Introduction

The State of the World

As you have just started reading a book on aquaponic farming, we're going to make some basic assumptions. We're going to assume that you understand the urgency of climate change and are familiar with such terms as "peak oil" and "sustainability" and "localization." We assume that you don't need convincing that industrial agriculture is, by its very nature, a system of increasing costs and decreasing returns which turns arable land, one of humanity's greatest resources, into sterile landscapes requiring constant chemical fertilization. The fertilizers themselves are derived from fossil fuels, a dwindling and polluting resource.

Industrial agriculture has disrupted the natural methods of farming that have sustained humans for millennia. It produces low-quality food heavily depleted of the essential elements necessary for human health. Fertile land becomes barren, human health deteriorates, and the whole system requires vast infrastructures to grow, store, move, store again, move again, store yet again and so on, before it is finally sold to us in all its nutrition-lacking glory. The whole system is fragile and rigid, every link in the chain essential and requiring large inputs. If even one link breaks, all efforts are spoiled and all food wasted. In permaculture terms, the system lacks any semblance of redundancy.

Industrial agriculture is inherently unsustainable, and the system is breaking down. Global food supply is increasingly unstable with food prices sharply increasing in many parts of the world. Here in North America this reality has been mostly hidden due to government subsidies.

Once in a lifetime droughts are now common. Pollinator colonies are collapsing. Super weeds, resistant even to the poisons that created them, are rampant. The industrial promise of low food prices is being revealed as the sham it always was.

We continue to rely on industrial agriculture at our own peril. Change is required.

In summarizing our food system in this manner, we assume we're preaching to the choir. We assume that you want to be part of the solution — the movement to reclaim our food systems — for the sake of both healthy ecosystems and our own health, and to allow future generations the opportunity to survive if not thrive.

The growing movement to counteract the ills of industrial agriculture and globalization is robust and filled with vitality and energy. It is a movement of the people for both the people and the land. It is a movement designed to endure. The central tenet is localization.

Produce locally. Buy locally. Use locally. Support locally. Be local.

Relocalization of food production can take two primary forms: moving backward or moving forward.

Moving backward means using the time-tested methods that have sustained humans since agriculture was invented. It is the revitalization of traditional, small, labor-intensive organic farms. It is nurturing the land and managing natural ecosystems, creating soil teeming with microorganisms and farming in harmony with and within the limits of local environments. It is an ancient system whose flag might best be represented as a shovel and compost pile.

Moving forward is using technological advancements and scientific knowledge to produce food outside of natural ecosystems, virtually anywhere it is needed. It is using resources and ingenuity to create our own ecosystems to produce food with almost no environmental impact, in almost any climate. It is building the capacity to produce food locally in all seasons with highly efficient labor and water use. We believe aquaponics is moving forward.

We are advocates for both moving backward and forward. These methods are not in competition: both have advantages and disadvantages and are vital to food sustainability. We have the utmost respect for traditional farmers. We have chosen to be pioneers. We are aquaponic farmers. Join us!

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What Is Aquaponics?

A Primer on Aquaponics

THE WORD "AQUAPONICS" was coined in the 1970s as a combination of the words "aquaculture" and "hydroponics." Aquaculture is the cultivation of aquatic animals and plants in natural or controlled environments. Hydroponics is the growing of plants without soil, using water to carry the nutrients. The term "aquaponics" was created to designate the raising of fish and plants in one interconnected soilless system.

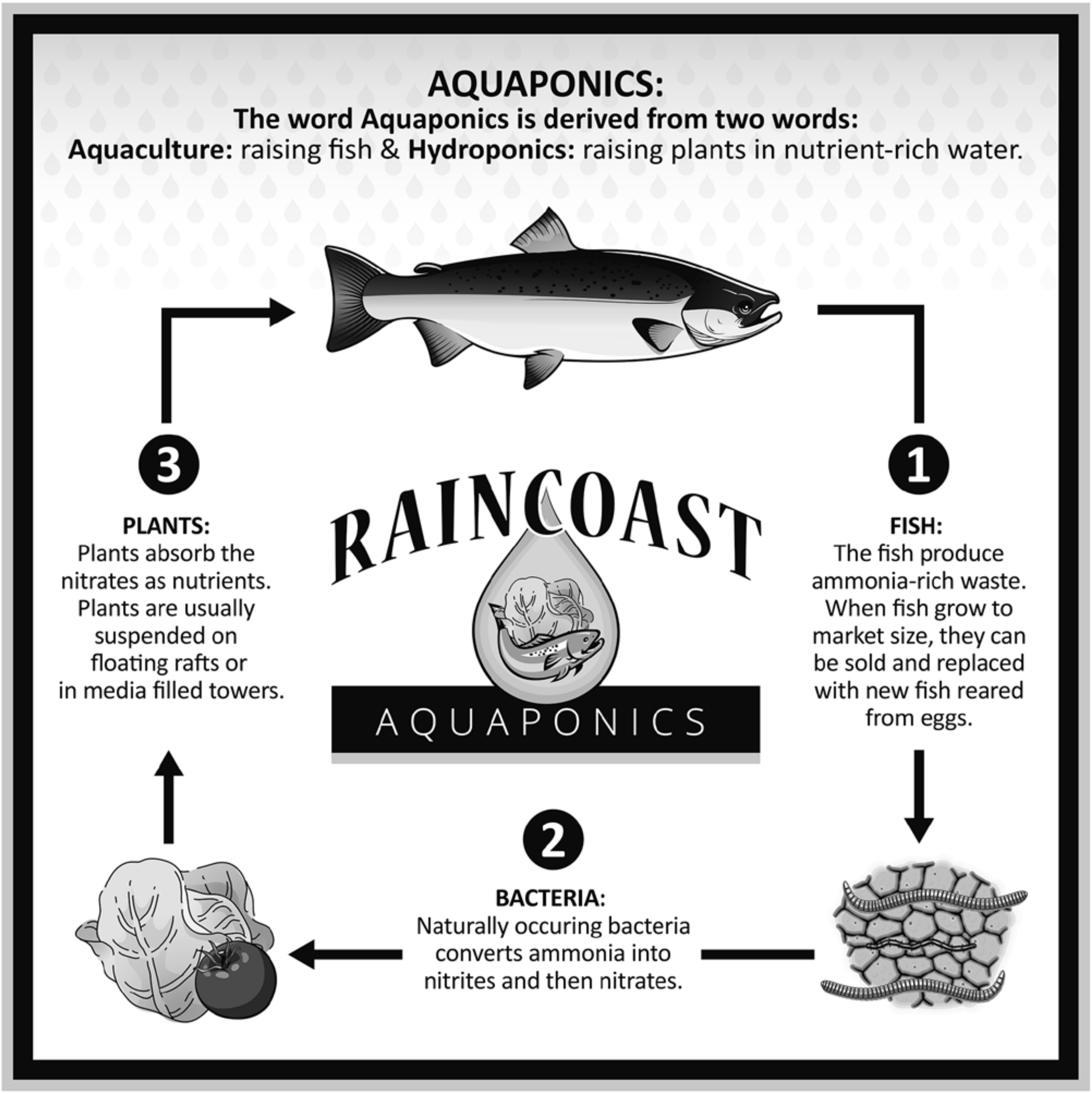
Aquaponics can solve the major problems of both freshwater aquaculture and hydroponics.

The major problem in land-based aquaculture is that fish waste in the water creates continuously elevating levels of ammonia. If left unchecked, this toxic element will rapidly kill the fish. The aquaculture industry typically uses one or both of two options to resolve this problem: a constant supply of fresh water to replace the toxic water and/or expensive filtration systems. Neither is ideal. The former not only uses voluminous quantities of our precious fresh water but also creates equally large quantities of high-ammonia water that is toxic to any natural ecosystem. The latter is simply very expensive. The high cost is especially pertinent to smaller commercial operations as most filtration units only make financial sense at large economies of scale.

Fish farms in natural bodies of water, often called "open net pens," are rife with problems, notably their potential for negatively impacting wild fish stocks. We do not support such farms, and they are not considered in this book.

The major problem in hydroponics is the ongoing need for large inputs of fertilizers. A soilless production system means all the minerals — all the food — required by the plants must be continually added. Fertilizers are expensive, and the vast majority are fossil-fuel derived, often referred to as “chemical” fertilizers. Available organic fertilizers are not commonly used because they are less water soluble, thus more likely to cause problems and can be several times more expensive than their chemical counterparts. Hydroponic farms are often also a major water consumer as many use a drain-to-waste system.

The aquaponic cycle.



Even hydroponic farms that recirculate water must drain and replace their water regularly as they do not host a living ecosystem that balances itself.

By combining fish and plants into one system, aquaponics can solve the primary problems of both aquaculture and hydroponics. Fish waste provides a near-perfect plant food and is some of the most prized fertilizer in the world. The plants, using the minerals created from the waste, do most of the work of cleaning the water for the fish.

The fish feed the plants. The plants clean the water. The symbiosis is as logical as it is effective.

The third living component in aquaponics is bacteria. The whole system hosts specific types of bacteria that serve two roles. One family detoxifies ammonia in the effluent by converting it into nitrates. Another family mineralizes organic material (primarily fish feces and uneaten feed) by breaking it down into its elemental constituents, which are usable by plants. Without this vital conversion in a closed system, both fish and plants would rapidly die. Establishing the bacterial cultures and monitoring their health is one of most important tasks of an aquaponic farmer. We cover this topic in depth in Chapter 6.

A Very Brief History of Aquaponics

Although modern aquaponics is only a few decades old, the concept of combining fish farming and plant production for mutual benefit is thousands of years old.

Since ancient times, fish have been raised in flooded rice paddies in China. The fish and rice are harvested at the same time annually, and the technique is still used today. Ducks, sometimes in cages, were kept on the edges of fish ponds so their excrement could be used to feed the fish.

The Aztecs had advanced techniques of aquaponic farming called *chinampas* that involved creating islands and canals to raise both fish and plants in a system of sediments that never required manual watering, achieving up to seven harvests per year for certain plants.

In 1969, John and Nancy Todd and William McLarney founded the New Alchemy Institute in Cape Cod, Massachusetts, and created a small, self-sufficient farm module within a dwelling (the "Ark") to provide for the year-round needs of a family of four using holistic methods to provide fish, vegetables and shelter. In the mid 1980s, a graduate student at North Carolina University, Mark McMurtry, and Professor Doug Sanders created the first known closed loop aquaponic system. They used the effluent from fish to water and feed tomatoes and cucumbers in sand grow beds via a trickle system. The sand also functioned as the biofilter of the system. The water percolated through the sand and recirculated back to the fish tanks. McMurtry and Sanders' early research underpins much of the modern science of aquaponics.

The biggest leap came from Dr. James Rakocy at the University of the Virgin Islands. From around 1980 through 2010, he was Research Professor of Aquaculture and Director of the Agricultural Experiment Station, where he directed voluminous research on tilapia in warm-water aquaponic systems. His research on the conservation and reuse of water and nutrient recycling remains the greatest body of modern work on aquaponics. Though it took many years to develop, by around 1999 Dr. Rakocy's system had proven itself to be reliable, robust and productive. His developments are used today from home to commercial-scale aquaponics.

Our work has been primarily developing systems and protocols that have allowed us to modify the work of such visionaries as McMurtry and Rakocy to cold-water production, better suited to colder environments.

Aquaponic Ecomimicry

Ecomimicry is the design and production of structures and systems that are modelled on biological entities and processes. Aquaponic systems are manufactured environments that attempt to replicate a complex natural system. Every component and process in an aquaponic system has a natural counterpart.

Imagine a freshwater ecosystem. At a high elevation is a lake in which fish constantly produce waste in the form of ammonia and feces. A river flows from the lake carrying these wastes. Along the bottom of the river are layers of gravel and sand which are home to various bacteria and invertebrate detritivores (worms, insects, crayfish, etc.)

As waste-laden water flows down the river, feces sink to the bottom and are trapped in the gravel where it is eaten and broken down by detritivores and bacteria, converting it into elemental constituents and minerals. Ammonia (a toxic form of nitrogen) in the water is nitrified into nitrates. Without bacteria and detritivores, the waste would eventually build to toxic levels.

The river continues downstream to lower elevations and eventually meets a wide, flat wetland area. Here it slows and spreads out, depositing mineral-rich sediments where vegetation abounds.

After being filtered of its nutrients and sediments in the wetland, the water ends its downhill journey in the ocean. But this is not its end. Evaporation and evapotranspiration from plants combine to form clouds, and their moisture falls as rain, which collects in large bodies of water such as lakes, and the cycle repeats.

All these natural processes are found in an aquaponic system: the fish tanks are the counterpart to the lake, the filtration systems are the gravel in the river, and the hydroponic subsystem is the wetland. The main water pump serves as clouds by returning the water to the high point in the system: the tanks.

As we are mimicking a natural ecosystem, many challenges found in an aquaponic system are also found in nature. Nature had billions of years to evolve solutions which may be replicated in aquaponic farms by imitating nature.

Aquaponics, Permaculture and Sustainability

We believe aquaponics is a system of permaculture. All three tenets and twelve principles of permaculture design are realized within an aquaponic system, from conception and design to operation.

One of the core tenets of permaculture is the "return of surplus" which is maximizing the efficient use of resources and eliminating waste. Often, waste can be eliminated simply by recognizing it as a resource and using rather than discarding it. An aquaponic system has this tenet at its core, as observed in the relationship between fish, bacteria and plants.

Aquaponics has inputs and outputs. When permaculture design principles are applied, the inputs are minimized and used efficiently and the outputs are recycled back into the system as inputs. At Raincoast Aquaponics, we extract five different uses from every kilogram of fish feed and three uses from every liter of water.

The fish feed is used to raise fish (1), which in turn feed plants (2) via the bacteria. The resulting fish waste is captured and converted to a fertilizer product (3), and the crop residue (compost) is fed to pigs and converted into bacon (4). Pig waste is composted and used to build soil for growing field crops (5).

Water is first used to purge fish prior to harvest (1), and then used to top up the main system (2). The effluent flushed from the system is used to water field crops (3) after most of the fish waste has been extracted.

Aquaponic Plant Systems

There are several commonly used aquaponics systems whose names refer to the method of plant production. Systems of raising fish are all very similar, thus not considered in naming aquaponic systems. In all systems, two basic functions are found: water is cycled between the fish and the plants, and bacteria convert fish waste to beneficial minerals.

The four most commonly used aquaponic plant production systems are: Deep Water Culture, Drip Towers, Nutrient Film Technique and Media Bed.

Deep Water Culture (DWC): water flows down long troughs of water, typically about 12″ deep, like a slow-moving stream. Rafts, typically made

DWC troughs with floating polystyrene rafts.

from styrofoam, float on the water with a pattern of holes cut into them. Small open-bottom pots, called net pots or slit pots, fit into the holes. Plants are supported in the pots by a variety of different mediums. The roots of the plants are suspended and grow in the moving water.

Drip Towers are tubes, typically made from PVC, with either holes or a slit running the length of the tube on one side, suspended vertically in rows. The towers contain a growing media into which plant roots grow. Water is continuously fed into the top of each tube and collected at the bottom to cycle through the system again.

Nutrient Film Technique (NFT) also uses tubes, typically PVC, with holes on one side. Whereas drip towers are suspended vertically, NFT tubes are mounted horizontally on a slight angle with the holes facing upwards. Plants are grown in small net pots inserted into the holes in the tubes. Water, continuously fed into the high side of the tubes, flows down in a thin film contacting the roots and is collected at the low side to cycle through the system again.

Healthy roots under a DWC raft.

Media Bed is a type of flood and drain production with numerous possible configurations. In all configurations, watertight growing areas are flooded at regular intervals by pumps then drain back to cycle through the system. The growing areas are filled with a pebble-like medium, often expanded clay aggregate but sometimes simply gravel. Plant roots grow throughout the medium.

While there are pros and cons to each system, in our opinion the only two systems worth considering for a commercial operation are DWC and drip towers. Media bed systems are not practical due to the maintenance required to remove trapped solids and the higher risk of rapid crop failure if a mechanical problem occurs. NFT systems are widely used in hydroponic production but are inferior to drip towers and DWC for both bacteria colonization and space usage. We strongly suggest DWC or drip towers for commercial production. This book is based around a DWC system.

ZipGrow™ Towers.
CREDIT: BRIGHT AGROTECH

ZipGrow™ Tower array.
CREDIT: BRIGHT AGROTECH

Deep Water Culture Systems

The primary advantages of DWC are:

- Less expensive to construct
- Even light distribution
- Increased thermal mass due to the large volume of water in the system
- Ability to selectively move individual plants for thinning and spacing
- Greater options for pest control

Less expensive:

Cost is by far the biggest advantage of DWC. For a 120′×36′ greenhouse, you can expect to spend at least US$50,000 more to install a drip tower system compared to DWC.

Light distribution:

All plants in a DWC system have relatively equal access to light. As they are all on one horizontal plane, they are potentially only partially shaded by their immediate neighbors. In contrast, the vertical design of a tower system means an increased potential for shading, particularly for the lower plants and all the more so when using supplemental light that will not penetrate as effectively as sunlight.

Thermal mass:

DWC systems contain about three times more water than a drip tower system due to the volume of the troughs. A DWC system in a 120′ greenhouse will have approximately 66,000 liters. A tower system will have approximately ⅓ this volume (18,000 L). The additional water serves as thermal mass which buffers temperature during cold and hot periods, and does so where it is needed most, immediately around the plants.

Thinning and spacing:

Rafts have both advantages and disadvantages. A primary advantage is that individual plants can easily be removed from the system or relocated which allows you to start plants closely spaced and spread them out as they grow.

Pest control:

It is also easy to see and remove problem plants such as those with pests, mold or mildew. Additionally, plants in a DWC can be directly washed with system water without losing the water. This is a highly effective method for maintaining plant health and is not possible in a tower system without losing the water used.

The disadvantage to rafts is that they are near ground level (approximately 1′ above ground), thus the work involves regularly bending over. Fully loaded rafts can weigh 30–40 lbs. and can be awkward to move, though carrying rafts with mature plants over long distances is not needed or recommended in our system as most harvesting takes place at the troughs.

Drip Tower Systems

All mentions of towers or the performance and layout of towers in this book refer to ZipGrow™ Towers by Bright Agrotech. These are the only towers we specifically recommend.

The primary advantages of drip towers are:

- Potentially increased numbers of plants per square feet of growing space
- Increased nitrifying capacity, as the tower media has a large Bacterial Surface Area
- Increased oxygen availability to plants due to the high porosity of the media
- Potentially easier workflow

Increased plant sites:

Income from an aquaponic system is mostly made from plants, not fish, so an increase in plant sites directly corresponds to an increase in potential income.

Increased Bacterial Surface Area (BSA):

BSA is the area within a system that nitrifying bacteria can colonize. Large BSA increases are only found in matrix-based tower systems such as ZipGrow™ Towers. The superior BSA due to the media used in ZipGrow™ Towers is a substantial advantage. A 5′ drip tower can provide approximately 150 square feet of BSA in the tower media. DWC without additional biofiltration provides approximately 6 square feet of BSA in the same space.

Increased oxygen availability:

In DWC systems, plant roots are submerged under water which limits the types of plants suited to the system. Supplemental oxygen must be added by an aerator, and its availability to the plants is limited by the oxygen carrying capacity of water which is approximately 10 ppm at 15°C.

With drip towers, roots grow into a porous media through which water is slowly trickled. Rather than being submerged in water, roots are directly exposed to the air and thus the oxygen in the air is available to the plants. Tower systems are self-aerating due to the high air/water exchange as water trickles through the media.

Easier workflow:

The workflow in both systems is simple once practiced. The primary difference is that in DWC all the plants are located at the same height (about 1′ off the ground). In a tower system using 5′ towers, plants range in height from about 1′ to 6′ and the towers can be easily carried around.

DWC or Drip Towers — Our Recommendation

It is important to understand that if properly designed, constructed and operated, both DWC and tower systems will produce beautiful plants and high-quality fish. We use DWC so admit our bias. We acknowledge that towers have some distinct advantages and recommend them as an excellent production system, but overall we believe DWC is superior.

Plant Sites and Light Availability

While drip towers have an advantage in plant sites, the difference between the two systems is not as great as it might seem. A 120′×36′ greenhouse with 86′ of plant production area has the potential for 8,000 plant sites using 5′ drip towers and 6,192 harvestable plant sites using DWC (see Chapter 2).

The increased plant capacity for towers (8,000 vs 6,192) would seem like a game changer, but we do not agree. The 8,000 number is based on the recommended spacing for ZipGrow™ Towers of 20″ between plant centers side to side and 16″ centers back to front, with 36″-walkways between arrays.

Our concern is that, in a temperate latitude or colder, light will not sufficiently reach the lowest plants. Our concern is doubled during the 4–6 months a year when lighting supplementation is required. In contrast, in a DWC system the plants are all at one horizontal level, thus access to light is virtually identical throughout the greenhouse and light supplementation is evenly distributed. So while towers have a theoretical advantage in plant sites, we feel the limitations on light distribution greatly reduces if not eliminates this supposed advantage.

We also note that to house 8,000 plant sites requires 4 arrays with 5 rows of towers per array in a 36′-wide greenhouse. This means the walkways are only 28″ which will further reduce light penetration and creates a tight working area. Note that this spacing leaves walkways that are narrower than the 36″ recommended by ZipGrow™ for light penetration and working space. If you reduce to 3 arrays, you can widen the walkways to 48″ which increases light penetration but also reduces the total plant sites to 6,120.

Another option is to use 3 arrays with 6 rows per array instead of 5. This allows for 7,152 plant sites and 35″ walkways with rows 18″ on center. The downside of this option is that it may be problematic for the plant production schedule, which involves rotating towers through an array as plants mature. A 40′-wide greenhouse will help solve this problem by increasing walkways to about 38″ with 4 tower arrays.

Ultimately, we feel that any gain in plant sites in a tower system is countered by a lack of equal light, or that providing equal light means virtually the same number of plants sites as in DWC.

Bacterial Surface Area

The greatly increased BSA of a tower system that uses a matrix media is a real advantage. However, it is important to understand that the bacterial colony capacity of DWC is more than sufficient to raise healthy fish and excellent plants. Additionally, BSA can be increased in any system with the use of a biofilter module, as we have done in our design.

From a functional standpoint, the extra bacterial capacity of drip towers means that you will have more wiggle room in terms of the total fish load in the system and you can be less precise with the quantity of fish feed (excess fish feed also breaks down into ammonia). In other words, the primary advantage of the increased BSA is not increased plant production, which is where your profits come from, but in increased fish capacity and in needing to be less precise with how you run your system. Note that the increased BSA only applies to matrix-media based systems such as ZipGrow™.

Available Oxygen

While greatly increased oxygen is a real advantage for drip towers, the oxygen levels in DWC are more than sufficient to raise most types of plants rapidly. So while the advantage is clearly to drip towers in oxygen capacity, both systems will excel if designed and run properly.

It should also be noted that the same characteristics that allow towers to be self-aerating also cause the water to gain or lose heat quickly due to its exposure to the air. Hence tower systems have much less thermal stability than DWC systems.

Filtration

The media used in towers act as thousands of filters. The filtration capacity in a tower system is unparalleled. That said, as with most other tower advantages, the filtration in our DWC design is more than sufficient to produce at levels of high efficiency in volume over the long run. The advantage is to towers, but it is less important than it seems.

Our Conclusion

All things considered, we feel the advantages of a tower system are considerably less than they first appear when compared with our DWC system. When you factor in the advantages of DWC, notably the lower cost of construction and the consistency of light availability, we feel DWC is the superior system.

To be clear, we approve of and recommend tower systems such as ZipGrow™ for aquaponic production. They have been proven to excel. We do, however, feel the benefits compared with a well-designed DWC system are less than tower proponents claim and that the benefits do not justify the considerable extra cost, unless cost is not a concern for you. Though this book is based on a DWC design, we will at appropriate times throughout convey information specific to tower systems.

Backyard vs Commercial Systems

Backyard systems typically cannot be scaled up to commercial systems of the size discussed in this book. We have constructed numerous backyard systems over the years. They are a fun project that can be very productive, and we highly recommend them to everyone with the available space and basic building skills. The differences between a backyard system that might contain as little as 100 liters of water versus a 120′ DWC system that contains 600 times that volume are considerable.

In a small system that might occupy less than 10 square feet, most components can be made quite simply or easily sourced at the local hardware store. Problems in the system such as leaks are easy to see, easy to fix, and the repercussions of a failure are small.

In a commercial system that will likely cost hundreds of thousands of dollars, where leaks might not be visible as much of the water pipe is buried, and where problems can lead to losses of whole fish cohorts or plant crops worth many thousands of dollars, the design of the system has to be commensurate to the risk. Additionally, the scale of a commercial system requires entirely new components, such as a large particle filter (we use a Radial Flow Separator — see Chapter 2), UV sterilizers and a waste collection system.

While all aquaponic systems share the same basic parameters such as the cycling of water and the fish-plant ratio (see "The Golden Ratio" in Chapter 3), the design of commercial systems is different from backyard systems.