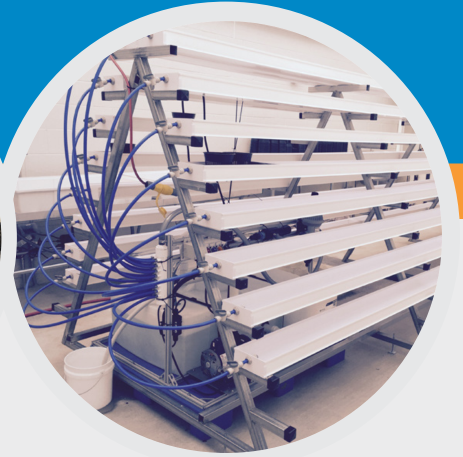
Aquaponics:

Expanding Sustainable Agriculture A USDA Toolkit



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1 The author gratefully acknowledges research support from Emeritus Professor Thomas Kakovitch, Mr. Jeffrey Cowan, and University of the District of Columbia students Hakeem Mumford and Jessica Qintanilla.

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Figure 1Mr. William Hare and Dr. Thomas Kakovitch observing new Tilapia at UDC CAUSES Firebird Farm

What is Aquaponics

Aquaponics refers to a method of producing food by combining growing fish and other aquatic organisms (aquaculture) and growing vegetables in nutrient rich water rather than in soil (hydroponics). The plant nutrients come from the fish, who provide fertilizer for the plants. As the vegetable plants absorb the nutrients, the water is filtered and can be reused in the fish tanks. The co-production of vegetables and protein creates a number of benefits: it saves water, reuses waste materials, eliminates or reduces the need for commercial fertilizers, and typically reduces the growing time - since nutrients are consistently available in liquid form. A comprehensive review of aquaponics was done by the Fisheries and Agriculture Organization of the United Nations and published in 2014.

A Brief History of Aquaponics

The Aztecs are believed to have developed the first aquaponics system in the form of islands made of food plants that drifted in shallow lake areas (chinampas). The plants were cultivated using waste materials dredged from canals surrounding Aztec cities. The waste materials served as fertilizer for the food plants. In South China, Thailand, and Indonesia rice was cultivated in paddies that also supported fish life and other aquatic organisms. These organisms produced fertilizer for the rice plants grown in the same patties. From its inception, aquaponics was therefore built on the symbiotic relationship between nutrient/waste producers (animals) and nutrient/waste users (plants).

Recent Economic Developments

Fish production through aquaculture has grown rapidly and is currently a $1.3 billion industry. As ocean harvests decline, the cultivation of fish in cages, ponds, and tanks has increased to meet the increasing global demand for fish and other aquatic organisms. The waste products from aquaculture can be a source of plant nutrients. Utilizing the nutrients to grow produce creates an aquaponic system. Aquaculture producers have begun to use aquaponics to reduce nitrate waste from their operations and to create an additional income stream by combining hydroponic plant production with aquaculture. The Southern Regional Aquaculture Center (SRAC) published a guide for aquaculture producers that explained this integration process.

Modern Aquaponics Developments

Several commercially successful aquaponics systems have been developed in the United States in the past thirty years. The North Carolina State University system developed by Mark McMurtry and Doug Sanders, was started in the 1980s. Their system used an in-ground fish tank in a greenhouse and pumped the water from the fish tanks through sand beds that supported plants and served as bio-filters for the fish waste. Another early system is the Speraneo system at S&S Aqua farm in Missouri. The system was developed in the 1990s by Tom and Paula Speraneo. The six-tank fish system is integrated with long, planted pea-gravel beds, which produce up to 70 pounds of produce for every one pound of fish grown in the tanks. Since the early 2000s, the University of the Virgin Islands' aquaponics system has been producing Tilapia and vegetable plants in a large outdoor system. Their aquaponic production of basil resulted in three times the yield than basil grown with traditional production methods.

Figure 1Mr. William Hare and Dr. Thomas Kakovitch observing new Tilapia at UDC CAUSES Firebird Farm

The New Aquaponics

Aquaponics can be viewed as a prime example of sustainable agriculture. It demonstrates two critical aspects of sustainable practices: (1) it reduces resource use and (2) it reduces waste. Aquaponics is viewed as an organic way of producing food. It therefore speaks both to the health aspects and to the environmental aspects of our food system. It also makes it possible to produce food where land is scarce or not commonly used for food production.

Urban Aquaponics

Urban aquaponics plays a particularly important role in addressing both the health/food access and the environmental/sustainability aspects of food production. Cities are diverse and often bi-furcated. In Washington DC, for example, three of the city's eight wards located east of the Anacostia river are home to 32 percent of the DC population, but to only 9 percent of its grocery stores. Also, 88 percent of the 520 DC food retailers do not offer fresh produce. A 2009 USDA report concludes that predominantly low income and minority neighborhoods generally lack access to healthy food and experience disproportionately high rates of preventable food related illness including obesity, diabetes and hypertension. Urban aquaponics can Improve access to high quality fresh food in underserved urban neighborhoods.

Meeting Economic, Social and Environmental Goals

Urban Aquaponics is an intensive production method that has the potential to change our food system from a large scale and centralized system to a small scale and decentralized one. It can be especially viable if one views urban aquaponics as an entry point to the value chain of food sourcing, food processing, food distribution and waste and water recovery. The Urban Food Hubs of the College of Agriculture, Urban Sustainability and Environmental Sciences (CAUSES) of the University of the District of Columbia recognize the power of urban aquaponics to re-localize the value chain of food production (1) food production, to (2) preparation, (3) distribution, and (4) waste and water recovery (see Figure 1). Urban aquaponics offers a way to reimagine not only food production, but the whole food system as decentralized, small scale, highly efficient and sustainable (see O'Hara 2015 a).

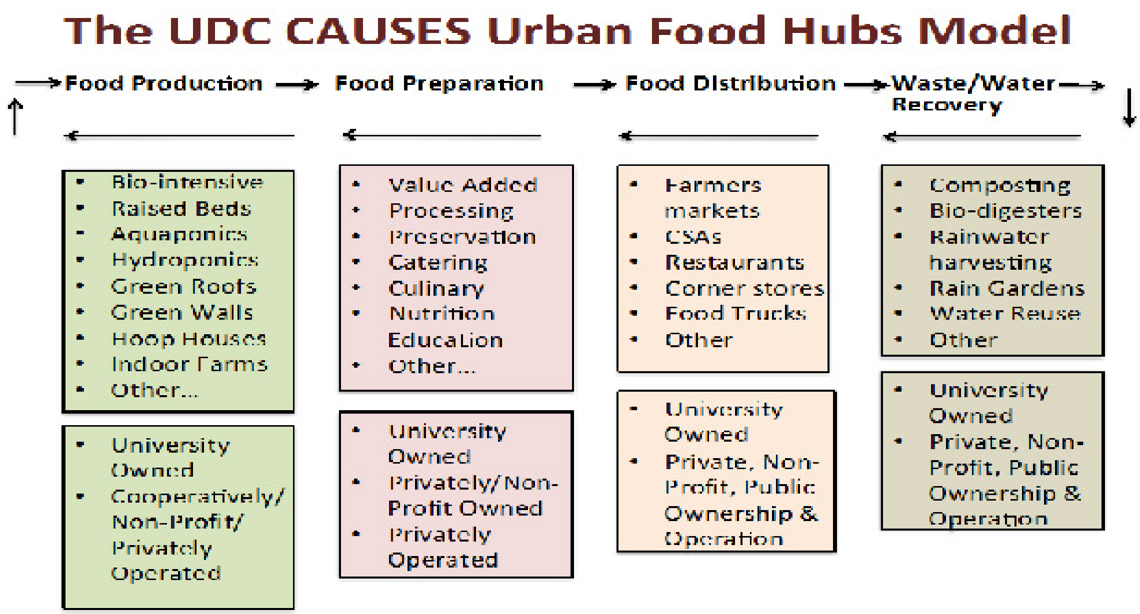


Figure 1: Four Integrated Components of the Food System

Information About Urban Aquaponics

- The United Nations Food and Agriculture Organization report, Small-scale aquaponic food production; Integrated fish and plant farming, is a comprehensive guide to all facets of aquaponics production. The main website has links to individual chapters dedicated to fish, plants, bacteria, water quality, system design, system management and other useful topics.

- The USDA report issued by the Hydroponics and Aquaponics Task Force focuses on the future of organic aquaponics and hydroponics and also includes details on the current state of the aquaponics practice and industry.

- Aquaponics—Integration of Hydroponics with Aquaculture from ATTRA contains a concise summary of the essen tials of aquaponics, an overview of several successful aquaponics systems, and an extensive list of resources. ATTRA is a National Sustainable Agriculture Assistance Program developed and managed by the National Center for Appropriate Technology (NCAT).

- Another popular resource is the Online URBAN Aquaponics Manual, which is published in Queensland Australia. The manual offers information on a wide range of topics relevant to urban aquaponics from systems design to plant and fish selection to choosing the right growing medium.

How does Aquaponics work?

Understanding the Basics

Aquaponics is an efficient method of growing fish and plants in a symbiotic, recirculating system. In addition to fish and plants, bacteria are a third indispensable component of aquaponics. Bacteria convert the waste from the fish part of the system into nutrients that are useable by the plant part of the system.

Aquaponics mimics the cycle of nature: fish are fed and produce waste; bacteria convert the waste into valuable plant food; plants absorb the nutrients and filter the water; the water goes back into the fish tanks. Without bacteria, this cycle cannot be sustained. A successful aquaponics system must therefore keep the bacteria thriving.

The Aquaponic Nutrient Cycle

Aquaponics relies on a balance in the aquatic ecosystem where the fish and plants live. Fish waste, in the form of ammonia, needs to be oxidized by the bacteria into nitrate. Bacteria make use of the nutrients from the fish waste and turn them into plant-available nutrients.

Water Quality Conditions

The water quality conditions important to bacteria health include pH, dissolved oxygen, high surface area to support growth, water temperature, and protection from sunlight radiation. SRAC published a guide that details the nitrogen cycle and how to best manage it. Nitrogen is transferred between the fish and the plants by converting ammonia into nitrates. The fish waste, which contains ammonia (NH_3), requires nitrosomonas bacteria to convert ammonia to nitrites (NO_2) and nitrobacter bacteria that convert nitrites into nitrates (NO_3^-), a plant-available form of nitrogen. Figure 2 depicts the symbiotic plant, fish and bacteria cycles of an aquaponic system. Fish tanks and plant beds can be arranged in a variety of ways.

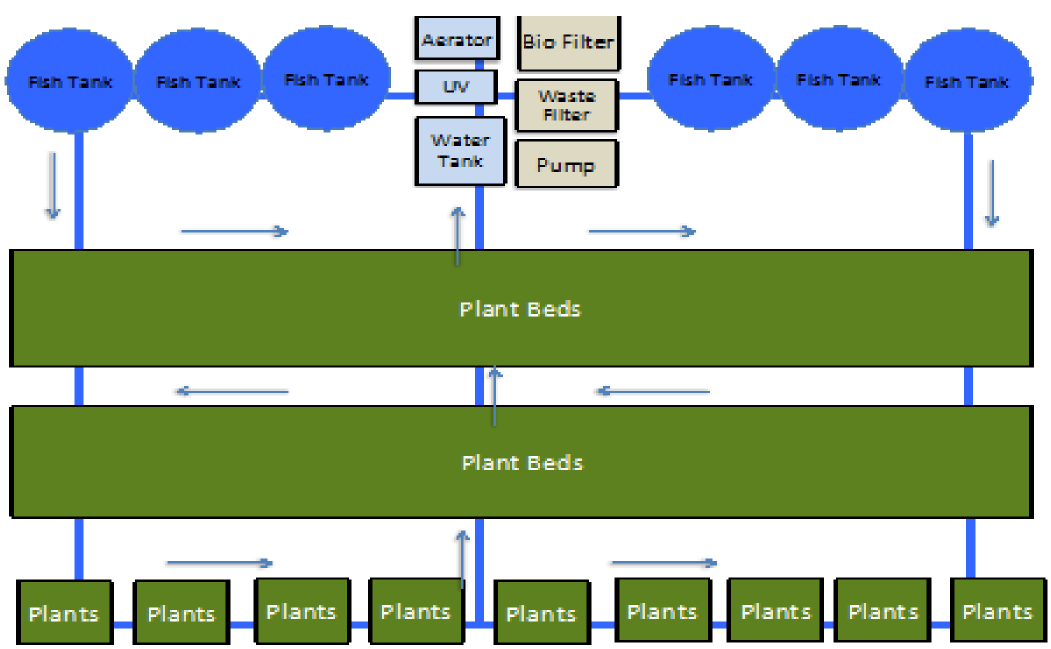


Figure 2: Basic Components of an Aquaponic System with directional water flows

Planning your Aquaponic System

Building a successful aquaponic system requires three distinct planning, design and implementation steps. They are summarized in the flow chart below and discussed in further detail in the next chapters.

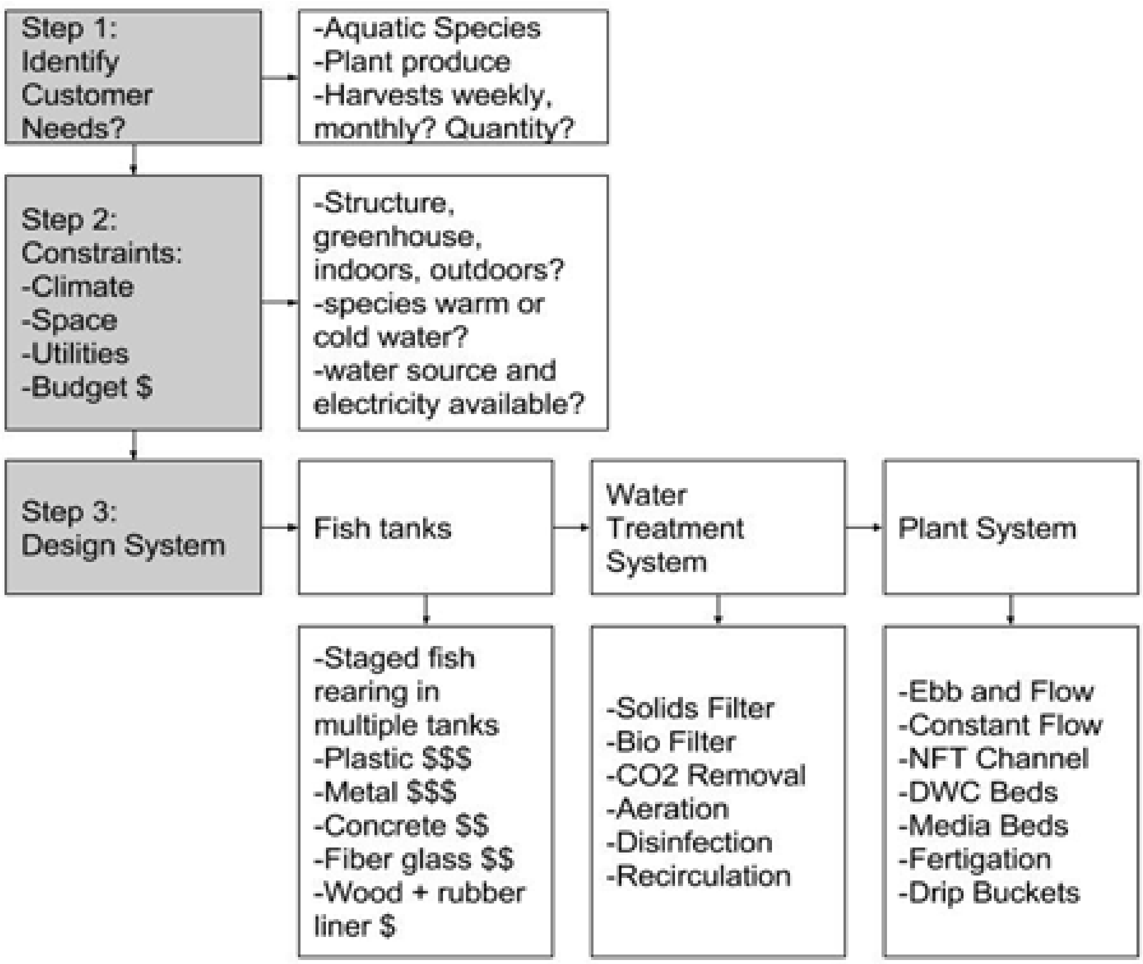


Figure 3: The Three Step Process of Planning and Building a Successful Aquaponic System

Designing a Small Scale Aquaponic System

Three basic functions comprise an aquaponics system: the fish system, the plant system, and a water treatment system. The most basic aquaponics systems merge the plant system and the water treatment system into the same unit. The only two mechanical components needed in these small systems are a water pump and an aerator. The fish waste is filtered and processed by bacteria into fertilizer for the plants in the water treatment component of the system. The water pump recirculates the water from the combined water treatment/plant system back to the fish tanks. The aerator dissolves oxygen into the water for the fish, the bacteria, and the plant roots. Figure 4 depicts the basic components.

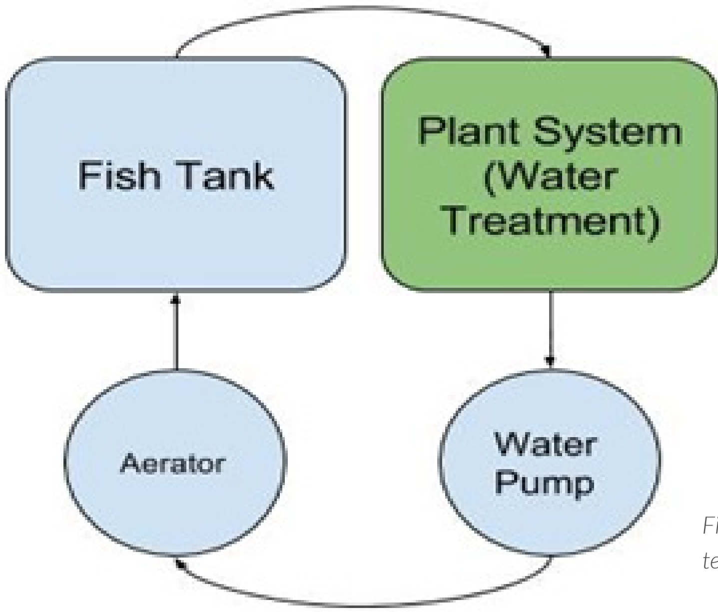
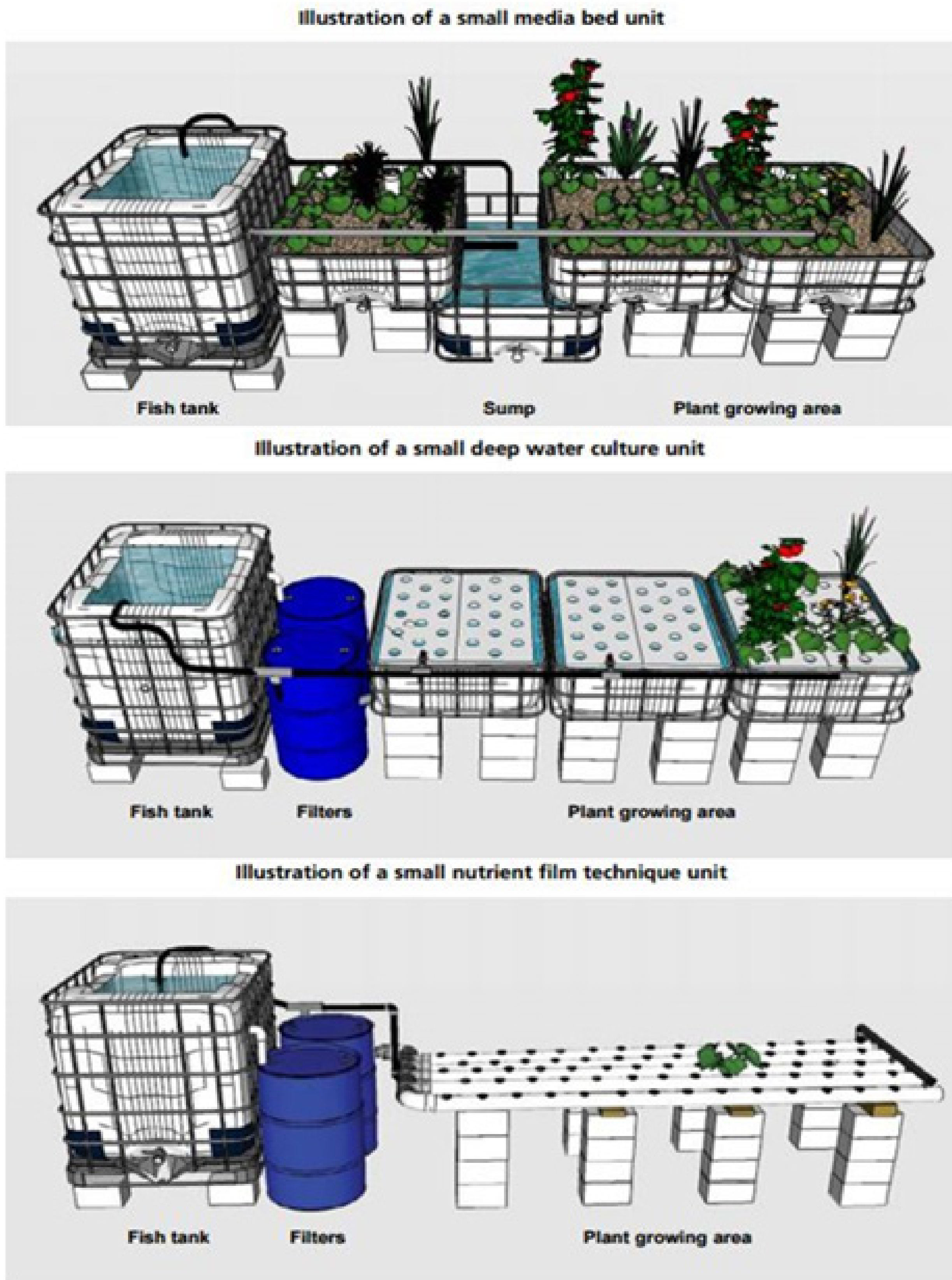


Figure 4: Components of a small-scale system with directional water flow

The Basic Design

In the most basic aquaponic system, a fish tank and a plant system are plumbed together to create a recirculating water flow between the two. Fish tanks should be at least 30" deep and allow for a minimum of two gallons of water per pound of fish harvested. A 275 IBC tank is a good option for a fish tank. It is inexpensive and can structurally hold the needed water volume. Figure 5 shows an example of a linked fish and plant system. Figure 6 depicts three design options published in the comprehensive guide for designing small-scale aquaponic systems of the Food and Agriculture Organization of the United Nations – a media bed, a deep water bed, and a nutrient film system.

Figure 5: Small aquaponics system made from an IBC tank. Photo Source: BackyardAquaponics.com

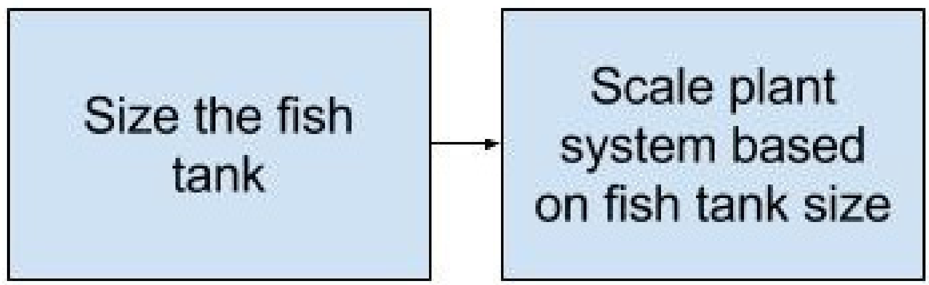


Illustrations Sourced from FAO Fisheries and Aquaculture Technical Paper No. 589 "Small-scale aquaponic food production, integrating fish and plant farming," Somerville et 2014.

Figure 6: Three plant systems design options for small-scale aquaponic systems

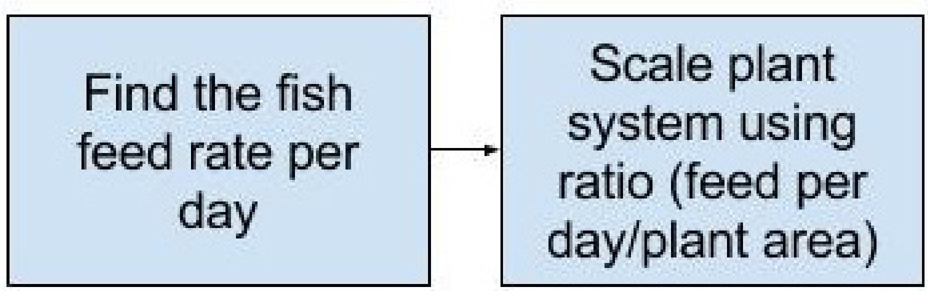
Designing the plant system based on water volume

A key design question is how much plant production the fish/waste part of the system can support. Assuming that you will want to have 100 pounds of fish in the tank at harvest time, your plant system can be sized using a 1:2 ratio of cubic feet of water in the fish tanks to cubic feet of plant area. If your fish tank holds 200 gallons of water, divide it by 7.48 (the number of gallons in one cubic foot) to get the cubic feet of water (27 ft3). Using the 1:2 ratio, the plant system will have an area of 54 ft3 (cubic feet) which is approximately 4' wide by 27' long and 6" deep. This ratio is a good guideline to design a flood-and-drain system with a media bed of pea gravel or clay pebbles to hold the plants.



Designing the plant system based on fish feed

Another option for calculating the plant system is to use the fish feed ration per day. Assuming 100 pounds of fish in the tank at harvest weight, a plant system can be sized using the ratio of 60 to 100 grams of fish feed per day, per square meter of plant growing area. If your fish tank holds 100 pounds of fish you can assume you will be feeding one percent of the fish body weight per day, or one pound of feed per day. One pound equals approximately 454 grams; divide the amount of feed per day by the 60 to 100g and you will have a plant area of approximately 7.5 square meters or 81 square feet. This equates to an area of approximately 4' by 21'. This ratio is a good for guideline for designing a floating raft system.



Design Tools for Small-Scale Aquaponic Systems

Here are some resources for designing simple aquaponics systems for a few hundred dollars.

- **FAO Fisheries Step-by-Step Guide to Constructing a Small-Scale Aquaponic System**

    o The guide offers instructions for three different plant systems including media bed, nutrient film technique, and deep water culture. Each system is built using diagrams and pictures and lists of parts and tools that are required.

• NCRAC Aquaponics webinar video for How To Do It Yourself

o The video is a comprehensive, one-hour presentation on aquaponics and hydroponics from NCRAC at the University of Iowa. Topics include the definition of aquaponics, how aquaponics works, system functions, designs, profitability, food safety and harvesting.

• SRAC Principles of Small-Scale Aquaponics paper

o The structure of a small aquaponic system, its plant unit, fish unit, water treatment system, crop management, and water quality are discussed.

• SRAC Construction a Simple Aquaculture System for Instructional Use paper

o A step-by-step guide for making an aquaculture system from two rain barrels. Also covers fish rearing, filtration, and biofiltration.

• CTAHR How to Guide for Building and Operating a Small-to-Large Scale Aquaponics System

o The system built in this guide is based on the UVI system of fish tanks and a floating raft plant system using wooden boxes with a rubber liner.

• Purdue University's Aquaponics Introduction Video

o This 15-minute video presents aquaponics as a growing method, its system functions, design criteria, and scaling the design.

• Iowa State's Aquaculture Extension Lecture on Aquaponic System Design and Management

o This one hour recorded webinar details all of the aspects that need to be considered for an aquaponic grower to build their own system or to purchase a ready-made one.

• Backyard Aquaponics catalog of designs (web blog and providers of commercial services)

o The blog offers several drawings and pictures that the aquaponics builder should consider before designing an aquaponics system.

• Hobby System Calculator from Aquaponics Solutions (web blog and commercial provider)

o The Excel based calculator tool helps you size your plant media bed to match the fish feeding rate and to find the water volume in the fish tanks based on the density of fish.

Here are a few systems you can purchase ready-to-go for a few thousand dollars.

- Crop King's small aquaponics system
- Farmtek's small aquaponics system
- Aquaranch's small aquaponics system
- Aquaponics USA's small aquaponics system

Designing a Commercial-Scale Systems

A commercial scale aquaponic system has the same three basic components that a small-scale system has: fish tanks, plant system, water treatment system (see figure 7). The main differences between a hobby system and a commercial system are fish density and the scale of production. The higher the fish density, the more sophisticated the water treatment system. A commercial scale system will also increase the capital investment required to build it. Commercial fish production density in aquaponics starts at half a pound of fish per gallon of water and typically runs up to one pound of fish per gallon of water.

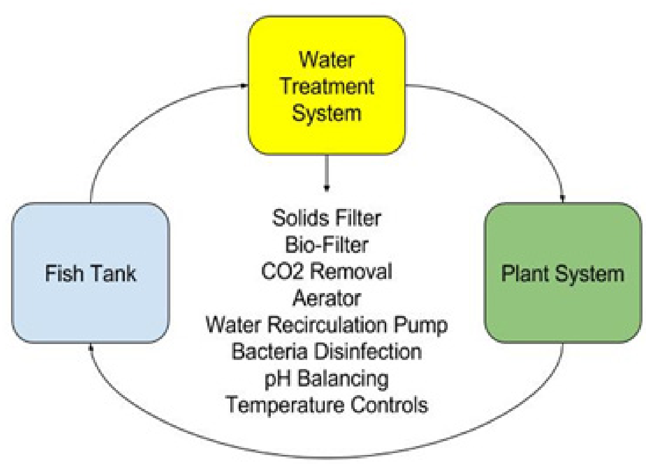


Figure 7: Basic Components of a Commercial Scale Aquaponic System

Don't Design without a Market in Mind

The most important consideration in designing a commercial-scale aquaponic system is your market. Your market will determine the type of produce you will want to grow, your production volume, and the frequency with which you will want to harvest and get your product to market. The second most important consideration is your local climate and your local site characteristics. Climate creates constraints that will drive the requirements for maintaining air and water temperature and light availability for the plants. Figure 7 shows the basic components of a commercial-scale system.

The Fish, The Fish Tanks

The fish tanks of a commercial-scale aquaponic system can be constructed relatively inexpensively from a range of materials including concrete and wood or metal using rubber liners. They can also be plastic tubs, but this option can be more costly. Figure 8 shows a rubber-lined tank fish tank with an inexpensive metal support structure. Figures 9, 10 and 11 show commonly used plastic tubs and plumbing options. The tanks are sized to allow two gallons of water per pound of fish at harvest weight. This is the starting point for commercial stocking density and is a common rule of thumb for a commercial system.

Fish tanks should be designed so that the solid fish-waste can be removed from the tanks and be filtered out of the water by the water treatment system. There are several options available for plumbing the waste flows to capture both floating waste and settled solid waste. SRAC's 453 (see link below) offers a thorough discussion of tank design and options for removing waste solids. The engineering guide developed by Ebeling and Timmons (see link below) provides pictures of various fish rearing tanks and a discussion of the engineering considerations for designing the fish and water treatment components.

Figure 8: Rubber-lined Fish Tank

Figure 9: Plastic Fish Tank and Waste Syphon System

Figure 10: Plastic Fish Tank and Plumbing Option for Solid Waste Removal

Figure 11: Standard Plastic Fish Tank

Choosing the Right Fish

Environmental and market conditions are the two main factors that determine what fish to grow. Different fish perform better in different environments and pair better with different kinds of plants. For example, fish that prefer warmer water should be matched with warm weather plants. Popular warm-water and cold-water fish species include tilapia (warm weather), trout, perch, arctic char and bass. Tilapia is the most commonly used fish in aqua ponics because of its ability to withstand large fluctuations of pH, temperature, and dissolved oxygen in water. Conservative estimates recommend stocking fish at a density of one pound per 10 gallons of water (SRAC 5007). More sophisticated operations can be as dense as half a pound of fish per gallon of water. The key to fish density - and by extension to the nutrient production - of an aquaponic system is its aeration capacity. The more effective the aerator, the higher the fish density that can be maintained.

Plants, Choosing the Right Plant System

If the fish part of an aquaponic system is the nutrient producer, the plant part of the system is the nutrient user. The plant system must be sized to remove enough nutrients from the water to maintain the water quality for the fish, and to maintain the plant growth without supplementing the system with fertilizers. The three most common plant systems for commercial scale aquaponics are floating raft or deep water culture (DWC), nutrient film technique (NFT), and media beds. Most commercial-scale plant systems are scaled using the daily feed ratio. James Rakocy recommends stocking enough fish for the plants to consume between 60 to 100 grams of food-nutrients per day per square meter of growing space. Researchers at the United Nations Food and Agriculture Organization estimate that the appropriate balance for leafy greens is between 20 to 50 grams per square meter per day; for fruit bearing vegetables the ideal ration is between 50 and 80 grams per square meter per day. To calculate these rations accurately, it is important to know how much the fish eat. Most adult fish consume between 1% and 2% of their bodyweight per day. In planning your plant system, you will also need to know what volume of produce you are aiming for and what your anticipated harvest rate is (daily, weekly, monthly).

Consistent Feed Levels

One way to keep the nutrient levels for the plant system fairly constant and to avoid large fluctuations in available nutrients for plant production, is to have fish at different stages of maturity in the system at all times. Since most fish take about six months to maturity, we recommend that a basic aquaponic system should have six fish tanks (or multiples of six tanks). When the system is first launched, only one tank will be stocked. A month later the second tank will be stocked and so forth until all six tanks are stocked. By the time the sixth tank is stocked, the first tank is ready for harvesting. One tank will then be harvested every month and one tank will be stocked every month. Each tank will require a different level of feed based on the maturity of the fish in that particular tank. This will ensure that over all six tanks, a relatively stable amount of fish feed will be in the system at all times; and a relatively stable amount of nutrients will be produced as fertilizer for the plants.

Plant Choices

A large variety of plants can be grown hydroponically including leafy greens, herbs, tomatoes, peppers, cucumbers, squashes, but also berries. Leafy greens are the easiest plants to grow hydroponically. Larger fruiting crops like tomatoes, squash, and berries require a higher fish density to supply sufficient nutrient levels for the plants. Crop density tends to be higher in an aquaponic environments than in soil environments. As a rule of thumb, lettuce and other leafy greens can be grown at a density of 20 to 25 plants per square meter, and fruiting plants can be grown between 6 and 8 plants per square meter. In addition to growing conditions, plant maintenance considerations will determine planting density. Too small a space between plants will make it difficult to access the plants for maintenance such as pruning and harvesting.

DWC

The Deep Water Culture (DWC) method consists of large troughs of water with rafts made out of Styrofoam material floating on top of the water. Holes in the rafts hold plant net-pots or rock wool cushions that allow the plant roots to float in the nutrient rich water below (see figure 12). DWC systems support a wide variety of plants from leafy green plants to fruiting plants but perform best in large-scale productions of leafy greens. The downside to DWC systems is that they are heavy and require stronger pumps and filtration systems to keep the large volume of water circulating and well aerated. DWC systems tend to be most popular with commercial growers. One advantage is that a DWC system provides plenty of water to the plants. Should a power failure occur, the plants will stay alive longer than shallow media beds and NFT channels. The downside of DWCs in an urban setting is that the amount of water circulating through the system and the weight of the system is substantial. The fish tanks will require a firm surface for support, but in a DWC system the plant beds will also require ground support. If the water becomes too stagnant, a DWC system can become a breeding ground for insects and pest control may be challenging - especially in an urban environment.

Figure 11: Standard Plastic Fish Tank

Nutrient Film Technique (NFT)

The Nutrient Film Technique uses narrow channels of perforated pipes or open gutters to hold plants, with the roots submerged in a thin stream of water running through the pipes. NFT systems work well for leafy green plants like leaf and head lettuce, micro-greens, and a variety of herbs. NFT systems are lighter and smaller than DWC systems. However, NFT systems also require extra filtration and it can be more difficult to manage the water flow and water quality. Good aeration is key to the successful operation of a NFT system. When the water flow in an NFT fails on a hot summer day, the plants may have only an hour to survive without water. Since the plant roots float in a shallow film of water the channels can dry up very quickly when evaporation is high. A backup generator is almost imperative; not only for the sake of the fish but also for the plants grown in an NFT system (see figures 13 and 14).

Figure 13: Lettuce grown in an NFT system of perforated pipes

Figure 14: Microgreens grown in an NFT channel system

Media Bed Systems

Media Bed systems consist of hydroponic troughs filled with small media-like clay pebbles, perlite, vermiculite, coco peat, or gravel serving as root support for the plants and as microbial substrate. Media bed systems are the easiest to operate. They can support heavier fruiting plants better than DWC or NFT systems. In a media bed system, the media can function as both a solids filter and as a bacterial bio-filter. However, media beds can be expensive, and can be less efficient for quick-turnaround crops like herbs or lettuces. A media bed system is somewhere in between a DWC and NTF system in terms of the system's ability to withstand shock, such as a power outage. The media fillers vary in terms of their capacity to buffer a system against shock events, and in terms of their durability and ease of maintenance. Vermiculite and coco peat have excellent water retention qualities, while clay pebbles and gravel have less water retention qualities. Gravel however is very durable and has a long life span. The durability of vermiculite and perlite is low, and coco peat and clay pebbles have moderate durability. Clay pebbles are also the most expensive option while gravel is cheap. Figure 15 shows a table-top Media Bed design.

Figure 15: Media Bed used for herb production

Drip systems or bucket systems are another hydroponic growing method. In this system, the nutrient rich water is supplied to plants grown in flowerpots or buckets via a pipe with a drip nozzle. Similar to the media bed method, the buckets can be filled with a variety of materials including clay pebbles, gravel, Styrofoam chips and plastic strips. This method is not commonly used in aquaponics but it has been successfully used to grow fruiting plants that can grow very tall and prolific with this method.

Figure 16: Dutch/ Drip buckets

Water, The Water Treatment System

The water treatment part of the aquaponic system maintains the water quality (and thus the growing conditions) for the fish and plants. Since the water from the fish tanks is re-circulated through the water treatment system and the plant system, a key factor for the water treatment part is the rate of fish feed per day. The higher the feed rate, the more waste will be created in the system and greater nutrient levels are available for the plants and the bacteria in the system. Higher amounts of fish feed increase cost and keeping the feed rate at the right level has implications for the productivity of the fish as well as the plant portion of the system. Figure 17 depicts the step by step process for sizing your water treatment system and Figure 18 shows a complete water treatment system.

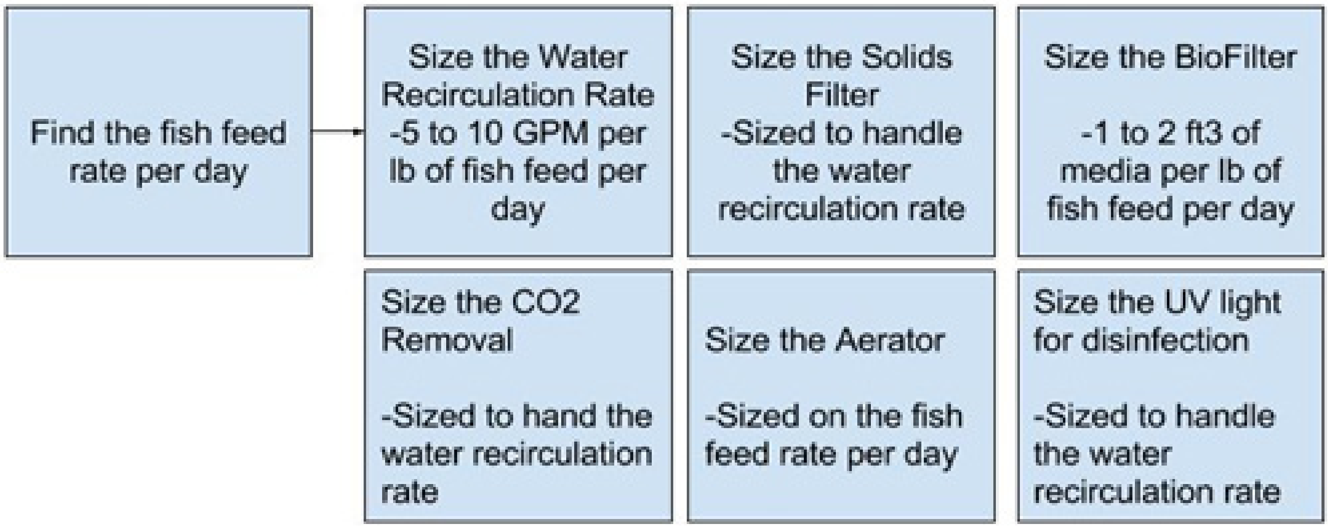


Figure 17: Sizing the Water Treatment Components of an Aquaponic System

The main components of the water treatment system are a recirculating pump, a solids filter, a bio-filter, aerator(s), a CO_2 removal system, and bacteria disinfection system.

- **Water Recirculation Pump** – The water recirculation rate is typically sized between 5 and 10 GPM (Gallons Per Minute) of flow through the water treatment system for every pound of fish-feed per day. In addition, the water pump must also produce sufficient pressure to move the water through restricting pipes and to overcome the pressure from water height differences in the system. Water pumps for aquaculture and aquaponics are available from many vendors.

- **Solids Filter** – The solid waste from the fish system and other organic solids in the tanks must be filtered out of the system. Filtering out these mineral and organic solids keeps the water clear and prevents anaerobic bacteria from accumulating in the system. Solids filters come in many types such as swirl filters, screen weirs, drum screens, and sand and bead media filters. Generally, the solids filter is sized based on the water recirculation rate. The SRAC guide 453 and Ebeling and Timmons Engineering guide are good sources to help you select a suitable solids filter.

Figure 17: Sizing the Water Treatment Components of an Aquaponic System

- **BioFilter** – The purpose of the biofilter is to house the nitrifying bacteria that break down the fish waste into nutrients for the plants. The biofilter has two main characteristics: (1) it houses media that have a high surface area density on which the bacteria can grow; and (2) it provides the necessary water movement or agitation to clear debris from solids and from dead bacteria colonies out of the system. The biofilter requires dissolved oxygen that can be supplied by an aerator. SRAC's guide 453 and Ebeling and Timmons Engineering guide can help you select the right biofilter for your water treatment system.

• **Carbone Dioxide Removal CO2** - A new, patented aeration technology made by Kakovitch Industries has given aquaculture and aquaponics designers some new flexibility that is especially valuable in urban and peri-urban settings where space is at a premium and where noise pollution may be a concern. The KI Flo-Vex Aerator provides a near-saturated dissolved-oxygen discharge from the water recirculation pump. The aerator is installed in-line with the water flow from the recirculation pump. This method removes the need for a separate aeration blower and raises dissolved oxygen levels independent of the water depth in the system. The aerator has also been demonstrated to be more energy efficient and less maintenance intensive than blown air systems because it does not require diffuser screens and has no mechanical moving parts (see figure 17). The Flo-Vex aeration device is used in the urban aquaponic systems pioneered by the University of the District of Columbia.

• **Aerator** - Traditional methods for dissolving oxygen into water include air compressors, air pumps, airlift pumps, and blowers. All of these mechanical methods use air bubbles to cause oxygen transfer from the atmosphere into the water. Most of these will have diffuser screens to create a fine air bubble discharge to increase the efficiency of the oxygen transfer. The general guidance is to design your aeration system so that all of the oxygen in the water can be replaced within 30 minutes. The rate of aeration is sized based on the fish feed rate per day. A general rule of thumb is that two to three CFM of air need to be bubbled into the system at a 40" water depth for every pound of fish-feed fed per day. The plants and bacteria will also require additional dissolved oxygen. Plant systems with six or more inches of water should have 0.3 cfm of bubble aeration per square foot of area. The efficiency of these aeration systems is limited by the depth at which the air can be released into the water. Shallow water does not allow enough time for efficient oxygen transfer from the air bubbles into the water column. Discharges of air that are too deep can cause nitrogen gases to accumulate that lead to disease in the fish. Bubble aerators that use air compression can also cause considerable high noise levels, which may pose a problem in urban and peri-urban environments.

• **Aerator Advances** - A new, patented aeration technology made by Kakovitch Industries has given aquaculture and aquaponics designers some new flexibility that is especially valuable in urban and peri-urban settings where space is at a premium and where noise pollution may be a concern. The KI Flo-Vex Aerator provides a near-saturated dissolved-oxygen discharge from the water recirculation pump (see figure 19).

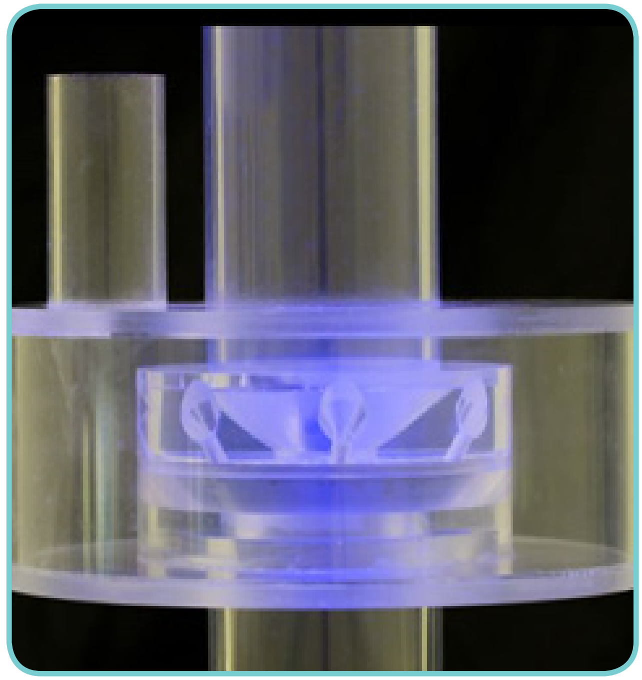


Figure 19: The Flo-Vex Aerator used in Urban Aquaponics

The Flo-Vex aerator is installed in-line with the water flow from the recirculation pump. This method removes the need for a separate aeration blower and raises dissolved oxygen levels independent of the water depth in the system. The aerator has also been demonstrated to be more energy efficient and less maintenance intensive than blown air systems because it does not require diffuser screens and has no mechanical moving parts (see figure 18). The Flo-Vex aeration device is used in the urban aquaponic systems pioneered by the University of the District of Columbia

● **Bacteria Disinfection** – The biofilter is considered the center of bacterial activity of an aquaponic system. However, bacteria populate all surfaces of an aquaponics system, including in the fish tanks and in the plant beds. Disinfection can be used as a means of keeping bad bacteria (such as those that cause food safety concerns) from traveling through the system. There are, however, two main schools of thought: The first one argues that an aquaponic system is essentially a bacteria farm that converts fish waste into plant nutrients. Killing-off bacteria is therefore counterproductive. A properly maintained system with a healthy bacteria environment will presumably outcompete any invasion of bad bacteria. Disinfecting the system is unnecessary at best and counterproductive at worst. The other school of thought is that bacteria should be concentrated in the biofilter. Bacteria that travel in the water can be neutralized through disinfection with Ultra Violet lights (UV) for example that are integrated into the system. Food safety standards for aquaponically produced food may require the use of a UV light or other means of disinfection. A number of different systems are available on the market.

● **Starting the Biofilter** – Before you introduce fish into your aquaponics system, the biofilter should be active with bacteria. SRAC 4502 provides a step-by-step procedure for staring one.

Tools for Designing an Aquaponic System (Tank Size, Plant System Size, Feed Ratios)

● **SRAC 453 Aquaculture Review of Current Design Practices**
o This guide reviews the design for fish tanks, water flows, and water treatment system components in detail giving the designer an overview of current design practices.

● **FAO Fisheries Aquaponics Design Guide**
o This comprehensive guide highlights important design considerations for everything from site choice, lighting, structures, tank culture options, and water treatment components and options for constructing or purchasing them.

● **ATTRA Introduction to Commercial Aquaponic Systems**
o This resource reviews the design of three types of commercial-scale aquaponics systems and gives reference resources for more detailed information.

● **SRAC Overview of Critical Considerations for Design**
o The document details the design of fish tank culture and water treatment system functions and considerations for aquaculture.

● **FAO Key Considerations for Setting Up Aquaponics Systems**
o Considerations for the aquaponics designer are outlined in this guide, including economic, environmental, and logistical factors that influence design options.

● **SRAC 454 Integrating Fish and Plant Culture**
o This guide discusses the major factors that need to be considered when adding a plant system onto an aquaculture system including critical ratios for design.

Tools for Designing the Water Treatment Component

● **SRAC Review of Component Options**
o This resource discusses each of the components of the water treatment system in detail including function, maintenance and sizing ratios.

● **SRAC Management of Recirculating Systems**
o The operation of a water treatment system, discussion of the design functions, and key troubleshooting hints are available in this detailed resource.

● **UFL Water Recirculation and Filtration**
o The resource briefly details the water flow and filtration design functions and limitations.

● **FAO Bacteria in Aquaponics and the BioFilter**
o The guide presents the nitrification process in detail and covers all the important design, maintenance, and functional characteristics of this part of the water treatment system.

● **Engineering Guide for Aquaculture and Aquaculture by Ebeling and Timmons**
o The resource gives engineering design "rules of thumb" for aquaponics designers who are considering designing their own system or purchasing one.

• FAO Fisheries Water Quality Analysis

o The water treatment analysis guide presents all the necessary testing criteria for evaluating the function of the water treatment system. It tells the operator what they should be testing and when as well as providing hints for troubleshooting poor water quality conditions.

Here is a list of vendors of Water Treatment Systems and other Aquaponics Systems Components

• Kakovitch Industries sells and installs their urban aquaponics and hydroponics systems, as well as their Flo-Vex aeration device, and offers consulting services for urban aquaponics.

• Integrated Aqua Systems, Inc. sells aquaculture systems and components as well as system integration services and consulting.

• Pentair Aquatic Ecosystems offers consulting services to design, engineer, and install large-scale aquaponics systems, including urban farms. Pentair also offers aquaponics supplies, complete systems and electronic monitoring technology.

• Nelson Pade offers commercial aquaponics systems, designs, consulting, and training.

• Burdette Industries offers commercial aquaculture and aquaponics systems, designs and consulting.

Tools for Designing the Fish Component

• Fish Species – FAO Fisheries presents a detailed discussion of fish life cycle and feeding considerations.

• SRAC Fish Species Profiles - Each aquatic species for fish rearing are discussed in detail.

• Fish Nutrition – SRAC details the nutrition needs and options for feeding aquaponic species.

• Non-Native Fish - Species concerns for aquaculture are discussed by SRAC

• Tank Culture of Tilapia – SRAC details the system considerations for Tilapia production

• Fish Pests and Disease controls are reviewed by FAO Fisheries.

• FAO details the process for making homemade fish feeds.

Tools for Designing the Plant Component

• FAO Aquaponic Plant Species and Systems

o The main plant system designs are discussed along with what plant species are suitable for each system.

• FAO 12 most common aquaponically produced plants

o The production characteristics for each of the twelve most common plants grown aquaponically are discussed in this resource.

Other Resources for Designing an Aquaponics System

There are several resources that provide information on urban aquaponics. An interesting design study was conducted by WORCESTER POLYTECHNIC INSTITUTE. It documents WPI's efforts to design and install an aquaponics greenhouse in an urban area in the city of Worcester. For a smaller scale system, Farm Exchange put together a collection of instructional videos teaching you how to build a backyard aquaponics system. The Southern Regional Aquaculture Center published several fact sheets on aquaponics, including information on the economics of aquaponics, and on water quality considerations.

• Commercial Aquaponics Production and Profitability is a peer-reviewed, published survey of commercial aquaponics operations.

• An International Survey of Aquaponics Practitioners details the production methods, experiences, motivations, and demographics of aquaponics practitioners.

• The Aquaponic Solutions website includes fact sheets, formulas, and calculators for sizing aquaponic systems.

• A publication entitled Challenges of Commercial and Sustainable Aquaponics describes challenges to aquaponics production and approaches to overcome them.

• Many aquaponics vendors also offer complete design and installation services along with aquaponics supplies.

o Kakovitch Industries sells urban aquaponics and hydroponics systems, as well as their Flo-Vex aeration device, and offers consulting services for urban aquaponics.

o Integraded Aqua Systems, Inc. sells aquaculture systems and components as well as system integration services and consulting.

o Nelson and Pade sells complete aquaponics systems and offers a range of training and consulting services.

o Pentair Aquatic Ecosystems offers consulting services to design, engineer, and install large-scale aquaponics systems, including urban farms. Pentair also offers aquaponics supplies, complete systems, and electronic monitoring technology.

o Bright Agrotech specializes in vertical aquaponic farming which can be extremely useful in urban areas.

o Evo Farm provides aquaponics design, installation, and maintenance services.

o Aquaranch sells complete aquaponics systems.

o Aquaponics USA sells aquaponics supplies and complete systems.

Location Matters

General Site Considerations

Location - The installation site of an aquaponics system requires careful consideration especially in an urban setting. The most basic requirement is a solid, flat foundation that can hold the water weight of the fish tanks, and that is level so that it can support a system that may rely, at least partially, on gravity flows. The USDA Urban Agriculture Toolkit offers some useful site preparation examples. Structure – Both indoor and outdoor aquaponic systems are viable. An unused or underutilized building for example, may be a great option for an aquaponic system as long as the structure can support the weight of the fish tanks. If the system is to be installed in a greenhouse, be sure to check your local zoning regulations and other ordinances. In many municipalities a green house is considered a permanent structure and as such it falls under local zoning regulations. A hoop house, which is a lighter weight green house that typically does not require a cement platform, is considered a moveable structure, and typically does not fall under the same zoning regulations as a greenhouse structure.

Soil - Urban soils can be contaminated especially with lead, but arsenic contamination may also be an issue. Since aquaponics systems grow vegetables hydroponically in nutrient-rich water, they offer a great solution to urban soil contamination. The EPA offers guidelines on brownfield utilization that may offer some useful considerations if you are considering installing a system on a contaminated site.

Preparing the Site – Some sites may have a land use history that resulted in site disturbances that can make it challenging to install a commercial-scale aquaponic system. This is especially true in urban and peri-urban locations. A vacant lot, for example, may have been a former building site or a gas station. This may pose serious challenges to getting the site level and the surface compacted enough to hold the weight of the fish tanks. Construction debris such as big chunks of cement, or the caved in tanks of a former gas station may require considerable work that can be quite costly.

Figure 20: Site Development of the East Capitol Urban Farm in Washington DC

Local Development Resources - Be sure to check your local resources for possible assistance. In Washington DC, for example, the DC Building Industry Association takes on volunteer projects in support of worthy causes. In 2015 DCBIA selected the site development work for the East Capitol Urban Farm, which is one of the Urban Food Hubs of the University of the District of Columbia. Without the support of the DCBIA, the site development costs for the East Capitol Urban Farm and its state-of-the-art aquaponic system would have been prohibitively high. Sometimes urban neighborhoods can offer ideal site conditions. A former tennis court, basketball court, or playground can be an ideal surface for installing an aquaponic system. Site development costs can be minimal in these cases.

Building Density and Zoning – An aquaponic system can in principal be located in close proximity to residential buildings. This means that the system must be designed in a way that minimizes noise pollution and avoids waste generation and water run-off. For example, how is potential water runoff from the site captured? Will there be any soil-based production on the site? Some aquaponics systems use fertigation (irrigating crops with nutrient rich water) as a productive way to utilize an (sometime temporary) oversupply of nutrients from the fish tanks. Raised bed gardens that are installed in close proximity to an aquaponics greenhouse can be a great way to take up excess nutrients and to improve the aesthetics of the site at the same time.

Figure 21: The Aquaponic System at the East Capitol Urban Farm in Washington DC

Water Source - If you plan to use municipal water, check it first for factors such as chlorination, pH and water hardness. Chlorine can be off-gassed in a recirculating aquaponics system, but chloramines that are commonly used in rural and sub-urban water supply, must be filtered or otherwise eliminated from the water before it can be used to raise fish.

Water Drainage - Even though most aquaponics systems are closed-loop, it may at times be necessary to change out a large percentage of water in the system. In addition, operator errors do occur and may cause the tanks to overflow. Therefore, ensure access to proper drainage. To reduce the potential risk of water runoff, you can also install a holding tank on the site. A good site plan will envision both planned and unplanned situations and will address not only the anticipated smooth operation of the aquaponic system, but options to trouble-shoot should things go wrong.

Electricity - Any aquaponic system will require electricity for water pumps, aerators, environmental controls such as heating and air conditioning, and possibly for lighting. Access to electricity may be easy in an urban setting, but can be quite costly. For example, running an electric line to a hoop house may be a simply hook up that your local utility will offer for a modest fee; or it can cost several thousand dollars to bridge a few yards from the closest power line to the greenhouse of your aquaponic system. In addition, it will be wise to plan for backup electricity to prevent a potentially catastrophic system collapse in the case of a power outage. A backup generator may be a good solution for this. It will be important to consider how the generator gets activated in case of a power outage occurs when no one is at the aquaponic facility. Electricians can install automatic transfer switches to manage this problem.

Operating off the Grid - A question that is frequently asked is whether an aquaponic system can be operated off the grid,on solar power, for example. The answer is yes. An aquaponic system can, in principle, be operated using solar energy, or some other alternative energy source that eliminates the need for access to electricity. Yet any system will require consistent and dependable access to energy. In the case of solar, this may require substantial battery power to ensure a sufficent supply of energy during times when solar energy generation is low.

Energy Use - Energy efficiency and the overall energy demand of an aquaponic system is an important consideration that impacts operational costs. Most commercially viable systems will require a greenhouse or indoor setting to protect the system and to maximize its potential output. Consider the local climate to determine if you need additional heating, air conditioning or other environmental controls.

Species Choice Can Impact Energy Use - Energy use can be reduced by switching out the fish and plants in the system seasonally. For example, tropical fish like tilapia thrive during the summer months since they tolerate higher water temperatures. During the winter months cold water fish may thrive without heating the greenhouses. The plants too can be switched based on seasonal conditions similar to the crop rotation one would follow in an outdoor growing environment. Growing warm weather corps like tomatoes, peppers, egg plant, charts and herbs during the summer months, and cold weather crops like winter squash, kale, collards and cabbage during the fall and winter season can significantly reduce energy usage. Ultimately, your business plan will determine whether consistent year round production of lettuce, basil and hot peppers, for example, may be advantageous despite the higher energy use required.

Light – Plants need light to grow by the process of photosynthesis. Maximizing natural light will reduce energy use. A hoop house or greenhouse installed either on the ground or on a roof top may provide sufficient light for the plants to thrive. Yet given the space constraints of urban environments, LED lighting may be an option to maximize growing space by stacking the plant systems vertically. This will save space, but increase the energy use. Be sure to check your sunlight hours and look for shadows from nearby structures.

Resources for Accessing Utilities - To address site development related issues in your community, it may be best to contact your local energy and water authorities as well as your municipality's regulatory commission office. You can also contact your local USDA Natural Resource Conservation Service (NRCS) office for both financial and technical assistance and to help you determine your best options for using water and energy efficiently.

Special Sensitivities of Urban Aquaponics - The urban environment is generally limited in growing space compared to traditional aquaculture and hydroponic farming. A neighborhood lot does not have several acres in which to spread out. Because urban aquaponic systems are smaller, they rely on high density and high yields to be productive. The design choices for urban aquaponic systems may be constrained by limited land availability, sunlight blockage from neighboring buildings, zoning restrictions, water discharge restrictions, waste management regulations, and noise pollution concerns. The University of the District of Columbia has several urban aquaponic and hydroponic systems in operation in Washington, DC. Their design optimizes high density, high yield production for small land areas while limiting water discharge and noise pollution.

Harvesting – Harvesting fish and switching out crops in the DWC, NFT or media beds based is driven by your business plan and more specifically your revenue projections. The fish harvest should take place after a clarifying period of 3 to 5 days where the fish are not fed. If you follow the six-fish-tank-rule suggested earlier to ensure a steady nutrient supply, you stop feeding the tank that you want to harvest. Otherwise you will need a clarifying tank to which you can move the fish to before harvesting. The water in the clarifying tank should be exchanged frequently during this period of time.

Operational Considerations

Daily Operation – Daily maintenance tasks that keep an aquaponic system running smoothly include feeding the fish, testing the water quality, checking water levels, cleaning pump filters and solids filters and removing debris from the plant system. Many of the maintenance tasks can be automated or engineered out, but they must be attended to consistently.

Water Quality Testing – The plant and fish conditions will tell you a lot about your system once you get it running smoothly. For example, if the fish aren't eating you may have a water quality issue. Experienced growers will tell you that the changes in the sound and smell of the system can be an indicator that something is off.

Testing the system on a regular basis is required even for experienced aquaponic growers. Key tests include: pH, Ammonia, Nitrite, Nitrate, water temperature, water hardness, and dissolved oxygen. Water clarity is also a way to judge the health of your system. Commercial operations will also test for micro and macronutrients. SRAC 452 gives a good overview of various water quality considerations and guidelines for troubleshooting.

Monitoring - Advanced monitoring and control systems can assist in the operation of an aquaponic system and can ensure proper function even if no one is present on location. These monitoring systems can track a wide range of parameters like pH, dissolved oxygen, temperature, and light and can communicate them wirelessly. A grower can set up alerts to signal if the pH gets too high, the water temperature drops too low, or if the electricity goes out. Many of these monitoring systems have the capacity to make adjustments remotely. They are available in different price ranges and levels of functionality. Some popular companies offering monitoring systems are Clearton, Pentair, YSI, Campbell Scientific, Argus, and Osmobot.

Resources for Operators - Like every living organism, an aquaponic system requires daily attention. Since the system is based on the continuous flow of water, anything that disrupts the water flow can have a cascading effect and cause problems throughout the system. Gathering experience about the operational requirements and characteristics of a living system is like writing a story and building a body of knowledge. This not only happens in formal training sessions but also in the informal process of working on the system and troubleshooting if needed.

Figure 22: Aquaponic Certificate participant in Washington DC performing water tests

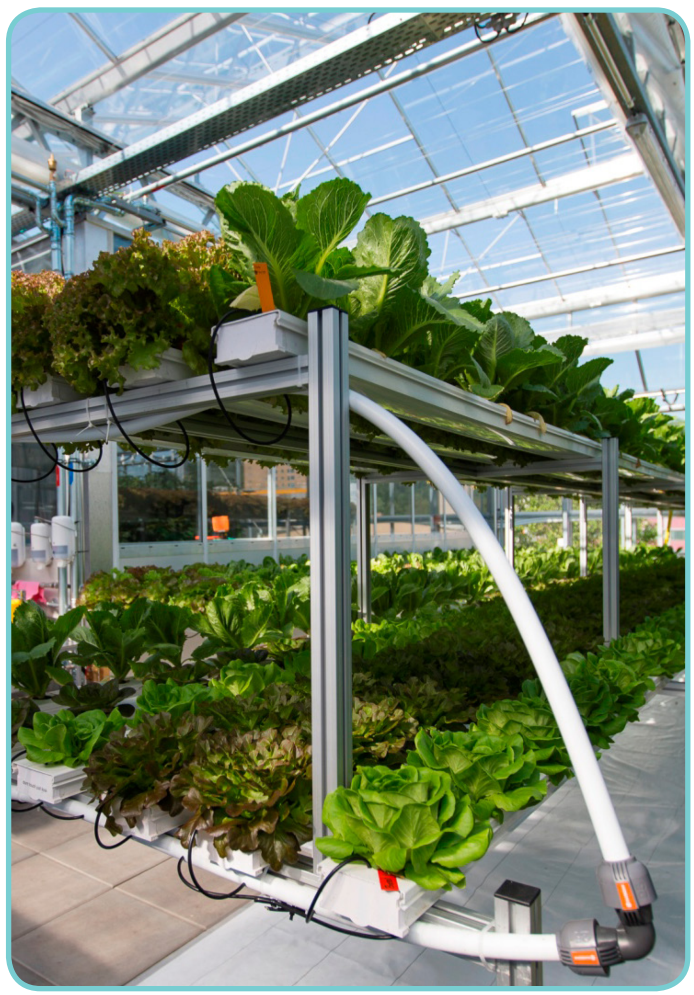
Several blogs and websites seek to create an information sharing and support network for aquaponics operators:

Backyardaquaponics.com is a website that creates a user-friendly space that allows new and experienced aquaponic users to gather and exchange ideas about small-scale backyard aquaponic systems.

Aquaponicsnation.com- this site has a community that discusses aquaponics, aquaculture, and sustainable food production.

Aquaponics.net.au- this website has an international forum where users all over the world discuss the practical uses of aquaponics.

Aquaponicsuniversity.com-website that offers online aquaponics classes.



How Do I Pay For this?

An aquaponic system can in principal be located in close proximity to residential buildings. This means that the system must be designed in a way that minimizes noise pollution and avoids waste generation and water run-off. For example, how is potential water runoff from the site captured? Will there be any soil-based production on the site? Some aquaponics systems use fertigation (irrigating crops with nutrient rich water) as a productive way to utilize an (sometime temporary) oversupply of nutrients from the fish tanks. Raised bed gardens that are installed in close proximity to an aquaponics greenhouse can be a great way to take up excess nutrients and to improve the aesthetics of the site at the same time.

Know your Market(s)

As with every investment, knowing where your revenue will come from is critical. Researching your markets is therefore the first step to success, especially since your business objectives will also drive the design of your aquaponic system (see figure 3). The type of produce you grow will determine what is the best design for your plant system. Rather than going for volume, you may want to consider niche markets. Multiple revenue streams can be important when you secure the financing for the aquaponic system. Aquaponics can support a variety of revenue streams and business plans. A brief discussion of a few options follows. Your own creativity will add new and better options as well. Urban environments may be especially fertile ground for innovative business models. So think creatively, but do your market research!

Growing for Restaurants and Grocery Stores - Micro-greens, edible flowers, lettuce mixes, and herbs are among the highest revenue generators of hydroponically grown produce. Micro-greens for example will take about ten (10) days from germination to harvest in a hydroponic greenhouse or indoor growing environment. If seeding of the greens is staggered, you will be able to establish a pattern of daily harvests or multiple harvests per week. If the greens are grown for grocery stores, packaging and labeling will be required. Greens are typically packaged in clear plastic clamshell containers. Herbs can be packaged in see-though bags. Both are best preserved when they are harvested live with the root ball intact. Be sure to have a well-established pattern of harvesting, packaging and delivery that is negotiated with their buyer(s). If the edible flowers or greens are grown for local restaurants, packaging can be kept to a minimum and the produce can be delivered on covered cardboard trays, for example. Alternatively, the aquaponic grower can invite chefs from local restaurants to harvest themselves once or twice per week. Berries are another option. Strawberries, for example, can do well in an aquaponic environment and the small, flavorful European varieties make a beautiful plate and are in demand at high-end restaurants.

An NFT system is the most suitable system for micro-greens, herbs, lettuce and lettuce mixes and small berries. Depending on the types of greens, it may be best to keep the channels open and to roll the growing medium (rock wool mats for example) directly into the gutters and slightly push the seeds into the medium. This works best for micro-greens and edible flowers. Head lettuce and herbs are best grown in perforated pipes or in NFT channels with covers, whereby one bunch of herbs or one head of lettuce is grown per hole. Instead of propagating herbs or head lettuce directly in the pipes it is best to have a media bed to start the plants in a medium like rock wool cushions, and to transfer each cushion into one of the holes in the NFT channels once the plants have reached about one or two inches in height.

Growing medium, seeds and maintaining a tightly controlled growing environment may be among the most important variable inputs of an NFT system. Your most costly input often is labor. Harvesting and packaging will require close attention and care when you are growing for higher-end markets. They will expect flowers and micro-greens where no leaf and no petal is crushed or bent from improper cutting.

Growing For Ethnic Crop Niche Markets

The term "ethnic crop" refers to plants that are not native to the Americas. Given the diversity of restaurants and food traditions in urban communities, urban aquaponics systems can satisfy some of the ethnic crops niche market that may be unique to urban communities. Market research conducted in Washington DC, for example, indicated strong demand for these somewhat unusual vegetables. Particularly popular in the Washington DC area are garden eggs, kitelley, hibiscus and a variety of hot peppers, as well as greens and herbs. Restaurants and specialty grocery stores that cater to diverse ethnic communities are potential buyers of these crops. Some crops can also be transported without impacting quality and can potentially be produced in peri- urban and rural communities. Some ethnic crops, especially herbs, can be raised and sold in pots, others will have to be picked and packaged for sale. If the plants are raised and delivered in pots, heating and cooling needs during delivery can be minimized without jeopardizing the freshness and quality of the produce.

Since aquaponics offers a controlled growing environment it can be more suitable for adapting ethnic crop varieties to a particular local growing environment rather than outdoor soil production. The USDA Ethnics Crop Research https://www.nal.usda.gov/afsic/ethnic-crops , Sustainable Agriculture Research and Education (SARE), and the Local/Regional Market Research & Analysis Program of the Agricultural Marketing Service (AMS) offer useful resources to assist you in assessing the viability of an ethnic crops specialization for your aquaponics system. Depending on the type of ethnic crop plants you want to grow, NFT channels, media beds and drip buckets may be best suited for ethnic crop production. Nutrient needs will vary from a high demand for nitrogen for greens to higher levels of phosphorus for fruit bearing plants like eggplants and peppers. Ethnic crops tend to be warm weather crops and will require a growing environment with a steady ambient air temperature year around.

Growing for Seedling Production

Another promising business model is focused on growing plant seedlings. As every gardener knows, the time window during which a wide variety of plants seedlings, flowering plants and herbs are available is typically about six weeks. Outside of this short time frame it is almost impossible to get plant seedlings.

As year-round indoor growing -including aquaponics and hydroponics – expands, so will the year-round demand for plant seedlings. Seedlings can be the backup system for large growers. They can also be a niche market especially when they adopt a pattern that is counter-cyclical to the rest of the market. A variety of vegetable plants, herbs and flowering plants can be sold as seedlings. Delivery and sale can occur directly out of the same trays and pots in which the plants are grown, and no further transplanting or packaging may be necessary. Direct sales out of the greenhouse or indoor growing facility may also be an option. Parks, recreational facilities, golf courses etc. can also be viable customers. Most likely, they will expect direct delivery of the plant seedlings. Growing seedlings requires a fairly consistent year- round growing environment with heating during the winter months and cooling during the summer months.

Growing for Local Residents

Generating revenue through direct sales to customers can be challenging, yet the price point is typically higher than for sales to distributors or grocery stores. There are a range of direct-sales options, but three are especially popular: farmers' markets, food trucks, and CSAs. In Washington DC alone, over 40 farmer's markets are in operation on different days of the week. The range of operating hours allows local growers to get their product to market two or three days per week. Packaging is typically minimal, since produce is displayed on tables in cardboard boxes or in crates. Most farmers' markets are seasonal. Operating an aquaponic system that produces year-round can therefore be a great advantage.

A food truck can expand the farmers' market model and can bring fresh produce to consumers during times when markets are not operating. The truck must be equipped with racks to stack produce crates and boxes and must have moderate refrigeration so that the produce stays fresh and visually appealing. Packaging requirements are minimal, similar to those of a farmer's market. Produce trucks can deliver produce to underserved neighborhoods where full service grocery stores are unavailable and where access to fresh produce is limited.

CSAs (Community Supported Agriculture) deliver fresh produce, typically once a week, to a central pickup location or directly to CSA members' homes. Rather than charging a price per pound, CSAs charge their customers a flat fee upfront at the beginning of the growing season. In exchange, CSA members receive a weekly delivery of fresh produce that is in season. Some CSAs also offer a lower fee for customers willing to assist with crop maintenance, harvesting and delivery. CSAs typically require minimal packaging since produce is delivered in bags, boxes or crates where customers return their crates every week and switch their empty crates for new ones filled with fresh produce. Some have questioned the viability of CSAs arguing that it is difficult to scale the model. Cooperatives of multiple growers, including a mix of urban, peri-urban, aquaponic, hydroponic and soil based producers, can offer a viable strategy for expanding the CSA model and building-in some degree of choice for the CSA customer. 4-Foods is an example of a CSA that has successfully scaled its business model.

Growers who want to meet the needs of local residents will have to grow a wide variety of produce, unless they join with other growers in a cooperative model. Growing for a local market will also require sensitivity to cultural food traditions. Depending on your location, your crop mix should reflect a seasonal variety of spring crops like spinach, peas, and lettuce, summer cops like tomatoes, beans and peppers, and fall crops like kale, winter squash and cabbages. In most locations, this seasonal rotation will lower utility costs by adapting the growing environment to closely resemble the ambient conditions across the seasons. Given the variety of crops that will be needed to serve the local end user, a combination of NFT channels, media beds, and drip buckets may be best suited for the plant system design. If space is less constrained, a DWC setup may also offer the necessary flexibility of the plant system. The DWC floats can hold net pots of varying sizes and shapes. A wide variety of vegetable plants and herbs can be grown and even delivered in pots for ultimate freshness.

Growing for Improved Health

Urban Food desert neighborhoods typically experience significant food related health problems that can be prevented through improved access to fresh food. Improving public health can therefore be an important business model for urban aquaponic growers. Particularly valuable crops may be those that are high in nutrients and high in vitamins. In addition to growing vegetables and herbs, a business model focused on public health may include plants that are known for their medicinal qualities. Growers specializing in this market niche will be especially successful if they can combine their food production business with nutrition education and counseling. Dieticians are now permitted to prescribe a therapeutic diet and patients with food related illnesses no longer have to consult a medical doctor. Aquaponic growers interested in this market niche may also consider partnering with specialists in herbal or traditional medicine. Depending on the types of plants, NFT, media beds, and DWC systems may all be suitable for local produce production focused on improved health.

Growing for Added Value

Urban agriculture may have a strong social component, in addition to its food production aspects. Revenue streams can come not only from vegetables and fish production, but also from using the aquaponics facility for educational and training purposes, and even for events. This may appear somewhat contradictory, as aquaponics facilities must be clean and sanitary. This does not make them suitable for high traffic from student groups, local residents and visitors. Yet experience with urban agriculture suggests that a diverse revenue stream is key to the commercial success of small-scale production facilities, especially when land is at a premium and expansion opportunities are limited.

Given the interest in new agricultural methods like hydroponics and aquaponics, training can be a core component of a successful business plan. Collaborations with local schools, vocational programs, and community colleges can also offer valuable opportunities. The same is true for value added options that may include collaborations with culinary institutes and other hospitality sector partners. Smoking and drying fish and drying, canning and pickling vegetables can also add value and a diversified revenue stream. A local grower in Washington DC, for example estimates that 50 percent of her revenue stems from food production and 50 percent from value added products like pesto and edible centerpieces. A New York City grower estimates that only 30 percent of revenue comes from their food production and 70 percent comes from events.

The Price Point Dilemma

A question that is frequently posed is whether urban aquaponics is commercially viable? The answer is, it depends. Capital investments for urban aquaponics systems can be substantial, especially if site development costs are high. On key to viability is the revenue potential. Growing demand for locally grown food and seasonal produce, and the continued expansion of the local foods movement, offers significant revenue potential. Yet high revenue markets do not address the needs of urban food desert neighborhoods that lack access to fresh food.

These neighborhoods may not have the purchasing power to generate the revenue necessary to cover the capital investment costs plus operating expenses of an aquaponic system. To serve a low income local market will require a commitment to a socially responsible business model where a portion of the high-end revenue generated might subsidize lower revenue markets; or where a portion of the capital investment will come from grants or public sector partners.

Market research is key finding the market niche. It will help you determine the market niche for your aquaponics business and whether it is viable to position your business for food production as the main revenue source, or whether value added markets will be included as well. A cooperative model that includes production, value added marketing and that shares high capital costs of installation, may also be a viable option. Be sure to research the availability of grants that can support your socially responsible and/or cooperative business models.

It may also be possible to lease an aquaponic system in your local community. For example, as the only public university in Washington DC, the University of the District of Columbia is investing in four urban aquaponic systems and four urban hydroponic systems. Each system will be operated by a local grower through an agreement that allows the grower to lease the system by paying a percentage of revenue back to the University. This reduces the overall cost of operating an aquaponic system since the capital investment is covered by the university-partner. The following section offers some starting points to research available resources for developing revenue streams and offsetting investment costs.

Estimating Revenue and Production Costs for Aquaponics Systems

The success of any aquaponics business will ultimately depend on the ability to scale or to diversify the revenue stream. The calculations in examples 1 and 2 are based on 500 lbs of fish and the plant production area of 22.68 m2 it supplies with nutrients. This is an area of approximately 10 by 24 ft., in other words, small for any agricultural production. Even a modest hoop house of 30 by 60 will provide 1800 ft2 or eight times the growing space. If one assumes at least partial installation of a NFT system of two or three vertical layers, the growing space could be expanded to 2500 ft2 or more in growing space. A 30' x 60' plant area (1800 ft2 in growing space) would require 39 lbs of fish feed per day or approximately 2,300 lbs of fish at harvest weight. Such a system could potentially generate $100,000 or more in revenue. Increasing the space utilization by introducing stacked NFT channels or media beds will further increase the profitability of an aquaponic system even without expanding into other value added opportunities.

In this section a method for estimating the revenue of an aquaponics system is outlined. There are two example calculations done for a small aquaponics system. The fish system in the two examples produces 500 pounds of tilapia annually. Example one uses basil herbs as the plant product and example two uses leaf lettuce. Estimating the pounds of basil produced in an aquaponics system with 500 pounds of tilapia is done by using the nutrient density ratio of the plants: 100 grams per square meter from the fish feed. This value represents the total growing area of the plant system: 22.68 m2. There are a number of parameters that you will need to track in order to get a good sense of the production economics of an aquaponics system. They include the following:

- what kind of fish you will grow;
- what kind of plants you will grow;
- how many pounds of fish you plan to harvest annually;
- what fish stocking density you will maintain (assume 1 pound of fish for 2 gallons of water);
- how much fish feed you will need per day;
- what crop density you will maintain;
- how many pounds of produce you anticipate to harvest annually;
- the price of fish at harvest.

Other information you will need is the price of the vegetables at harvest and production costs for both fish and plants. The following assumptions were used:

• The production cost of tilapia and Lettuce were based on Carole R. Engle's "Economics of Aquaponics," published by SRAC in July 2005.

• The density of lettuce planting and harvest weight per square FAO Fisheries' "Appendix 1 – Vegetable production guidelines for 12 common aquaponics plants".

• The number of harvests per year was used from FAO Fisheries' "Appendix 1 – Vegetable production guidelines for 12 common aquaponics plants".

• The fish feed rate per day was assumed to be 1% of the harvest weight of the fish.

• The stocking density of fish in the tank was chosen to be 1 lb of fish per gallon of water.

• The nutrient density requirement of the plants was assumed to be 100 grams per square meter of plant area per day.

Assumptions used in Example 1 below:

• Fish revenue – (500 lbs of fish per year)*($2.50 price of fish per pound at sale) = $1,250

• Fish feed rate per day – (500 lbs of fish at harvest weight)*(1% of body weight) = 5 lbs of fish feed per day, or approximately 2268 grams.

• Nutrient density available for plants – (2268 grams)/(100 grams) = 22.68 square meters of plant area (using the 100 gram per square meter rule).

• Plant revenue – (22.68 square meters of plant area)*(4.4 lbs of harvested plants per square meter)*($10.20 dollars per lb)*(8 harvests per year) = $8,143.03.

• Production cost of fish – (500 lbs of fish)*($2.50 per lb cost) = $1,250.

• Production cost of plants – (22.68 meters of plant area)*(4.4 lbs of plant per square meter)*($0.75 dollars per lb of plant cost)*(8 harvests per year) = $598.75.
Total net revenue – ($0 fish net revenue)+($7,544.28 plant net revenue) = $7,544.28

The Analysis of Example 1 shows that the fish harvest barely breaks even since the revenue from the fish sale is equal to the production cost. However, the plant harvest netted $7,544. The example does not provide any allowance for fish or plant losses. A reasonable allowance for loss is 10%. The production cost of fish and plants assumes the cost of feed, seedlings, energy, and labor. The cost of fish feed varies. FAO Fisheries uses an estimate of $0.56 per kg for fish feed which would cost approximate $464 per year. Labor costs were estimated at 46% of total production costs for a tilapia and lettuce aquaponics system (see Tokunaga et al in their 2015 study) Harvesting plants and fish can be assumed to be year-round. A more conservative estimate is 8 months. The growing season can be extended especially when growing in greenhouses with environmental controls. Also supplementing natural light with LED grow lights can extend a growing season but will increase production costs.

Parameter	Value	Unit
Fish Type	Tilapia	
Plant Type	Basil herbs	
pounds of fish harvested per year	500	lbs/year
stocking density of the fish in the system (assume 1 pound of fish for 2 gallons of water)	0.5	per gal
fish feed lbs per day	5	lbs/day
plant crop density per square meter or foot	4.4	lbs/m2
total plant area to be harvested	22.68	m2
number of plant harvests per year	8	harvests
price of fish when sold	2.5	dollars
price of plant crop when sold	10.2	dollars/lb
production cost of fish	2.5	dollars
production cost of plants	0.75	dollars/lb
Fish Revenue	$ 1,250.00	
Plant Revenue	$ 8,143.03	
Fish Revenue Net Production Cost	$ -	
Plant Revenue Net Production Cost	$ 7,544.28	
Total Net Revenue	**$ 7,544.28**	

Assumptions used in Example 2:

• Fish revenue – (500 lbs of fish per year)*($3.51 price of fish per pound at sale) = $1,755.

• Fish feed rate per day – (500 lbs of fish at harvest weight)*(1% of body weight) = 5 lbs of fish feed per day. This is equal to approximately 2268 grams.

• Nutrients available for plants – (2268 grams)/(100 grams) = 22.68 square meters of plant area (using the 100 gram per square meter nutrient requirement).

• Plant revenue – (22.68 square meters of plant area)*(20 heads of harvested plants per square meter)*($1.78 dollars per head of plant)*(12 harvests per year) = $9,688.90.
• Production cost of fish – (500 lbs of fish)*($2.50 per lb cost) = $1,250.

• Production cost of plants – (22.68 meters of plant area)*(20 heads of plant per square meter)*($0.41 dollars per head of plant cost)*(12 harvests per year) = $2,231.71

• Total net revenue – ($505 fish net revenue)+($7,457.18 plant net revenue) = $7,962.18.

Parameter	Value	Unit
Fish Type	Tilapia	
Plant Type	Lettuce	
pounds of fish harvested per year	500	lbs/year
stocking density of the fish in the system (assume 1 pound of fish for 2 gallons of water)	0.5	per gal
fish feed lbs per day	5	lbs/day
plant crop density per square meter or foot	20	heads/m2
total plant area to be harvested	22.68	m2
number of plant harvests per year	12	harvests
price of fish when sold	3.51	dollars
price of plant crop when sold	1.78	dollars/head
production cost of fish	2.5	dollars
production cost of plants	0.41	dollars/head
Fish Revenue	$ 1,755.00	
Plant Revenue	$ 9,688.90	
Fish Revenue Net Production Cost	$ 505.00	
Plant Revenue Net Production Cost	$ 7,457.18	
Total Net Revenue	**$ 7,962.18**	

The Analysis of Example 2 shows that at a fish sale price of $3.51 dollars per pound the fish production generated a profit. The lettuce production netted $7,457.18 and used a density parameter of heads of lettuce per square meter instead of pounds per square meter. Data is limited on aquaponics production in the available literature and finding good examples can take some digging. The lettuce crop can be ready for harvest in four weeks whereas the basil herbs need up to 6 weeks before harvest. The harvest time for the plant and fish types selected in your economic analysis will have a significant impact on the economics of an aquaponics operation.

The success of any business will ultimately depend on the ability to scale or to diversify the revenue stream. The calculations in examples 1 and 2 are based on 500 lbs of fish and the plant production area of 22.6 m2 its supplies with nutrients. This is an area of approximately 12 by 15 ft. in other words, small for any agricultural production. Even a modest hoop house of 30 by 60 will provide 1800 ft2 or ten times the growing space. If one assumes at least partial installation of a NFT system of two or three layers the growing space could be expanded to 2500 ft2 or more in growing space. Given the previous calculation of $9,500 for a small unit of 500 fish and 1800 ft2 in growing space, a modest hoop house can generate $100,000 or more. Increasing the space utilization by introducing stacked NFT channels or media beds will further increase the profitability of an aquaponic system even without expanding into other value added opportunities.

Economic Tools for Aquaponics

• FAO Fisheries Small-scale aquaponics food production publication has economic examples for production of small aquaponics systems as well as a detailed discussion of the 12 most common aquaponically grown plants. Use these resources to help with economic estimates and to lookup the nutrient need, water quality need, and harvest characteristics of plants.

• James Rakocy et al give production values for Tilapia, Basil, and Lettuce in their report on harvests at the UVA aquaponics system.

• SRAC's 5006 publication by Carole Engle reviews the key economic considerations for aquaponics systems as well as researched estimates of production costs and an analysis of the economic feasibility of aquaponics in the United States.

• SRAC's 4400 publication by Carole Engle gives an introduction to the factors involved in aquaculture production for marketing fish products.

• SRAC's 350 by Siddhartha Dasgupta and Robert Durborow offers a researched enterprise budget for the sale and marketing of fish and the price ranges for on-farm sales and delivered sales.

• Commercial Aquaponics Production and Profitability is a peer-reviewed, published survey of commercial aquaponics operations. This is an international survey of aquaponics producers which is a good tool for understanding the market.

• The USDA's report by the Hydroponics and Aquaponics Task Force focuses on the future of organic aquaponics and hydroponics and also includes detail on the current state of the aquaponics practice and industry.

• An International Survey of Aquaponics Practitioners details the production methods, experiences, motivations, and demographics of aquaponics practitioners.

• Challenges of Commercial and Sustainable Aquaponics describes challenges to aquaponics production and approaches to overcome them.

• ATTRA gives a list of the different fish and plant species that can be grown in aquaponics systems.

• Tokunaga et al published their findings on the production of Tilapia, basil, and lettuce at three aquaponics farms in Hawaii. Use this for help finding parameters for economic analysis.

Finding the Right Resources

A number of federal resources are available to support your aquaponics business venture. The USDA Agricultural Marketing Service can assist you in assessing your market options. Available resources include the Farmers Market and Local Food Promotion Program that offers programs to connect growers with consumers. The USDA Rural Development program also offers Value Added Producer Grants to help fund marketing research and market development.

Support may also be available through your local Land-grant University and its Specialty Crop Block Grant Program. This program offers small grants to support the implementation of initiatives developed by local organizations committed to expanding the production and consumption of Specialty Crops.

The USDA Food and Nutrition Service (FNS) Supplemental Nutrition Assistance Program (SNAP) offers Farmers Markets authorization program that assists farmers' markets and direct-marketing initiatives of local farmers to become authorized to accept SNAP benefits. Eligible markets may also qualify for free SNAP Electronic Benefits Transfer (EBT) programs that make it easier for eligible farmers market customers to access available benefits through a handheld device such as a phone or i-pad. Some communities double what eligible customers will spend at their local farmers market. This helps to increases the purchasing power in neighborhoods that may be in need of fresh local produce but may lack the financial resources to support a local aquaponic grower.

Support from the USDA SARE program made it possible to develop of A Multi-farm CSA Handbook that provides guidance on cooperative markets, and on starting a CSA. You may also want to check out 4P Foods which is a private business that has developed a viable approach to expanding the local CSA model my making it scalable. http://4pfoods.com

The USDA Farm Service Agency FSA Farm Loan Program provides credit, conservation, disaster, and emergency assistance programs that help improve the stability and strength of the agricultural economy. Several of the available programs may be suitable to support the development of an aquaponic production facility, or offer credit to cover the capitol and infrastructure development costs needed to develop a facility. You may also want to contact your local FSA offices for information about available resources.

Community Resources

The New Entry Sustainable Farming Project has developed a resource guide for selling at a farmers' market. This guide provides information to farmers about everything from choosing a market, to applying to sell at a market, designing market displays, setting prices, making sales, and keeping proper sales records.

The United States Environmental Protection Agency Urban Farm Business Plan Handbook is a great resource. It covers how to develop your business plan including organization and management, marketing, operations, and financial strategies. Investors may also be a viable option to support the launch of your aquaponics business. Yet make no mistake. Investors want their investment back and rarely support lifestyle businesses. To attract the attention of an angel Investor your business must be commercially viable and scalable. If your business idea is accepted, an angel investor may provide you with the invaluable opportunity to present your business in a 'Shark Tank' type setting (http://www.cnbc.com/live-tv/shark-tank/full-episode). Even if you don't land an investment deal, the experience can be tremendously valuable in getting support from other viable sources including from foundations and non-profit collaborators. An example is the DC Arch Angels group (http://www.dcarchangels.net).

Considering the Risks

An aquaponics grower must consider several risk factors and must manage these risks throughout the operation of their system.

Pests, price swings and other challenges

Aquaponics businesses can face a number of challenges that must be managed. Some are associated with the technical nature of the business. Others are associated with the market condition for local produce. For example, a grower may encounter unexpected swings in water pH, or deficiencies in plant nutrients, or an unexpectedly high fish mortality rate.

Because the practice is still new, there is no guarantee that an expert is available to diagnose and solve every problem you will encounter as an aquaponic grower. Chat rooms and blogs can be a big help and there is a growing social media network of aquaponics growers that can assist a grower to solve some of their technical or operational challenges. The Aquaponic Gardening Community website for example, includes information and chat-rooms with experts to answer aquaponics question. There are also a number of commercial operations that offers a full range of products and services, including consulting services (see for example http://pentairaes.com/commercial-solutions/commercial-aquaponics; http://theurbanfarmingguys.com/aquaponics-how-to; https://urbanfarmers.com/technology/aquaponics/) Yet despite the growing number of resources available, be prepared for a steep learning curve if you want to run a successful urban aquaponics business, especially during your first growing season.

Pests and diseases can pose significant challenges that can harm aquaponic plants just as much as plants grown in soil. Physical protection such as a greenhouse or building, environmental controls like heating and cooling, and the design of the system itself can help to mitigate pest and disease risks. Key to any successful pest management is absolute cleanliness. No food should be allowed in an aquaponic greenhouse. You may consider requiring anyone accessing the facility to walk through a disinfectant bath. Another important best management strategy is to reduce plant waste and to recycle plant materials to produce compost or gas in a bio-digester where possible. These kind of operational strategies will reduce pest and disease risks. The system must also be designed in such a way that a power outage will not result in major disruptions including flooding, crop loss, and fish loss.

And finally, a grower must consider economic risks (see for example SRAC 5006). The cost of an aquaponic system can be difficult to estimate, and there is only a short track record of production data and commercial success. While demand for locally grown produce is growing, not all markets may be accepting of produce from a novel growing method like aquaponics. The key to success can be in the close proximity between grower and consumer and in combining production with education so that potentially skeptical consumers can be informed about the benefits of aquaponics. Engaging the community in the success of an aquaponic operation and making it transparent how aquaponics works and why it is a sustainable production method may be invaluable and may proof to be an important ingredient of a successful operation.

Food Safety

Food Safety is the implementation of proper procedures to avoid dangerous contamination of food. In other words, running an aquaponic system is much like running a laboratory. Proper Standard Operating Procedures (SOPs) are imperative, and cleanliness of the facility is vital. What ultimately will ensure the food safety of an aquaponics system is the proper education and training of those running it. Proper hand washing, proper cleaning of the produce, safe cold storage and other measures that are a part of common food safety standards are must. Some food retailers will also require their own food safety inspections of an aquaponics producer with whom they seek to enter a contract.

In addition to testing their system for water quality and nutrient load, a successful aquaponic business must also conduct food safety tests and regularly test the system for harmful bacteria. Two options are principally available. One option is to integrate a UV light or similar device into your system as an integral step of the recirculating water cycle. A second option is strict standard operating procedures that cover the entire aquaponic production process itself to make sure that the bacteria rich environment of the system is itself protected against unwanted bacteria.
In October 2015 a new food safety certification legislation, also known as the FSMA (Food Safety Modernization Act), went into effect. It is a third party certification and inspection program that requires an independent review of food safety standards similar to the third party certification standards associated with testing laboratories. FSMA consists of a set of rules that outline the safety standards growers and food processors must meet in order to have their operations recognized as FSMA compliant (see for example http://www.fda.gov/Food/GuidanceRegulation/FSMA; or https://www.friendlyaquaponics.com/2016/08/25/food-safety-certification-aquaponics/)
A recent publication from the Northeastern Regional Aquaculture Center also provides an overview of risks associated with raising fish on a large scale. While urban aquaponics systems tend to be small scale, the high fish density of most of these systems may nonetheless introduce some of the same vulnerabilities associated with larger scale aquaculture operations.

Making the Case for Sustainability

Urban aquaponics is more than a cutting-edge food production method. It also offers several social and environmental benefits that add to the economic benefits the methodology offers. As previously discussed, the commercial viability of any aquaponics facility will depend on its specific business model. High revenue crops like micro greens, edible flowers, and herbs can offer tremendous revenue opportunities especially in urban markets that offer a rich diversity of restaurants and ethnic food venues. Yet these high revenue markets do not address the need for healthy and affordable food choices of low-income neighborhoods that have no full-service grocery store. A possible solution may be a diversified revenue model that produces for the high-end market and subsidize production for lower local markets that have high food security needs. Another option may be a cost-sharing model. In this model, public sector partner like a municipal economic development office or a private sector partner makes an upfront investment to fund the site development costs and construction of an aquaponic facility. The facility is then available for lease to a producer (or a group of producers) who must only concern themselves with the operating expenses of their business without having to cover the initial capital costs. This is the model adopted by the University of the District of Columbia. Through Sustainable Development grants from the CD Office of Planning, the DC Department of Energy and Environment, and the Anacostia Economic Development Corporation, the University is DC is building several aquaponic and hydroponic systems across the District of Columbia. In this model, the aquaponic facilities can serve as business incubators that build local capacity, create jobs, and improve access to affordable healthy food choices.

Another option may be that the municipality compensates the aquaponic grower for the positive social and environmental contributions of their business. This is not a common model, but it deserves consideration if a community wants to build local economic capacity and address their need for improved social and environmental benefits. The field of ecological economics offers examples of how one can calculate the value of social and environmental side benefits of economic activity (see for example http://www.isecoeco.org ; see also O'Hara 1996, 1997, 2001, 2014, 2015b). This economic value can then become a baseline for compensatory payments that add to the economic viability of a business model committed to improved health, environmental quality, and employment opportunities. Some of the benefits are briefly discussed in the next section.

Social Benefits

Aquaponic production can have a range of social benefits for the community where the facility is located. As a local food production system it offers in principal the same benefits that other methods for producing locally grown food will offer. Michigan State cooperative extension lists seven key benefits: (1) locally grown food is more flavorful; (2) eating local food is eating seasonally; (3) local food has more nutrients; (4) local food supports the local economy. (5) local food benefits the environment; (6) local food promotes a safer food supply and (7) Local growers can tell you what's in their food (see for example: http://msue.anr.msu.edu/news/7_benefits_of_eating_local_foods).

Some of these local food benefits will depend on the specific practices adopted by a grower. For example, flavor can depend on the nutrients in the system. Environmental benefits may be impacted by the energy use of an aquaponic system. Growers who are less committed to making their system net energy positive (or at least energy neutral) may not grow seasonally, but may grow the same salad mix year around. The decentralized food systems model that aquaponics can support may reduce the need for food transportation and improve freshness.

Improved access to affordable high quality food will have public health benefits. The University of California Davis has published a report on the social, health, and economic impacts of urban agriculture. MIT has researched the potential economic impacts of urban aquaponics. Seeing how food is grown can also be an effective catalyst for changing eating habits and for eating more fresh vegetables.

A local aquaponic system can also revitalize a neighborhood and can become a focal point for building a sense of community. This is especially true when the produce is produced for a local farmers market or for a CSA. A commercial aquaponic operation that is committed to hiring some of its workforce from the local neighborhood can make a positive contribution to neighborhood revitalization and improve real estate values. And aquaponics can improve the aesthetics of a neighborhood. While food safety concerns inside the greenhouses may prevent a facility from being readily accessible to its neighborhood, some attention to the surrounding area can go a long way. Raised bed gardens, trellises, and vertical growing systems can bring tremendous enhancements to an urban neighborhood that will benefit the grower and the local community.

Environmental Benefits

One of the primary environmental benefits of aquaponics are the tremendous water savings it offers. tremendous water savings. The recirculating design of an aquaponic system uses on average only ten (10) percent of the water used in conventional agricultural production. If greenhouses or hoop houses are used to install an aquaponic system the surrounding area of the greenhouse can be landscaped to offer additional water management benefits by increasing permeable surfaces in the cityscape, for example. Many cities have an aging water infrastructure that is below capacity. As water percolates below the surface rather than shooting off the pavement, the water management benefits can be considerable. Urban aquaponic growers can make a persuasive argument about these benefits to their local municipality.

Other benefits may result from the reuse of unused or underutilized buildings that can be successfully repurposed for aquaponic production. Additional environmental benefits can result from the reduced need for food transportation as aquaponic closes the gap between food production (farm) and food consumption (fork). The overall carbon footprint of aquaponics, however, will depend on the energy efficiency of the system itself.

Aquaponics Education and Training

As with any new technology, training and mentoring is critical to ensuring the success of aquaponic production. Several networking resources have already been mentioned. Additional resources follow.

Technical Assistance

The USDA Natural Resource Conservation Service (NRCS) provides conservation planning and technical assistance in consultation with farmers. The NRCS works in both rural and urban areas.

ATTRA, the National Sustainable Agriculture Information Service provides publications related to many topics relevant to small scale and urban farm production irrespective or whether conventional or more high-tech production methods are used.

The University of Florida's Small Farms and Alternative Enterprises Center offers a variety of aquaponics resources, including a start-up guide, information on producing in aquaponics systems, applicable regulations, and food safety information.

Several aquaponics vendors also offer technical assistance and training. For example, the Aquaponic Source offers aquaponics supplies, complete systems, and consulting services.

Nelson and Pade sells complete aquaponics systems and offers a range of training and consulting services.
Friendly Aquaponics offers complete aquaponic systems and consulting services.

Training

Support and training for aquaponic production is available from a number of state and regional agricultural extension centers, as well as from colleges, and universities. The USDA funds Regional Aquaculture Centers which offer research and educational programs. Some well know centers include:

- Southern Regional Aquaculture Center (SRAC)
- Northeastern Regional Aquaculture Center (NRAC)
- North Central Regional Aquaculture Center (NCRAC)
- Western Regional Aquaculture Center (WRAC)
- Center for Tropical and Subtropical Aquaculture (CTSA)
- The Freshwater Institute offers workshops and publications on recirculating aquaculture for agriculture producers.
- The University of the District of Columbia's College of Agriculture Urban Sustainability and Environmental Sciences offers an Urban Aquaponics Certificate program with hands on training at their urban aquaponics sites and at Fire Bird Farm.
- The University of Maryland has aquaculture training offered by their Sea Grant program.
- Ongoing aquaponics workshops are offered at the University of the Virgin Islands Agricultural Experiment Station.
- Iowa State University hosts the Agricultural Marketing Resource Center that offers a range of aquaponics resources.
- The University of Florida has aquaponics resources available.

Commercial providers of aquaponics training include:
- The Aquaponics Source
- Friendly Aquaponics
- Nelson and Pade
- The Aquaponic Farming Course

Conclusions

Aquaponics is a method for co-producing fish and vegetables in a symbiotic growing environment. Advances in technology make it possible to intensify and scale aquaponic production so that it can be viable in locations that have no space constraints, and in locations where space is limited. The fact that plants in an aquaponic system are grown hydroponically rather than in soil makes it an option for food production in urban and peri-urban areas where soil contamination may be an issue. This is a commonality that aquaponics has with hydroponics. And while hydroponic systems are easier to balance the advantage of aquaponics is that it has its fertilizer production built in. A well-balanced system will not need any to supplement any fertilizer whether organic or inorganic.

Aquaponic systems can be installed outdoors, in greenhouses and in re-purposed commercial buildings. And they can be used to produce a wide variety of fish, aquatic organisms, vegetables, and horticulture plants. This flexibility is a definite strength of aquaponics that make it viable in rural settings traditionally associated with food production and in peri-urban and urban settings that have no land-use history of food production.

Economic data on aquaponics is sparse given how new and emerging the technology is. Yet the flexibility of the methodology make peri-urban and urban settings especially promising locations. Urban markets offer high revenue potential and when combining aquaponics with other value-added options can offer a range of successful business models.

At the same time, aquaponics offers a way to address the serious food access and distribution inequalities that are especially prevalent in urban communities. The fact that aquaponics can be a viable solution for improving food-security and creating jobs in food desert neighborhoods points to the need to calculate the economic benefits of aquaponics differently. Rather than looking only to the economic bottom line, the social and environmental benefits of aquaponics must also be taken into account. By adding the triple bottom line benefits of sustainability and improved resilience, aquaponics can lead the way to a more complete assessment of how we manage two of our most life sustaining resources: our food and water.

Figure 23: The East Capitol Urban Farm

UDC CASE Study: Urban Aquaponics at East

The University of the District of Columbia is the only Landgrant University in the United States that is exclusively urban. Its College of Agriculture, Urban Sustainability and Environmental Sciences (CAUSES) offers research based academic and community outreach programs that improve the quality of life and economic opportunity of residents and organizations in the District of Columbia. The College's landgrant programs are organized into five landgrant centers: (1) Center of Urban Agriculture, (2) Center for Nutrition, Diet and Health, (3) Center for Sustainability and Resilience, (4) Center for Architectural Innovation and Building Science, and (5) Center for 4H and Youth Development.

The focus of CAUSES is on urban agriculture and urban sustainability. The UDC Urban Food Hubs operationalize this focus. Each Urban Food Hub consists of four integrated components that comprise the entire value chain of the food system: (1) food production, to (2) preparation, (3) distribution, and (4) waste and water recovery (see Figure 1). Food production in an urban setting must be highly intensive and produce a large amount of food on a limited amount of land. The urban setting also demands that waste is kept to a minimum and is reused wherever possible for composting or bio-digestion; water use too must be kept to a minimum and must be captured for reuse wherever possible.

The Case for Urban Aquaponics in Ward 7

One of the UDC Urban Food Hubs is the East Capitol Urban Farm located in Ward 7 in the East of the city. Ward 7 is home to 71,000 residents of and several of its census tracks are food deserts with no full service grocery store within two miles. To improve the area's food security CAUSES partnered with the DC Housing Authority to transform a three-acre corner lot, which had previously housed an municipal building into an urban farm. The farm has an 30 x 85 ft hoop house with a six tank aquaponics system, a community garden consisting of sixty raised bed gardens that are used by the neighborhood, a playground area, a rain garden, and even a rice patty. The site serves as a national model for using vacant urban lots while demonstrating on-site storm water management and local food production. The East Capitol Urban Farm offers weekly workshops on how to plant, maintain and harvest food plants, but also nutrition education, entrepreneurship classes, and a weekly farmers market.

Funding Source

UDC CAUSES was the winner of a Sustainability Award from the Washington, DC Department of Energy and Environment and the DC Office of Planning. The awards are available to local businesses and organizations for sustainable energy, water use, recycling and other "green projects".

The Site

The 3 acre location for the urban farm was a demolition site where a municipal building had been torn down. The city owned the land and was willing to let the University use the land for three to five years to demonstrate the viability of an urban farm at a former building location.

Structure

The land use granted to UDC CAUSES is only for three to five years so the structure for the aquaponics facility had to be moveable. No permanent foundations were permitted and no building structures allowed. A greenhouse structure is considered a temporary structure in Washington, DC. The greenhouse is a 30' x 84' metal hoop structure with a double-wall plastic covering.

Soil

The former building site was littered with construction debris and had big chunks of cement in the ground. Urban sites can have a land use history that results in other disturbances that may be difficult to address. Urban soils can be contaminated especially with lead. In Washington DC we have also found arsenic contamination in some urban neighborhoods. Since aquaponics systems grow vegetables hydroponically in nutrient rich water, they can offer a great solution to urban soil contamination issues.

Local Resource Help

The DC Building Industry Association (DCBIA) takes on worthy projects as volunteer projects. DCBIA selected the site preparation for the UDC East Capitol Urban Farm as one of its volunteer projects. The prepared the site as a voluntary donation. Without DCBIA support, site preparation costs would have been in excess of $300,000 for a three-acre site.

Market Access

The farm is located across the street from public transport and is situated in an urban neighborhood. The Capitol Heights Metro Station provides residents from other neighborhood in the district convenient access to the weekly farmers market where the aquaponics products are sold.

Aquaponics System

UDC CAUSES partnered Kakovitch Industries was chosen by UDC CAUSES to partner with them on the DOEE grant as the technical solution provider for the aquaponics system. The Chairman of Kakovitch Industries, Thomas Kakovitch P.hD, is the holder of a patent on a new aeration device which was preferred for the aquaponics system because of its suitability for both high aquaponic production and energy conservation characteristics. The aquaponics system has a six-tank fish rearing component, an advanced water treatment system, and uses continuous-flow media beds and drip bucket for the plant system.

Fish

The aquaponics fish rearing system has six, 650 gallon plastic tanks with metal support stands. This six-tank model allows for a monthly harvest of up to 325 lbs of fish and an annual production of up to 3,900 lbs of fish. The stocking density of the fish in the tanks is designed for 1 lb of fish per 2 gallons of water. The water is heated or cooled by a water heat pump. Species such as Tilapia, Carp, Rainbow Trout, Small-mouth Bass, and Catfish can be grown in the system.

Figure 24: East Capitol Urban Farm Aquaponic System

Plants

The continuous-flow media beds were chosen for the system because of their flexibility from growing options and water-height variability per 3' x 6' grow bed. The media beds can support a variety of produce such as lettuce, greens, herbs, and many types of fruiting plants. There are 18 media beds inside the greenhouse and over 50 drip buckets which are used for green peppers and tomatoes. Outside the greenhouse there are large areas on the three-acre site with soil grow beds where water from the fish tanks is used for fertigation of the soil. The total nutrient capacity of the aquaponics system could produce up to 62,000 lbs of produce annually.

Water Treatment System

The advanced water treatment system was designed and manufactured by Kakovitch Industries. The system is designed to use a higher than average water recirculation rate, solids filtration down to 20 microns, UV disinfection system, centrifugal force CO_2 degassers, MBBR biofilter, and Flo-Vex aeration which provides dissolved oxygen from atmosphere using the water flow of the recirculation pumps.

Urban Considerations for Aeration

Alternatives to bubble aeration in a re-circulated aquaponic systems include using pure oxygen gas. However, for urban aquaponics the storage of pure oxygen gas is unlikely to be permitted because it is highly combustible. UDC CAUSES had the following list of constraints for the aeration system given the urban setting which also let to the choice of the Flo-Vex aerator.

- No mechanical compression
- Minimal noise
- No liquid oxygen
- Oxygen is dissolved, no air bubbles
- Flexibility to use the system for fertigation
- Flexibility to modify plant systems to maximize options
- Maximize net energy generation and minimize energy input
- No air diffusers or "air stones"

Aerator

The aerator used in the UDC aquaponics systems is the Flo-Vex aerator which is the patent of emeritus professor Thomas Kakovitch. This new, patented technology uses only water as a working fluid and creates a dissolved-oxygen saturated water-discharge using only the water flow from the recirculation pump. There is no need for a separate aeration blower or compressor and dissolved oxygen levels can be maintained independent of water depth. The aerator has also been demonstrated to be more energy efficient than blown air systems.

Most importantly, the Flo-Vex aerator keeps both pH and the bacteria in the system in balance. In three years of continuous operation we have not had the need to lower the pH or insert bacteria into the system. Typically, aquaponic systems experience an increase in the pH that has to be brought back into balance. Since the Flo-Vex does not use compression or friction to insert oxygen, the microorganisms that naturally occur in the system are maintained. In contrast, the heat that typically accompanies the aeration process eliminates naturally occurring microorganisms that stabilize the system.

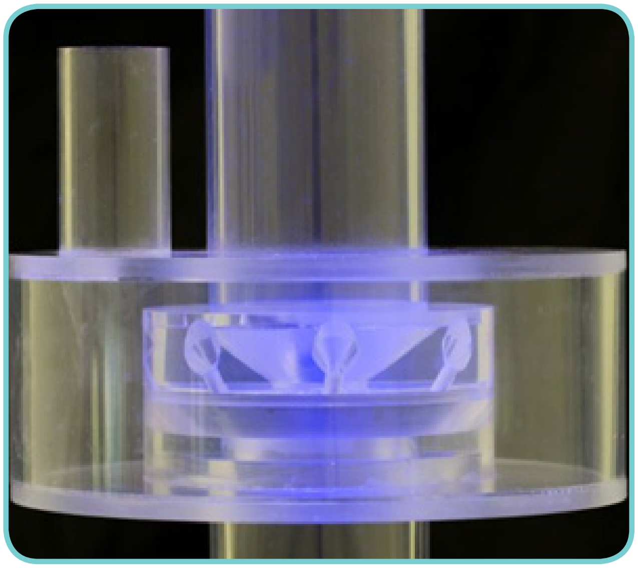


Figure 25: The Flo-Vex Aerator

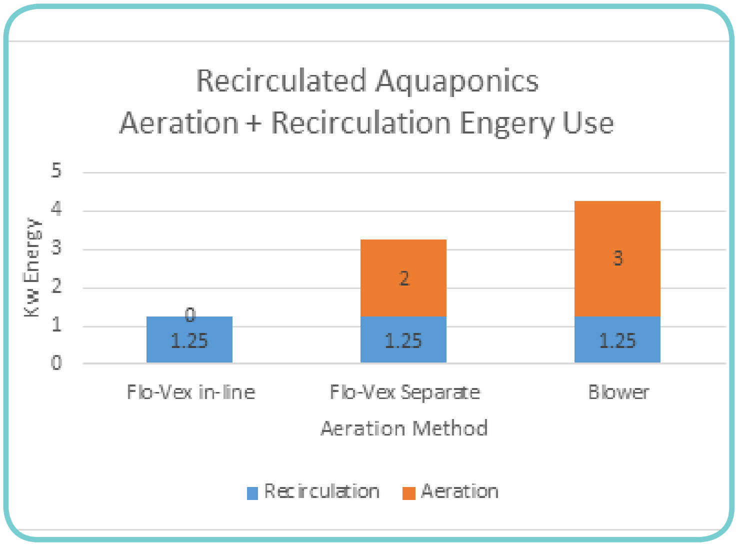


Figure 26: Performance of Flo-Vex and Blower Aeration

The UDC Urban Food Hubs and their innovative Urban Aquaponic systems are an example of a sustainable, small scale, decentralized (urban) model of agriculture that can utilize small urban spaces effectively to produce high quality food where most food consumers live, namely in cities and metropolitan areas. The intention is not to meet all of our food security needs through urban agriculture. Yet urban agriculture and the vision it creates of a sustainable decentralized food system are an important complement to our large scale, centralized food system and will improve the overall sustainability and resilience of our food system.

References