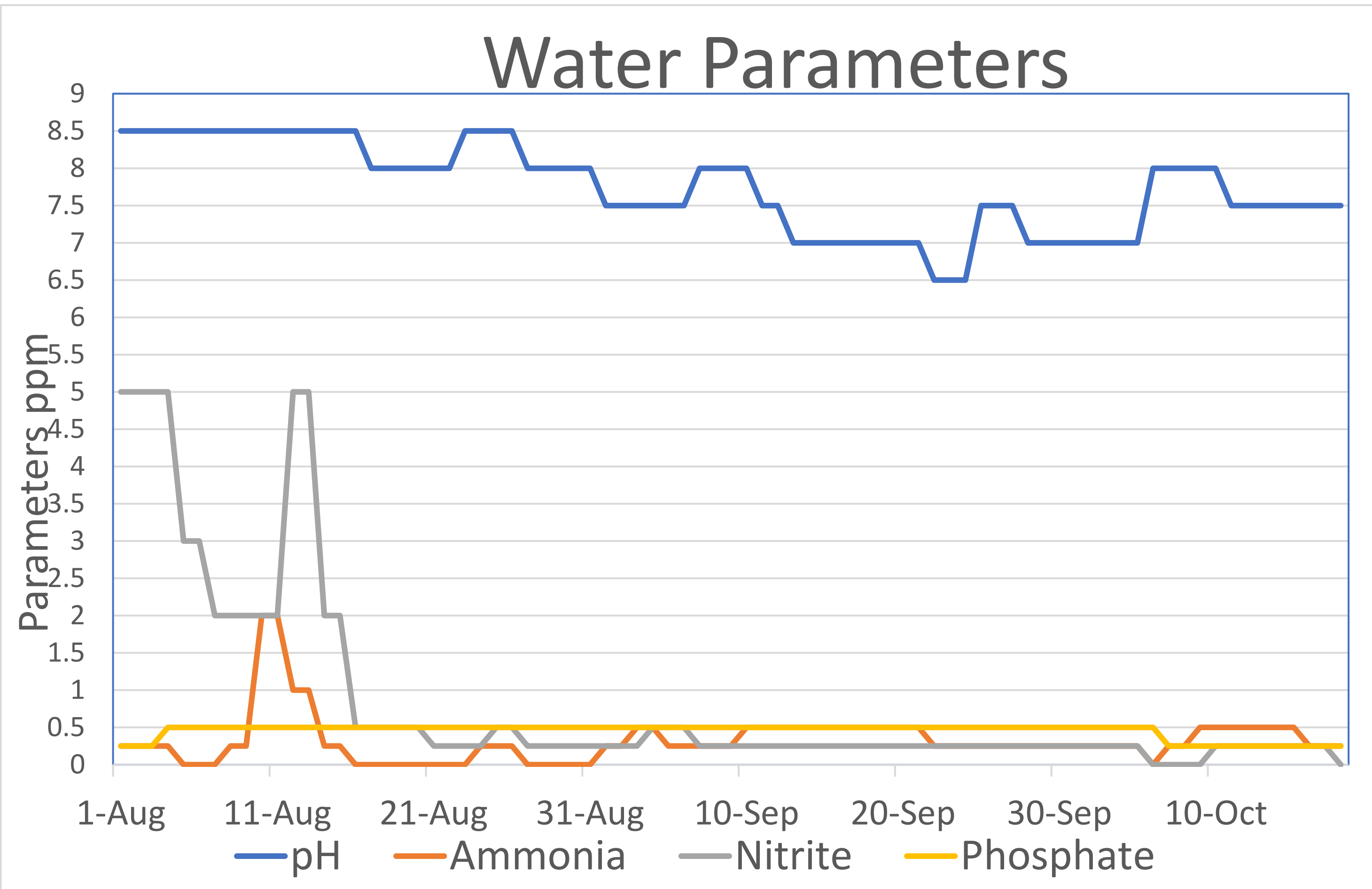
System Management Requirements

This section covers general management practices from a wide variety of operators for optimal system health and backed up with information gathered from operating my own small scale system. These observations can be used as a light guide for those thinking about starting their own systems in an easy to understand fashion.

Water Quality.

Arguably the most important aspect of an aquaponic system is to measure and maintain water quality/parameters that must be kept within safe levels for aquatic life to thrive and crops to produce. Upon filling the system with water the first time, an ammonia starter will be needed to kickstart the nitrogen cycle in the system. If fish are available at the start then they work as an excellent ammonia source, but an equal alternative of pelleted fish or dog food would suffice. After the initial bacteria begins its culture in the water, parameters should stable out with ammonia and nitrites around 0.5ppm, phosphates around 0.25ppm and a pH around 7.5. At this resting point the fish will be in a safe zone with a buffer before being too high to sustain life while phosphates are low enough to avoid large algae blooms and the water pH is basic enough to deter harmful parasites or fungus.

Graph 1 represents data from the first three months of operating a juvenile aquaponic system where measurements began as soon as the nitrogen cycle started, and Nitrites became measurable in the water column. The visible spike in mid-August represents the changing of feed that the fish were receiving to a larger size. The fish were slow to take to the new sinking pellets and therefore left feed in hard to remove places in the system to slowly decompose and release high levels of ammonia. After this spike and the nitrifying bacteria culture matured, the water parameters became more constant with only small fluctuations depending on how much the fish wasted feed. The water pH from the city of Fayetteville comes at a constant 8.5 into the system and can be seen spiking the water pH each time more water was added to the naturally acidifying water (Graph 1).



Graph 1. Measured water chemicals from the first three months of operation to view the beginnings of the nitrogen cycle. Graph created by data from Jesse Blanchard.

While not included in the graph with the other water parameters, other important nutrients are also present in an aquaponic system. Potassium for example, is not readily available in the water added to the system and may be added as needed in the form of cheap potassium hydroxide (caustic lye) for low water pH around 6.0 systems and potassium sulfate for high water pH above 8.5 systems. "Potassium deficiencies will show up initially as interveinal chlorosis (when the space between the plant veins yellow, but the veins stay green), starting in the older growth. This is because potassium is mobile in the plant, allowing the plant to reallocate what potassium it has from the old growth to the new, delicate growth" (Storey, 6 Things You Need to Know About Potassium in Aquaponics, 2017). It is important to establish that potassium deficiency symptoms may also be a desynchronization of potassium, calcium and magnesium. If this is the case, then both calcium and magnesium pills can be added to the system as needed. This can be done in small increments until new growth lacks yellowing veins or brown edges.

Fish Growth and Health.

Caring for the fish in an aquaponic system is often the most labor intensive and interactive aspect of daily maintenance and serves as a control measure for the nitrogen cycle in the system as a whole. Because the fish in the system are the only things directly being fed, this is the only nutrient source entering the system that can be errored on both low and high sides to create imbalances in the whole system while stressing the fish. A general rule of thumb in the aquarium hobby is to feed as much as the fish will eat in two minutes time twice a day, but because aquaponic fish are often grown for harvest, this can be increased to three or four times a day (Sharpe, 18). As long as excess feed is taken out of the system after a regular feeding the likelihood of an ammonia spike or imbalance is rarely an issue once the system has established itself. This daily feeding can be done by hand or carefully measured out through automatic feeders to ensure that the fish have enough feed to sustain growth. It is also important to note that temperature highly influences the amount of feed the fish will accept with higher temperatures raising metabolic rates and increasing appetite.

Overall fish health can be measured through growth rates, appearance and behavior on a daily basis as well. When fish become stressed, they often rest at the bottom of the tank or near the surface with dull colors and reject opportunities to feed. If this behavior becomes apparent at any time, water quality needs to be checked and corrected as needed. If water parameters are within acceptable levels, then an issue with the fish itself may be possible. Some choose to cull or remove the fish as soon as this sick behavior occurs while others choose to transfer the afflicted fish into smaller tanks where they can be closely monitored and medicated if needed. Issues of this type often occur when first receiving fish as they may come in sick or just be adjusting to new water quality or just before harvest as their size and diet requirements produce more waste in the water.

On the lighter side of things, breeding healthy fish once they reach an appropriate size is always an option for both replenishing harvested stock and keeping a constant ammonia source in the system while saving money from not purchasing new fish stocks. Either alongside or a repurposing of the hospital tanks for medicating sick fish, a one male to three or four female ratio can be added induce breeding in a safer environment than the grow out tank. Most species will breed upon being introduced to the new tank with fresh water and something as simple as a planting pot that they can fit inside. Species such as tilapia can breed and produce self-sufficient fry in less than two weeks and can be bred immediately after the removal of the fry. While this method for replenishing stocks is not for all and requires more work transporting fish between tanks, it is a viable option for long term operations.

Plant Management.

Oddly enough, while operating an aquaponic system the most produced item in the system requires the least amount of care. Once the seeds are planted and germinate, the plants only need to be placed in their final grow-out area, lightly trimmed on occasion and harvested. Fruiting plants including tomatoes and squash rarely need any trimming once established and their only care requirement involves picking ripe fruits and providing supports for heavy limbs. This can be achieved with simple wire or wooden frames once plants reach maturity. Crops such as cucumbers, melons and berries consist of vines that must be trained along support structures while maturing and then picked from while producing. Herbs and spices such as rosemary, mint, thyme, and basil grow extremely rapidly and only require trimming which serves also as harvesting.

For those who wish to continue the same genetic strands of produce, seeds can be harvested and dried for replacement. For fruiting plants this simple process requires picking the fruit and removing the seeds before drying and storing or replanting. Leafy greens are even easier to receive seeds from and often occurs with a day or two of accidental neglect as they produce flowers at the top of stems that upon pollination give an abundance of seeds. From my experience, plants like mint produce new stalks through their roots and can take over an entire section of grow beds or clog drain pipes at a rapid pace, so it is advised to grow mint in its own section to remove the chances of choking out other crops. Figure 9 shows the explosive and harmful growth of mint in the greenhouse system.

Figure 9. Mint overgrowth and drain blockage only five days after the last trimming. Photos sourced from Jesse Blanchard.

Pest Control.

Of the many vermin that may plague an aquaponic system, the most common are typically found in most gardens and can be dealt with in similar and responsible ways. Even in confined greenhouse settings, pests such as mites, aphids, caterpillars, moths, beetles, weevils, flies, slugs and grasshoppers can rapidly infest the plants. Because of the inclusion of an aquatic species and important bacterial colony, chemical pesticides should not be used on an aquaponic system unless complete and perfect care is taken to avoid contact with the water and substrate. Cleaner methods for pest control are often as simple as rotating types of crops grown, using safe compounds to change the pH of the environment, or the addition of a species that will consume the problematic species. Rotating crops in the system gives pests, such as beetles and aphids, less time to establish themselves in a lasting colony that may spring up each time weather conditions meet their requirements. Changing the pH similar to the example above with the aphids and mold is another cheap and viable method as long as no drastic changes are made to the water.

Introducing a new species to the system can also serve as an effective solution to many common pests. Insects similar to and including ladybugs consume aphids, arachnids consume flies and ants, frogs consume most insects and arachnids, and snakes will take care of anything that can fit in their mouths. While it may seem simple to simply add a control species and solve the current problem at hand, this can lead to imbalances in the food chain and create new issues. Care must be taken when adding new species as they may take over with an adequate food supply and few predators. To avoid this issue, only add a small population as a test and be ready to add a predator to the species that was just added and so forth. If imbalances occur, the inclusion of the next predator species can be added one after another until an easily removable predator balances out the system. Of the possible pest control measures, this miniature biosphere method is both extremely effective while reducing extra input costs and removing the need for harsh chemicals that can harm the aquaponic ecosystem as well as the surrounding natural ecosystem if allowed to spread.

Moving up the scale in pest size, mice and rats are known to chew on electrical cables and rubber tubbing and can be trapped in baited live traps or in common mouse traps to quickly remove them from the system. Alternatively, a healthy cat housed nearby and given free reign may produce a similar outcome in rodent issues. Any larger pests may require trapping to relocate or termination as smaller traps and integrated pest management may not handle racoons, possums, or birds of prey. To avoid issues with pests of this size it is advised that an indoor or covered system be used if needed.

Section 3. Greenhouse System Results

Figure 10. Greenhouse system as viewed from the south with compost heater in preparation for cold winter months to come. Photo source from Jesse Blanchard.

Beginning with two fifty-gallon barrels equipped with solid waste collectors and stocked with hardy bluegill in an effort to add fertilizer to the garden, this project evolved in both size and complexity finally reaching a 1,200 gallon system housed in a ten by sixteen foot greenhouse complete with its own compost heater (Figure 9). The final product includes: one in ground lined sump tank holding approximately 600 gallons, a one hundred gallon juvenile fish tank, a three hundred gallon fish grow out tank, three fifty gallon drums cut in half and converted into flood/drain grow beds filled with pea gravel and expanded clay, one fifty gallon lined raft planter, and twenty six foot of 3” PVC pipe filled with water and planting pots.

All but the compost pile is encased within the polycarbonate paneling of the home built greenhouse with four side windows and one small vent window on both ends. The structure itself is concrete footed and supported by ten treated 4x4s with a peak height of thirteen feet. Of the building process the greenhouse itself took the longest to construct at three months because many sections required an extra set of hands and could only be worked weekends. Once the structure was completed, the construction and addition of grow-beds and fish tanks connected by PVC pipes took less than a week to begin cycling water.

On July 27, 2018 one hundred and thirty Blue Tilapia were added into the system as inch long fingerlings to ensure approximately one hundred survivors after transportation stresses of shipping. The Blue Tilapia fingerlings were purchased online from Tilapia Depot in St. Augustine, Florida for $1.25 apiece. "Blue Tilapia are commonly used with aquaponics and are the number one seller because of their cold hardiness, surviving down to 50 degrees and can also withstand a high temperature of 98 degrees" (TilapiaDepot, 2019). As projected, due to transport stresses and early competition, the final count rests around eighty to ninety healthy fish averaging one pound and a half in February 2019. Three algae eating plecos were temporarily added alongside the tilapia for early algae control and grown out to be sold back to the local fish store after the tilapia were large enough to handle any algae blooms. On the same day the fish were added to the system, seeds were scattered onto the wet pea gravel pots in the floating raft system to begin germination and growth shortly after. By taking this approach, ammonia levels from the growing fish were high enough to kick off the nitrogen cycle and provide nutrients for the newly rooting seed. Both fish and plants continue to grow healthily in junction despite various setbacks and changes to the system over nearly one year of operation.

Costs and Benefits of Greenhouse System in Year One

Costs.

The total cost as of February 2019 is about $6,165.00 in purchased materials for construction of the greenhouse and the system inside along with the fish, seeds and later improvements. A vast majority of the cost are tied to the greenhouse and physical system and came out to be approximately $5,295.98. Much of this high cost can be attributed to the quality design of the greenhouse structure itself. Equipment such as pumps and heaters used to operate the system came out to be approximately $520 before improvements to remove some energy requirements. The plant seeds and tilapia cost only $251.68 with a high survivability rate of fish at approximately eighty to ninety still growing rapidly.

Table 1.

Operational Costs of Running the Greenhouse System for the First Year

Yearly Greenhouse Utility Costs							
Item	Amps	Watts	kWh (AxW/1,000)	Hours/Day	Days per Year	Cost per Unit kWh	Annual Total
560 gph Pump	1.2	120	0.144	24	365	0.1	$126.14
330 gph Pump	0.8	120	0.096	24	365	0.1	$84.10
210 gph Pump	0.45	120	0.054	24	365	0.1	$47.30
Air Pump	1.6	120	0.192	24	365	0.1	$168.19
Radiator	12.5	120	1.5	24	160	0.1	$576.00
Tower Heater	12.5	120	1.5	24	160	0.1	$576.00
Water Heater	2.5	120	0.3	24	160	0.1	$115.20
							$1,692.94
			Water	60 Gallons per Week	52 Weeks	$00.015 /Gallon	$46.80
						System Total	**$1,739.74**

Note: All values are calculated at maximum values to project the maximum costs possible before any future improvements are made to the system.

Operational costs for the system come in the form of water and electrical utility costs and have been calculated based on averages paid monthly in Farmington, Arkansas under Ozark Electric and Washington Water Authority. Table 1 represents the first year of operation and will be used to make predictions for costs future costs after improvements are made. For example, all three pumps are currently being removed and better insulation will be prepared for next winter to cut out the cost of heating the greenhouse for approximately 160 days of the year- the most expensive portion of operational costs.

Alongside infrastructure and operational costs, labor hours have also been calculated based on time of construction and operational maintenance of the system. Much of the physical labor for construction was primarily completed by two or three workers at a time during weekends with clear weather. Group hours of work came out to be approximately 55 combined hours between three workers. At a rate of $15 per hour as a rounded value of an average construction wage of $14.80, the total cost of labor comes out to $825 (Payscale, 2019). This is a high end estimate as many of the added hours were simple tasks that required more than one person to hold items to be secured. Many of the construction tasks could be completed solo, but the addition of help made the construction process easy.

Operational maintenance has been conducted by one person for mere minutes per day due to the addition of automated fish feeders and lack of any major issues in the system. Most days required approximately three to five minutes of refilling automatic feeders, harvesting ripe produce and looking over the system for any issues. While this management can hardly be classified as labor, at a $15 per hour rate the cost of management can be estimated between $25 and $40 per year with no major issues to manage. This estimate is probably on the low end but was calculated based off the greenhouse system management requirements and does not include time spent watching the system for enjoyment.

Benefits.

Gains from the greenhouse aquaponic system in the first year of operation can be measured in terms of educational aspects, produced items in tilapia and fresh produce, experience and overall enjoyment from operation. While the last two do not have a direct dollar value assigned to them, it can be stated that without the interest to see this project through completion, the initial cost would have been too high a barrier of entry. In terms of education from research and operating the system, aquaponic tutorial classes can be taken to learn the science and techniques of aquaponics. One such class is offered by Nelson & Pade for $1,195 and is titled the Aquaponics Master Class (Pade, 2019). The up-front educational cost of a class similar to this was avoided through self-research and operation of the greenhouse system.

Items produced though the first year of operation included tomatoes, jalapeno peppers, bell peppers, yellow squash, fresh cut mint, fresh cut basil and tilapia fillets. Prices for these products are $2.39, $2.39, $5.99, $2.39, $14, $7.99, and $2.88 respectively on a per pound basis (Walmart, 2019). In the first year of production the greenhouse system will have produced approximately six pounds of tomatoes, one pound of jalapeno peppers, one pound of bell peppers, four pounds of yellow squash, fifteen pounds of mint, three pounds of basil and one hundred and fifty pounds of tilapia fillets. With the prices listed above, the greenhouse system generated approximately $694.65 in produced items.

While not measured monetarily, the experience and enjoyment of constructing and operating the greenhouse system is immeasurable. Watching the system mature in water quality and livestock became a hobby in the back yard for personal viewing pleasure. The sound of water constantly flowing and the warm temperatures in the greenhouse made for an excellent place to read or study as well as a great place to relax and watch the mini ecosystem in action. The tilapia quickly became very personable and curious to anyone in the greenhouse as they hoped for foods and would often pile up on top of each other for a better shot of being fed. Along with a personal appreciation for the system, others showed great interest in receiving tours of the system with explanations of how it worked. This too brought further enjoyment from owning the system. All these factors together made the system an educational and fun method for producing some high-quality garden vegetables.

Net Value and Future Projections.

Outlined above, the greenhouse system did not turn a profit in the first year of production due to high cost of infrastructure materials, equipment, labor hours, and the cost of livestock in relation to produced items, education and intangible hedonic values from operation. But this is not as bad as it appears on the surface. As with many practices, it takes money and time to make money and aquaponics is no exception. Outlined below is a six year projection of costs and benefits of the greenhouse system when factoring in improvements and changes in produced items in order to add more value to the established system. Values in Table 2 represent changes from potential additions to production costs and benefits in U.S. dollars in order to estimate the expected pay off timeline of the greenhouse system as a long term means of producing high quality products in the coming years.

Table 2.

Estimated values of production for the first six years of operation for the greenhouse system including improvements and added sources of valuable products to be added concluding year one of production.

Greenhouse System 6 Year Projection								
Year Beginning July 1, 2018	2018	2019	2020	2021	2022	2023	2024	Total 6 Years
Production Costs in $								
Infrastructure	5,296	-	-	-	-	-	-	5,296
Labor	825	90	50	-	-	-	-	965
Management	30	30	30	30	30	30	30	210
Livestock	252	400	-	-	400	-	-	1,052
Feed	150	150	150	150	150	150	150	1,050
Operations	1,693	420	420	420	420	420	420	4,216
Repairs	25	50	50	50	50	50	50	325
Improvements	120	400	100	-	-	-	-	620
Total	8,391	1,540	800	650	1,050	650	650	13,733
Production benefits in $								
Crops	695	1,100	1,100	1,100	1,100	1,100	1,100	7,295
Tilapia Fillets	144	-	-	-	-	-	-	144
Baitfish	-	440	440	440	440	440	440	2,640
Fertilizer	-	960	960	960	960	960	960	5,760
Total	839	2,500	2,500	2,500	2,500	2,500	2,500	15,839
Total Costs	8,391	9,931	10,732	11,382	12,432	13,083	13,733	13,733
Total Benefits	839	3,339	5,839	8,339	10,839	13,339	15,839	15,839
Net	(7,552)	(6,592)	(4,893)	(3,043)	(1,594)	256	2,105	2,105

Learning from operational costs in primarily heating through the first winter, the decision to change from warm water tilapia to colder water tolerant baitfish, koi and goldfish was a necessity to save future costs as well as provide other benefits. Ideally, removal of expensive heaters in the greenhouse will save near $1,000 per year. Tilapia from the greenhouse system will be netted out and relocated to a closed personal pond to be further grown out and harvested in the fall before the fish die as a result of water temperatures dropping below 60 degrees

Fahrenheit. The baitfish that will be purchased and grown out will be used to feed an already existing culture of trophy largemouth bass in a personal pond while also being used as a bait supply for winter and spring striped bass fishing – a yearly hobby of the family. Golden shiners are the popular species to fill this role and plans to purchase 2,000 fingerlings at 1 1/2 inches in length for approximately $400 from Anderson Minnows is in place (AndersonMinnows.com, 2019). Growing the minnows an estimated four to six inches per year and restocking every three years, expected values for the use of the minnows will be somewhere between $440 and $600 annually.

Along with the shift to golden shiners in place of tilapia, a secondary tank will be used to house fancy koi, goldfish and fathead minnows. These decorative fish are not only for enjoyment in the greenhouse system but will also be relocated to a larger personal pond for further viewing pleasure and algae consumption once they are gown out to approximately one foot in length to ensure survivability. Initially they will be housed in the 100-gallon water trough as a source of ammonia during the transition between tilapia and golden shiners. No monetary value has been placed on the fish that have been gifted to the system due to the dietary nature of these fish that mainly consume algae with some supplemental protein feed while providing nutrients to the system in equal value. It can be noted that healthy adult koi are often purchased in the hundreds to thousands of dollars range. This gives the option to sell fancy koi at a high profit in the future if needed.

Additional benefits for the greenhouse system in the coming years include revenues from sellable products including fish waste fertilizer, seedling garden plants and even aquatic plants available for planted aquariums and ponds. With improvements to system design, solid and liquid waste will be available for extraction to be sold as high-quality garden fertilizer. While a majority of this product will be offered to family friends and neighbors, potential pricing may be near $30 per five-gallon bucket and tentative sales of ten gallons per week puts potential revenue from fertilizer alone at $960 through the growing season each year. Paired with the fertilizer, the potential to sell individual seeding plants and $1 or $2 per plant serves to add more sources of income for the greenhouse system. With the Styrofoam raft system as an excellent seedling starter, the potential to make $150 to $200 on seedling plants is not out of reach. Similarly, aquatic plants are highly sought after for those with planted aquariums and decorative ponds. With varied prices on a wide variety of species, estimated revenue from the culturing of aquatic plants may generate as much as $300 annually.

To conclude, the total cost of constructing, operating and managing the greenhouse aquaponic system for the first year comes out to be approximately $8,391. The total benefits of operating the greenhouse system for the first year comes out to be a value of $1,889.65. While this is considerably under the total cost of the system, the experience and enjoyment of the system made it a valued addition to the home and became the start of a new personal home hobby to be expanded upon and improved in the coming years of operation. After five years of operation, the greenhouse system should pay itself off and begin generating a profit when taking into account improvements with a shift to baitfish, seedling and fertilizer products. While this is only an approximation of possibilities with the greenhouse system, it is well within the realm of possibilities to manage and current plans for shifting in the direction of valuable products are being evaluated further.

Section 4. Discussion

Operating an aquaponic system does come with a wide variety of decisions in problem solving, improvements, and future goals. This section consists of personal accounts from operating the greenhouse system and includes problems and solutions associated with the system and how those lead into both current and future improvements to further tailor the system towards what the family wants and for optimizing production.

Experience from Operation

Problems and Solutions.

Following the second law of thermodynamics, even an established system with steady water parameters and growth rates on all sides in a winterized greenhouse can fall into disarray in no time at all. Over the past six and a half months of operation I have encountered a litany of issues ranging from minor algae blooms to nearly devastatingly low water temperatures but have managed to continue operation and am still harvesting tomatoes in February from July seeds. Through many minor and four major setbacks, this system has truly shown how resilient and forgiving it can be through its ability to stabilize itself and bounce production back up in less than a weeks' time.

Problem one came about while filling the flood/drain barrels with pea gravel and expanded clay around the bell syphons when the amount of media added displaced enough water to change the water fill rate. Because of this volume change, the bell siphons that I had tuned in to drain the tanks would either continue draining if the flow rate was too fast or not drain at all if the flow rate was too slow. This caused issues with dry media and stagnant water respectively- both of which cannot support a healthy bacteria culture. After much deliberation over the true cause of this issue, the solution was inevitably to upgrade to a from a 330 GPH pump to a 560 GPH pump and redial the flow rates to each tank. Additionally, strings were added to the outer bells to manually lift the bells out of the water in order to control water height and drain acceleration in the case of a backup.

Problem two had nearly just as easy a fix as the first when the system did as nearly all new water reservoirs undergo when an abundance of nutrients becomes available. Around the two week mark from adding tilapia fingerlings, the water clarity went from completely clear to a cloudy green overnight with algae spores freely floating in the water column and carpeting any submerged surface. With rapid growth rates, green algae can choke up a system and reduce flow rates while depleting the water of oxygen during times without sunlight. This detrimental issue had to be solved before the tilapia suffered from oxygen deprivation. Tilapia are naturally omnivorous and eat algae in abundance, but with only 120 fingerlings in a three hundred gallon tank there was no chance that they would be able to make much of a dent in the bloom. I wanted to stay away from adding chemicals to combat the algae with worries of causing more long-term harm than good so instead opted to add three Common Plecos (*Hypostomus Plecostomus*) from the local pet store. While sizes differ per species and it isn’t always clear exactly what is being purchased, a relatively safe estimate is around eighteen inches of armored algae eater. I purchased these three juvenile fish for around $4 a piece at two inches and added two of them to the three hundred gallon and one to the one hundred gallon tank. While the algae problem didn’t dissipate as fast as it appeared, the water was back to near perfect clarity within four days of adding the plecos. These fish are known for rapid growth to begin with, but put them in an environment with an abundance of space and available food and they grow at a rapid rate- pushing six inches at the end of August and nine to ten by December.

Unlike the first two issues, problem three posed much more of an issue around the latter half of October when small, plant eating aphids found their way into the greenhouse and attached themselves to the just flowering cucumbers and squash plants. As it turns out aphids not only do damage by consuming the leaves of plants, but also with their waste in the form of honeydew. With the cucumbers being planted above everything else in the greenhouse there became a film of sticky sap on nearly every surface within hours of noticeable aphid activity. Not only was this dew a nuisance to clean off everything, but paired with warm and humid temperatures white mold started to spring up on every covered surface being replenished by the next day until the aphid swarm was dealt with entirely. Over the span of one-week aphids above and mold below wreaked havoc on a majority of the plants in all grow beds as many stems had to be trimmed off to slow the spread of both harmful pests. This problem had to be solved quickly.

With some asking around for a solution that would solve the problem without the use of harmful pesticides that would kill off the beneficial bacteria and accumulate in the fish, the general consensus was to raise the pH on the plants to around 9.5. This pH is well above the survivability threshold of both aphids and white mold. To do this I mixed a small amount of Dawn Dish soap with one quarter cup baking soda and water in a spray bottle to coat the leaves each night. This had to be done at night because the soap that helped hold the baking soda on the leaves would work as a lens and burn the plants in direct sunlight and needed time to slowly leech into the leaves. Results were slow but consistency within the better part of a week the last of the aphids and mold were removed from the system.

The next few months brought new growth and balance to the system with little maintenance and only minor issues with pumps getting clogged on occasion. Unfortunately, as the daylight hours shortened and temperatures fell the most recent problem arose- keeping the water temperature above 55 degrees Fahrenheit. Initial attempts to heat the water were the addition of 300 watt aquarium heaters to the main two fish tanks and two electric space heaters to keep the overall air temperature up on cloudy days and at night, but this proved to be much more expensive than planned. Since the greenhouse is located on an equestrian farm with large quantities of manure piled up and spread as fertilizer the idea of a compost heater to warm the water came into play. By coiling three hundred feet of ½ inch tubing in the elevated pile we hoped to capture heat energy from the decomposing manure and wood shavings by slowly looping water through the pile and back into system. With temperatures in the pile ranging between 120 and 135 degrees Fahrenheit, we theorized that this would drastically increase the temperature of water pushed through. In reality, the water temperature did not rise more than one degree unless we turned off the pump and allowed the water to rest in the pile and heat over the span of thirty minutes. After some quick designing, compost heater mark 2 was put into the pile. Made out of three-inch PVC pipe, the five by two-foot square with water in and water out spouts on the top was leveled and filled with water. Allowing the water to fill the pipe entirely increased the residence time for heating water before returning to the system. Initially, returning water temperatures raised by four to six degrees Fahrenheit on average, but slowly receded to a less significant two degrees Fahrenheit. Even though this temperature rise was not enough to combat the near single digit nights, it added a small and renewable safety buffer at little cost to improve upon in the future. Plans for improving upon this renewable resource as a heating device will be revised and improved upon at a later time.

Improvements.

Throughout half a year of operation many changes have been made to raise efficiency and/or cut overall operational costs. Many of these changes were minor adjustments to flow rates by increasing or decreasing pipe or pump sizes but cases similar to the addition of a manure compost pile required more detailed planning and labor. Current efforts are being made to design airlift devices to replace costly water pumps as the primary means of system flow. By utilizing two continuous flow and one geyser flow airlift pumps, the system can remove the three water pumps rated at 560, 340 and 230gph being used currently with one pond aerator rated at 60 liters of air per minute. This air pump is already being used to add oxygen to the system, but by simply adding the two airlift pumps (Figure 10), the one aerator can double as both aeration and water mover. It is not known exactly how much this will affect flow rate until final testing is completed, but early tests with the geyser pump nearly match the 340gph water pump at a six food head height.

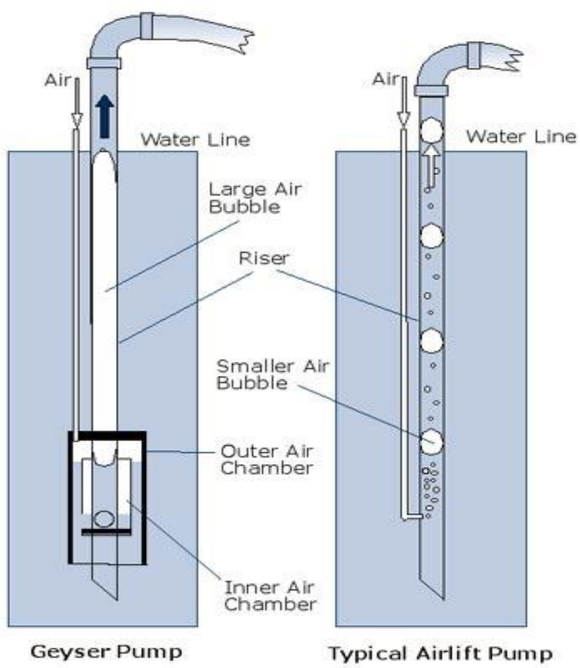


Figure 11. Continuous vs. Geyser Airlift Pump from *New Pump Technology May Improve Small Package Plant Treatment*. Figure created by Natalie Eddy (Eddy, 2002).

By displacing water with buoyant air bubbles, airlift pumps take advantage of water cohesion and adhesion by both pushing and pulling water molecules up in a confined zone to move large quantities of water with a lower energy requirement than traditional water pumps. Although both airlift designs are capable of raising water above surface level, because of the added pressure and larger air bubbles in the geyser pump, it is able to lift water to a higher head than a continuous flow is capable of. If a higher head is required, then the geyser pump with larger air bubbles forcing small amounts of water up the tube will be necessary. Acting as a reverse bell syphon, the geyser pump fills with submerged air creating higher pressure that pushes water out the bottom until the air hits the lowest point of holding and releases pressure up the intake and rapidly forces water up. Because of this it is important to make sure that all fittings are either locked or glued in place as this violent jolt of water will separate any unfixed connection. Continuous flow air pumps create a steady but weak flow of water by use of small air bubbles continuously raising water to the exit point of tube at a low pressure and are simple and reliable forms of water movement if not much head height is required.

Future Plans.

As discussed previously, production will be shifting from tilapia fillet production to a primary focus on golden shiner baitfish and decorative koi and goldfish. With this change, the size of the main fish tank will need to increase which include the removal of the 300-gallon water trough to be replaced with a 1,200-gallon lined box to house the golden shiners. The 100-gallon water trough that was going to be used as a fingerling tank for tilapia will be used to house juvenile koi and goldfish until they are large enough to be moved to the outdoor personal pond. Upon release of these decorative fish, the addition of fingerling largemouth bass may be placed in the 100-gallon tank to raise for release as well.

Similarly, the addition of small cleaner organisms including pond snails, freshwater muscles and crayfish or prawns may be possible in the near future to keep the system cleaner while also providing potential harvestable products. Because these organisms do not require much light and require a constant flow of water, the in-ground sump tank may be a possible housing area. Additional work may need to be done to the lined sump tank as both clams and crayfish may attempt to burrow through the thin pond liner and effectively drain the entire system. Simple cages to contain clams is a common practice and may also be an option for the prawns if elevated off the liner to keep them from reaching through and tearing the liner. Freshwater snails do not possess as much a threat to the water holding integrity of the system but do hold the potential to block up water pumps or overflows. Despite these issues, the addition of one or more of these cleaner organisms may be extremely beneficial to further stabilize the water ecology.

Of all future additions to the greenhouse system, I am most interested in the relocation of the family beehive located at the other end of the property to the backside of the greenhouse. Pollination up until this point has relied mainly on hand pollination by use of a cotton swab between male and female flowers to produce fruiting. Some small insects aided in this process, but the time-consuming task of hand pollination will come to an end once the bees are given access to the abundant source of pollen inside the greenhouse. We captured the bee swarm around six years ago and called in a family friend to box them and start off our hive that we get honey from twice a year. The bees are currently located at the far end of the property since we were not certain if they would be aggressive to people, but after years of care no signs of aggression have occurred. Moving the bees closer to the house and directly behind the greenhouse will greatly increase the pollination rate to save time and promote a healthier environment for the crops. According to Sally, the family friend who keeps bees at multiple locations, the hive may be ready to split into two separate hives to further spread pollination from these important species.

Section 5. Future Goals and Conclusions

Possibilities of Implementation and Improvement

Customizable Scalability.

Excluding extreme cases of incorporating extremely large fish or trees, home aquaponic systems can be tailored to fit nearly any desired purpose; whether the owner wishes to produce enough to sell in local markets, produce enough to feed their family, or to serve as an aesthetically pleasing talking piece, the possibilities are endless. Owners have the freedom to choose between a wide variety of edible or ornamental fish species along with many types of fruiting fruits and vegetables or even supplemental herbs and spices to meet their household needs. Aquaponic systems are able to produce each portion of a balanced meal with fish protein, fruits, vegetables, carbohydrates and even the herbs and spices to top them. Additional preparation work would be required for this, but the ability for one convenient system to provide all inputs is invaluable.

Tanks for holding fish are available in sizes small enough to fit a work desk all the way up to pond sizes able to fill an entire back yard. While these tanks do need to be size appropriate for the fish species selected, the variable options in selecting or designing tanks are only limited by imagination and budget as decorative pond pieces will be much more expensive and design intense than a pre-made aquarium tank or barrel. Decorative ponds often used for koi and goldfish appeal to the aesthetic portion of hobbyist who may have no issue with the addition of garden ready produce with the bonus of further filtering the water for the prized fish. Many ponds hold a wide variety of aquatic plants such as water lilies, cattails, moss balls and grasses, but with a small media filled container or two plumed into the filtration system, the waste water receives an extra bit of filtration that gives back to the owner in harvestable produce. While the addition of aquaponic components will most likely not produce a profit in this case unless the producer overstocks the pond and has available space for many grow beds, the added natural filtration with a small return is better than paying for filtration alone.

Similarly, those looking to take a more aquaculture approach in producing quality fillets may choose to use a cheap container such as a water trough to house rapid growing fish including tilapia and catfish with the bonus of harvestable produce that also filters the water for the fish. By taking the aquaponic approach to producing fish, the producer can save money on filtration systems that require constant cleaning maintenance by taking advantage of the natural filtration of the nitrification process and plant uptake of the excess nutrients. As described in previous sections, the cheap process of constructing the plant grow beds are a viable option in converting a traditional aquaculture system into an aquaponic system that is capable of producing desired crops along with the capacity to increase stocking densities in the fish tanks for more fillets come harvest time.

Along with the producer oriented are the aquarist who enjoy tropical aquarium fish for viewing pleasure. Aquaponics fits this niche as well as it does what many aquascapers try to accomplish with the addition of aquatic plants with the added benefit of harvestable crops. Paired with aquatic plants often found in the tanks for decoration, the producing crops further filter out the water and allow the owner to stock the fish tank with more fish to surpass the “one inch of fish per gallon” recommendation. Aquariums are often set up indoors or in garages which further removes the possibilities of pests being an issue, massive temperature changes and can be viewed and managed easier than those set up outdoors. With the addition of a small media filled grow bed or net pots in PVC pipes, the home aquarium can produce more than the viewing pleasure of a traditional aquarium and makes for a more interesting talking piece for those who already enjoy talking about their aquarium set-up.

On the fish side of things, species such as perch, catfish, tilapia, and bass fit well into warmer climates averaging around 70 degrees Fahrenheit, while trout, sturgeon, salmon, koi and goldfish fit into cooler climates ranging from mid-fifties to sixties. Typically, the main three fish used in small scale systems are tilapia, catfish, and goldfish because of their resilience to poor water qualities, disease resistance and breeding opportunities. Listed in Table 2 are nine of the most common aquaponic fish in the United States and general parameters to consider when selecting fish for an aquaponic system. Diet, water temperature and water pH are the most important considerations when selecting fish livestock as these parameters have little room for error before high mortality rates occur.

Table 3.

Popular Aquaponic Fish Selection with Care Requirements

Common Aquaponic Fish Parameters							
Species	Diet	Water Temp (F)	pH	Stocking Density	Tank Size	Edible	Beginner Friendly
Tilapia	Omnivorous	70-80	7.0-8.0	High	Medium	Yes	Yes
Catfish	Omnivorous	75-85	7.0-8.0	High	Medium	Yes	Yes
Trout	Carnivorous	55-65	6.7-7.7	Medium	Large	Yes	No
Perch	Carnivorous	67-77	6.5-8.5	High	Medium	Yes	Yes
Bass	Carnivorous	65-75	6.5-8.5	Low	Large	Yes	No
Barramundi	Carnivorous	77-86	6.5-7.2	Medium	Large	Yes	Yes
Goldfish	Omnivorous	65-78	6.5-8.0	High	Small	No	Yes
Carp	Omnivorous	80-82	7.5-8.0	Medium	Med/Large	No	Yes
Koi	Omnivorous	65-78	6.5-8.0	Medium	Med/Large	No	Yes

Note: Adapted from Castelo (2018.)

Smaller baitfish can also be successfully grown in aquaponic systems if desired, but often require higher water quality standards and more care than the larger fish listed above. Common freshwater baitfish include threadfin/gizzard shad, shiners, fathead minnows and select species of goldfish. While these baitfish are highly sought after by fishermen, keeping them healthy can be more of a challenge than expected. Without a continuous flow of fresh water and a high dissolved oxygen level, these fish will turn red in the nose and die in minutes. Although the other baitfish options are more resilient to poor water quality, all require fresh water and high dissolved oxygen for successful growth. From years of experience keeping these fish for striped bass fishing, it can be concluded that these fish do not fare well in confined water sources due to their low ammonia tolerance and high ammonia excretion rate when stressed.

On the plant side of things, nearly anything with a root system that relies on nitrates to grow can be cultivated in temperatures above freezing. Popular crops such as tomatoes, lettuce, watermelon, peppers, broccoli, cucumbers, squash, berries as well as herbs and spices all excel in aquaponic systems and can produce higher quantities than they would grow traditionally without the extra nutrients supplied by the fish. Additionally, many aquatic plants seen in the aquarium hobby can be grown in mass quantities in an aquaponic if housed separately from the fish tank or with plant friendly fish. Stem plants such as rotala, ludwigia, pennywort, hornwort, primrose, stargrass and java moss are common in the aquarium hobby and require the same nutrients as terrestrial plants with the only difference being that they are fully submerged in the water. These decorative plants are placed in aquariums as both decoration and as a means for cleaning the water. Most of these aquatic plants require some sort of substrate to root into, but once established they are capable of doubling when cut. Any portion of the stem is capable of generating a whole new plant- hence the name “stem plant.” Currently there are no operations reporting the growth of stem plants in aquaponic systems, but the possibility is present.

Along with being customizable, aquaponic systems vary in size and scope. Systems can be designed and a constructed on a small scale with juvenile fish and seedling crops at a low cost in a nursery style for preliminary testing and later scaled up for production. While very small, fry offer high quantities of ammonia as they consume large amounts of feed to sustain growth. The high ammonia converted into nitrates in the system will produce many leafy greens including herbs and spices with little space and a low volume of water. This can be achieved with a couple of ten through twenty gallon aquarium tanks, one water pump, one air pump, a few plastic totes filled with pea gravel, and some PVC pipe to tie it all together. Many of these systems can be constructed for under $100 and require minimal maintenance or care other than feeding the fish and harvesting greens.

Moving up the size scale, the introduction of brood stock, or breeder fish, requires slightly larger breeder tanks ranging from thirty to sixty gallons to initiate spawning. At this point the ammonia levels will increase with the higher stocking density and more media beds for crops will be required to filter out abundant nitrites in the water. Additionally, new fry will need a larger tank to grow to max size. The addition of a grow-out tank can be utilized to house the rapidly growing school of fish. Paired with this, new grow beds for higher plant production can be added once again. This process of increasing system size can be continued all the way up to commercial size if desired, but new methods for capturing profits through vertical integration will most likely be required.

Vertical Integration for Sustainability.

With data becoming more readily available amongst agricultural production worldwide, it has become apparent that change in production methods will be required to adjust for growing populations while minimizing externalities that harm the natural environment. While there is not one clear solution to solve the interconnected pieces of a varied world market that can account for the needs of all populations in a beneficial manner, aquaponic systems may serve as an instrumental tool in production practices to maximize outputs and minimize harmful externalities. Aquaponic systems inherently create a low input loop of nutrient cycles in a controlled environment that can be fine-tuned to primarily conserve space, water, and energy. With vertical integration practices in place an aquaponic operation can convert what would normally be considered waste products into beneficial or profitable additions, i.e. fish waste into fertilizer, plant trimmings into worm vermicomposters, and breeding operations to increase harvest dates, etc. Not only would these practices directly benefit the system itself, these practices would condense operation to one location and reduce costs of transportation and off site processing. While this applies more to large scale commercial operation, small scale producers still receive benefits from vertical integration as they are able to further cut costs and increase outputs while gaining the option to enter new markets if desired.

Many aquatic species breed at a faster rate and have a higher feed conversion ratio than their terrestrial counterparts and this behavior can be utilized for year round production cycle of grow-out opportunities. For example, tilapia can be bred by simply adding cover for the males and females to be separated from the rest of the school. Because the females produce eggs nearly continuously until a male fertilizes them, this method initiates breeding action immediately. Because tilapia are mouth brooders and hold their eggs in their mouths, females with enlarged mouths can be removed from the school to hatch their fry and then removed to avoid cannibalism of the young. From here the fry can be grown in their own tank and graded based on size to move those large enough to the grow-out tanks. While breeding to fry only takes five to seven days, raising fry to a large enough size to survive the grow-out tank may take upwards of two months. Because of this, multiple tanks can be utilized in order to maximize survivability. This option is advisable for those with some experience in breeding fish with an understanding of fry to brood stock care.

Non-cannibalistic species such as koi and goldfish do not require separation but do require steady water parameters and adequate food to initiate spawning. Although these fish often have lifespans surpassing ten years and do not breed often, the option is still available to those who wish to produce high quality decorative fish. This also applies to tropical aquarium fish, but many of those species require very specific water parameters and a trigger to initiate spawning behavior. This option is not advised for beginners.

Of the more realistic options for adding value to the system, worm composters may be one of the simplest and most valuable contributions to operate in junction with an aquaponic system as any waste from both livestock and crops can simply be discarded into the worm bin to be broken down into two valuable products: worms and vermicompost. Worm species such as the well-known red wiggler (Eiseni fetida) are ideal composters that consume decomposing organic material and excrete valuable fertilizer. Red wigglers are often priced around $20-$35 per pound depending on the area and are sought after by garden hobbyist, fishermen, and other composters alike. Not only can the worms be sold to add a cash inflow to the system, they can be used in the system itself as an extra food source for the fish. The worms cannot replace feed entirely but will suffice in lowering the amount of feed needed to grow the fish in the system and promote overall health. Whether the worms are sold or fed to the fish their byproduct, vermicompost, is highly sought after by gardeners to be used as a potting soil to sustain their gardens. Prices for this product range anywhere from $5 for a pound to $3 per pound when bought in bulk. Cheap to produce and easy to manage, worm composters can be sized and constructed to fit the organic load of any system this option is highly recommended for any operation.

Similar to replenishing fish stocks from breeding, saving seeds from plants that outperformed the others removes the need to purchase new seeds each year while ensuring the next generation of crop is better suited for the aquaponic environment. Older plants that are starting to slow on production can be replaced in this manner to ensure the highest use possible per generation. Most fruiting crops provide an abundance of seeds per fruit that can be dried and re-planted or stored to be used later. Some crops such as lettuce, broccoli and mint must be sacrificed and allowed to grow past a harvestable state in order to flower and produce seeds. Only one plant will need to be sacrificed per generation to produce seeds. This option is highly recommended for any crop producer as each iteration will be better suited to the parameters of the system and provide better results.

Educational Opportunities.

Becoming more popular in a classroom setting, many small scale aquaponic systems are utilized in science classes for their layered chemical and biological properties. These systems are usually no more than a ten gallon aquarium with a media bed and some small herbs but can still be used to explain chemical processes such as the nitrogen cycle alongside a functioning biological system that is eye catching and entertaining for any age group. Aquaponics USA is introducing their small scale EZ-Reach EZ-22 STEM Food Growing System starting at $4,394 into classrooms to create a fun and educational project for young children. “An Aquaponics STEM Food Growing System can be used to demonstrate various principles taught in technology, plant life cycles and their structure, how to make effective use of recycled materials, low-tech/high-yield gardening, ecological issues, biology, chemistry, physic and sustainable farming” (AquaponicsUSA, 2019). The addition of such a low maintenance system with a living ecosystem can be paired with in class lectures as a physical example of natural systems outside the classroom. Simple guided exercises such as feeding fish, trimming and harvesting from plants, and measuring water quality can provide a hands on learning experience that draws in students more than a textbook example. Once again, a system of this size is customizable as well as affordable. While more assembly is required than with the EZ-Reach EZ-22 STEM system, a quick online search will produce a multitude of systems priced as low as $75 and provide various takes on best options to fit a classrooms needs.

Similarly, online vloggers and educators like “The Aquaponics God” Brooklyn Saint Michell, owner of *The School of Aquaponics*, offer 200+ video lectures for over 14,000 students in order to promote aquaponic systems in a lighthearted but effective way (Michell, 2019). With 24/7 access, the free online courses go through in-depth explanations of system design, science, and maintenance with videos, demonstrations, and quizzes to give the user tools needed for an “Aquaponics God Certificate.” The innovative techniques used by Brooklyn are a powerful tool in promoting aquaponic systems as the high yielding and profitable educational device for explaining natural systems in a controlled and safe environment.

Conclusions

While further research is needed in order to fine tune aquaponic systems based on their design, size and species used, small scale aquaponic systems are a viable option for the DIY hobbyist trying to reduce their reliance on store bought fresh produce. With an abundance of custom designs composed of cheap and convenient pieces available with a quick online search, the affordable at home system requires only a location and minor technical skills to construct. Operational care and management of an aquaponic system range from small water flow tunings and feeding that can be completed in mere minutes each day up to large scale remodeling projects at the operator's desire. As long as water parameters are maintained and fish are fed, these systems often take care of themselves in a balance between fish, bacteria, plants, and pollinators.

Although my home system was not profitable throughout the first year of operation, the overall success of maintaining a healthy nitrogen cycle while providing for the tilapia in the system brought with it priceless lessons in biology, chemistry, general plumbing and construction, aquaculture, horticulture and countless ideas for moving forward. While I did not ever have any issues with cycling the system and maintaining a healthy bacterial culture, issues with water temperature, pests, and water flow rates have sparked plans for expanding and improving the current system towards something cleaner and requiring even less maintenance than the current system.

Alongside operating the greenhouse system, I also learned just how much work and planning is required for conducting an anonymous short public survey. I was able to get 31 participants to complete this survey and decided its data was not conclusive enough to determine acceptance of home aquaponic systems. The participants were primarily college students who did not have an area for a system, business professionals who did not have the time to manage a system, and hourly associates who did not have the time, place, or funds to operate an aquaponic system. Many of these participants were extremely interested in aquaponic systems and often participated in long conversations about how the systems worked and the various types of fish and plants available in one easy system. In hindsight conducting the survey was a waste of time and more could have been learned about public interest in conversation rather than the use of specific questions.

To conclude, custom aquaponic systems for home use *are* a feasible and user friendly option for producing fresh fruits and vegetables in an educationally fun manner without the risks of making a large investment. Whether their aim is to create a high yielding produce garden, raise some fish for harvest in a clean environment, create a luscious koi pond, or simply gain some experience in home farming, an aquaponic system can be customized to meet any circumstance. Care must be taken to ensure that the proper fish species and crops are chosen to avoid high costs in operation, but if valued correctly then an aquaponic system has the potential to pay for itself within five years of operation. As more commercial and hobbyist systems spring up across the world and new techniques emerge, the availability for any producer to enrich their growing experience expands exponentially with new DIY techniques and technological opportunities in aquaponic systems.

References

AgMRC. (2018, November). *Aquaculture Fin Fish Species*. Retrieved from Agricultural Marketing Resource Center: https://www.agmrc.org/commodities-products/aquaculture/aquaculture-fin-fish-species

AndersonMinnows.com. (2019). *Golden Shiner*. Retrieved from Anderson Minnows: http://www.andersonminnows.com/species3.php

Aquaponics, B. (2012). *The Nitrogen Cycle.* Backyard Aquaponics, Jandakot, WA.

AquaponicsUSA. (2019). *Aquaponics STEM Food Growing Systems in the Classroom*. Retrieved March 2019, from Aquaponics USA: https://www.aquaponicsusa.com/

Arizona, U. o. (n.d.). *Starting an Aquaculture System*. Retrieved from https://cals.arizona.edu/azaqua/extension/Classroom/startup.htm

Baptista, P. (2014, June 4). *Water Use Efficiency in Hydroponics and Aquaponics*. Retrieved from ZipGrow: http://blog.zipgrow.com/water-use-efficiency-hydroponics-aquaponics/

Brand, R. (2014). Common Pleco- The Care, Feeding and Breeding of Common Plecos. *Aquarium Tidings*.

Brown Jr., P., Brown, J., & Rubio, A. (2013, January). U.S. Shrimp Imports Down as EMS Hits Asia. *The Global Aquaculture Advocate*, pp. 60-63.

Cambridge. (n.d.). *Hydroponics*. Retrieved from Cambridge Dictionary: https://dictionary.cambridge.org/us/dictionary/english/hydroponics

Castelo, J. (2018, September 4). What are the Best Fish for Aquaponics and Where do I Buy Them? *World Water Reserve*.

Castiglione, L. (2018, August 15). *Increase of Tilapia Imports Prior to Tariffs: Seasonality or Securing Volume?* Retrieved December 11, 2019, from Undercurrent News: https://www.undercurrentnews.com/2018/08/15/increase-in-tilapia-imports-prior-to-tariffs-seasonality-or-securing-volume/

Dhwty. (2014, April 7). *Chinampas, The Floating Gardens of Mexico*. Retrieved from Ancient Origins: https://www.ancient-origins.net/ancient-places-americas/chinampas-floating-gardens-mexico-001537

Eddy, N. (2002, January 1). New Pump Technology May Improve Small Package Plant Treatment. *National Small Flows Clearinghouse*. Small Flows Quarterly .

Fu, S. (n.d.). *The Nitrogen Cycle for Aquaponic Systems.* Retrieved March 21, 2019, from Aquaponics System Solutions: Do-It-Yourself Aquaponics Systems: http://www.aquaponicssystemsolutions.com/nitrogen-cycle/

Gab. (2015). *Combating Algae Problems in Aquaponics Systems*. Retrieved from DiyAquaponicsTips.com: https://diyaquaponicstips.com/combating-algae-problems-in-aquaponics-system/

Jobescompany. (2019). *Jobe's Grow Liquid Fertilizer*. Retrieved March 2019, from https://jobescompany.com/product-category/fertilizers/liquid/

Lockwood, G. S. (2013, January/Febuary). Where is Aquaculture Headed. *The Global Aquaculture Advocate*, pp. 50-52.

Mckinnon, D., Trott, L., Duggan, S., Brinkman, R., Dan, A., Castine, S., & Patel, F. (2008). *Environmental Impacts of Sea Cage Aquaculture in Queensland Contex- Hinchinbrook Channel Case Study (SD576/06).* Townsville: Australian Institute of Marine Science.

Michell, B. (2019, January). *The School of Aquaponics*. Retrieved March 2019, from https://theschoolofaquaponics.com/

Optimalfishfood. (2019). *Optimal Aquaponic Feed*. Retrieved from Optimal Fish Food: https://optimalfishfood.com/product-category/optimal-aquaponic-feed/

OuroborosFarms. (2019). *Ouroboros Farms*. Retrieved March 2019, from https://www.ouroborosfarms.com/

Pade, N. a. (2019). *Aquaponics Master Class for Teachers*. Retrieved from Nelson Pade: https://aquaponics.com/store2/aquaponics-master-class-for-teachers/#

Payscale. (2019). *Hourly Rate for Industry: Construction*. Retrieved from Payscale.com: https://www.payscale.com/research/US/Industry=Construction/Hourly_Rate

Pentair. (2016). *Aquaponics Technology and Desighn Workshop.* Apopka: Pentair Aquatic Eco-Systems.

Rakocy, J. (2012). *Our Story*. Retrieved 2 11, 2019, from The Aquaponic Doctors: http://theaquaponicsdoctors.com/our-story.php

Rakocy, J. E. (1989). *Tank Culture of Tilapia.* Southern Regional Aquaculture Center.

Rees, E. (2014). *Algal Blooms Fed by Climate Change, Farm Polution and Aquaculture .* Chinadialogue Ocean.

Sawyer, T. (2010, November 15). *The Definition of Aquaponics.* Retrieved March 21, 2019, from The Aquaponic Source: https://www.theaquaponicsource.com/blog/the-definition-of-aquaponics/

Sharpe, S. (18, November 15). *How Much and How Often Should You Feed Fish*. Retrieved from The Sprice Pets: https://www.thesprucepets.com/how-much-and-how-often-should-you-feed-aquarium-fish-1380923

Slabaugh, S. (2017). *Bell Aquaculture Sold for $14 Million.* Star Press.

Spiff, S. (2014). *Make a Bell Siphon.* Retrieved June 1, 2018, from Instructables: https://www.instructables.com/id/Make-a-Bell-Siphon/

Storey, N. (2017). 6 Things You Need to Know About Potassium in Aquaponics. *Upstart University*.

Storey, N. (2017, December 13). *The Most Important Things to Know About Phosphorus.* Retrieved March 20, 2019, from Upstart Univerisity: https://university.upstartfarmers.com/blog/most-important-things-about-phosphorus

TheHomeDepot. (2019). *TheHomeDepot.com*. Retrieved March 2019, from https://www.homedepot.com/

TilapiaDepot. (2019, January 1). *Blue Tilapia*. Retrieved June 2018, from https://tilapiadepot.com/collections/blue-tilapia

Troell, M., Tyedmers, P., Kautsky, N., & Ronnback, P. (2004). *Aquaculutrue and Energy Use.* ResearchGate.

Tveteras, T. (2013, January). Production: Global Fish Review. *The Global Aquaculture Advocate*, pp. 10-11.

USGS. (2015). *Aquaculture Water Use*. Retrieved April 5, 2019, from https://www.usgs.gov/mission-areas/water-resources/science/aquaculture-water-use?qt-science_center_objects=0#qt-science_center_objects

Walmart. (2019). *Walmart.com*. Retrieved March 2019, from https://www.walmart.com/

WQA. (2019). *Scale Deposits*. Retrieved from Water Quality Association : https://www.wqa.org/Learn-About-Water/Perceptible-Issues/Scale-Deposits