AN AQUACULTURE
TECHNICAL BRIEF

An Aquaponic Journey into Local Food

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A PUBLICATION OF THE UNIVERSITY OF WISCONSIN-MILWAUKEE SCHOOL OF FRESHWATER SCIENCES AND UNIVERSITY OF WISCONSIN SEA GRANT INSTITUTE

December 2021

AN AQUAPONIC JOURNEY INTO LOCAL FOOD

OVERVIEW

Eating locally is important. Author and journalist Michael Pollan has a good philosophy: eat food, not too much, mostly greens. Pollan suggests that eating locally is the best way to access food at its nutritional peak, which is beneficial to personal health. Eating locally also supports local food economies and is less damaging to the environment than the conventional corporate food system. This paper is about my journey learning to produce mostly greens through the development and operation of aquaponics systems.

Aquaponics refers to a food production system that couples aquaculture (raising aquatic animals such as fish, crayfish, snails or prawns in tanks) with hydroponics (cultivating plants in water). An aquaponics system is a symbiotic environment whereby the aquaculture water, rich in nutrients from fish waste, is provided as a fertilizer to the hydroponically grown plants. The plants, in turn, act as water filters and return detoxified water to the fish.

Yellow perch fingerlings swimming in an aquaponics tank.

Many definitions of aquaponics recognize the *'ponics'* part of this word, which refers to growing plants in water with a soil-less media. It is from the Greek word *'ponos'* meaning work or toil. So, literally speaking, aquaponics is putting fish and the nutrient-rich water to work. In this process, aquaponics mimics a natural ecosystem; that is, it represents the relationship between water, aquatic life, bacteria, nutrient dynamics and plants. Similar to nature, aquaponics harnesses the power of bio-integrating these individual components: exchanging the waste by-product from the fish as a food for the bacteria, which is converted into a perfect fertilizer for the plants, that absorb these materials and return the water in a cleaner and safer form to the fish.

In 2009, I founded (and funded), a non-profit local food center that has relied on an aquaponics system as its primary growing medium. I began the venture wanting to give back some of the economic resources I had accumulated over my lifetime and career. The time spent in this endeavor has been both rewarding and therapeutic, but not without its challenges. After years in this venture, without a doubt, the personal benefits far exceed the economic inputs.

Since 2009, I have built and operated three increasingly complex systems: models 1, 2 and 3. For each model, I had an initial set of objectives, which changed and evolved over time. The experience of working through each model increased my knowledge and skills to the point where I now successfully produce greens that are distributed to the local community through community supported agriculture (CSA).

Additionally, my experience with these three aquaponics models provides a basis for understanding the advantages and disadvantages of aquaponics as a vehicle for an even larger-scale production of food for local communities, one that incorporates newer technologies in green energy. That is, I have enough understanding to envision what could become a model 4.

Michael Pollan provided me the local food vision. I was also influenced by local experts like Will Allen, founder of Growing Power; Fred Binkowski, University of Wisconsin-Milwaukee School of Freshwater Sciences; and Jim Held, University of Wisconsin Extension.

THE MODELS

Model 1 evolved from my curiosity about *if* aquaponics actually worked. My first challenge was to design and build a simple system in my home using an aquarium and houseplants. With model 1, I successfully grew plants using fish waste as the nutrient source.

Next, I wanted to know *how* it all worked, so I built model 2 to learn the science of aquaponics. This was a more complicated endeavor requiring an expanded design and construction: a 12-by-12-foot bi-level solarium and fish habitat incorporating my back porch. With this new system, basic microbiology and aquaponics (how aquaculture and hydroponics work together) were becoming clearer to me.

Ten months later, as I observed other aquaponic startups across Wisconsin, I began looking for a location for a larger scale model 3. My objective was to scale up and build a pre-production food system; one that could guide me to a full-scale market-oriented local food business that would bring locally grown, nutrient-rich food to the community. I also wanted to share what I learned with like-minded entrepreneurs, providing them a template and data. To accomplish this, I attached a 36-by-48-foot greenhouse to an existing 25-by-95-foot agricultural storage building, which housed two 1,750-gallon aquaponics systems that fed 1,680 square feet of raised bed plant surfaces, troughs and gutters. The system design houses up to 1,600 4- to 8-inch yellow perch.

Models 1, 2 and 3 are recirculating aquaculture systems (RAS), which operate by filtering water from the fish habitat for reuse throughout the system — there is no water discharge. In an aquaponics RAS, the concept provides for solids removal, the conversion of ammonia to nitrates, and oxygenation. These systems can be much more complex, but from a more basic perspective, by keeping the water moving and oxygenated, removing solids as best you can, and nitrifying the ammonia, you can successfully raise fish and grow plants.

With the increasing complexity of models 1, 2 and 3, my skills in building and maintenance also developed, along with expertise in managing the primary participants found in any aquaponics system: the fish, the plants and the bacteria. I developed a deep understanding of the relationship of water, light and photosynthesis, as well as handling pests, environment and supplements.

With a goal of developing a full-scale enterprise that serves as a local food center, a number of other issues come into play, such as generating revenue, marketing, system sustainability, organizational management, and recruitment and management of employees and volunteers. This would be the objective of the future model 4.

This paper introduces aquaponics as a stepwise process using four increasingly complex models that address both the science and the business aspects of a full-scale operation. As always, the takeaway is that there is a substantial difference between what one would like to do and plans accordingly, and that which is in actuality practical for a sustainable business operation and a flourishing greenhouse. The key is flexibility.

MODEL 1: **I wanted to know *if* aquaponics works**

I became curious about aquaponics when, in 2009, I discovered a working model at Growing Power on West Silver Spring Drive in Milwaukee, Wisconsin. Growing Power founder Will Allen had been operating a local food operation there since 1993. Aquaponics was novel and became an important center of inquiry in Milwaukee, a city troubled with lack of fresh food access in many of its neighborhoods. I researched aquaponics online and developed interest; I thought it was cool and wanted to know more. After a second trip to Growing Power and additional information from Jim Held, aquaculture specialist at University of Wisconsin Extension, I was hooked. But where to start?

My experience with raising fish consisted of a part-time job as a teenager at a Woolworths' pet department. I was responsible for keeping fish tanks and bird cages clean and the animals fed. My experience with growing local food was equally limited. I mucked horse manure and weeded my family's 2-acre garden when growing up. In starting this new aquaponics endeavor, I didn't have a lot to go on except a toolbox full of tools, some plumbing and electrical experience, and a little money.

Building an aquaponics system, even a small one, requires finding a location. My two sons had just moved out of the house, so why not replace two teenagers with 100 fish? I commandeered the first level bedrooms of my 1899 three-story home. It was a good choice because as the owner I had flexibility to modify the interior surfaces (drill holes, add outlets, install water lines and drains). Additionally, the rooms had tall 30-by-60-inch windows with full southern exposure, which is important for plant growth.

My initial system, model 1, was an assembly of parts; a multiple-tank aquarium linked to six 18-by-30-inch plant beds positioned in the two southern exposure windows, figures 1 and 2. The base system consisted of four 35-gallon glass aquariums that I had purchased online. I also bought a lot of additional aquarium supplies online that were never used and now I have an abundance of abandoned aquarium equipment readily available. Buy only what you need.

I specifically chose aquariums with a single three-fourths-inch hole drilled through the glass at the bottom of the tank that allowed the tanks to function with standpipes for drainage. I didn't understand the functionality of this type of drainage initially and figuring out how to plumb the tanks into a central drainage system involved a learning curve. Once I mastered that technique, I had two, then four tanks elevated above the floor of my back bedroom. The four tanks weighed

IN SPITE OF MY LACK OF EXPERIENCE WITH GROWING PLANTS USING FISH WASTE, THERE WAS SUFFICIENT RETURN ON MY EFFORTS TO JUSTIFY CONTINUING THIS LEARNING ADVENTURE.

Figs. 1 and 2. An assemblage of parts. Four 35-gallon aquariums, six 13-by-18-inch plastic plant beds and two southern exposure windows. (P. Wilborn, 2010.)

about 960 pounds, so I reinforced the floor from the utility room located below.

Eventually this utility room also provided a central source for system water discharge and redirection upward to the window plant trays. I had plumbed the four tanks for a water take-off that was pumped vertically 8 feet to the top of three plant trays in the window of the bedroom. As I became more confident with the system, I ran a hose and drain to the adjacent bedroom window where there were three additional plant trays.

The two major challenges I faced with the new system were choosing the appropriate size pump to distribute the water through the system and making fish tank and plant bed connections that did not leak.

In choosing fish, I relied on advice from Jim Held, who referred me to a University of Wisconsin-Madison professor who owned a fish farm. I purchased about eighty 2- to 4-inch yellow perch. Now I had my fish and had to learn how to keep them alive. The first challenge was making sure that the fish had adequate oxygen for the two-hour journey from southern Dane County to Port Washington, Wisconsin.

After the trip, I was able to successfully acclimate the fish from the water temperature in my 5-gallon travel buckets to the water in the new aquaponic system. I then had the unanticipated challenge of getting the fish to eat. After about two weeks without success, and about 60% casualties, I called on Jim, who referred me to Fred Binkowski at the University of Wisconsin-Milwaukee School of Freshwater Sciences. Fred told me about blood worms (larvae of the midge fly) and brine shrimp (sea monkeys) as a method of feed-training the yellow perch to eat. Who would have thought fish needed to be trained to eat?

Why did I choose yellow perch? First, because they are popular for fish fries in this part of Wisconsin and would provide an instant revenue stream. Second, I wouldn't have to heat water because normal room temperature (63° to 77° F) is within the ideal temperature range for yellow perch. Third, because I could plan on technical advice about perch from the experts at UW-Milwaukee and UW Extension. Last, I would have some price flexibility when I sold my yellow perch. (See the Selecting the Appropriate Fish section for information on the marketability of fish raised in aquaponics systems.)

The most successful plants in the initial plant trays were watercress and philodendrons, although I had tried several other greens with varying degrees of success. At that time, I was using Hydroton (clay pebbles) plant bed media, as well as some small pots filled with soil. In spite of my lack of experience with growing plants using fish waste, there was sufficient return on my efforts to justify continuing this learning adventure. The important takeaway was that if you feed fish, have adequate lighting and use a quality growing medium, aquaponics appears to work.

There was something else that was keeping me going with aquaponics: an interest in connecting aquaponics with local food production. At the time, there was a lot of excitement in Milwaukee about aquaponics as a source of local food. Several individuals and groups held networking meetings and educational workshops on the topic. I jumped into this aquaponics/local food community and began building my network of like-minded local food promoters, including Jon Bales, Leon Todd, James Godsil and Matt Ray. I was learning how to construct and operate a simple aquaponics model at the same time I was learning how to promote local food. Even with all this effort and solid networking, I was still very much a novice. With this realization, I began the development of model 2.

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MODEL 2: **I wanted to know *how* aquaponics works**

It was about four months after I introduced fish and plants in model 1 that I started looking for a place to direct my new efforts, that is, model 2. My initial goal was to find space to build a structure outside of my house. I thought an 18-by-24-foot greenhouse addition to my garage would be ideal (figure 3). While the southern exposure wasn't perfect (I could only count on approximately 66% of the summertime light), it was a perfect location right off the Port Washington, Wisconsin, downtown district — a place that would provide my neighbors ample access to freshly grown, local food.

Unfortunately, neither my neighbors nor the Common Council thought much of this idea. Long story short: my request was rejected after several months of conversations with the city of Port Washington Planning Commission. At the end of the final meeting, however, the local building inspector took me aside and told me I could do anything I wanted if I built an addition to my house, rather than my garage. This hadn't occurred to me, and it was the perfect solution! I not only found a location for model 2 that was accessible to neighbors, but it also provided full southern light exposure.

Model 2 is a two-story structure with a solarium on the porch level (first floor of the house) and a fish habitat on the lower level (walk-out basement). The solarium is constructed of a 12-by-12-foot wood frame with a translucent double-walled polystyrene exterior. The fish habitat is an enclosed wood frame structure that is well insulated with reinforced structural integrity to carry the live weight of the solarium above it. See figures 4 through 6.

Both of these spaces rely on a heat exchanger baseboard radiant heating system that uses the hot water created from the boiler in the house. The boiler water heats the glycol passing through the heat exchanger

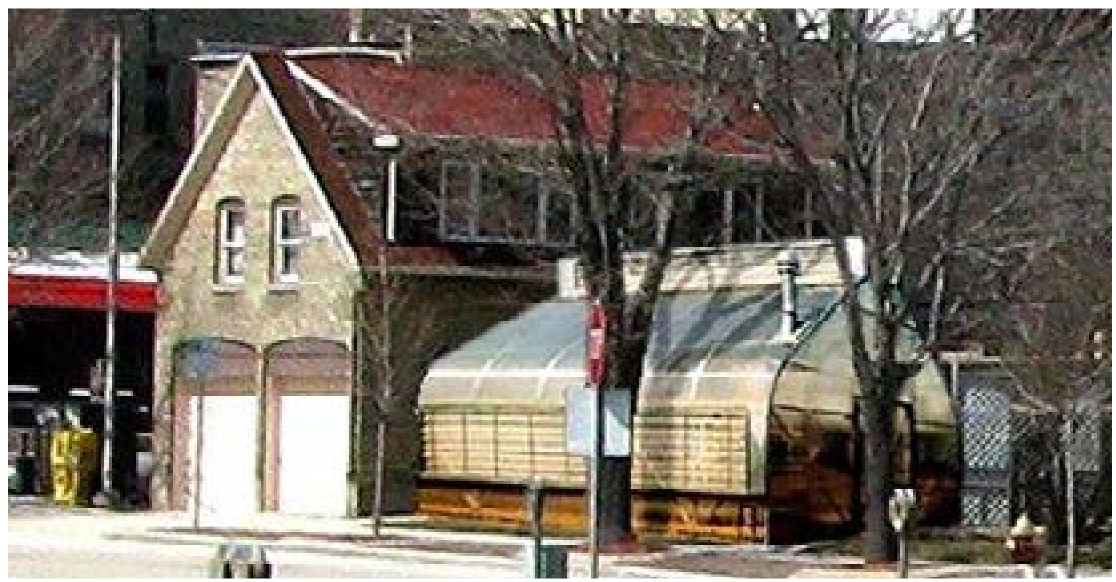


Fig. 3. Concept rejected by the city of Port Washington Common Council: a greenhouse addition to a residential garage. (P. Wilborn, 2010.)

Figs. 4 and 5 (left). **Model 2 revised design as an addition to my house.** (P. Wilborn, 2010.)

Fig. 6. Fish habitat of model 2. (P. Wilborn, 2010.)

which radiates heat from perimeter baseboard panels in the solarium and fish habitat spaces.

My review of the different aquaponics projects around Milwaukee at that time suggested that the simplest aquaponic plant structure design for this space would be a wood frame structure supporting a flat plywood tray with a pond liner. This design replaces the plastic trays of model 1, while a 300-gallon plastic stock tank replaces the four aquariums.

How does model 2 work? The fish habitat contains a 300-gallon Fleet Farm plastic stock tank that holds 300 3- to 5-inch yellow perch. Adjacent to this tank is a 35-gallon plastic trash bin that acts as a sump pump to move the water up to the solarium. The 1,000-GPH pump has a rated capacity of moving 300 gallons of water per hour. However, the 10-foot rise reduces that capacity because the pump head pressure must adjust for pumping against gravity.

The solarium has a bi-level frame structure holding two 4-by-8-foot plant trays. The frame is made of three-fourths-inch plywood, 2-by-4-inch perimeter lumber, and 45 mil EPDM rubber pond liner (Firestone Pond Guard). The fish tank water is pumped to the top tray, then using gravity is routed to the lower tray, then passes through a 10-gallon tote filled with PVC ribbon filtering material, and finally back to the 300-gallon fish habitat. The 10-gallon tote serves two purposes: it provides surface area for friendly bacteria to grow, and it collects solids that can be pumped out of the system.

For the plumbing, I used various 1.5- to 2-inch plastic PVC parts and fashioned them into a drain. There are drains available for purchase that are suited exactly to the plywood/pond liner configuration. They can save design and building time but are more expensive.

Initially, I used Hydroton as the media base in the plant beds, but then learned that pea gravel is slightly better for maximizing the surface space where bacteria grow. Bacteria are critical to the nitrification process. Nitrification — converting the ammonia from the fish water to nitrites and nitrates (plant food) — is key to a healthy system. Model 2 introduced me to the importance of surface space.

Model 2 also provided me an introduction to managing a larger number of fish, especially the need to monitor certain aspects of their care: water temperature, turbidity of water and adequate oxygen levels. Model 2 also provided a demonstration of the impact of the exterior weather (sun, clouds, temperatures and wind) on the interior workspace. I discovered that growing in the solarium in April and May is different from in July and August or in January and February. There are many subtle variables to understand, such as the availability of sun, the length of day, the variability of temperatures — not only seasonally, but also daily, between the morning, afternoon and evening.

THERE ARE MANY SUBTLE VARIABLES TO UNDERSTAND, SUCH AS THE AVAILABILITY OF SUN — NOT ONLY SEASONALLY, BUT DAILY.

In terms of harvest, model 2 successfully provides greens year-round and produces enough protein (from fish) for a family of four. Unlike the greens, which keep growing and recycling, once the fish are harvested, they need to be replaced. Model 2 did not provide a sufficient volume of produce and protein to be economically sustainable beyond feeding my own family and treating a few neighbors. It was clear that the costs — labor, heat, water, electricity and equipment — would increase as the size and productivity of a system grows, and to create an operation that could grow enough produce to reach the community and be seen as a local food source, self-funding would likely be needed to balance any revenue shortfalls. An objective of expanding the operation would be to find economy of scale to sustain this local food endeavor, and this became the reason for pursuing model 3.

In June 2019, nine years after the original model 2 construction, the system was modified to operate as a hydroponic system with an aquaculture-nutrient support component. That is, the plant bed was isolated from the fish habitat so that any system water directed to and used by the plants was no longer returned to the fish; the plants now have their own recirculation system that is replenished with fish system water as needed. In this process, the efficiency of water usage was maintained (there was no waste or discharge), but extra filtration of the system water was required to keep the fish healthy.

The additional filtration was accomplished by improving the biofilter design to reduce the toxicity of the fish-produced ammonia by strengthening the nitrification process. The new design directs the water from a holding tank in the solarium to the bottom of a 55-gallon barrel (the biofilter), then allows the water to flow up through layers of increasingly finer material: large stones, small stones, pea gravel and sand. The detoxed water is then directed back into the fish habitat.

In the modified hydroponic system, the fish water is manually directed into a separate holding tank and then pumped vertically to the upper plant tray. Fish nutrients as well as commercial nutrients are added for the purpose of promoting plant health and growth.

MODEL 3: **I wanted to build a commercial system**

THE DESIGN AND CONSTRUCTION OF THE GREENHOUSE

Much of my interest in aquaponics was driven by my association with those who were promoting an urban method of growing food locally. Many were interested in summer neighborhood/community gardens and a number specifically focused on aquaponics. In late 2011, I continued to consider aquaponics a doable option, but I needed a larger operation to move forward. At that time, the two larger models that I continued to watch with great interest were Sweet Water Organics and Growing Power, both in urban Milwaukee.

With examples of developing aquaponics systems in the area, I was prepared to explore designing a system of my own. I contacted Kubala-Washatko Architects to help me visualize a workable model. We came up with the aquaponics design illustrated in figure 7, consisting of a greenhouse connected to a conventional building.

The configuration is a long building with a greenhouse with full southern exposure on one side and a workspace for raising fish and food production on the other. The workspace was to be of conventional frame construction and the greenhouse would be steel frame with a double-sided clear rigid plastic exterior.

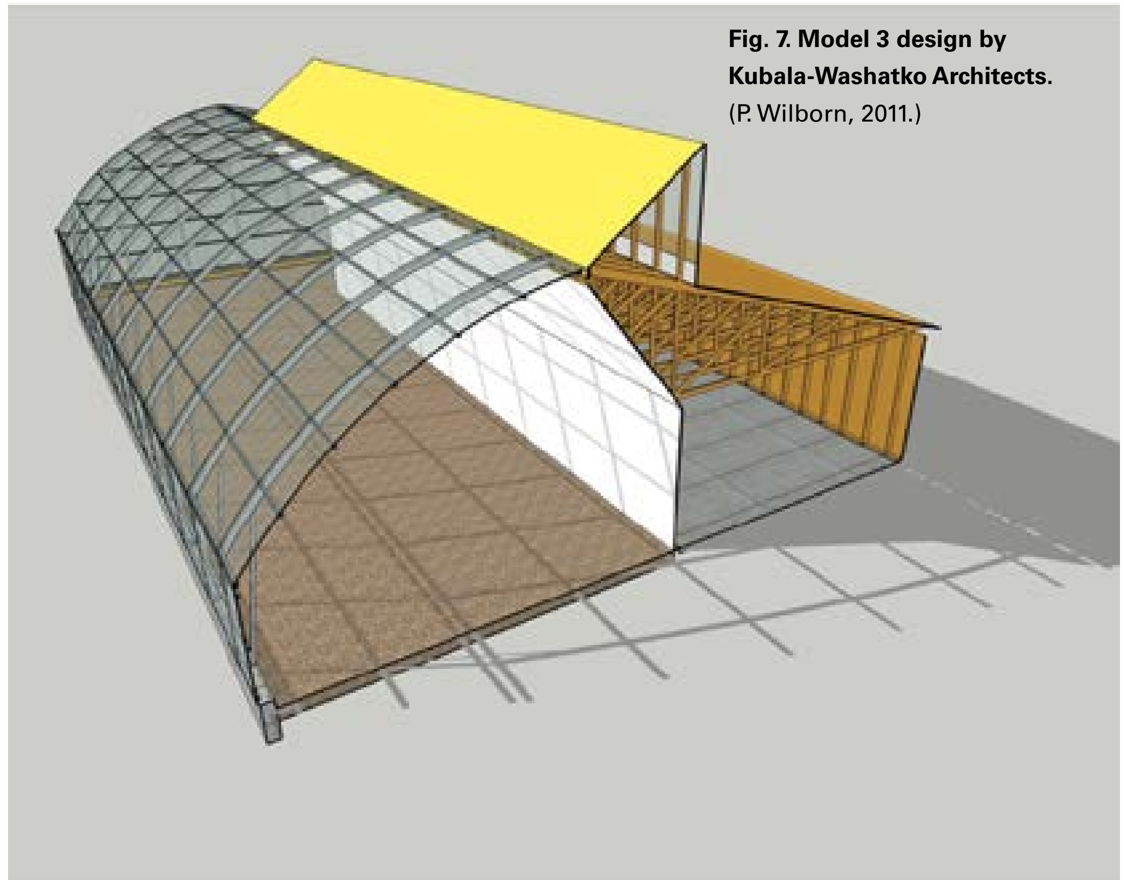


Fig. 7. Model 3 design by Kubala-Washatko Architects. (P. Wilborn, 2011.)

The greenhouse would be adequately ventilated in the summer and heated in the winter to keep the temperature at a year-round 70 degrees.

At this point in the planning, I had gained experience from model 2 as well as the information I regularly gleaned from my aquaponics network. I saw many things to consider, as well as many things to avoid. As importantly, I also had to consider how I could afford to bring these ideas to fruition as model 3.

In terms of financing, a loan was not a viable option, nor were donations or bake sales. I didn't know enough about aquaponics to convince anyone that it was a good idea worthy of funding, so developing an investor pool also was not an option. I tried grant writing but found it to be too constraining; the criteria for funding often did not match well with my goals and the reporting requirements were burdensome. I was awarded one $800 grant from WE Energies for a thermal curtain in model 3. Otherwise, after about a half-dozen attempts, I gave up on grant writing.

I resigned myself to self-funding. The most liquid of my retirement funds were in the stock market. Like most investors in 2008-2012, I was experiencing a steady decline in the value of my portfolio. In 2011, I decided I could lose my money as fast as my stockbroker could, so I bailed out of the market and invested those funds in aquaponics.

For business organizational purposes, given my aquaponics research as well as educational mission, I determined the most appropriate economic approach to this new endeavor would be best served as a non-profit organization with a 501c3 status. So, all that was left for me to do was to find a place to bring these ideas and planning efforts together.

In May 2011, a location for model 3 — and my concept of a future in aquaponics — was heavy on my mind. One day I was driving home, and I gazed to my left and saw the old, worn-out long wood structure shown in figures 8 and 9. It had been an agricultural storage building, part of a long-closed feed mill located just outside of Port Washington, Wisconsin, in the unincorporated community of Knellsville (pronounced ki-NELS-vil).

My immediate response was disbelief. I had been driving past this property for years and had never really noticed this building. I couldn't believe how well it fit the architectural drawing of my conceptual model. In the next several months, I contacted the owners and negotiated a five-year lease with two five-year options on the seven-bay, 28-by-94-foot wood frame building to begin in August 2011. I also located and purchased a 36-by-48-foot FarmTek greenhouse kit and began the process of figuring out how to make this idea come to life. This was the beginning of model 3.

My carpenter friend who had built model 2 was in on the project. In addition, a young farmer-wannabe (like myself, *but young)* and my two sons were ready to help. My wife, Amy, must have also thought it was a good idea (or she didn't think it was a bad idea) because she joined the team as well. However, neither she nor I truly understood the scope of the project to which we all were committing.

The term "greenhouse kit" suggests something far simpler than what it actually was. The so-called kit arrived via an over-the-road carrier and required a skid-steer loader to move the eleven large containers from the truck into the storage building. With that done, we closed the massive doors on the building and the truck

Figs. 8 and 9. A dilapidated agricultural storage building with pitched roof that would become the future model 3. (P. Wilborn, 2011.)

drove away. Because this story is about aquaponics and not about bringing a vintage wood frame building with a marginal roof back to life, I will dispense with the restoration details. I will summarize, however, by noting that the reroofing, re-siding and painting of that old building took longer than expected; restoration lasted the entire initial term of my 5-year lease.

During the winter of 2011, the footings for the greenhouse were laid out, dug and poured. The following June and July, the greenhouse kit was constructed, and following the roof replacement, the interior of the seven-bay storage building was cleaned and prepped for a fish habitat, plant germination space and a local greens growing and marketing operation.

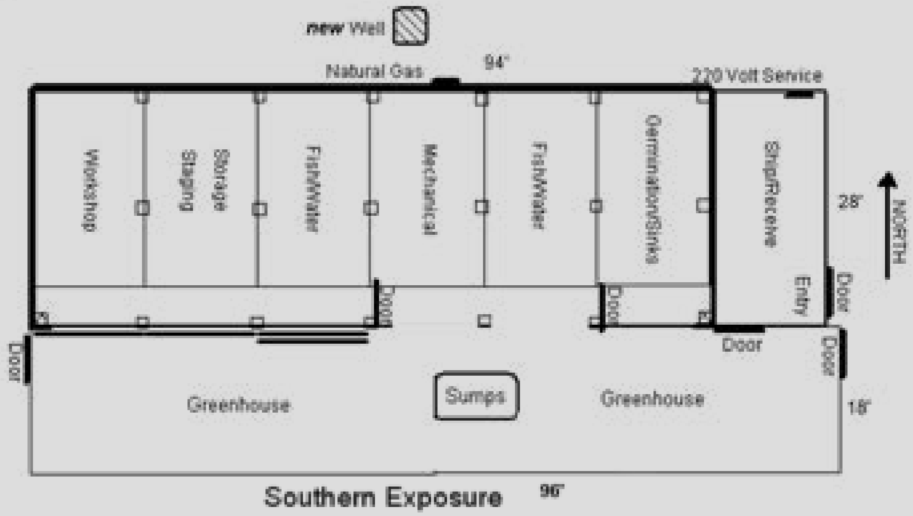
The original greenhouse kit design provided for a 36-by-48-foot rectangular gothic-style greenhouse with a double-walled polystyrene exterior and a 16-foot roof ridge. I modified this design so that the final greenhouse was an 18-by-96-foot structure that attached to the south side of the 28-by-94-foot storage building and had a single-pitched roof sloping down to the north (figure 10). The south wall of the storage building was 16 feet high where the greenhouse ridge attached, and the north wall was 12 feet.

The storage building had seven bays, each with its own 14-by-16-foot wooden sliding door capable of sliding over or under the adjacent door. The design of the aquaponics facility used each of these bays for specific purposes (see figure 11). Traffic flow was supported by the installation of pedestrian doors between the each of the bays and between the storage spaces and the greenhouse. The large 14-by-16-foot sliding doors were secured in place establishing access between the greenhouse and the fish habitat and various workspaces.

Fig. 10. Model 3 with greenhouse attached. (P. Wilborn, 2012.)

The logic behind the greenhouse being attached to the storage building was to have a partially temperature-controlled growing space benefit from the adjacent conventional temperature-controlled fish habitat/workspace. During late summer 2012, the HVAC unit was installed in the mechanical bay and two natural gas-fired furnaces were installed in the greenhouse. A private well was also installed. There were several iterations before finalizing the configuration illustrated in figure 11.

As of August 2012, the greenhouse and the storage building were 100% enclosed. I had some ideas regarding ventilation requirements from model 2, but the reality of the tremendous gain from the sun in such a large greenhouse was that the heat buildup was a real eye-opener with air temperatures of 100 degrees in summer. This condition would require substantial



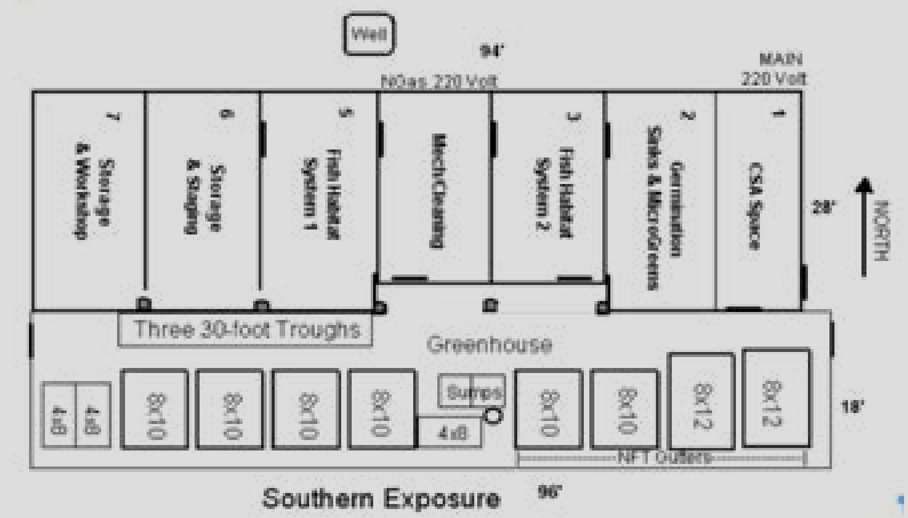


Fig. 11. (above) **Model 3 initial plans.** (P. Wilborn, 2011.)

Fig. 14. Model 3 evolved plans. (P. Wilborn, 2014.)

Figs. 12 and 13. Installation and functionality of retractable thermal curtains. (P. Wilborn, 2012.)

ventilation and shading to reduce temperatures during the summer. Heating during the winter was also an issue. We would need to innovate with fans, vents, louvres, and heating and cooling units.

In the first critical effort to ventilate, we installed two vent fans on the east end of the greenhouse and two electrically synchronized vents on the west end. In addition, four solar-operated ridge vents were installed at the greenhouse/building joint, along with six louvres at the base of the south wall. The louvres allow for a chimney-like flow of air to the ridge vents. Two manually operated gable vents on the peaks of the east and west walls were also installed.

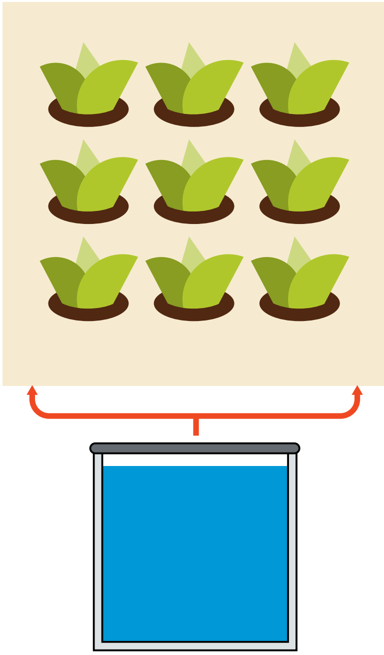
There were two additional efforts to stabilize the interior environment. In the next effort we installed sliding overhead thermal curtains and a seasonal 20-by-100-foot exterior shade cloth. These curtains vary from 30% UV protection up to 90% and are typically installed at the beginning of the summer (April/May) and are taken down in the fall (September/October). They can successfully drop the interior temperature 5° to 10° F.

With the support of a grant from WE Energies, we installed retractable thermal curtains that we use during both the summer and winter, as seen in figures 12 and 13. With our 96-foot-long greenhouse, we rely on three curtains, each with its own tract, pullies and draw cords. The curtains ride on the overhead lateral supports and isolate the upper third of the interior space from the lower two-thirds. In the summer with the curtains closed, we further shade the greens and isolate the upper level temperatures of 130° to 140° F from the maximum 85° to 100° F in the growing space. In the winter, we use the curtains after the sun disappears to isolate the upper third of the greenhouse from the lower two-thirds and thereby reduce the amount of furnace time that it takes to maintain our 56° F interior temperatures.

As the interior environment was being stabilized, the design of the aquaponics side was also progressing. I started by configuring the greenhouse with as much growing surface as possible, then created the number of enclosed water areas (fish tanks) required to serve the nutrient needs of the projected plants. Other areas of the facility that needed to be resolved included the storage and workspaces for maintaining the aquaponic system, the interior and exterior of the building, as well as space for the handling, processing and marketing of the harvest of the greenhouse. There were reams of internet information available for designing aquaponic systems, as well as for buying pre-engineered ready-to-go systems. As a do-it-yourself (DIY) system, I used what information I could and needed to fill in the blanks.

The initial DIY efforts in building the aquaponics system involved identifying the necessary components, their costs and the appropriate sizing for a stable system. Each decision was followed by a series of second-guessing exercises. Many of the final answers came in the form of my own firsthand trial and error, or by visiting other systems and benefiting from the generosity of knowledge of those that worked or the misfortune of those that failed and were abandoned. Enduring the outcomes from the trial-and-error process was not easy, but it was critical. To survive this process, one had to be tenacious, industrious, extremely flexible and mostly lucky.

THE BASIC AQUAPONIC SYSTEM SHOULD PROVIDE ONE GALLON OF WATER FOR EVERY ONE SQUARE FOOT OF PLANT BED.



The diagram in figure 11 shows the initial plans of model 3 and accomplished getting the basic structure renovated and the greenhouse built as discussed above. Figure 14 represents the evolution of the PortFish model 3 local food center, including the design and construction of the fish habitat and the plant beds, which are addressed in the next two sections.

Fig. 15. Model 3 uses a total of four 300-gallon plastic tanks as fish habitat, two per 1,750 gallon system. (P. Wilborn, 2014.)

THE DESIGN AND CONSTRUCTION OF THE FISH HABITAT

It took a long time to squeeze a formula out of the available information, but eventually I came up with this one: the basic aquaponic system should provide one gallon of fish tank water for every one square foot of plant bed. The critical variable in this formula is the actual volume of biomass in the fish habitat related to the actual volume of plants that can be grown. Although the formula is not precise, and it will change as the fish and plants grow, it provides a guideline for beginning the process of building a sustainable and productive local food system in a balanced ecosystem.

The model 3 aquaponics system consists of two separate 1,750-gallon systems that support 1,680 square feet of greenhouse plant floor space. The primary consideration with the aquaculture component is providing sufficient fish waste-based nutrients to the plants while maintaining a healthy environment for the fish. The pumps, tanks, pipes, fittings, valves and drains of the fish habitat can get expensive. So, getting the measurements and exact water delivery requirements right the first time (and more often the second time) is a challenge, but does eventually save on long-term expenses.

In model 3, there are two identical and complete recirculating aquaponics systems (RAS). Every RAS consists of three critical parts: the fish tank, the clarifier and the biofilter. These three components follow the tenet — you feed the fish, the fish create waste that is converted to plant food, and the plants grow by filtering waste/nutrients out of the water. This system works.

The Fish Tank. In each system the fish live in two 300-gallon plastic stock tanks (intermediate bulk containers, or IBCs) that were purchased from Fleet Farm for $140 each (figure 15). The dimensions of these tanks are 54 by 80 inches with a 40-inch depth. A hole is drilled in the bottom of each stock tank for installation of a two-inch PVC standpipe. The standpipe maintains a specified volume of water in the tanks and allows for the recycling of the system water as it overflows into the clarifiers.

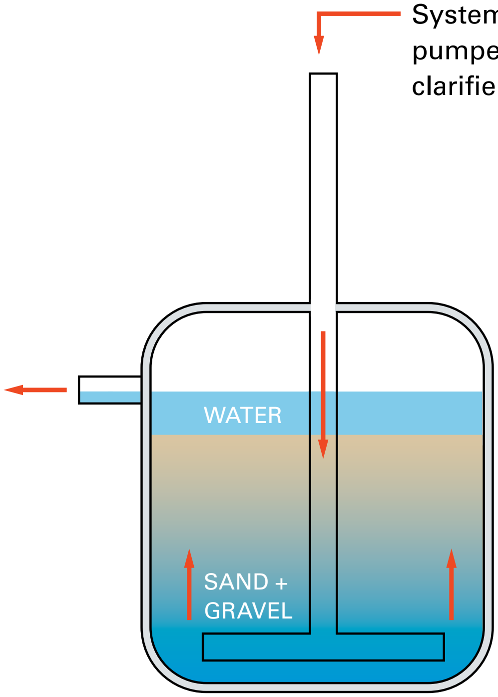
The Clarifier. Each RAS has a clarifier that consists of two separate 55-gallon barrels plumbed to receive the water from the standpipes. As the solid waste suspended in water leaves the fish tanks, it is directed to the bottom of the first clarifier, where the water flow is slowed by two baffles that promote the solids sinking to the bottom of the tank. This water then similarly passes to the next clarifier, solids sinks and the water continues onward through the system.

The solids are manually removed from the bottom of the clarifier using a hose connected to a pump, then stored in an elevated 55-gallon barrel holding tank that accumulates and settles the solids to a higher concentration. The barrels are elevated to take advantage of gravity, which helps the solids settle at the bottom. After 24 hours of settling, the upper, clearer water is drained back into the fish tanks, while the settled solids are drained to 5-gallon buckets and placed in an evaporator system. With controlled drying of the evaporator, the waste is converted to a timed-release fertilizer, similar to Milorganite. We use this fertilizer in the spring and summer in raised planting beds. The sludge can also be poured directly on exterior plant beds or compost piles but tends to cake when it dries.

The Biofilter. As the water moves through the clarifier, it enters a transition tank that allows it to move in two directions: one flows directly out to the greenhouse to water and fertilize the plant beds; the other is pumped up to the top of a 4-inch PVC column that extends down into the two biofilters. These are 55-gallon barrels filled three-quarters full of white sand, pea gravel and aggregates. The purpose of these materials is to provide surfaces for bacteria to reside. Bacteria are important to RAS because ammonia is consumed by the bacteria and converted to nitrites, then nitrates, which are absorbed by the plants. This process is known as nitrification. The water is then returned to the transition tank where it flows either out to the greenhouse or repeats the trip through the biofilter. Because the system is in constant motion, there is no concentration of ammonia, nitrites or nitrates at any one location, making the water safe for the plants. Figure 16 is a diagram of the biofilter in the model 3 systems.

An additional benefit of the transition tank is that with the use of a heater, a water temperature of 70° F can be maintained during the winter months. This promotes the activities of the bacteria in the biofilters, whereas lower water temperatures (60° to 65° F) inhibit the

SAND/STONE/PEAGRAVEL BIOFILTER



Bacteria incubation period

Nitrosomonous = 30 days

Nitobactor = 45 days

* 1 lb. sand to 1 gallon system water.

** Aggregates are 30% stone/pea gravel (lower layer) and 70% sand (upper layer).

*** A system water transition tank is heated during winter months for bacteria.

Fig. 16. Diagram of a sand/stone/pea gravel biofilter constructed from a 55-gallon drum and 4-inch PVC.

nitrification process. I used a 220-volt titanium heater for this purpose.

After the system water leaves the transition tank and is routed to the greenhouse, it is returned to the two 300-gallon IBC stock tanks for each RAS that rest about four feet below grade. These IBC tanks have two functions: they hold excess system water and provide for the continuous distribution of water.

There are two water pumps located in each of the IBC tanks. One of the pumps simultaneously circulates the system water to the plant beds and to the fish and is called the day pump; the other pump circulates to the fish only and is called the night pump. They are important because during the night the fish have less exposure to the daytime warmed water during the summer and the cooled water during the winter; this system eliminates the extreme water temperatures of the daytime exposure in the plant beds year-round.

ENDURING THE OUTCOMES FROM THE TRIAL-AND-ERROR PROCESS WAS NOT EASY, BUT IT WAS CRITICAL. TO SURVIVE THIS PROCESS, ONE HAD TO BE TENACIOUS, INDUSTRIOUS, EXTREMELY FLEXIBLE AND MOSTLY LUCKY.

It keeps the fish habitat water between the temperature range of 60° to 85° F as opposed to the plant bed temperature range of 55° to 90-95° F. This temperature control process is further facilitated by the 55-gallon holding tanks, which benefit from the 70° F year-round ambient temperature of the heated space where the fish reside.

SELECTING THE APPROPRIATE FISH

How does one select the appropriate fish for their aquaponics system? That question would best be preceded by another question: Which plants are most desired on the hydroponics side? Tomatoes, basil and peppers will not grow in the cold water that koi, yellow perch, bluegills or goldfish prefer between October and April. However, tilapia may be perfect for sharing a RAS with those plants. See table A. There are other determining factors in choosing which fish to raise. One factor is the regular supply of fish (availability of fingerlings and the ease of spawning) because the supply affects the ability to grow and sell fish in an efficient feed-to-fish weight gain cycle. Another factor is the market demand for a particular fish and whether there is any retail price flexibility. A comparison between yellow perch and tilapia illustrates this factor.

There was a time when yellow perch were abundant in the Great Lakes, particularly in Lake Michigan. Since the 19th century, many Wisconsinites look forward to a heaping plate of fried yellow perch for a typical Friday fish fry. Those days of abundant Lake Michigan perch are gone, but the demand remains very high and so do the prices. For the past several years, yellow perch were available to Wisconsin from Lake Erie, but since 2020, that supply has also dwindled. The demand for yellow perch remains and the market price in 2021 is $15 to $25 per pound.

	YELLOW PERCH	TILAPIA
Optimal	70° to 75° F (21° to 24° C)	82° to 86° F (28° to 30° C)
Stressed	79° F (26° C)	below 68° F (20° C)
Lethal	91° F (33° C)	50° F (10° C)

Table A. Temperature range limits for yellow perch and tilapia.

Tilapia is also a common fish for aquaponics; however, demand and pricing vary substantially from that of yellow perch. Tilapia is readily available from multiple foreign markets. Given that it is delivered frozen, there are no limitations on being able to maintain a ready supply. Because there is a steady supply of this fish, there are also substantial limitations in pricing. An August 2021 price review of tilapia indicated a range of $5.50 to $12.50 per pound with $7.25 the mean pricing. The price of tilapia tends to be set regionally and is generally fixed, whereas the price of yellow perch is locally driven and much more variable.

Finally, the method of raising fish can be an important determinant in choosing which fish to raise. A system designed for abundant aeration and fast water cycling, like the model 3 RAS, enables the commercial systems to stock fish at high densities. However, there are many types of fish farming systems other than RAS. These include pond culture, flow-through (single-pass), cage

or net pen, or in/on bottom system, water column and surface systems. Each of these system designs has its own parameters for the best breed of fish and density of the stock.

There are many fish/marine animal options for aquaponics, but selection of the right one for you is dependent upon habitat requirements, associated costs, water temperatures, availability of space and the type of plants to be grown.

Figs. 17 and 18. Greenhouse hydroponic beds growing various kinds of produce in rafts. (P. Wilborn, 2014 and 2015.)

THE DESIGN AND CONSTRUCTION OF THE PLANT BEDS

The interior configuration of the 18-by-96-foot greenhouse leaves very little extra space. As shown in figure 14, there are three 4-by-8-foot plant beds, six 8-by-10-foot beds, two 8-by-12-foot beds, as well as work surfaces, mechanical spaces and aisles that provide access to the plant beds and growing surfaces. It is important that the bed access space includes the space needed for a worker's body to bend and lift the 2-by-4-foot, 2-inch-thick rafts that contain the harvestable plants.

Model 3 uses three methods of hydroponic growing: the raft system, the nutrient film technique (also known as NFT or gutter system) and the media-based system. Each has its own application.

Raft Systems. For large-scale growing, the raft system provides the best solution for volume output. See figures 17 and 18. We use 8-by-10-foot beds, lined with 45-mil EPDM pond liner. These are built with 2-by-10-inch lumber and plywood bases and are raised and supported 18 inches from the ground. The system water depth is 6 to 8 inches. As seen in figures 15 and 16, these plant beds allow for ten 2-by-4-foot rafts, made of Dow brand blue board insulation panels, each with 33 holes to receive the 1-inch rockwool plugs and plant seeds.

Nutrient Film Technique. The NFT system is used during winter months to create an inventory of young plants. This is necessary due to the impact of shortened daylight hours and longer growing periods (what takes 30 days to grow during the summer takes 60 to 65 days from November to March). The NTF gutters are filled with rockwool plugs thereby allowing young plants to grow while they wait for space in any recently harvested empty rafts in the plant beds. The NFT (figure 19) system provides a steady flow of system water down the gutters, nourishing the plugs and then returning to the IBC tanks and pumps. This method assures regular growth during the winter when growth is slower. It is not used from May to September when the rockwool plugs can be planted directly into the rafts.

Fig. 19. NFT system is ready for winter growing of young plants. (P. Wilborn, 2021.)

Media-based System. The 18-inch by 30-foot media-based troughs are raised and vertically mounted, and have RAS system water pumped into them at multiple points along the trough to ensure equal distribution of nutrients to all plants, similar to the NFT method. The plants are contained in trays or pots with a non-soil tree mulch. When fish water-to-nitrates conversion rates are too low to provide enough nitrification to clean the system water, either Hydroton or pea gravel can also be used in these troughs in place of the mulch. These plants depend solely on the nutrient-rich system water; no additional nutrients are added to either the troughs or the gutters. Media such as Hydroton and pea-gravel (figure 20) can provide adequate bases for root systems but tend to be less efficient for higher-volume commercial systems that rely on either NFT or rafts. These troughs are located on the north wall of the greenhouse, thereby providing shade for other plants.

MANAGING TEMPERATURE AND LIGHT

In Wisconsin, interior greenhouse temperature and light change significantly throughout the year, as well as throughout the day. Leveraging these variables not only has the economic benefit of reducing expenses but is also critical to the health, well-being and survival of your plants and fish.

For example, lettuce is a cool-season plant and prefers temperatures between 60 and 70° F during the day, but no lower than 50° F at night. In the winter months, we heat the greenhouse to a minimum of 56° F. In the summer, it is more challenging to grow lettuce in a greenhouse. Relying on heat-tolerant varieties is helpful, and a ventilation system designed to minimize heat accumulation is critical.

The summer temperatures in the greenhouse vary from 80° F to the mid-90s most of the time. However, during July and August the temperatures can reach 100° F. Even the heat-tolerant lettuce varieties we use tend to droop during the day but manage to recover overnight. Occasionally the leaves can burn from excessive sun and heat exposure. As addressed earlier in detail, we have multiple strategies to control the summertime ambient temperatures.

- Two 24-inch fans and two electrically sequenced 24-inch vents
- Four solar-operated ridge vents and six side-wall louvers
- A 20-by-100-foot exterior shade cloth
- Three retractable thermal curtains
- Two manually operated gable vents on the east and west walls

We rely on two 100K BTU furnaces in the greenhouse and a single HVAC system in the enclosed space to maintain a 70° F year-round environment.

What about lighting? Sunlight based on 100% southern exposure, as opposed to artificial lighting, is the desired lighting source in model 3. The choice between sunlight and artificial light directs one's initial efforts in finding an appropriate location for growing. If one relies on artificial lights, any building, anywhere will do. If one wants to harness what the sun has to offer, then 100% southern exposure is most desirable, and involves growing in a greenhouse.

In positioning the grow beds, it is important to realize that the intensity of light decreases exponentially with distance, so a plant twice as far away from the source receives only one-quarter the light and will not grow as well as ones closer to the light source. Any obstructions or shade would have that same impact. Typically, plants placed evenly below the curved surface of the greenhouse all receive equal amounts of southern exposure light.

We do use some artificial lighting (±5% overall) for four specific growing areas. The primary space is our hardening table at the center of the greenhouse. Four-foot T-8 fluorescent lights provide extended wintertime lighting (16 hours of light) for the young two- to four-week-old plants. These lights turn on at 4 a.m. and shut off at 8 a.m. and then turn on again at 4 p.m. and shut off at 8 p.m. We also do something similar for our baby greens (kale, chard and sorrel) in the 30-foot elevated troughs, i.e., we keep the T-8s on all night. We use grow lights in our seed germination process and T-8s for our microgreens.

As we rely on southern exposure lighting, we experience the annual variations associated with long summer daylight and shortened winter daylight. This creates plants maturing in 30 to 35 days in the summer and in 50 to 65 days in the winter. This is where using the NFT gutter system for young plant pays off between October and May.

Fig. 20. A mix of Hydroton and pea gravel support bacteria that promote the nitrification process providing nutrients to plants. (P. Wilborn, 2021.)

WHAT WE GROW AND WHY

Our primary crop is lettuce, and our best performing varieties, selected for summer heat tolerance, are Adriana bibb lettuce, Starfighter green leaf lettuce and Ruby Sky red leaf lettuce. All are purchased from Johnny's Selected Seeds. Our lettuce seeds are germinated in 1½ - inch rockwool cubes that come in 98-cube sheets. After three to four weeks, the individual plugs are moved to the 1½ - inch diameter holes in the 2-by-4-foot rafts (or gutters in winter). The varieties of lettuce are the result of trial-and-error reviews and the elimination of other lettuces that had not performed well in the aquaponic system.

The other plants in our greenhouse include Swiss chard and red Russian kale as microgreens and as mature plants, arugula as microgreens and mature plants, red-veined sorrel, nasturtiums and watercress. The watercress is grown in the three 4-by-8-foot plastic beds directly in system water. The other greens are grown in pots using NFT.

Independent of the aquaponic system, we grow two microgreens: radishes and sunflowers. We use a non-soil medium, tree mulch, in a 9-by-20-inch tray that is covered with seeds and dampened regularly during a nine-day period. We have three exterior raised beds that provide a broader range of produce in summer, and an additional twenty 3-by-5-foot cold frames which provide 10 to 11 months of growing for cold-loving plants like chard and spinach.

In terms of choosing which plants to grow, think about how they will be marketed. It is best to determine which plants or vegetables can be successfully and regularly sold at higher rates than consumers are used to paying in the chain food stores. Local food generally cannot compete pricewise because the volume is smaller, and expenses are higher. It can compete, however, in terms of freshness, timely delivery and at the level of the consumer's personal values.

Selling greens with an increased marketing value, such as convenience or variety, is known as a value-added product, and something worth considering. All the greens grown in model 3 find their way into PortFish's salad blend: three lettuces, baby greens (kale, Swiss chard, arugula, sorrel and watercress) and microgreens (radish and sunflower). This value-added salad blend is sold in 4-ounce, 8-ounce and 1-pound bags. Our market consists of restaurants, farmers' markets, a local co-operative and our own community supported agriculture (CSA) activity. Selling at retail prices is always preferred to selling wholesale because it produces more revenue.

There is a market appeal to buying local food from an aquaponics system, but enjoying success is all about creative marketing methods. Further marketing ideas are available on the internet and are a critical element of an aquaponics business plan.

ADDITIONAL CONSIDERATIONS FOR A SUCCESSFUL OPERATION

The information described thus far illustrates how PortFish navigated the development of models 1, 2 and 3. It represents a constant learning curve in aquaponics over more than five years. It would be nice to be able to plan things out and have them work the way you imagine. But in aquaponics, every system is unique. The way forward is uncharted, so all you can do is chart your experiences and challenges, troubleshoot, and learn from mistakes. Again, the willingness to endure the trial-and-error process is critical. One must be tenacious, industrious, extremely flexible and hope for a little luck along the way.

In addition, there are matters associated with operating a local food center above and beyond those unique to using an aquaponics system. Serious consideration of each of these matters is warranted to ensure success and sustainability. They include maintenance, pests, nutritional supplements/deficiency issues, drainage, municipal permits, approvals and licenses, and employees and volunteers.

MAINTENANCE

There are two kinds of maintenance: emergency maintenance and preventive maintenance. Maintenance is important for both the physical building and the aquaponics system: fish, plants, plumbing and electricity. Diagnosing a problem can sometimes be challenging, but if there is regular preventive maintenance, understanding and managing emergency issues becomes much easier.

We have found that regular monitoring (at least weekly) of the plants and various systems is crucial to detecting problems at an early stage. In terms of the plants, this might include pests (see below) or powdery mildew.

Powdery mildew is caused by the damp environment in the greenhouse during the cool, cloudy months and is best prevented by choosing mildew-resistant plant varieties. When it does appear, we have been able to control mild powdery mildew with a weekly application of baking soda, dish soap and vegetable oil in water, thoroughly spraying all surfaces of the plant and stems. This non-toxic mixture rinses off easily by the consumer.

To further our controls, we use the services of the University of Wisconsin-Madison’s plant pathology lab, the Plant Disease Diagnostic Clinic, and their entomology identification service, the Insect Diagnostic

Lab, for identification of problems and advice on treatment.

In terms of the fish, if their behavior varies over a several-day period, or if more than two fish expire at any one time, there is usually a problem. The first action should be a water quality test that includes measuring the levels of nitrates, nitrites, ammonia, water temperature and especially pH.

When turbidity (clarity) of the water is an issue, we find that a 10 to 20 percent water exchange will typically correct the problem. However, this process tends to be wasteful, and therefore regular monitoring is prescribed.

In terms of the physical habitat system, water on the floor or slowed or stopped water flow is a serious issue indicating a malfunction of either one part or multiple parts of the system. Finding the source of a water flow or containment issue is as easy as following the path of the water and its dripping. Fixing it is where the challenge lies.

PESTS

Just as viruses, fungi and microbes are part of our day-to-day experience, pests are there too. In DIY aquaponics food systems, you can count on being affected by a wide range of pests: aphids, whiteflies, thrips, etc. Once a pest is discovered, the battle begins. Instead of using insecticides, developing a pest-predator food chain is the most natural approach to pest management. A fact that may not be obvious initially but becomes so over time is that if you don't have a pest budget, you will be overwhelmed by pests.

One of our biggest challenges involves aphids during the cooler months of the year. Typically, they begin to appear in force in October and run until May. We have identified the aphids in our system as potato aphids, and their natural predators are lady beetles (ladybugs), aphidius ervi (parasitic wasps) and praying mantes. Aphidius ervi are most affective, and ladybug larvae round out our regular team. Praying mantes are also beneficial, but they have unrestricted appetites for anything smaller than themselves, which can include the other beneficial predators. Praying mantes do contribute to the effort, but at a cost.

The key to winning the pest battle is to make the aphids part of the predators' food chain. Initially the pests will appear to have infested or overwhelmed the plant beds, but by bringing in the predators in September or October, the aphids become embedded in the food chain and their impact slowly begins to stabilize.

We periodically have infestations of diamond-back moth larvae in the watercress. One method of control is to cut back the plants to reduce plant bulk, flood the plant bed and submerge the plants for two to three hours, then drain. We repeat this process weekly until the issue is resolved. This repetition interrupts the development cycle of these moths as adults, larvae and eggs. In extreme conditions when an immediate solution is needed, we use a biological soap spray. However, this method is most effective in limited applications.

Installing fine screens over the vents and doors can minimize the initial entry of pests; however, this can reduce air flow and physical access to the greenhouse. We take great pains to avoid bringing outside plants into our greenhouse, thereby preventing the accidental introduction of pests or disease. This is an easy rule to overlook, and the results can be disastrous.

Small insects are the most typical pests in an aquaponics system. However, we were once surprised by a large rodent that moved in under the lettuce beds and mowed down a good percentage of our crop. Unfortunately, our solution was to feed the rodent to its demise using bromethalin. It wasn't until we found this large rodent burrowed into the ground that we discovered it was a full-grown groundhog that had been harassing us. We then installed a half-door at the west end of our greenhouse to keep out rodents out — large and small.

NUTRITIONAL SUPPLEMENTS AND DEFICIENCIES

Gardeners are good at reading plants. It is one thing to see that a plant is expiring because it needs water. It is another to be able to tell if there is a nutrient deficiency or a disease. In aquaponics, many nutrient issues are addressed in the engineering of commercial fish feed, which is formulated to provide the fish with all the nutrients they need to grow. Fish waste and residual fish food are then processed by bacteria that convert them into nutrients that plants need to grow.

It is generally expected that a healthy aquaponics system will provide all the nutrients plants need. However, within the range of small DIY to large commercial operations, there is wide variation in each system's waste conversion and nutrient-use process that maintains the appropriate nutrient flow from fish to plants. There are two ways nutrient flow can be negatively influenced. First, the pH levels of the water may inhibit a plant's ability to take up nutrients that are present in the water. Second, the conversion of fish waste to nutrients may not provide all the necessary nutrients that the plants need.

"Nutrient lock-out" is when the roots of the plant are unable to take up the nutrients that are present, and so additional fish waste and nutrients will not help. It is caused by either unsuitable pH levels in the water and soil, or by overfeeding. Managing pH is the way to ensure that a system can take advantage of the nutrients that are being provided by the fish. When pH levels are too high or too low, it is a symptom of a problem that is often difficult to tease out. It may be the pH of local water sources, the accumulation of excess waste clogging the system, or a problem associated with the filtration process. Regardless, the only way to know if your plants are able to access the nutrients in the water is to keep a close eye on pH by measuring it regularly.

We operate our system at pH levels of 7.0 to 7.2. We have had conditions where the pH has increased to 8.0 to 8.4, a level near optimal for fish, but too high (or too base) for the plants. Using phosphoric acid, we have brought our base system back down to the pH level at which we know our system works best. When the pH level of our system is below 7.0, it is too acidic.

We manage low pH with applications of hydrated lime. Managing pH using these two applications is effective. However, if the system's pH varies consistently from an optimum level, there may be something else influencing nutrient conversion. A review of the filtering system may lead to solutions.

When the pH is stabilized but plants show signs of distress, it is often the gardener's eye that can identify the nutrient needs and determine a course of action to supplement deficiencies. The most common deficiencies in plant nutrients in aquaponics systems include iron, potassium, calcium, magnesium and phosphorus. Through observation, the gardener can identify the symptoms associated with specific deficiencies. For example, iron deficiency generally affects the color of plants with an overall yellowing of leaves and is resolved by adding chelated iron to the system.

Because aquaponics systems are all different in terms of design, size, water source, fish species and plants that are grown, the need for nutrient supplements varies. In our model 3 system, we have not observed or needed to treat any phosphorus deficiency.

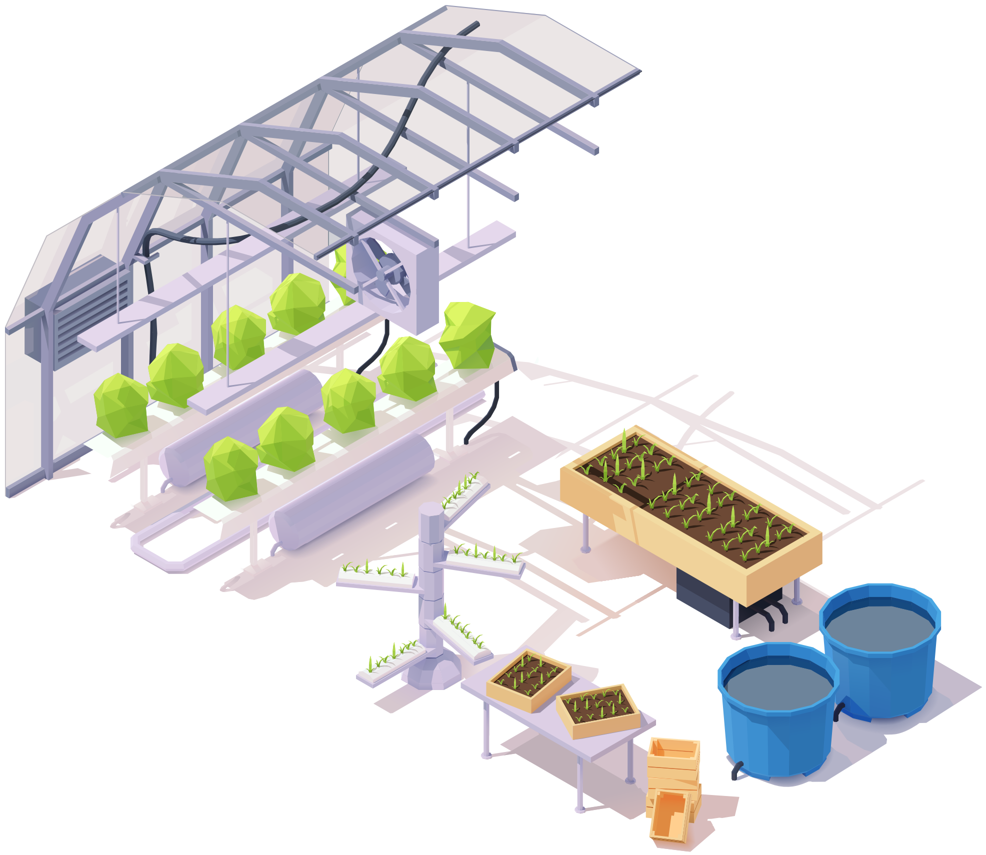
We have responded to other various conditions in our system and use two nutrient supplements on a weekly basis for the overall health of the plants: iron in the form of liquid chelated iron and magnesium in the form of Epson salts. We have added other supplements on an as-needed basis, including calcium chloride to address stunted growth of plants and rotting roots caused by powdery mildew and potassium sulfate to address abnormal curling and cupping leaves of plants.

Plant supplements can be added directly to the system water, indirectly via potted plants or via foliar sprays. The key is to add an adequate amount of supplements to the system in a way that simultaneously maximizes the impact on the plants while minimizing the impact on the fish, bacteria or water chemistry.

We add the chelated iron and Epsom salts directly to our delivery sump, the 300-gallon intermediate bulk containers. In this process, we shut off the water delivery to the fish and allow the supplements to be distributed to the plants for a period of 15 to 20 minutes. This does leave the fish without the proper water circulation for a short period of time, but it protects them from unintended effects on water chemistry while delivering the supplements to the plants.

The calcium chloride and potassium sulfate supplements are delivered through foliar spray. When applying, we are careful not to overspray so that the supplement remains on the plants and does not enter the water and impact the fish. Other examples of foliar spraying are biological soaps for pest control and our own home-mixture for powdery mildew.

With the exception of the extreme case of the groundhog, we have never used petrochemical fertilizers or conventional pesticides in our aquaponics system. We are firm on this policy. We are not certified organic, but we practice the certification guidelines.



DRAINAGE

If your aquaponics system is in the city, the municipal water system should work fine for all of your needs. When disposing of any water, it should be by design environmentally safe for the municipal system. If you have a recirculating aquaponics system (RAS), the only water loss should be a minimal amount caused by evaporation and transpiration. An occasional spill or water-exchange should not represent a challenge to the municipal system.

In terms of a non-municipal setting like model 3, water discharges of any volume are not favored by the Wisconsin Department of Natural Resources. Again, if you are operating an RAS, discharges should not be a problem. If extreme events occur, such as equipment failures or water discharges, some redesign or accelerated preventive maintenance of the system may be warranted.

MUNICIPAL PERMITS, APPROVALS AND LICENSES

Obtaining the correct permits, approvals and licenses for legal compliance can be a challenge, but they are necessary for your success. Patience with municipal ordinances and employees will go a long way.

As discussed above in "Model 2 – I Wanted to Know how Aquaponics Works," I was not able to get the municipal approvals necessary to proceed with my original concept of a greenhouse built as an addition to my detached garage. But then I discovered that I only needed a building permit to add a solarium to the back of my house. This was easily done, and patience with the process paid off.

My next encounter with permitting came with my move of the aquaponics operations to Knellsville with model 3. That process included a request to the Town of Port Washington Plan Commission (a separate entity from the city of Port Washington) to add a greenhouse to the abandoned agriculture storage building. We had a couple of meetings, did some planning and the project was approved with a conditional permit. Although the storage building was located in an industrial zoning district, the ordinance made allowance for agricultural use. The ordinance also allowed for commercial use, but there were several reasons we decided against that path. First, the building permit requirements for a commercial building were significantly more complicated and more costly than for an agricultural building. Second, our building design (a steel and plastic greenhouse addition to a wood frame structure) was not allowed for a commercial use.

The next permit I needed was a fish farm license from the Wisconsin Department of Natural Resources. While planning model 3, I inadvertently discovered this license was required for model 2 as well. I obtained the two required fish farm licenses at the same time.

The next permit would have come from the Wisconsin Department of Agriculture and Consumer Protection following a health inspection and a commercial kitchen license approval. This process requires meeting dozens of complicated standards which can result in the permit being denied or approved conditionally, the latter requiring further inspections. For model 3, the process was further complicated because it happened as the state was shifting its responsibility of this permitting process to the individual counties across the state.

Finally, if you plan to sell your foods at a farmers' market, you will likely need a mobile vendor's permit. As would be expected, each of these permits and licenses involves a fee and will add additional costs to your operations. The permits, approvals and licenses mentioned here represent the ones most likely to be required in order to legally operate an aquaponics local food center. Check with your local and state municipality for confirmation.

EMPLOYEES AND VOLUNTEERS

There have been from four to six employees at any one time working with PortFish in model 3. Typically, they consist of one to two gardeners and three to four harvesters. There are also employees that work on the fish habitat and provide preventive maintenance. They enjoy the benefits of working in local food production. Providing a safe and therapeutic work environment along with a paycheck helps to motivate employees, in addition to knowing they are helping promote our local food mission.

PortFish has had only two volunteers for most of its years of operation. Because there is no compensation for management, I am the primary volunteer. I also do maintenance, engineering, new construction, the primary harvesting, and multiple other cleaning and management jobs associated with running a non-profit organization and promoting local food. My wife, Amy, is the other volunteer without whom this project would have never accomplished what it has. Amy helps maintain the health and integrity of the plant beds, and she manages the CSA (customer-supported agriculture) function.

For a volunteer to be useful and to have the interests of the organization at heart, in my opinion, the relationship with that person needs to be personal. As the organization has matured, we were fortunate to have an additional volunteer, Ruslan Ahundov, who well serves the PortFish mission, and we are thankful for their contributions.

At the start of the model 3 activities, I was fortunate to have a young wannabe-farmer (like myself) working with me. I compensated him with room, board and some cash, but mostly his participation was based on his desire to learn and willingness to endure the ups-and-downs of a start-up local food organization. Because he was instrumental in organizing the model 3 system and establishing several operating procedures, this relationship represented the important passage of PortFish from a start-up to an organization with solid potential. When the young farmer decided it was time to move on, I made the jump to hiring employees with a traditional payroll, and that pivotal decision allowed PortFish to continue to flourish.

SURROUND YOURSELF WITH LIKE-MINDED PEOPLE AND BE WILLING TO BE PART OF THE SOLUTION.

MODEL 4: **A Vision of an Aquaponic Future of Local Food**

After more than a decade of building and refining PortFish, we are obligated to consider a future model 4 version of aquaponics. This new model would function along the same guidelines and protocols as model 3, with a greatly enhanced capacity for production and distribution as a sustainable local food center.

For production, model 4 would continue to rely on fish waste for growing plants. It would continue a greenhouse component with southern exposure for year-round lighting to capitalize on natural energy. It would include enclosed workspaces for water management and food processing, as well as outside raised plant beds and cold frames during the spring-summer growing activities.

Model 4 distribution would continue with the salad blend as the primary value-added product. It would continue its relationships with compatible local food partners for sales, and it would continue creating additional revenue streams with wholesale partners such as food stores and restaurants.

There would be, however, two major differences between Model 3 and Model 4 – the physical configuration of the system and the management and applications associated with the system water. The model 4 design would consist of an attached greenhouse and workspace located adjacent to a 2- to 4-acre spring-fed pond. Pond water would be drawn into the greenhouse for the hydroponics segment of the aquaponics operations. Instead of relying on an enclosed recirculating system as in model 3, a natural pond would generate the nutrients and microorganisms, incorporating nature and its systems into an aquaponics system.

The other difference would involve management and practical activities associated with the system water. The water brought in from the pond for the plants would be circulated through a network of holding tanks for temperature control, oxidation and other water dynamics activities. Instead of coming from the pond directly to the plant beds or being routed directly from the plant beds to the pond, intermediary activities would be developed to revitalize the water, maximize its nutrient content and ultimately broaden an understanding of the natural water component of this system. Natural spawning activities would also be incorporated in model 4.

PortFish, Ltd. has thrived based on donations as a non-profit organization and a reliance on self-funding. While sales revenue from the salad blend and contributions by various partners supported some of the expenses associated with the operations of model 3, cashflow shortfalls have required occasional cash injections from its board of directors to maintain operations and activities. These injections have diminished substantially over the years, but they do persist. A new funding mechanism will need to be factored into a model 4 version of PortFish.

Also crucial to the prosperity of PortFish has been the synergetic relationships with various local food/ aquaponics operations that have come and gone in the Milwaukee area and across Wisconsin. These operators generously shared access to their systems and relevant operating information and are greatly appreciated. They include:

- Sweetwater Organics, Milwaukee (James Godsil)
- Growing Power, Milwaukee (Will Allen)
- Central Greens, Milwaukee (Bowen Brook)
- KP Simply, Baraboo (Donna Meunier)
- Natural Green Farms, Racine (Jo and Joe Heineman)

Why would model 4 succeed when so many other groups have not? Relying on its existing base of a thriving aquaponics program, a solid network of local food partners, and the confidence of the individuals and families that support the organization by purchasing the product, the PortFish operational model has real potential. While finances will likely always be a concern, the prospects of sustainability are increased by:

- combining the mechanics of aquaponics with natural resources like southern exposure and a pond,
- having a deeper understanding of water technology,
- having year-round greenhouse production at higher levels than previously accomplished, and
- expansion of distribution partners.

Timing is also important. Growing public awareness of the need to address climate change makes organizations like PortFish ideal for converting the conversation into action.

A FINAL WORD ABOUT THE JOURNEY

You can begin an endeavor like PortFish on your own, but you cannot grow and operate such an endeavor without a loyal group of partners. I did the profitability math early on as part of my business plan (which was never finished – it's a moving target anyway) and decided that given the economics of the existing conventional food system, profitability was not in the cards. Breaking even could be a goal, but the essential reason for this local food effort still had to be the journey itself. This is very different from a goal of successfully meeting 100% of my costs and expenses, including any return on my investment.

So, if it is the journey that is your goal, surround yourself with like-minded people and be willing to be part of the solution, even if that means it is not always your brilliant ideas, or your money, or your sterling personality that allow for the success of the venture.

No possibility of a profit? Go non-profit with an educational theme. Be patient, and like-minded people will show up. Be tolerant, mostly flexible, and enjoy the ride.