DESIGN OF AN AQUAPONICS SYSTEM

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ABSTRACT

This Senior Project discusses the design, cost analysis, and evaluation of an aquaponics system. The system incorporates aquaculture and hydroponics to create a source of fish protein and various crops. The system was sized based off a minimum requirement of pounds of fish available per week. The system designed is capable of generating 2080 pounds of catfish, and 16,000 pounds of produce annually. The first year of operation the system will operate at a loss due to the significant cost of the components of the system, however, the project is projected to generate a minimum stream of revenue of $10,600 each year after that.

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Background

The Ceres Community Project is a largely volunteer organization that provides an opportunity for youths (ages 10-18) to gain community service hours, and learn about food and the plants they come from, as well as developing cooking skills while preparing nourishing meals to be packaged and delivered to Ceres “Clients” across the county. The “Clients” at the Ceres Project are patients who are suffering with life threatening illnesses, mainly cancer. Once someone is diagnosed with a life threatening illness they are able to apply to Ceres to receive up to four meals per week, for each client as well as their spouse and children if they have any. After the teens prepare the meals under the supervision of a professional chef and one or two volunteer chefs, they package the meals in high quality Tupperware and then they have another set of volunteers who make the home deliveries directly to the clients and their families.

The Ceres Project started with a woman named Cathryn Couch, who was kind and caring enough to make, package, and deliver meals to her dear friend who was battling cancer. A daughter of a friend of Cathryn wanted to help and learn to cook the nourishing meals she was making. Cathryn realized the potential in what they were doing and reached out for volunteers and quickly created a support network that grew into the Ceres Project.

Justification

The Ceres Project prides itself on providing nourishing meals using produce and proteins that are, “fresh, organic, nourishing, nutrient-rich, seasonal, minimally processed, grown sustainably, and locally, if possible, (Ceres). Ceres cares dramatically about the upbringing of the ingredients used in their meals, so much so that they have created their own Ceres Community Garden dedicated to growing organic sustainable produce to use in their meals. Ceres has partnered with organizations such as W.H.O.A. (Work Horse Organic Agriculture) to receive donations of produce, and for most all of its operation, the Ceres Project has relied on donations to fund its operations. Even with the new garden and produce donations Ceres has to purchase over 100,000 pounds of produce per year, as well as most of their chicken and fish. The W.H.O.A. farm has recently been downsized, and has become unable to contribute to the Ceres Project. By implementing an Aquaponics system on the site of their Sebastopol Garden, the Ceres Project will gain an efficient source of fish protein as well as growing produce to offset the recent reduction in donations from the W.H.O.A. farm. This system would make their operation more efficient and sustainable by reducing the quantity of fish protein they need to purchase, and reducing necessary produce purchasing.

Objectives

The objectives of this report are to generate an aquaponics system design, a system cost analysis, and a brief construction plan for the Ceres Community Garden in Sebastopol, California, as seen in Figure 1. The system should be able to provide the average needed fish protein of 40lbs/week, as well as creating an efficient source of organic produce each year to reduce reliance on donations. The cost to grow the produce created should be less than what it would be at market price, which will be determined through a cost analysis.

Figure 1: The Ceres Community Project Garden (GoogleEarth)

LITERATURE REVIEW

Aquaponics is the process of combining aquaculture, the raising of fish, and hydroponics, the growing of plants in a soil-less medium with water containing minerals and nutrients, and the integration of Nitrification Bacteria, to balance the system, (Rakocy, 2004). This combination works so harmoniously because the waste produced by the farmed aquatic animals (ammonia) is broken down by microbial nitrifying bacteria, into nutrients available for uptake by the plants, (Rakocy, 2004). In an aquaponics system water from the fish tanks flows down into and throughout grow beds where the plants absorb the nutrients that the fish excrete, the water then flows via gravity to a holding tank and is pumped back up to a biofiltration tank. This is where the water constantly passes through the biofiltration tank, where nitrification bacteria in the tank process the ammonia left in the water into nitrites and nitrates, as outlined in Figure 2. The water then flows back into the fish tanks clean of the harmful ammonia, and full of nutrients ripe for plant consumption. There can be many varieties of fish raised, the most common is Tilapia, and close behind are Catfish, Murray Cod, Perch, and Bluegill.

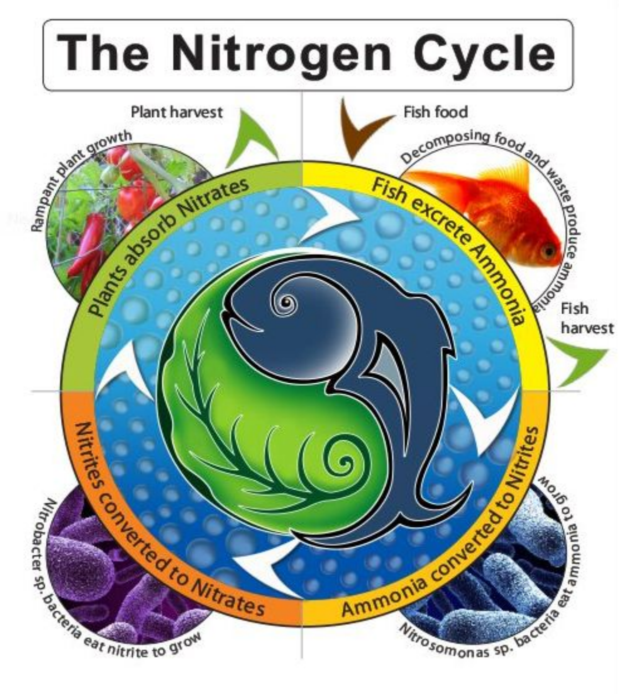


Figure 2: Nitrogen cycle within Aquaponics (Backyard Aquaponics)

Aquaculture

Many types of fish are capable of being used in the aquaculture subsystem. Due to the location of the intended system (Sonoma County) and California regulatory concerns, it is best to not use Tilapia, but to stock the system with Catfish. The Subsystem will consist of four large 1300gal tanks, for the various growth stages of the Catfish, to be raised in the system. The tanks will house the fish as they grow, with each tank constantly holding Catfish at different ages and therefore sizes. If the fish were all in one giant tank, the smaller ones would get injured by the larger fish, they would not be able to eat, and they would eventually die out. Though the fish are stored in four separate tanks, the water they live in will circulate through the entire system. Aerators will be used to oxygenate the water, so the fish are able to properly breathe. Automated fish feeders are the best and most consistent method of feeding the fish in the tanks. A basic fish food with a protein content of 36% will suffice for the system. Of that 36% of feed that is protein, 16% is Nitrogen. The fish are fed at 2% of body weight (Schwartz, 2016.) If the tanks are stocked with a total of 1040lbs of fish at any given time, then each time they are fed, they should receive 312lbs of feed.

Hydroponics Methods

There are various methods to grow plants within the hydroponic components of an aquaponics system, as well as different growing mediums to consider. There are three main methods of growing plants hydroponically, Deep Water Culture, Integrated Aqua-Vegiculture (IAV), and a Reciprocating (flood and Drain) system. Within the IAV or a Reciprocating system, the grow-beds need a soil replacement, a medium that will provide structure for the plants, that will allow easy movement of water through the system, and be able to drain quickly. Table 1 compares various media available for IAV or reciprocating systems.

Table 1: Grow Medium Comparison (Somerville, 2003.)

Medium	Cost	Weight	pH Impact	Water Retention	Dust/ Debris	Availability
Gravel	Low	High	Possibly	Lowest	Initial Rinse Only	Common
Sand	Low	Highest	Possibly	Low	Possibly	Common
Lava Rock	High	Medium	No	Medium	Needs Initial Rinse Only	Uncommon
Coir	Medium	Lowest	Yes	Medium	Yes	Common
Rockwool	Medium	Low	No	High	No	Uncommon
Hydroton	High	Medium	No	High	Needs Initial Rinse Only	Uncommon
Perlite/ Vermiculite	Low	Low	No	Medium	Periliteeeds Initial Rinse	Common

Deep Water Culture (DWC) Plants are placed in rafts that float in deep-water troughs, and their roots grow down through a porous container known as a net pot or netted pot. The net pots generally are set so just the bottom inch of the pot is in the water, leaving the rest dry to allow for access to oxygen. A DWC system offers high productivity at low costs and labor requirements. It is the simplest and most economical of all aquaponics methods. It allows for easier harvest as the roots are simply suspended in water and there is no leftover growing media to deal with.

Integrated Aqua-Vegiculture System   Plants grow in a soil-less medium such as gravel, as water constantly flows through the growing medium. The ideal medium for this is Hydroton, which is essentially hardened porous clay balls, which allow for easy movement of the water throughout the grow beds. This system utilizes trickle irrigation, where the grow beds have a constant but slow flow of water through the lower regions of the grow beds at the root-zone. (Rakocy, 2004.)

Reciprocating (Flood and Drain) System   The aim with a reciprocating hydroponic system, is to provide both water and oxygen to the plants in an alternating fashion, where the medium within the grow-beds are alternately flooded and drained rather than trickle irrigated, often using automatic bell siphons, to create the flood and drain effect. For a growing medium, Hydroton can be used, however, because of its ability to drain very efficiently, for this method of growing it may dry out the roots of the plants. The safer method would be to use a 50/50 mix of Perlite and Vermiculite for this style of hydroponics. (Khanal. 2016.)

Oxygenation /Aeration

Both the fish in the rearing tanks and the roots of the hydroponically growing plants require oxygen to survive and thrive, and in a recirculating system, together they will use it all up, if an aeration component is not incorporated into the system. This addition creates a flow of oxygen bubbles through the system and increases the concentration of dissolved oxygen to aid in the respiration of the fish, and the oxygen intake of the plant through their submersed roots. Oxygenation systems usually include a series of aerators, or air-stones, generally throughout the rearing tanks or within a degassing tank. Oxygen is essential for the fish, the plants, and the bacteria. They all absorb their oxygen through the content of dissolved oxygen in the water. The optimum dissolved oxygen (DO) levels for each organism to thrive are between 5–8 mg/liter. (Rakocy, 2004.) In a recirculating system with minimal disturbance, oxygen needs to be supplied through aeration in the rearing tanks, by means of air stones.

Solids Filtration

Within a functional aquaponics system, there is a need for the filtration of solids. One functional and common method of solids removal is a settling tank. A settling tank works by having water slowly flow through a pipe directed downwards, where the only path out is through a pipe located at the top of the open tank. It is here that water rolls off the surface into another pipe, allowing the solids to settle to the bottom of the tank by means of gravity, to be emptied through a drain valve. The water is then clear to move onto the next stage of the system. A diagram of a Settling Tank can be seen in Figure 3.

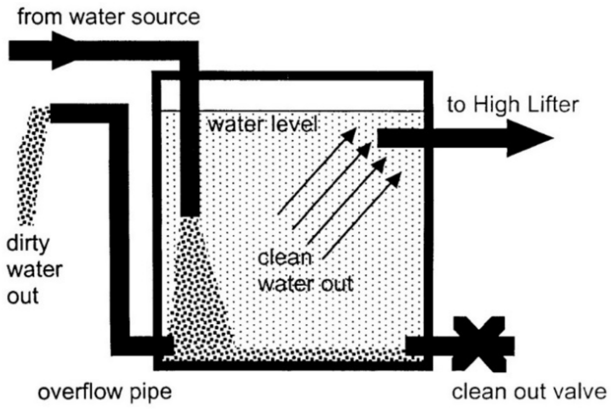


Figure 3: Settling Tank Diagram (Humboldt)

Sump Tank

A Sump tank is at the lowest elevation level of the system and is where the water is stored once it has passed through the Hydroponic subsystem; it is from here that the water is pumped back to a higher elevation where it will pass through a biofiltration tank, before returning to the fish rearing tanks.

Biofiltration Tank

The key to the biological reactions allowing this harmonious relationship between aquaculture and hydroponics to take place is the aerobic nitrogen conversion called nitrification, in which bacteria break down the ammonia and ammonium in the water produced by the fish, into nitrites and nitrates which are then taken up by the plants. The biofiltration tank is filled with a form of media that has lots of surface area, and is essentially a place for a bio-film to grow. The media used within this project are called BioBalls, and they are small spherical pieces of plastic that have many holes or ridges to increase the available surface area for bacterial growth. Table 2 shows the various forms of media and their potential to fix Nitrogen. The bio-film is filled with bacteria that carry out the biological conversion of ammonia. This process is part of the nitrogen cycle, shown in Equations 1, 2, and 3, and the equations are present in Figure 4, (Tyson, Treadwell, Simonne 2011,) and again in more depth in Figure 6 (Khanal. 2016)

Table 2: Biofiltration Media Nitrogen Fixation Capabilities (Schwartz, 2016)

Trickeling biofilter 30 square feet biofilter / gram Nitrogen as Ammonia		
Bio Barrels	64	sqft/cuft
Bio Balls	160	sqft/cuft
Bio Fill	250	sqft/cuft
Scrub pads	370	sqft/cuft

Stable ammonia levels range from 0.25 to 2.0 ppm; nitrite levels range from 0.25 to 1 ppm, and nitrate levels range from 2 to 150ppm. (Tyson, Treadwell, Simonne 2011.)

Equations within Nitrification Process (Tyson, Treadwell, Simonne 2011.)

$$(NH_4) \Leftrightarrow (NH_3) + (H^+) \quad [1]$$

$$(NH_3) + 1\tfrac{1}{2}(O_2) \Leftrightarrow (NO_2^-) + (H_2O) + (H^+) \quad [2]$$
$$+84\text{kcal mol}^{-1}$$

$$(NO_2^-) + 1\tfrac{1}{2}(O_2) \Leftrightarrow (NO_3^-) \quad [3]$$
$$+17\text{kcal mol}^{-1}$$

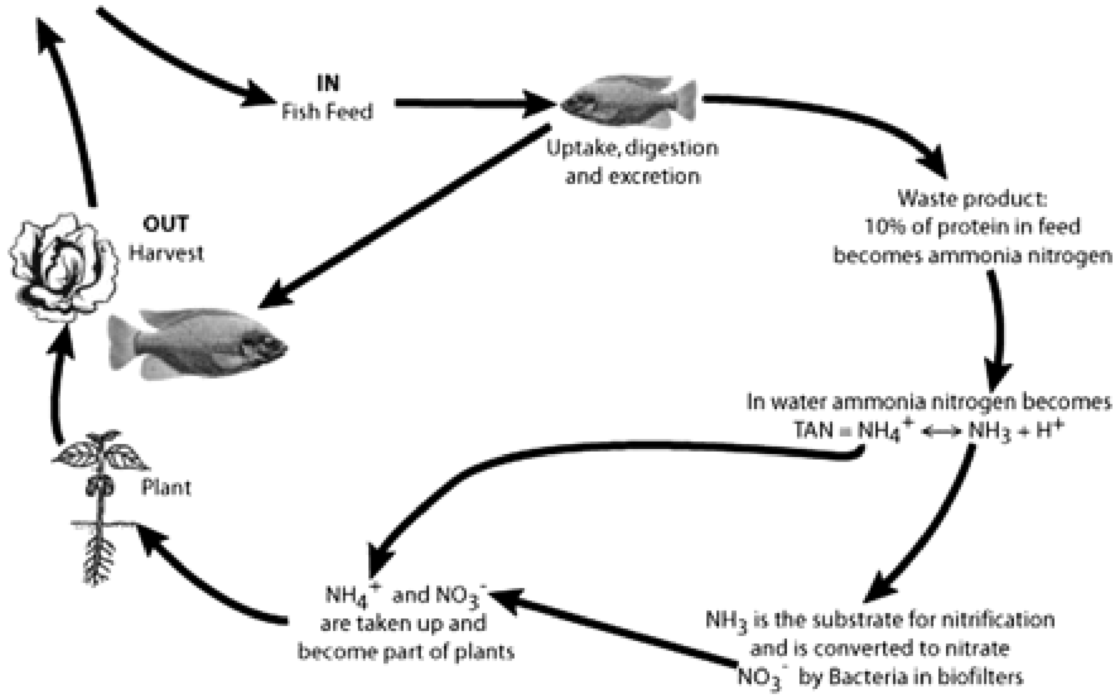


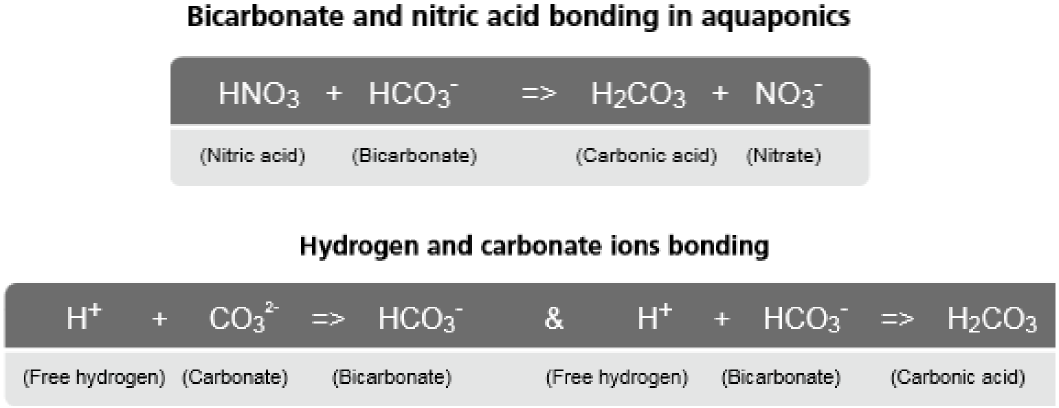
Figure 4: Nitrogen cycle (Tyson, Treadwell, Simonne 2011.)

Water Quality

pH One of the most influential factors over the success of an aquaponics system is pH. The pH is a measure of how acidic or basic the solution is, based on a scale of 1 (strong acid) – 14 (strong base.) Both the fish and the plants that would be growing in the system, are sensitive to pH. Most fish used in aquaponics have a pH tolerance range of 6.5-8.5, (Somerville, 2003.) If the pH raises above that range, the fish began to show symptoms of illness. The ideal pH for plant nutrient uptake is 6.0-6.5, and if the pH gets much higher, a phenomenon called nutrient-lockout occurs and the plants will have deficiencies in iron, phosphorous, and manganese, (Somerville, 2003.) The third major component of aquaponics, the bacteria, are also pH sensitive, with their ability to convert ammonia into nitrate reduced in acidic conditions below a pH of 6. Therefore, the optimum range for pH within an aquaponics system is slightly acidic, with a range of 6.5-7, (Somerville, 2003.)

Carbonate Hardness (KH) KH is a representation of the total amount of carbonates and bicarbonates dissolved in water, (Somerville, 2003.) The respiration of the fish creates increase~~d~~ levels of carbon dioxide (CO2) which naturally will convert into carbonic acid (H2CO3) within the water. This process takes away the free Hydrogen ions created from the nitrification process, and if unregulated, can create a decline in the pH (Somerville, 2003.) See equations in Figure 4. The importance of KH is that it acts as a buffer to pH change. The carbonates, when kept in balance, buffer pH change as they absorb the free (H$^+$) ions that would create high acidity if there were low KH levels. The ideal KH range is 60-140mg/L, (Somerville, 2003.)

Temperature Aquaponics systems tend to operate best between 18-30 degrees Celsius, (Somerville, 2003.) This is because temperature affects the rate of change for every aspect of the system, and if too low or too high, will create detrimental damage. Most aquaponics systems use tilapia which require warmer water temperatures, however this system will use catfish, a very hardy fish, that is capable of surviving even freezing



Bicarbonate and nitric acid bonding in aquaponics

HNO_3	+	HCO_3^-	=>	H_2CO_3	+	NO_3^-
(Nitric acid)		(Bicarbonate)		(Carbonic acid)		(Nitrate)

Hydrogen and carbonate ions bonding

H^+	+	CO_3^{2-}	=>	HCO_3^-	&	H^+	+	HCO_3^-	=>	H_2CO_3
(Free hydrogen)		(Carbonate)		(Bicarbonate)		(Free hydrogen)		(Bicarbonate)		(Carbonic acid)

Figure 5: KH Equations (Somerville, 2003.)

conditions. California does have a varied climate, however the weather in Sebastopol is generally pretty mild, mitigating most concerns over temperature.

Nitrite, Nitrate, and Ammonia   The various nitrogen levels all begin at the fish feed. The fish feed is 36% protein and 16% of the protein is nitrogen. The fish absorb just 40.0% of the nitrogen and excrete 34.65g of Nitrogen for every kg of feed, (Systems Analysis.) The fish waste is mostly ammonia, which is toxic to fish, and can create symptoms of poisoning at levels as low as 1.0mg/L, (Sommerville, 2003.) The ammonia (NH_3) is then converted, via bacteria, in two steps, into Nitrites (NO_2^-) and then into nitrates (NO_3^-).

This is the nitrification process. The first conversion is processed by Ammonia-Oxidizing Bacteria (AOB) Nitrosomonas, the second is carried out by Nitrite Oxidizing Bacteria (NOB) Nitrobacter. These bacteria are present in the system just about wherever there is surface area, but they thrive not only in the biofiltration tank, but in the root-systems of the growing plants. Once the ammonia is broken down into nitrates, the nitrates are absorbed by the plants, and eventually taken out of the system at harvest. The nitrogen levels will remain balanced as long as the plants take up the nitrogen originating from the fish feed.

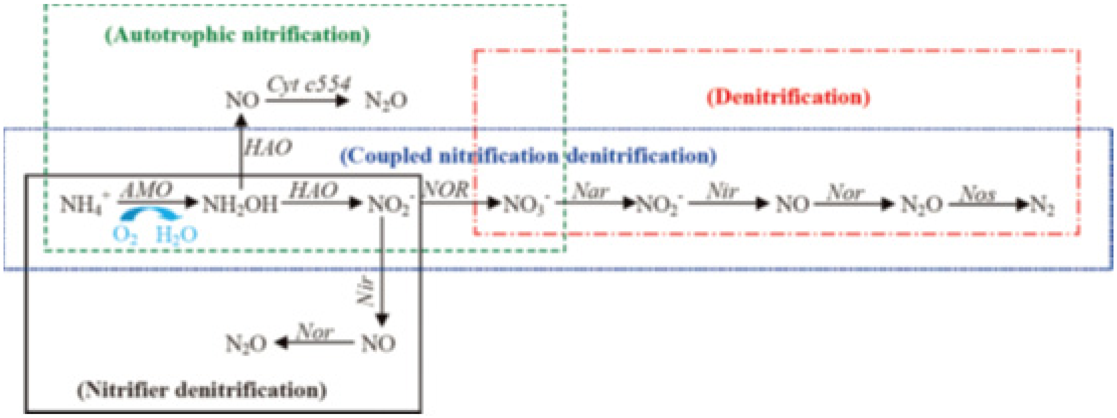
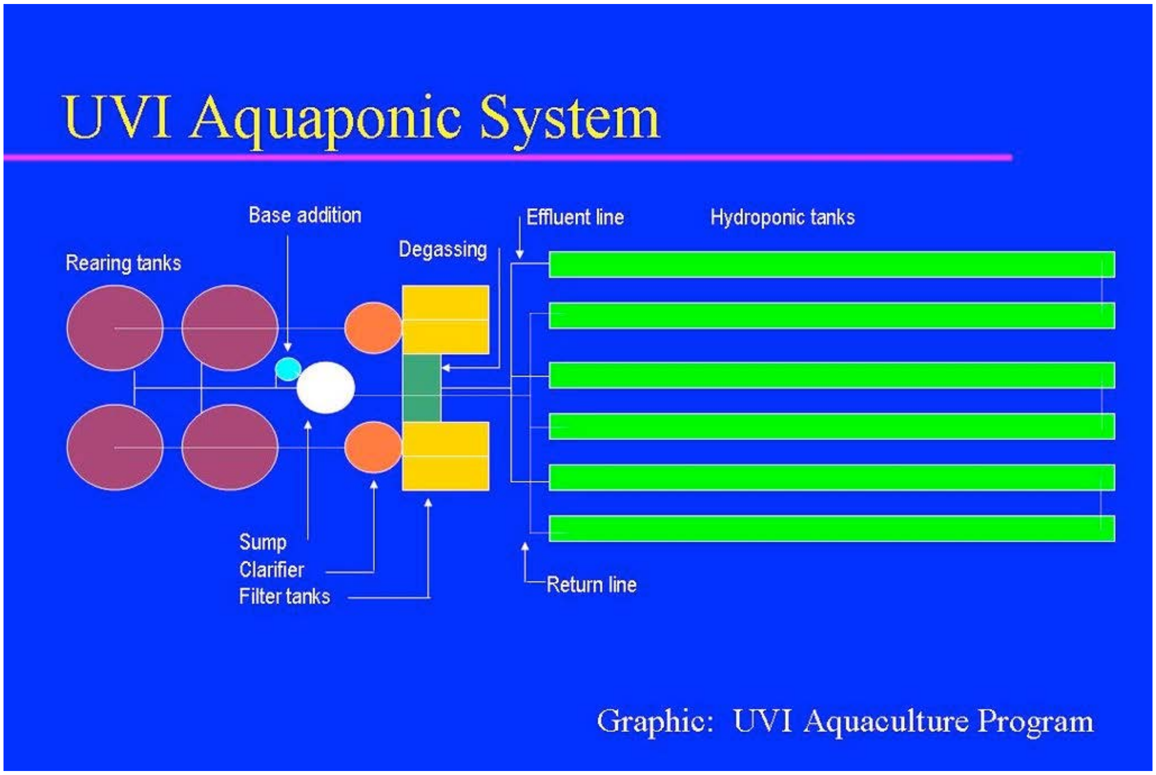


Figure 6: Nitrogen Cycle Chemistry Broken Down, (Khanal, 2016.)

Existing System Designs

As seen in (Figure 7), an existing design created by a team at the University of the Virgin Islands, designed to hold 111,000 liters and rear five metric tons of tilapia per year. This system has a greater capacity than the current need for the Ceres Project Community Garden. Its design also utilizes a large degassing system, which is generally only needed in such large commercial facilities, however, one will be included in this design as a measure of mitigation of potential drops in DO, or buildup of CO2 and excess nitrates, and any other gasses. Adaptations will be made to the following design, to modify and to slightly scale it down, (Rakocy, 2004.)


UVI Aquaponic System

Graphic: UVI Aquaculture Program

Figure 7: UVI Aquaponics system (Rakocy, 2004.)

<u>Operation</u>

The five main inputs to the system are water, oxygen, light, feed given to the aquatic organisms, and electricity to pump, filter, and oxygenate the water. Other lesser inputs are listed below in the supplemental section. Feed can be automated and refilled every week, however automation is not necessary, and can malfunction, thus it is recommended to have an employee/ volunteer to feed the fish, perform water quality tests, and visually inspect the system to ensure proper function. Other operation procedures would include water quality tests once a week to ensure pH, temperature, KH, and DO range acceptability, (Rakocy, 2004.) Operation would also include harvesting and restocking the fish when they reach market size. After harvesting the crops once they have grown, a new crop can immediately be planted.

<u>Supplemental</u>

A base addition tank, may be necessary to help control pH in larger systems. Some systems may run low in iron, which may need to be supplemented on a weekly-biweekly basis. Calcium and Potassium are used primarily to keep pH at the target pH of 7 within the optimum levels of 6.5-7.5. (Tyson, Treadwell, Simmone, 2011). Calcium (Ca^{2+}), potassium (K), and iron (Fe), may all need to be supplemented if water quality tests advise there is an imbalance. See Figure 8 to see common plant nutrient deficiency symptoms and causes.

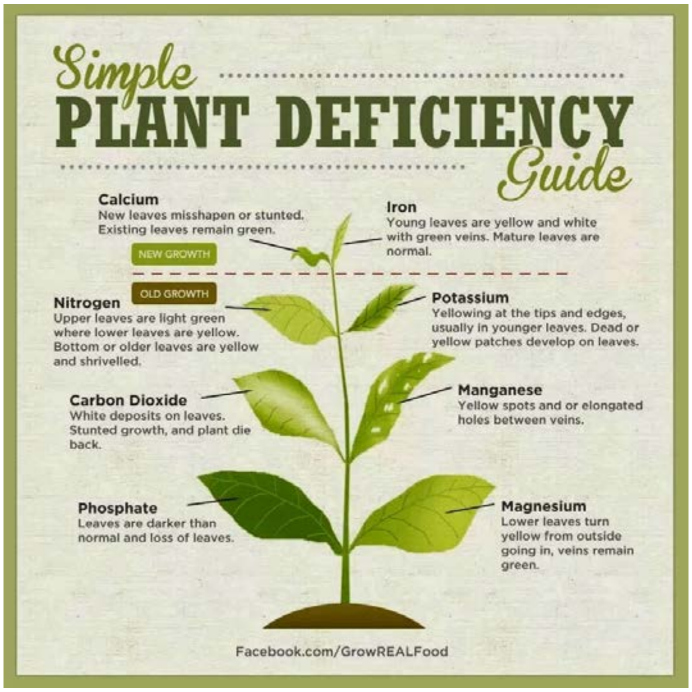


Figure 8: Plant Deficiency Guide (Hozier, Bradely)

Emergency Situations

In addition to basic maintenance steps there are certain precautions that should be taken into account to ensure proper function and persistence of the system, and survival of the fish. One of these parameters for mitigation of disaster would include a set of alarms to sound when the system has been disconnected from its water source, or the water levels drop past a certain volume/level. Another measure would be to include a backup generator within the system to keep the water aerated and circulating and the fish alive, in the event of a power outage. The importance of a generator is compounded when running a system where temperatures are low enough to warrant a water heater. Fortunately, this system is designed for catfish which prefer lower temperatures. The most important factor is to have a backup aerator, as the fish can die within hours if the available oxygen is depleted.

DESIGN PROCEDURE

The design procedure consists of the sizing of the aquaponics system, as well as sketching out a physical system design in Auto CAD. Nitrogen and aeration calculations can be reviewed in the following calculations section, or in Appendix B. Calculations, where the general Sizing Calculations are available. A cost analysis was then performed, available in Appendix Section C.

The Ceres Project estimated their use of fish in their meals at 40 pounds of fish per week, and the aquaponics system aims to provide those 40 pounds per week with the Catfish. Ceres also purchases at least $100,000 of produce each year to keep up with their demand, and that is after equal amounts of cash and produce are received in donations. $40,000 of that $100,000 in donations had traditionally come from W.H.O.A. farm. This system will help close that gap, and make the Ceres Project more self-sufficient.

Sizing the System

Fish: The primary calculation in determining the size of an aquaponics system was determining the quantity of fish (in pounds) to produce per year. If the need for fish was approximately 40 pounds per week, and the organization operates 52 weeks per year, then the quantity of fish to be produced throughout the year totals to 2080 pounds. A system should be stocked with approximately half the quantity of fish required for the year, (Schwartz, 2016.) Therefore, if 2080 pounds per year is needed, then the quantity of fish to be stocked at any given time should be 1040 pounds of fish.

Tank Size: A system with an aerator emitting pure oxygen, to increase concentration of dissolved oxygen, is capable of sustaining a maximum of 1.25 pounds of fish per 1 gallon of water in the tank. With aerators without pure oxygen, the maximum rearing density recommendation drops to 0.25 pounds of fish per gallon of water. (Schwartz, 2016.) This system will not use pure oxygen aeration therefore the maximum stocking density used was 0.25 pounds of fish per gallon, however, this project used 0.20 pounds of fish per gallon, to act as a buffer, as fluctuation within the systems can lead to poor fish health and even death. With 1040 pounds of fish in the system, the amount of water needed is 5200 gallons. With the fish and the water volume divided between 4 tanks, each tank should hold approximately 1300 gallons.

Growbed Space: The method that was used in this system, was based off the weight of the total fish in the system at any given time. The general rule of thumb based off fish weight was that one can have 0.1-1.5 square foot grow space per 1 pound of fish, depending on plant density, (Purdue, 2011.) This system was designed with a lower plant density, and therefore used 1.5 square foot per 1 pound of fish, totaling to 1,560 square feet grow bed space. This was rounded up to 1,600 square feet to simplify the construction of the grow beds, by adding 10 square feet to each of the four grow beds. The grow beds were designed to be stocked with a plant density at 1.5 square feet per plant, we end up with 1067 plants.

Plant Production: The total weight of production from those plants per year varies depending on many aspects of the system, mainly maintaining water quality, and ensuring enough Nitrogen in the system for the plants. The U.S. wide yield average for plants produced within an aquaponics system (pounds produced per plant per year) is approximately 16-30 pounds per year, (Pena, 2016.) Inferring from there one can deduce that for every available space for a plant in our system, there will be 16-30 pounds produced. From that range, based on our calculated number of plants we can gauge the production to be anywhere from 16,000- 32,000 pounds of produce. Assuming the lesser end of that range, as a safety factor for the system, 16,000 pounds of produce is a safe minimum estimation of the quantity of produce generated in a year.

Biofiltration Tank: Next the smaller components of the system were to be sized, such as the biofiltration tank. Full biofiltration tank calculations can be found in Appendix B. With 1040lbs (472. Kg) of fish in the system at any given time, and feeding them at 2% body weight, there is 20.8lbs (9.43Kg) of feed per day given to the fish. With a feed that is 36%protein, and net protein uptake (NPU) from the fish of just 40%, then a ratio of 34.56 grams of ammonia(NH_3) per Kilogram of feed is excreted as ammonia, (Schwartz, 2016.) So by multiplying by the (9.43Kg) of feed per day, there is 326 grams of Ammonia available for nitrification per day.

When sizing a biofiltration system, the aim is to determine how much volume (cuft) is needed to provide enough room for enough media (Bio Balls) to harbor the necessary quantity of nitrifying bacteria. From Schwartz's Notes, one can see that with 1000 square feet per Kg feed, at 36% protein, there is about 30 square feet of surface area required per gram of NH_3. (Schwartz, 2016.) Taking that 30sqft/gNH_3 and multiplying by the 326gNH_3 available from the feed, and one can deduce that the system requires 9,780 square feet of surface area from the BioBalls for biofiltration. Now we can factor in the 164 square foot per cubic foot ratio of the BioBalls, yielding a total of 61 cubic feet. To leave excess room for head and the BioBall media, this volume will be scaled up by 25%, setting the biofiltration tank at 76 cubic feet, or approximately 570 gallons, as shown in Equation 4 (Schwartz, 2016.)

326	grams N	*	30	sqft	=	9780	sqft	/	164 sqft	=	61.125	cuft	*	1.25	=	76.40625	cuft
	per day			per gram N					per cuft								
570	Gallons																

[4]

Aeration: In order to ensure the system has proper aeration, calculations for fish and bacteria oxygen use are used to determine the number of aerators (air stones) necessary, as well as the size of the air pump blower. Catfish O_2 use was gauged using values Table 3. Assuming a temperature of 15°C, a DO of 7ppm, and an average fish size of 500grams, a usage rate was determined to be 240 milligrams O_2 used per Kilogram of fish in system per hour, from Table 3. With 472Kg of fish in the system, we end up with a fish O2 usage rate of 113 grams per hour. To determine the O_2 use from bacteria converting ammonia, a usage rate of 4.6 grams of O_2 used per gram ammonia converted. With a rate of 326 grams of NH_3 per day, the bacteria use 62.5 grams of O_2 per hour. Adding these two we can see that the system uses 176 grams of O_2 per hour.

Table 3: Catfish Oxygen Consumption, (Schwartz, 2016.)

Oxygen Consumption Rate **Mg/KG/HR** Given 15*C H2O temp			
Size fish (g)	DO = 7mg/L	4mg/L	2mg/L
5	612.5	346	168
10	525	296	144
50	375	211	103
100	312.5	176	86
500	240	135	66
1000	170	96	46

It is important to note, however, that when designing a system one must, "design [the] system for twice the capacity that you calculate for two reasons: 1) The system may not operate as efficiently as designed. 2) When temperature goes up metabolic rate of the fish increases i.e. the oxygen consumption rate doubles when the temperature rises from 25-35 degrees c," (Schwartz, 2016). This doubling raises our O_2 use from 176 grams O_2 per hour to 352 grams O_2 per hour.

Table 4: Aeration evaluation, (Schwartz, 2016.)

Aeration Evalutaion				
Air Stones	Air	Depth (feet)		
size (in)	CFM (Cubic Feet per Minute)	1	2	3
		G//HR Oxygen		
1.5 x 1.5	0.25	1.3	2	2.7
1.5 x 3	0.5	2.6	4	5.4
1.5 x 12	2	10.4	16	21.6

Using 1.5-inch by 12-inch air stones shown in Table 4, generating O_2 at a rate of 16 grams O_2 per hour, the system will require 22 air stones, blowing at a rate of 2 cubic feet per minute. With a total CFM of 44, from Table 5 we can see that the air pump or, "blower" required, should be rated at 1.5 horsepower, based on Regenerative Blower Capacity shown in Table 4. Four air stones will be placed in each tank, and the remaining 6 will be placed in the degassing chamber.

Table 5: Regenerative Blower Capacity, (Schwartz, 2016.)

Regenerative Blower Capacity in CFM						
HP	Inches of water					
	20	30	40	50	60	Cut off inches (limits depth of tank)
1/8	14	3	-	-	-	
1/3	28	19	7	-	-	
1/2	35	28	21	11	-	
1	69	60	52	36		
1 1/2	110	100	85	65		
2 1/2	130	120	110	100		

Nitrogen Calculations

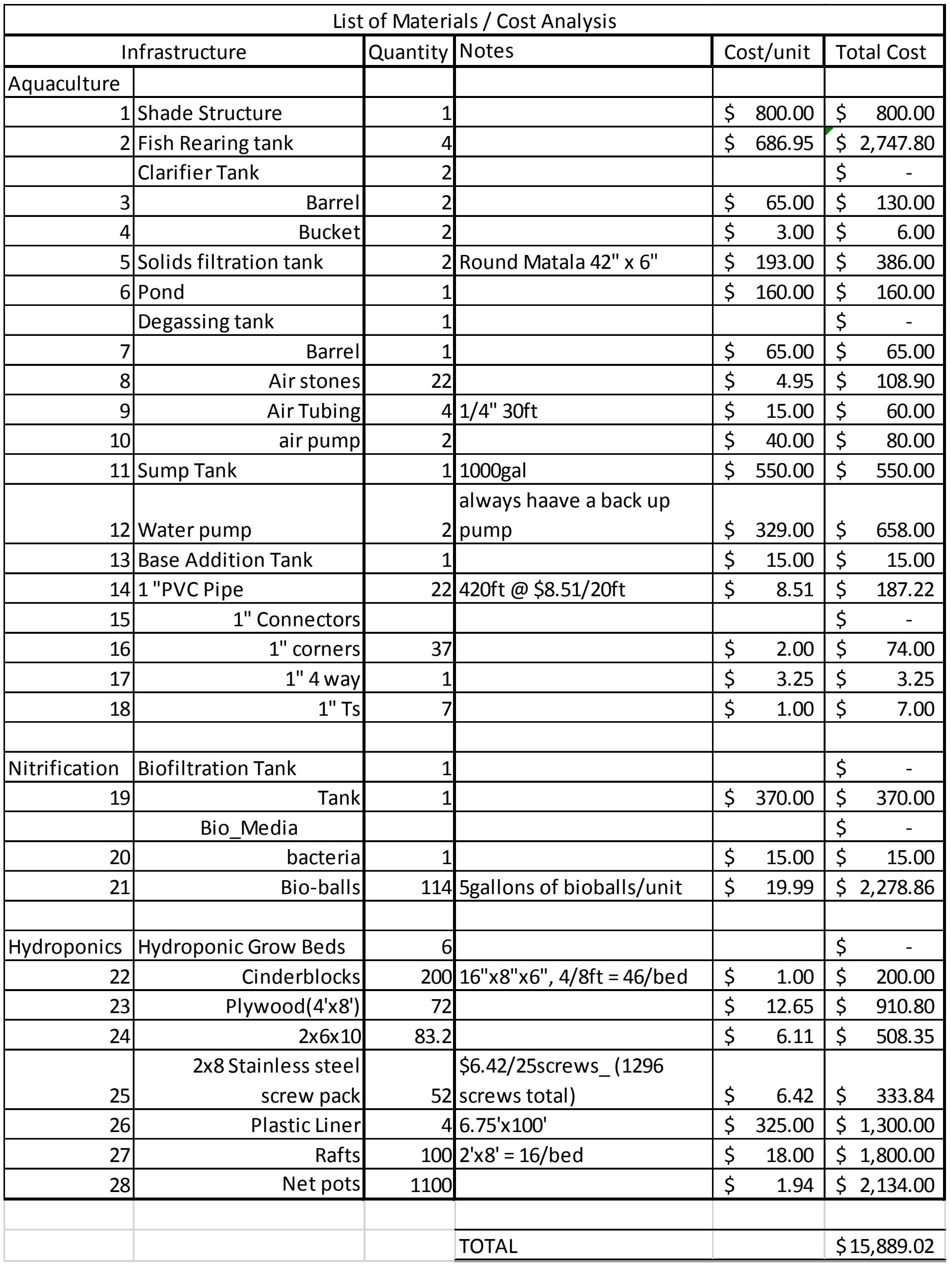
G	Nitrogen								
		NPU = Amnt. Of Protien taken up as fish flesh					1040	lbs fish at any time	
		Ammonia Excreted (G/KG) =		(1-NPU)(Protein %/6.25)(1000)			500	g. ea	
							471735.68	grams fish	
		NPU =	0.4				471.73568	kg fish	
		A.E. =	(1-0.4)(0.36/6.25)(1000) =	34.56	G (N)/ KG feed is excreted				
	at 36% protein =	1000/34.56	G ammonia/ KG feed						
		28.93518519	sqft/gram NH3	~30sqft/gram NH3					
		471.73568	kg fish fed at 2% body weight =	9.4347136	kg feed/ day		4.279510611	lbs feed/day	
		34.56	G (N)/ KG feed is excreted *	9.4347136	kg feed/ day				
		EQ							
			326.063702	grams nitrogen as ammonia/day			5200 Gal		
			326063.702	Mg NH3 /day			5200		
			16.56479961	Mg/L/Day					
							If the bio filter is not working the total ammonia in the system will rise 17 Mg/L/Day		
			326	gramsNH3/day					
				*30sqft/gN					
			9780	sqft	/ 164 sqft/ cuft				
			61.125	cuft	Biofiltration tank size				
			15.28125		0.25	+25% for room for media & head			
			76.40625	cuft	=	570	gallons		

Oxygen and Aeration Calculations

H.	Oxygen										
	O2 REQ										
		Size Fish		O2 consumption rate							
		500	g. ea	240	mg/kg/hr	@15C and 7ppmDO					
		1040	lbs fish	4.6	g O2	used per gram of Nitrogen converted from NH3 to NO3					
		471735.68	grams fish								
		471.73568	kg fish	240	mg/kg/hr	EQ	113,216.56	mg/hr			
							113.22	gO2/hr			
									1,499.60	g)2/day	
		568.556							62.48	gO2/hr	
									175.70	gO2/hr	
					With Air Stones from Table___						
				size	3X12	gO2/hr					
					depth2'			/16gO2/hr			
					cfm	2			10.98	*2=	21.96
							=	22	airstones		
					@2cfm	44					
			3 Air Stpnes in ea tank				`	1.5hp motor			
			2 Air Stones in	degassing chamber							

Cost Analysis

The major system components are listed as follows and can also be found complete with sources in appendix C: Four 1300 gallon Catfish rearing tanks, shading structure, 1600sqft of grow-bed space, a 570 gallon biofiltration tank, a sump tank, clarification and solids filtration tanks, a degassing tank, a base addition tank, an oxygenation/aeration system, a 160 gallon pond, and air and water pumps. The components were broken up into sections for the various components grouping them under Aquaculture, Hydroponics, Nitrification, and Operational/Other.



List of Materials / Cost Analysis

Infrastructure		Quantity	Notes	Cost/unit	Total Cost
Aquaculture					
1	Shade Structure	1		$ 800.00	$ 800.00
2	Fish Rearing tank	4		$ 686.95	$ 2,747.80
	Clarifier Tank	2			$ -
3	Barrel	2		$ 65.00	$ 130.00
4	Bucket	2		$ 3.00	$ 6.00
5	Solids filtration tank	2	Round Matala 42" x 6"	$ 193.00	$ 386.00
6	Pond	1		$ 160.00	$ 160.00
	Degassing tank	1			$ -
7	Barrel	1		$ 65.00	$ 65.00
8	Air stones	22		$ 4.95	$ 108.90
9	Air Tubing	4	1/4" 30ft	$ 15.00	$ 60.00
10	air pump	2		$ 40.00	$ 80.00
11	Sump Tank	1	1000gal	$ 550.00	$ 550.00
12	Water pump	2	always haave a back up pump	$ 329.00	$ 658.00
13	Base Addition Tank	1		$ 15.00	$ 15.00
14	1 "PVC Pipe	22	420ft @ $8.51/20ft	$ 8.51	$ 187.22
15	1" Connectors				$ -
16	1" corners	37		$ 2.00	$ 74.00
17	1" 4 way	1		$ 3.25	$ 3.25
18	1" Ts	7		$ 1.00	$ 7.00
Nitrification	Biofiltration Tank	1			$ -
19	Tank	1		$ 370.00	$ 370.00
	Bio_Media				$ -
20	bacteria	1		$ 15.00	$ 15.00
21	Bio-balls	114	5gallons of bioballs/unit	$ 19.99	$ 2,278.86
Hydroponics	Hydroponic Grow Beds	6			$ -
22	Cinderblocks	200	16"x8"x6", 4/8ft = 46/bed	$ 1.00	$ 200.00
23	Plywood(4'x8')	72		$ 12.65	$ 910.80
24	2x6x10	83.2		$ 6.11	$ 508.35
25	2x8 Stainless steel screw pack	52	$6.42/25screws_ (1296 screws total)	$ 6.42	$ 333.84
26	Plastic Liner	4	6.75'x100'	$ 325.00	$ 1,300.00
27	Rafts	100	2'x8' = 16/bed	$ 18.00	$ 1,800.00
28	Net pots	1100		$ 1.94	$ 2,134.00
			TOTAL		$ 15,889.02

Operational Costs		Quantity	Notes	Cost/unit	Total Cost
29	seeds	1	pack of 5000 seeds	$ 23.35	$ 23.35
30	Media Cubes	7	packs of 196	$ 4.00	$ 28.00
31	DO / pH Testing Kit	1		$ 142.00	$ 142.00
32	Water	700	$3.20 / 100 cuft H2O	$ 3.20	$ 2,240.00
33	Electricity	16330.83	14.08¢/kWh.	$ 0.14	$ 2,299.38
34	Catfish fingerlings	1000	944 round up to account for potential mortality	$ 1.00	$ 1,000.00
35	Feed	190	7570 lbs feed / year $115/40lbs = 190	$ 115.00	$ 21,850.00
36	Supplementals				$ -
37	Iron	1	Maxicrop plus iron (chelated iron/liquid	$ 24.46	$ 24.46
38	Calcium (and phosphorous)	1	Steamed bone meal	$ 12.26	$ 12.26
39	Potassium	1	banana peels	-	
40	Phosphourus (& potassium)	1	Sea Bird (or bat) droppings	$ 7.50	$ 7.50
			TOTAL		$ 27,603.60
			1st Year Grand Total		$ 43,492.62

A cost analysis was performed and prices of project components and inputs off of costs were found from various sources online, and it was determined that the Ceres Project would initially suffer a loss the first year, however after that first year, the system would pay off the initial materials cost, and start to generate a profit. The full cost analysis complete with sources can be found in Appendix C.

The total cost of the system components comes out to roughly $15,900. While the operational costs totaled to a projected $27,600.

While the initial $15,900 component cost will be made up of one time purchases, the operational costs at $27,600 are reoccurring each year. This sets the initial cost of components and first year of operation at $43,500.

With a going rate of $3 per pound for whole catfish, the 2080 pounds generates the Ceres Project $6,240. In addition, the minimum estimated 16,000 pounds of produce, at $2-3 per pound would generate anywhere from $32,000 to $48,000. When looking at the potential for the yield to surpass the minimum estimate of 16,000 pounds, the value goes up substantially.

If one were to look at the optimistic production values, calculated using maximum possible production weight of 32,000 pounds, and again at just $2-3 per pound the valuation would be placed at $64,000 to $96,000. That calculation was made recognizing that the maximum estimate is, in practicality probably out of reach, however, it is useful to show the potential of a fully optimized system.

RESULTS

The system as it is designed meets the project requirements of being able to generate 40 pounds of catfish per week, generating over 8,000 pounds of produce per year, and all combined into one cost efficient system. After the system had been properly sized, and the materials listed out, and the cost analysis was performed, it became clear that the project would be of great benefit to the Ceres Community Project.

The largest portion of the operational costs, is the fish feed. 1040 pounds of fish fed at 2 % of their body weight, receive roughly 20 pounds of feed per day. This totals to about 7500 pounds of feed per year. When purchasing feed at a cost of $115 per 40 pounds of feed, the cost rockets to over $21,000. While purchasing the fish feed is assumed in this project, alternative methods of raising fish feed can be implemented to reduce the cost of fish feed. These methods include growing fish feed (duckweed) within the system itself, or implementing a black soldier fly rearing system, to at least reduce the cost of feed inputs.

With the minimum estimated plant production at approximately 16,000 pounds, and assuming a conservative market value of $2.00 per pound for organic leafy produce. This generates a conservative estimate of approximately $32,000 worth of produce that would be made available to the Ceres Kitchen. Adding the $6,240 estimated value from catfish production there is a total value of $38,240. With a total cost of $43,500, the net profit after the first year would be a loss of $5,250. However, once those initial component costs have been paid out during the second year a profit of $10,636, however it comes out to $5,383, when you factor in the initial loss from the first year. The third and following years generate a profit of $10,600 per year, as seen in Table 6. This system is not perfect, but the numbers show it is a viable system to implement as its value increases with time, as well as the value gained system serving as an educational tool for community involvement and healthy living.

Table 6: Net Profit/Loss

		-	+	net
1st Year Cost		$ 43,492.62	38240	$ (5,252.62)
2nd Year Cost		$ 27,603.60	38240	$ 5,383.78
3rd + Year Cost		$ 27,603.60	38240	$ 10,636

Labor costs were not addressed as Ceres already has rotations of volunteers that help at the garden, who would be helping during times of harvest, as well as a garden manager who would take on and delegate the operational procedures, such as pH and water quality testing.

Though the system operated at a $5,250 projected loss for the first year, a profit of 5,383 the second year, and every year after that is projected to generate $10,600 in value of produce and catfish for the Ceres Project. One of the difficulties of maintaining a medium-large scale Aquaponics system is marketing and selling the fish that are raised, and seeing as aquaponics is done with freshwater fish, the options of popular fish to raise and sell can be problematic. This however is not a problem for the planned use of this aquaponics system. The Ceres project is always in demand of fresh and healthy animal proteins, and so an excess of catfish will not be a likely occurrence. As the system is designed, it is capable producing double the initial goal of produce grown. With the system operating above minimum projections, the system is more than capable of making up the deficit generate by the W.H.O.A. farms downsizing.

Figure 9: Preliminary Design

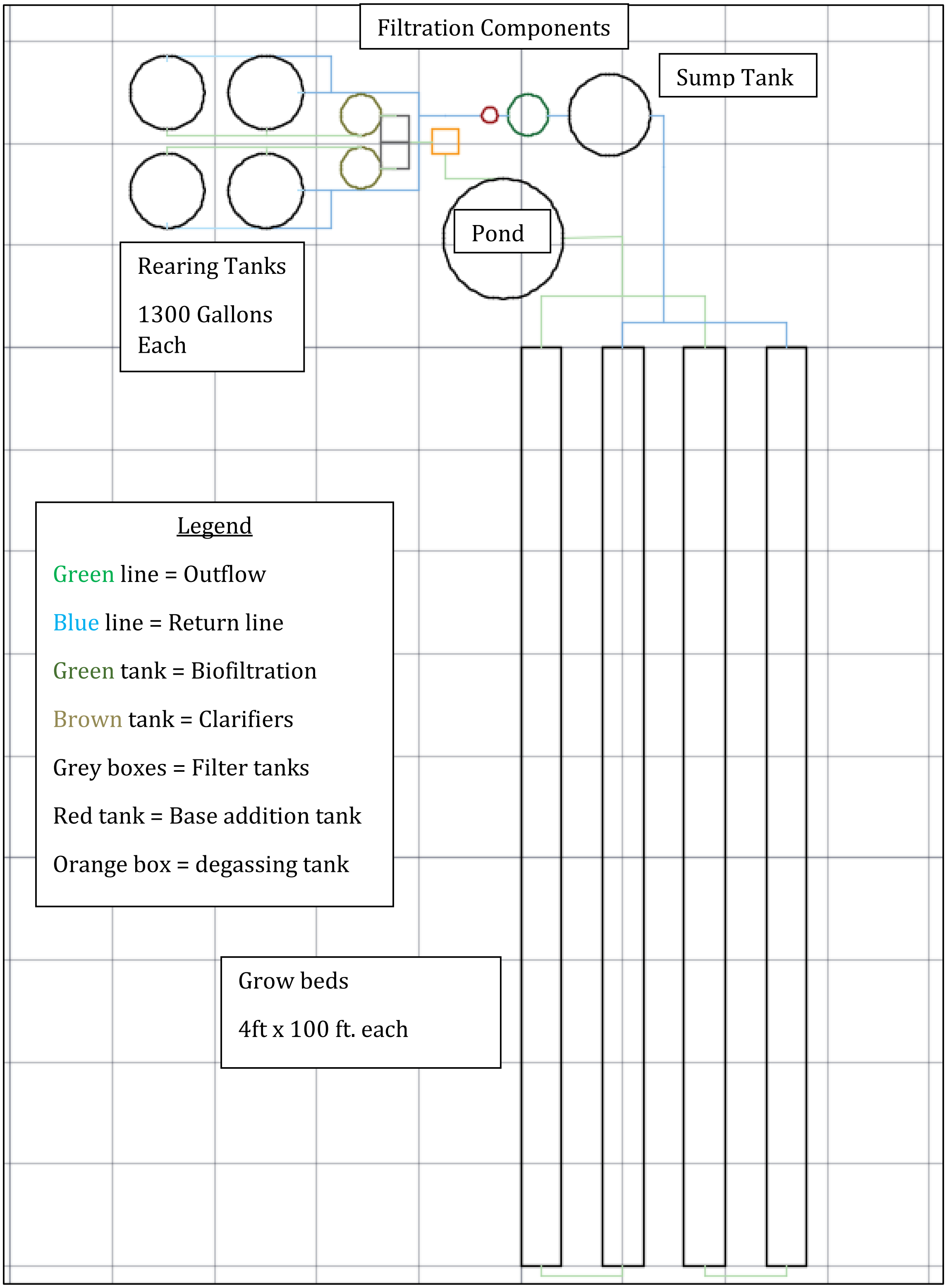


Figure 10: Final Design – Overhead View

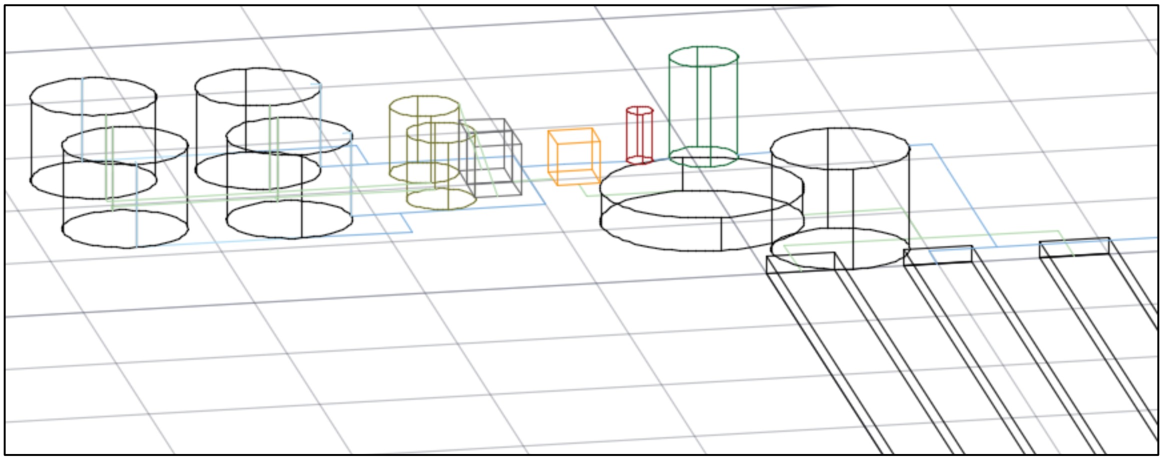


Figure 11: Final Design

The over all foot print of the system is 2,700 square feet. The grow beds themselves take up 1,600 square feet with 200 square feet between each of them. The tanks and other components cover a total of approximately 1300 square feet. The rearing tanks have a height of 5 ft and a diameter of 7.5 ft. The smaller componentes the clarifiers, filters, base addtion and degassing units, take up about 250 square feet, and are connected via PVC piping.The biofiltration tank is approximately 570 gallons, located behind the pond and next to the base addition tank, is to be filled with the 61 cubic feet of BioBalls as the media for the nitrifying bacteria. The sump tank is a 1000 gallon tank embedded in the ground behind the grow beds and the pond, which is approximately 170 gallons.

DISCUSSION

A few of the more complex areas of construction and the procedures needed to bring the system to operation would entail the construction of the grow beds and the installation of the biofiltration tank and stabilization of the water quality. The Grow beds are constructed simply using cinderblocks, plywood, 2x8x10s, the plastic liner, 2 x 8 stainless steel screws, the foam rafts, grow media cubes and the net pots. The bio filtration tank used for this project is a large tank filled with BioBalls. The rest of the system is connected via fitting the components together with the PVC.

The cost analysis does not include any labor costs, as the Ceres Project relies primarily on volunteers for its operation, and it would not be difficult for them to arrange for volunteers to aid in the construction and the operation of the system. The garden is already tended to by a garden manager and a rotating team of volunteers.

With the evolution of the project and the design, changes from preliminary designs were made. With the selection of a Deep Water Culture hydroponics method, the system was limited to smaller crops, as the plants are sitting on rafts and have little support compared to a method that utilizes a growing media that provides support. Thus, the system will primarily be used in the production of leafy greens. This is not an issue for the Ceres garden as they have plenty of other space for larger or heavier fruits and vegetables.

Throughout the design and sizing process several different fish types were considered, but after reviewing the regulations for northern California, which rules out Tilapia, the most common fish used in aquaponics. The final system design was chosen to rear Catfish, as they are legal to raise in Northern California, and they are better suited to the temperature ranges of Sebastopol, CA. Catfish have been known to work well in aquaponics systems as they are not very aggressive and are hardy in their ability to survive in varied water quality conditions and temperatures. Catfish are bottom feeders, so they must be fed with sinking pellets. Water quality should be checked at least once a week, with pH testing done every other day to ensure a healthy system.

The system design was also altered to switch the location of the pond and the sump tank, to put the pond closer to the garden area and make the system more aesthetically pleasing, and allow for easier viewing.

RECOMMENDATIONS

During the initial set up of the system, it is very important to monitor water quality as the new water is treated and the bacteria within the system become established. Several steps should be followed to ensure a successful set up, before adding fish to the system. Water drawn from a well or city line can have high levels of chemicals such as chlorine. Allowing the water to circulate for a few days will give time for much of the initial chlorine levels to decrease via evaporation. Making adjustments to adjust pH or other water quality measures, will allow the system to stabilize for better fish and bacteria health. For water quality, it is recommended at a minimum, that there should be test kits on hand for: Ammonia, nitrate, nitrite, pH, and DO. DO and pH are critical factor and are best tested with a pH / DO meter. Adding more air stones is a method to increase the DO if it falls too low. An important issue pertaining to water quality and plant health, is disease. It is recommended to regularly inspect the crops for discoloration, spotting, leaf deformity, and root rot. The two most common diseases effecting organisms within an aquaponics system are Aeromonas & Pythium, however, these diseases are far more common in strictly hydroponics systems where there is not already a natural balance of bacteria within the system. In addition, natural sources of pest management are recommended, such as introducing ladybugs and/or praying mantises, to do away with plant eating pests.

There are some features that this system could benefit from adding, but were not included within the system design for various reasons, mostly additional cost. These alternative additions include: 1) Adding a greenhouse, which would allow for greater temperature, humidity and ventilation control. In a greenhouse system, light systems could be used to increase the time the crops are growing. A green house would be beneficial in winter months, though the catfish are capable of surviving in freezing conditions. 2) Adding a shallow water bed for seedlings. This smaller bed would be used to sprout seedlings in media cubes in net pots to be transferred into the system in a staggered manner so there is less time between planting crops and the crops being harvested. A small fish tank for catfish fingerling breeding would cut down on operational costs and create a source of catfish to stock the system with. 3) A fish purging system could be added to freshen fish. A purging system is essentially a tank outside the system with very clean water that the fish stay in for 2-3 days before being harvested. This process supposedly improves the texture and taste of the fish. 4) Automation is a feature often include in aquaponics systems. It is possible to include a mechanism that would release a predetermined amount of feed to the fish tanks on a timer so a worker or volunteer does not need to be there every single day. While automation is a nice feature, it not necessary, can drive up cost, and is no substitute for physical inspection.

REFERENCES

1. Richard V. Tyson, Danielle D. Treadwell, Eric H. Simonne. “Opportunities and Challenges to Sustainability in Aquaponic Systems,” HortTechnology, Vol. 21, no. 1, 6-13, February, 2011.

2. Rakocy, J.E., Masser, M. and Losordo, T. “Recirculating Aquaculture Tank Production Systems: Aquaponics – Integrating Fish and Plant Culture,” Southern Regional Aquaculture Center Publication #454, 2006.

3. Rakocy, J.E. (1997) Tilapia in aquaculture in the Americas, Integrating tilapia culture with vegetable hydroponics in recirculating systems, eds Costa-Pierce B.A., Rakocy J.E. (World Aquaculture Soc, Baton Rouge, LA), Vol. 1, pp 163–184.

4. Goodman, E. “Aquaponics: Community and Economic Development,” Massachusetts Institute of Technology, 2011.

5. Rakocy, J.E., Bailey, D.S., Schultz, R.C., Thoman, E.S. (2004) Update on tilapia and vegetable production in the UVI aquaponic system. <http://ag.arizona.edu/azaqua/ista/ista6/ista6web/pdf/676.pdf> 17, Nov. 2015.

6. Diver, S. "Aquaponics - Integration of Hydroponics with Aquaculture."(2006). < https://attra.ncat.org/attra-pub/viewhtml.php?id=56>

7. "Aquaponics." YouTube. Purdue University, 27 Oct. 2011. Web. 19 Nov. 2015. <https://www.youtube.com/watch?v=26xpMCXP9bw>

8. Khanal, Samir K. "Bioenergy Research Group." *Bioenergy Research Group*. University of Hawaii, n.d. Web. 19 Feb. 2016.

9. Schwartz, Gregory. Personal interview. 12 Feb 2016.

10. Schwartz, Gregory. Systems Analysis Notes, *Evaluation of Facility and Management.*
Document form Gregory Schwartz. Feb. 2016.

11. Somerville, Christopher, Moti Cohen, Edoardo Pantanella, Austin Stankus, and Alessandro Lovatelli. "Small-Scale Aquaponic Food Production." *FAO Fisheries and Aquaculture Technical Paper* 7010th ser. 589.2070 (2003): n. pag. *FAO.org*. Food and Agriculture Organization of the United States. Web. 14. Jan. 2016.

12. Pena, Jose G. "Greenhouse Vegetable Production Economic Considerations, Marketing, and Financing." *Hydroponic Vegetable Production*. Aggie Horticulture - Texas A&M, 2005. Web. 19 Feb. 2016.
13. "Welcome to Ceres." *Ceres Community Project*. Ceres Community Project, Web. <http://ceresproject.org/>.
14. Hosier, Shanyn, and Bradely, Lucy. "Guide to Symptoms of Plant Nutrient Deficiencies." *University of Arizona* (n.d.): n. pag. *Arizona.edu*. University of Arizona, May 1999. Web.
14. <http://www.backyardaquaponics.com/information/the-nitrogen-cycle/>
15. < http://www.humboldtsolarwaterpump.com/important-filter-cleaning-settling-tank/>
16. GoogleEarth

APPENDIX A

How Project Meets requirements for the ASM Major

How Project Meets Requirements for the ASM Major

ASM Project Requirements:

The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving. This project addresses these issues as follows.

Application of agricultural technology: Aquaponics is the combination of the application of the agricultural technologies of aquaculture and aquaponics.

Application of business and/or management skills: A cost analysis was performed to see if the implementation and operation of this system would be beneficial to the Ceres project was conducted.

Quantitative, analytical problem solving: The design of the system as well as the cost analysis contained elements of quantitative analytical problem solving.

Capstone Project Experience

This project incorporated knowledge gained from the following courses;

129 Lab Skills/Safety, 133 Engineering Graphics, 151 AutoCAD, 142 Machinery Management, 301 Hydraulic/Mechanical Power Systems, 321 Ag Safety, 343/344 Mechanical & Fabrication Systems, 402 Ag Materials, 418/419 Ag Systems Management, Technical Writing, 340 Irr Warter Management, Bot121, BRAE447 Advanced Surveying

ASM Approach

Systems approach: The project involves the integration of multiple functions (aquaculture, and hydroponics), and the integration of nitrification systems to provide improved waste management and an efficient crop growing solution for The Ceres Community Project.

Interdisciplinary features: The project touches on aspects of irrigation systems, agricultural safety and waste management.

Specialized agricultural knowledge: The project applies specialized knowledge in the areas of irrigation and water management, and agricultural safety, aquaculture, and hydroponics.

Project Parameters and Constraints

1. 8,00lbs produce

   The system has been designed to be able to produce 16,000 pounds of produce, twice the initial goal.
2. sustainable

   The system is relatively sustainable, the only inputs other than feed and water quality stabilization measures is the water to add due to evaporation, as well as electricity to power the pumps.
3. 40lbs fish / week

   The system has been designed with the target quantity of 40lbs of fish / week.
4. financially sustainable

   After performing the cost analysis, the project was determined to be financially sustainable, after the second year of operation.
5. 2-person operation

   The system operation involves a simple procedure of planting the seeds in cubes, placing the cubes in the net pots, adding small quantities of water to adjust for evaporation, as well as biweekly water quality testing, and finally harvesting the vegetables and fish,

Physical: The system was designed with the limited space of the Garden in mind

Economic: A Cost analysis was performed to determine the economic viability of the project

Environmental: The project aids in the conservation of water as aquaculture uses just 2% of the water when compared to traditional farming water usage.

Sustainability: The project aims to help the Ceres project sustain itself. The physical system itself is sustainable in terms of its low water use.

Manufacturability: The components of the system are made up of Items available for purchase online

Health and Safety: The project components are made of materials certified as safe for use with food and water by the FDA. The project will ultimately be promoting the consumption of healthy foods.

Ethical: The fish tanks were sized with a large margin in the requirements of gallons of water per pound of fish, so as to not overcrowd the tanks with a high stocking rate, a point of slight controversy within aquaponics communities throughout the world.

Social: The project seeks to educate the clients/volunteers involved in the Ceres project, as well as local Sebastopol community members on the advantages of aquaponics systems, and healthy eating in general, and the site serves as a location for community gathering and education.

Political: The addition of the Aquaponics system to the Ceres garden would bring attention to the Ceres Project, and could potentially generate an increase in volunteer membership, hours, or donations.

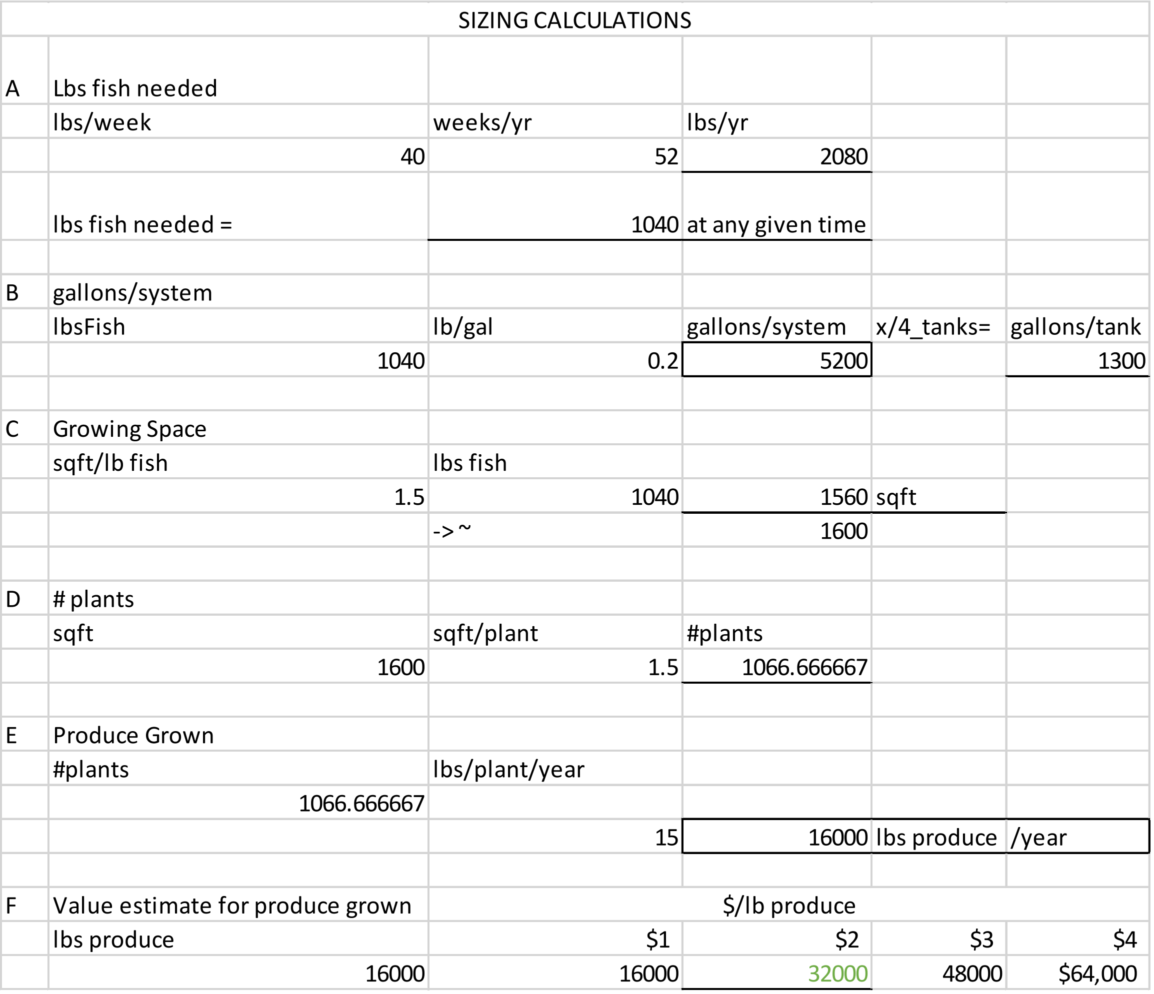
Aesthetic: The system will include a pond for aesthetic purposes.

Other – Productivity: The project will produce 2080 pounds of catfish per year and 16,000 pounds of produce per year.

Appendix B

Design Calculations

System Sizing Calculations



		SIZING CALCULATIONS			
A	Lbs fish needed				
	lbs/week	weeks/yr	lbs/yr		
	40	52	2080		
	lbs fish needed =	1040	at any given time		
B	gallons/system				
	lbsFish	lb/gal	gallons/system	x/4_tanks=	gallons/tank
	1040	0.2	5200		1300
C	Growing Space				
	sqft/lb fish	lbs fish			
	1.5	1040	1560	sqft	
		-> ~	1600		
D	# plants				
	sqft	sqft/plant	#plants		
	1600	1.5	1066.666667		
E	Produce Grown				
	#plants	lbs/plant/year			
	1066.666667				
		15	16000	lbs produce	/year
F	Value estimate for produce grown		$/lb produce		
	lbs produce	$1	$2	$3	$4
	16000	16000	32000	48000	$64,000

Nitrogen Calculations

G	Nitrogen								
		NPU = Amnt. Of Protien taken up as fish flesh					1040	lbs fish at any time	
		Ammonia Excreted (G/KG) =		(1-NPU)(Protein %/6.25)(1000)			500	g. ea	
							471735.68	grams fish	
		NPU =	0.4				471.73568	kg fish	
		A.E. =	(1-0.4)(0.36/6.25)(1000) =	34.56	G (N)/ KG feed is excreted				
	at 36% protein =	1000/34.56	G ammonia/ KG feed						
		28.93518519	sqft/gram NH3	~30sqft/gram NH3					
		471.73568	kg fish fed at 2% body weight =	9.4347136	kg feed/ day		4.279510611	lbs feed/day	
		34.56	G (N)/ KG feed is excreted *	9.4347136	kg feed/ day				
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			326.063702	grams nitrogen as ammonia/day			5200 Gal		
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			61.125	cuft	Biofiltration tank size				
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Oxygen and Aeration Calculations

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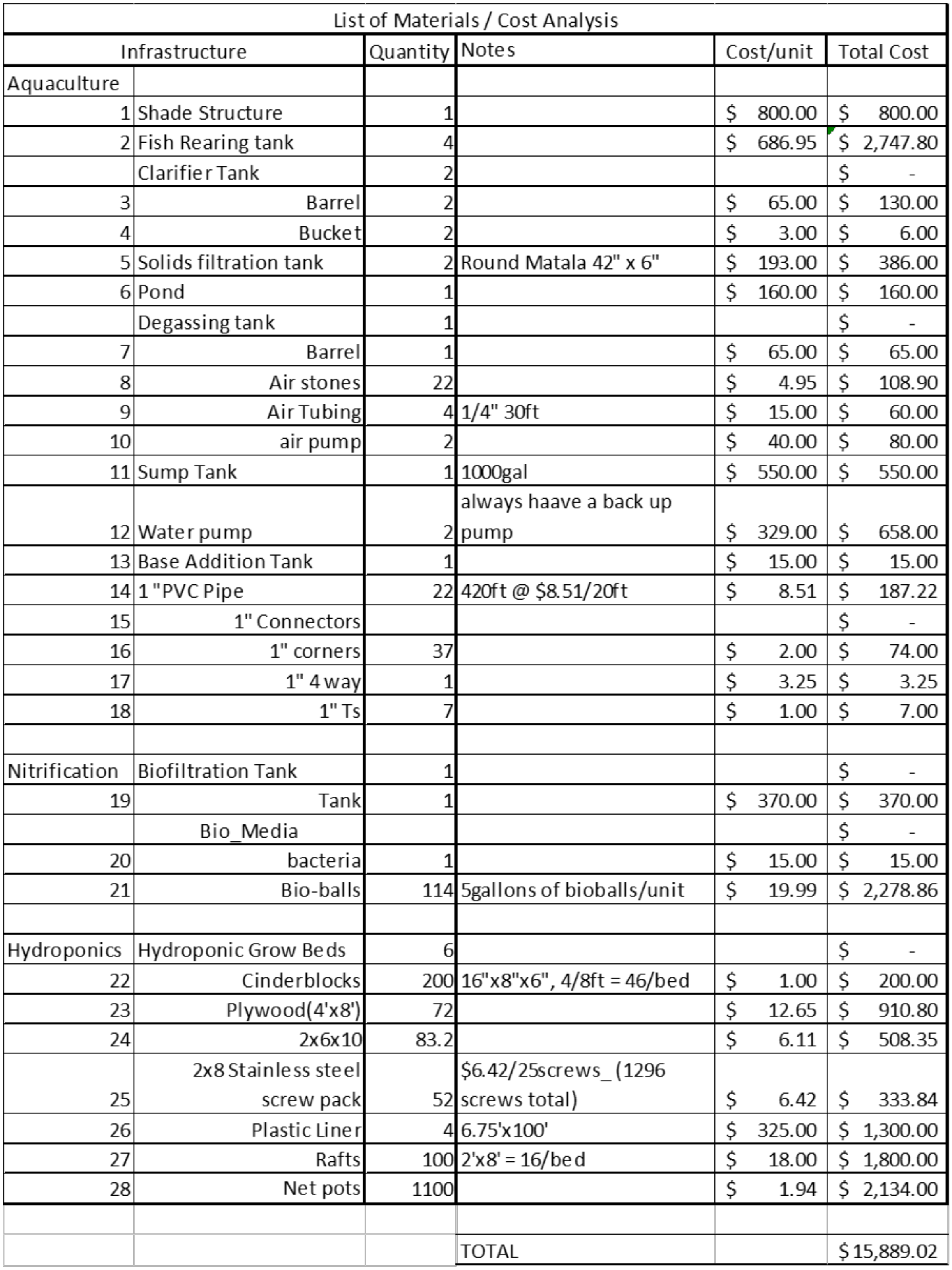
	O2 REQ									
			Size Fish	O2 consumption rate						
		500	g. ea	240	mg/kg/hr	@15C and 7ppmDO				
		1040	lbs fish	4.6	g O2	used per gram of Nitrogen converted from NH3 to NO3				
		471735.68	grams fish							
		471.73568	kg fish	240	mgO2/kg/hr	EQ	113,216.56	mg/hr		
		Fish O2 use					113.22	gO2/hr		
									1,499.60	g)2/day
		O2 used in nitrification							62.48	gO2/hr
		Total O2 use							175.70	gO2/hr
					With Air Stones from Table___					
				size	3X12	gO2/hr				
					depth2'			/16gO2/hr		
					cfm	2			10.98	
			568.556				=	11	airstones	
					@2cfm	22				
			3 Air Stpnes in ea tank				`	1hp motor		
			2 Air Stones in	degassing chamber						

Appendix C

Cost Analysis



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Aquaculture					
1	Shade Structure	1		$ 800.00	$ 800.00
2	Fish Rearing tank	4		$ 686.95	$ 2,747.80
	Clarifier Tank	2			$ -
3	Barrel	2		$ 65.00	$ 130.00
4	Bucket	2		$ 3.00	$ 6.00
5	Solids filtration tank	2	Round Matala 42" x 6"	$ 193.00	$ 386.00
6	Pond	1		$ 160.00	$ 160.00
	Degassing tank	1			$ -
7	Barrel	1		$ 65.00	$ 65.00
8	Air stones	22		$ 4.95	$ 108.90
9	Air Tubing	4	1/4" 30ft	$ 15.00	$ 60.00
10	air pump	2		$ 40.00	$ 80.00
11	Sump Tank	1	1000gal	$ 550.00	$ 550.00
12	Water pump	2	always haave a back up pump	$ 329.00	$ 658.00
13	Base Addition Tank	1		$ 15.00	$ 15.00
14	1 "PVC Pipe	22	420ft @ $8.51/20ft	$ 8.51	$ 187.22
15	1" Connectors				$ -
16	1" corners	37		$ 2.00	$ 74.00
17	1" 4 way	1		$ 3.25	$ 3.25
18	1" Ts	7		$ 1.00	$ 7.00
Nitrification	Biofiltration Tank	1			$ -
19	Tank	1		$ 370.00	$ 370.00
	Bio_Media				$ -
20	bacteria	1		$ 15.00	$ 15.00
21	Bio-balls	114	5gallons of bioballs/unit	$ 19.99	$ 2,278.86
Hydroponics	Hydroponic Grow Beds	6			$ -
22	Cinderblocks	200	16"x8"x6", 4/8ft = 46/bed	$ 1.00	$ 200.00
23	Plywood(4'x8')	72		$ 12.65	$ 910.80
24	2x6x10	83.2		$ 6.11	$ 508.35
25	2x8 Stainless steel screw pack	52	$6.42/25screws_(1296 screws total)	$ 6.42	$ 333.84
26	Plastic Liner	4	6.75'x100'	$ 325.00	$ 1,300.00
27	Rafts	100	2'x8' = 16/bed	$ 18.00	$ 1,800.00
28	Net pots	1100		$ 1.94	$ 2,134.00
			TOTAL		$ 15,889.02

Operational Costs		Quantity	Notes	Cost/unit	Total Cost
29	seeds	1	pack of 5000 seeds	$ 23.35	$ 23.35
30	Media Cubes	7	packs of 196	$ 4.00	$ 28.00
31	DO / pH Testing Kit	1		$ 142.00	$ 142.00
32	Water	700	$3.20 / 100 cuft H2O	$ 3.20	$ 2,240.00
33	Electricity	16330.83	14.08¢/kWh.	$ 0.14	$ 2,299.38
34	Catfish fingerlings	1000	944 round up to account for potential mortality	$ 1.00	$ 1,000.00
35	Feed	190	7570 lbs feed / year $115/40lbs = 190	$ 115.00	$ 21,850.00
36	Supplementals				$ -
37	Iron	1	Maxicrop plus iron (chelated iron/liquid	$ 24.46	$ 24.46
38	Calcium (and phosphorous)	1	Steamed bone meal	$ 12.26	$ 12.26
39	Potassium	1	banana peels	-	
40	Phosphourus (& potassium)	1	Sea Bird (or bat) droppings	$ 7.50	$ 7.50
			TOTAL		$ 27,603.60
			1st Year Grand Total		$ 42,914.62

Cost Over First Three Years of Operation

		-	+	net
1st Year Cost		$ 43,492.62	38240	$ (5,252.62)
2nd Year Cost		$ 27,603.60	38240	$ 5,383.78
3rd + Year Cost		$ 27,603.60	38240	$ 10,636

Cost Analysis Sources

#	Aquaculture	Source
1	Shade Structure	http://www.farmtek.com/farm/supplies/cat1;ft_shade_cloth_material;ft_sunblocker_bulk_shade_cloth.html
2	Fish Rearing tank	http://www.plastic-mart.com/product/5975/1300-gallon-open-top-flat-bottom-cylindrical-tank-crmi-1300ott
	Clarifier Tank	
3	Barrel	http://store.interstateproducts.com/products/Eagle-Drum-Equipment/Eagle-Blue-Lab-Pack-55-Gal-w Metal-Lever-Lock-Ring-1656MB?gclid=CNmQq9zR_swCFVNqfgodWAcAMg
4	Bucket	http://www.homedepot.com/s/5%2520gallon%2520bucket?NCNI-5
5	Solids filtration tank	http://www.thepondoutlet.com/r42blu-round-matala-42-x-6-blue
6	Pond	http://www.thepondoutlet.com/blue-damsel-preformed-pond-in-a-box?rid=base&source=googleps
	Degassing tank	
7	Barrel	http://store.interstateproducts.com/products/Eagle-Drum-Equipment/Eagle-Blue-Lab-Pack-55-Gal-w Metal-Lever-Lock-Ring-1656MB?gclid=CNmQq9zR_swCFVNqfgodWAcAMg
8	Air stones	http://www.horticulturesource.com/product_info.php?products_id=17032&gclid=CKfKjcnP_swCFVNqfgodWAcAMg
9	Air Tubing	http://cranecreekaqua.com/epages/3083f9c1-22be-4bc5-b38e-d5749c6aa0a8.sf/en_US/?ObjectID=693934&ViewAction=ViewFaceted&FacetValue_CategoryID=693934&CurrencyID=USD&CurrencyID=USD&FacetRange_ListPrice=&FacetRange_ListPrice=
10	air pump	http://cranecreekaqua.com/epages/3083f9c1-22be-4bc5-b38e-d5749c6aa0a8.sf/en_US/?ObjectID=693934&ViewAction=ViewFaceted&FacetValue_CategoryID=693934&CurrencyID=USD&CurrencyID=USD&FacetRange_ListPrice=&FacetRange_ListPrice=
11	Sump Tank	http://cranecreekaqua.com/epages/3083f9c1-22be-4bc5-b38e-d5749c6aa0a8.sf/en_US/?ObjectID=693934&ViewAction=ViewFaceted&FacetValue_CategoryID=693934&CurrencyID=USD&CurrencyID=USD&FacetRange_ListPrice=&FacetRange_ListPrice=
12	Water pump	http://www.everything-ponds.com/alpine-cyclone-8000-pond-pump.html
13	Base Addition Tank	http://www.thecarycompany.com/10-gallon-open-head-plastic-drum-56b11b?utm_source=google_shopping&m=simple&gclid=Cj0KEQjw7LS6BRDo2Iz23au25OQBEiQAQa6hwA0qvtqj3vA5__-H7V924JH5SlLLht_QStR8oMyEt5UaAjqB8P8HAQ
14	1 "PVC Pipe	http://www.homedepot.com/b/Plumbing-Pipes-Fittings-PVC-Pipe-Fittings/N-5yc1vZbuf5
15	1" Connectors	http://www.homedepot.com/b/Plumbing-Pipes-Fittings-PVC-Pipe-Fittings/N-5yc1vZbuf6
16	1" corners	http://www.homedepot.com/b/Plumbing-Pipes-Fittings-PVC-Pipe-Fittings/N-5yc1vZbuf7
17	1" 4 way	http://www.homedepot.com/b/Plumbing-Pipes-Fittings-PVC-Pipe-Fittings/N-5yc1vZbuf8
18	1" Ts	http://www.homedepot.com/b/Plumbing-Pipes-Fittings-PVC-Pipe-Fittings/N-5yc1vZbuf9
Nitrification	Biofiltration Tank	
19	Tank	http://www.plastic-mart.com/product/6575/600-gallon-plastic-water-storage-tank-43800
	Bio_Media	
20	bacteria	http://www.drsfostersmith.com/product/prod_display.cfm?pcatid=20064&cmpid=11cseYY&gclid=CMqf55vV_swCFQWUfgodBYkC5g
21	Bio-balls	http://www.bigalspets.com/bio-balls-300-count-approx-5-gal.html?utm_source=Google+Products&utm_campaign=Google+Products+Datafeed&utm_medium=Comparison+Shopping&gclid=CODd0_LU_swCFQ5qfgodw9YLSQ
Hydroponics	Hydroponic Grow Beds	
22	Cinderblocks	http://www.homedepot.com/p/16-in-x-8-in-x-6-in-Concrete-Block-068H0010100100/100322580
23	Plywood(4'x8')	http://www.homedepot.com/s/plywood?NCNI-5
24	2x6x10	http://www.homedepot.com/b/Lumber-Composites-Framing-Lumber-Studs/N-5yc1vZc3tc
25	2x8 Stainless steel screw pack	http://www.albanycountyfasteners.com/Phillips-Pan-Head-Sheet-Metal-Screws-Stainless-14-p/3270000.htm?1=1&CartID=0
26	Plastic Liner	http://store.globalplasticsheeting.com/hydroponicandaquaponic
27	Rafts	http://www.foamsales.com.au/collections/polystyrene/products/xps-blue-board
28	Net pots	https://www.1000bulbs.com/category/deep-water-culture-3-5-gallon-bucket-baskets/

Operational Costs		
29	seeds	http://www.johnnyseeds.com/p-6372-green-forest.aspx?utm_source=froogle&utm_medium=CSE&utm_campaign=MerchantAdv&zmam=80483139&zmas=1&zmac=1&zmap=2196JP.53&source=google_johnny_seeds&utm_source=google&utm_medium=cpc&utm_campaign=NB_PLA_GOOG&utm_term=shopping&utm_content=so0O1Ifdy_dc|pcrid|71808251533|pkw||pmt||&&gclid=CPar753Z_swCFQmVfgod5FYKOg
30	Media Cubes	http://www.ebay.com/itm/like/221860996474?lpid=82&chn=ps&ul_noapp=true
31	DO / pH Testing Kit	http://www.tequipment.net/Oakton/WD-35425-10/PH-Meters/?Source=googleshopping&gclid=COOPks65hc0CFdKIfgodv7EKjw
32	Water	http://ci.sebastopol.ca.us/webform/water-and-sewer-utility-contact-information
33	Electricity	http://www.pge.com/en/mybusiness/rates/tvp/toupricing.page?WT.mc_id=TOU_Summer_Readiness_SMB_TVP_adwords_20160404__textad&gclid=CPirj_f4mM0CFYhqfgod138P4w
34	Catfish fingerlings	http://freshwaterfishco.com/fish-we-raise/
35	Feed	http://www.123ponds.com/mllvmbag.html?utm_source=mllvmbag&utm_medium=shopping%2Bengine&utm_campaign=googleproducts&gclid=Cj0KEQjw7LS6BRDo2Iz23au25OQBEiQAQa6hwPTTTBUFMUmp-4aly81P_tmmQn5HkygiaQrKDGVE8roaArAQ8P8HAQ
36	Supplementals	
37	Iron	https://www.hydroponics.net/i/134001
38	Calcium (and phosphorous)	http://hydrobuilder.com/down-to-earth-fish-bone-meal.html?dzid=csegps_DTEFIBM&gclid=Cj0KEQjw7LS6BRDo2Iz23au25OQBEiQAQa6hwI3Sdq-KiAyiKPe0etOsf_wuZm6bDGzZcIQubsslOw0aAqiA8P8HAQ
39	Potassium	
40	Phosphourus (& potassium)	http://www.horizenhydroponics.com/sunleaves-jamaican-bat-guano-2-2-lbs.html?gclid=Cj0KEQjw7LS6BRDo2Iz23au25OQBEiQAQa6hwEadwvBufav-XG-9VxnFFhb0tSWVI3awu1J_YnNAdasaAork8P8HAQ