AQUAPONICS

Practical thesis in Australia

HAMK
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Bachelor's thesis

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ABSTRACT

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ABSTRACT

This thesis is about building an aquaponics system to an Australian farm. Commissioner of the thesis is Mr. Kevin Lynch. This thesis begins by introducing what aquaponics is, and continues by designing and building an aquaponics system to a farm in Australia. One of the goals is to learn more about aquaponics that's a growing idea all around the world and raise the farm's self-sustainability level. Information for the thesis has been gathered from several books, internet sources, followed by visits and interviews from users of existing aquaponics systems. The object of the thesis is to design, build and test an aquaponics system in Australia. The project has shown that there is no one and only correct way of building an aquaponics system, but many different ways of establishing a system. There has been many changes made to the system during the designing and testing process to make sure everything runs smoothly once the living organisms are in. Instead of buying everything especially for the system we've used a lot of materials that were available, and making them fit in the system. It did still require a lot of materials to be bought specially for the system. We will follow up the system for the first month. The project was successful, even it did not finish in time.

Keywords Aquaponics, hydroponics, aquaculture, circulating system.

Pages 51 p. + appendices 2 p.

TIIVISTELMÄ

MUSTIALA
Maaseutuelinkeinojen koulutusohjelma
Hevostalous

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TIIVISTELMÄ

Opinnäytetyön aiheena on rakentaa Australiassa sijaitsevalle tilalle kiertovesisysteemi. Työn toimeksiantajana on Kevin Lynch. Opinnäytetyö alkaa kiertovesisysteemin periaatteen esittelyllä, ja jatkuu systeemin suunnittelulla, rakentamisella ja testaamisella australialaisella tilalla. Opinnäytetyön tavoitteina on hankkia tietoa maailmalla kasvavasta kiertovesisysteemi ideasta ja parantaa tilan omavaraisuus-astetta. Tiedonlähteinä on käytetty useita kirjoja ja internet lähteitä, sekä tilavierailuja ja haastatteluja. Opinnäytetyön tavoitteena on suunnitella, rakentaa ja testata kiertovesisysteemi Australiassa. Projekti on näyttänyt että ei ole olemassa yhtä ja oikeaa tapaa rakentaa kiertovesisysteemiä, vaan tapoja on niin monta kuin tekijääkin. Systeemiin on tehty paljon muutoksia suunnittelu- ja testausprosessin aikana helpottaaksemme systeemin ylläpitoa ja huoltamista, kunhan elävät organismit ovat systeemissä. Sen sijaan, että olisimme ostaneet kaiken tarvittavan materiaalin erityisesti systeemiä varten, olemme käyttäneet paljon jo olemassa olevia materiaaleja tehden ne systeemiin sopiviksi. Systeemi saatiin kasattua, vaikkakaan emme pysyneet aikataulussa. Kasvit ja kalat kasvavat, joten projektia voidaan pitää onnistuneena.

Avainsanat Aquaponic kiertovesisysteemi suljettu kierto

Sivut 51 s. + liitteet 2 s.

Contents

1 INTRODUCTION

This thesis is about designing and building an aquaponics system at an Australian cattle farm. As a result, the farm's self-sustainability level will improve. The farm is already using its own beef and timber. Beef cattle are grown all year around on native pastures. Timber is cut on site from dead trees around the farm, using a portable sawmill and chainsaws.

The farmer came across the idea of aquaponics and begun thinking of building a system to the farm to improve the self-sustainability level. As other projects took over and building the aquaponics system got delayed it opened up a possibility to take on the aquaponics for a subject for the thesis. As a horse groom the writer doesn't have any previous experience from growing fish, hydroponics or an aquaponics. Thus the main object of the thesis is about what an aquaponics system is about, interviewing aquaponics farmers who have already a system that's been set up. The research eventually leads to designing, building and testing the system that is built to the farm. A big part of the building materials are either already found from the farm or bought second hand. Using second hand materials enables to reduce the cost of the system, but at the same time making some of the parts fit takes more time and effort. As the time went by the project did get delayed because of weather conditions and some unexpected circumstances. One of the challenges is constantly changing people and busy farm life in the middle of never ending projects. We did not manage to get the system up and running in time, thus writing the thesis has taken a lot more time than expected. It's taken at least two years from the idea to get to the point where we are testing and adjusting the system.

It's great to achieve information and practical experience from a not so commonly known subject. The idea of aquaponics is fascinating, as it is something so simple, and yet there are still so many different ways of doing it, and time required to do research about these methods. So what is aquaponics, airlift pump or bell syphon? Why the fish species that is most commonly used in aquaponics systems can't be used in the system that will be built at Koolombach? And what is the role of the nitrogen cycle in aquaponics? The following pages will introduce the idea of aquaponics, and provide answers to those questions.

The Aztec Indians raised plants on rafts on surface of lakes before the term *aquaponics* was known, in approximately 1,000 AD. Another early example can be found in South China, Thailand and Indonesia, where the cultivation and farming of rice in paddy field in combination with fish are cited as examples of early aquaponics systems.

Aquaculture + Hydroponics → Aquaponics

Aquaculture is a form of agriculture encompassing the propagation, cultivation and marketing of aquatic animals and plants, including fish for food and ornamentation, bait for the fishing industry, sport fish for restocking ponds and lakes, and fish for feed ingredients.

Hydroponics by definition means *water working*. In practical use, it refers to growing plants in a water and nutrient solution, without soil. A hydroponic culture allows a farmer to grow plants in a more efficient and productive manner with less labour, less water and less fertilizer because the plants are provided with the ideal water and nutrient ratios and optimum conditions for growth.

Aquaponics is a combination of aquaculture and hydroponic (soil-less plant culture) plant growth techniques. It doesn't require soil or any chemicals to produce a large amount of fish and vegetables in a small space. In aquaponics, the nutrient-rich water that results from raising fish provides a source of nutrients (Urea) for the nitrogen-consuming bacteria, which helps to clean the water where the fish live in by breaking down these compounds into nitrates, which then feed the plants and keeps them healthy. Water consumption is lower and plant density is usually at least twice that of soil based methods. As such the combination of aquaculture and hydroponics help to sustain an environment in which they both can thrive.

2 HISTORY

Long before the term *aquaponics* was coined, the Aztec Indians raised plants on rafts on surface of a lake in approximately 1,000 AD. Before the Aztec people had built a great empire in Central America, they were a nomadic tribe in what is today central Mexico. They settled near the marshes and rising hills, but were faced with a problem: How would they grow food? They solved this problem, which led them to become a great civilization.

The Aztecs did this by building large rafts out of reeds and rushes that they found near the lake. They set these rafts to float in the water and covered them with soil, which they gathered from the bottom of a shallow lake. They planted their vegetable crops on these chanampas, the floating islands that they created. When the plants matured, the roots grew through the soil and old chanampas can still be found in central Mexico. (Nelson & Pade 2008, 27-28.)

The earliest example of another branch of aquaponics can be found in South China, Thailand and Indonesia. This early example of an aquaponics system can be seen at paddy fields, where rice was cultivated with fish. These polycultural farming systems existed in many Far Eastern countries. They raised fish such as oriental loach, swamp eel, common carp, crucian carp and pond snails in the paddies. The ancient Chinese employed a system of integrated aquaculture where finfish, catfish, ducks and plants co-existed in a symbiotic relationship. Ducks were housed in cages over finfish ponds. Finfish processed the wastes from the ducks. In a lower pond, the catfish lived on waste that flowed from the finfish pond. At the other end of the system, the water from the catfish ponds was used for irrigated rice and vegetable crops. (Kirsten 2014.)

In modern times, fish farmers are exploring methods of raising fish while trying to decrease the dependence on land, water and resources. Therefore aquaponics emerged from the aquaculture industry. Traditionally, aquaculture was done in large ponds. However, within the past 35 years, lots of research has been made in recirculating aquaculture systems (RAS). As a benefit in recirculating aquaculture is that you can grow up to 0.34kg (¾ of a pound) of fish per 3.78 liters (gallon) of water. This means that large quantities of fish can be grown in a fraction of the space and water that a traditional method of aquaculture would require. As a disadvantage, in highly concentrated populations of fish a large volume of wastewater accumulates daily.

Early on, in the research of RAS (recirculating aquaculture system), experiments were done to determine the efficiency of aquaponic plants in consuming the nutrients in this waste water, thus helping to purify the water for the fish in the system. As research continued, terrestrial plants were tested and proven to be an effective means of water purification for aquaculture and this nutrient rich water a nearly ideal hydroponic solution for growing plants. Combining soil-less plant culture and fish farming is still fairly new, although practicing them has been traced to ancient times. Research in aquaponics began in the 1970’s and continues today with several universities worldwide. The Aquacultural Experiment Station at the University of the Virgin Islands (UVI), St. Croux, under the direction of Dr. James Rakocy, has earned world-wide recognition for over 25 years of work in refining aquaponic systems. (Nelson & Pade 2008, 27-28.)

3 AQUAPONICS

Aquaponics is cultivation of fish and plants together in a constructed, recirculating ecosystem. Aquaponics utilises natural bacterial cycles to turn fish waste into plant nutrients. A large amount of plant material can be produced in a small space. Aquaponics combines aquaculture and hydroponics. Aquaponics systems have three main elements: Fish, plants and bacteria. The farmer feeds the fish. The fish produce waste and ammonia, which are harmful for the fish in larger quantities. Water from fish is therefore guided to plants, where beneficial bacteria break ammonia first into Nitrites and then into Nitrates. Plants feed on the Nitrates and other nutrients, thus cleaning the water. (Figure 1.) Solid waste can be filtered out of water by either grow beds, in a media bed system, or by an additional filter. Clean, oxygenated water is returned to the fish tank.

“A natural microbial process keeps both the fish and plants healthy and helps sustain an environment in which they both can thrive.” (Nelson & Pade 2008, 14; Japan aquaponics n.d.)

All sized aquaponics systems utilise the same concepts and technology. Aquaponics system can produce fish and fresh produce on any scale, from small home systems to large commercial systems and anything in between. (Sylvia Bernstein 2011, XVI.)

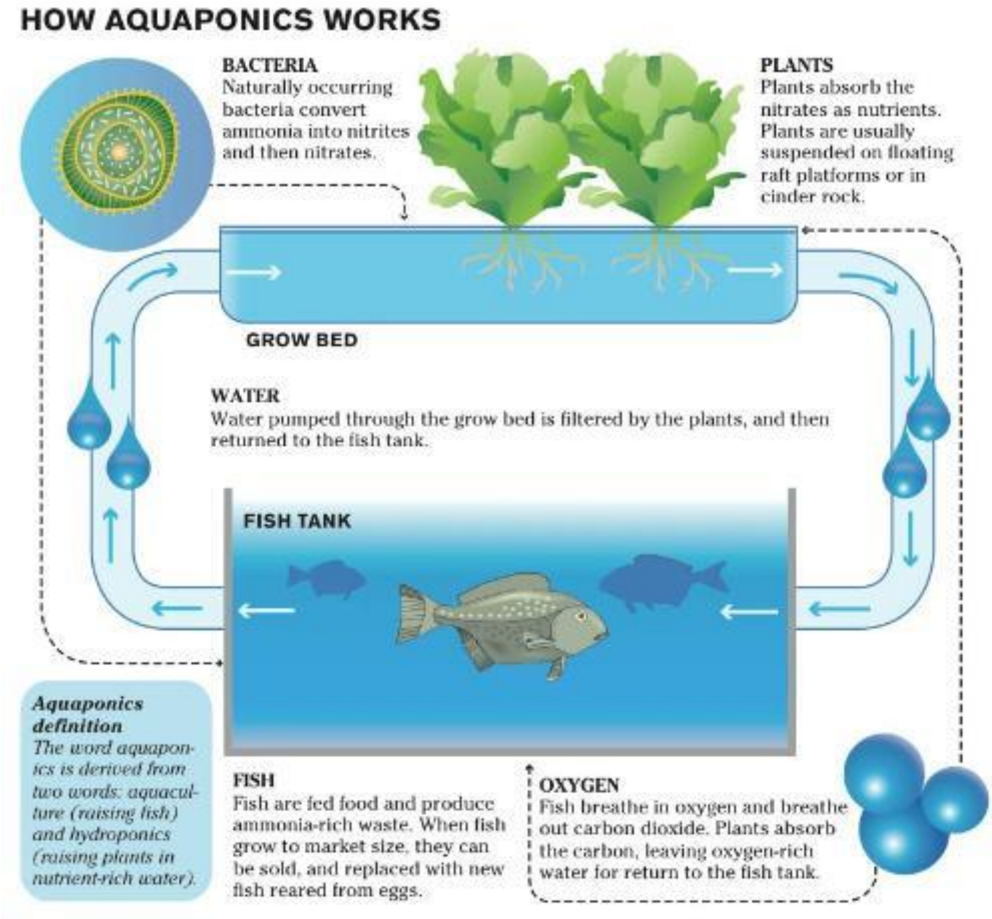

Figure 1 Aquaponics cycle includes many elements, including bacteria, plants, fish, oxygen and water. (Japan aquaponics n.d.)

3.1 Hydroponics

Hydroponics is now the most commonly used name for the process of growing plants without soil. The original form of hydroponics involved exposing plant roots directly to a nutrient solution. That explains the name. It derived from two Greek words: *hudor*, meaning water, and *ponos,* meaning work. Hydroponics is a highly versatile science and there are many ways of doing it. The common factor in all forms of hydroponics is that plants are grown in a medium containing no plant nutrient and supplied with a nutrient solution which contains all the necessary elements for satisfactory plant growth. (Sundstrom 1982, 1.)

The main advantage of hydroponics is that it is possible to grow things where in many cases it cannot otherwise be done. Other advantages include the fact that it is possible to grow two or three times as much in a limited area, faster growing rate tends to improve flavour and texture, plants don’t have to compete for moisture and nutrients, and hydroponics requires virtually no digging and weeding. As far as disadvantages are concerned, there is some effort and cost required for establishing a hydroponic unit. Some of the nutrient solution ingredients are also difficult to acquire. (Sundstrom 1982, 7-8.)

3.2 Aquaculture

"Aquaculture is a form of agriculture encompassing the propagation, cultivation and marketing of aquaponic animals and plants, including fish for food such as catfish, tilapia and trout, ornamental fish such as koi and aquaria, bait fish for the fishing industry, sport fish for restocking ponds and lakes and fish for feed ingredients." (Nelson & Pade 2008, 21.)

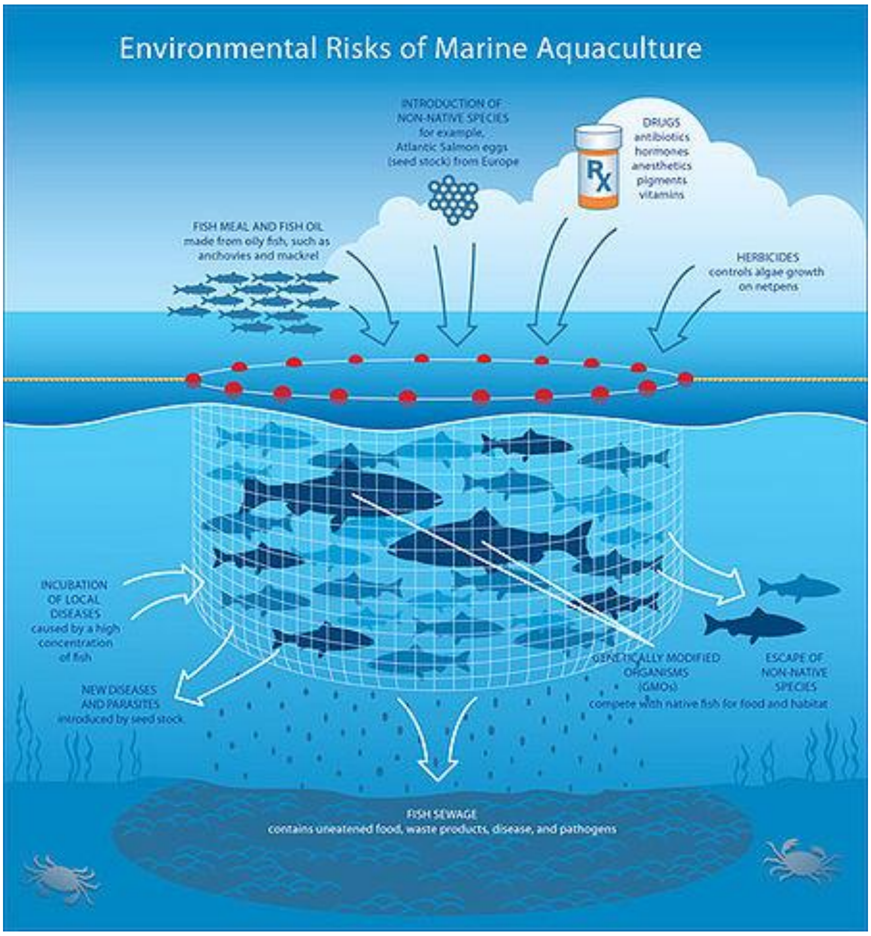

Figure 2 Risks of marine aquaculture for the surrounding environment. (Popularwoodworkingprojects n.d.)

In a recirculating aquaculture system (RAS) fish are raised in densely stocked tanks. Due to heavy stocking rates. As a result a high volume of waste occurs from the process. Mechanical and biological filtration is required to keep the water clean and healthy for the fish. Aeration is also required. Marine aquaculture introduces an environmental risk (Figure 2.) as the fish produce high concentration of waste in small area and introduces a risk of non-native species to new areas where they create a threat for native species. Wild populations of fish have decreased dramatically due to over-fishing, pollution and destruction of habitat. At the same time demand for fish has increased. With recirculating aquaculture fish farmers can raise large quantities of fish almost anywhere in a very small space, using a minimum amount of water. When a fish farmer adds hydroponic grow beds into a recirculating system, they eliminate some of the required filtration, utilize a waste product and raise additional crops in the form of vegetables. (Nelson & Pade 2008, 21-22)

4 DESIGNING AN AQUAPONICS SYSTEM

There are many things to consider when you are planning an aquaponics system. There isn't one and correct way to build an aquaponics system. In following chapters we open up what are the main types of an aquaponics systems. Nutrient film technique, raft or media bed? The choice depends on the goal, if the system is going to be a small backyard system or big commercial system and materials that are available. While the nutrient film technique and raft systems are good for commercial systems. For especially herbs and lettuce a media bed system can support bigger plants and is the cheapest one to build. After that we'll find out something about the plumbing, siphons and pumps.

4.1 Nutrient Film Technique

Figure 3 NFT system, the plants grow in special pipes in Brisbane.

The Nutrient Film Technique (Figure 3.) is a common method in hydroponic production. Plants are grown in channels where nutrient solution is pumped through. Ideally, the bottoms of the roots are exposed to the nutrient solution while the tops of the roots are kept moist but not waterlogged. Most NFT pipes are fed continuously at rate of about 1 liter per minute. Since plants are not growing in the media, it is crucial that they are kept moist at all times. This is the best choice if you wish to grow lots of plants, and less fish, and works most effectively for lettuce and herbs. It is a good choice for commercial systems and is highly productive. There are several disadvantages however. The system requires daily and periodical cleaning. You will need filters to separate fish solids. Plumbing can clog up and cause system failure. The volume of water within the system is minimal, thus it is riskier than raft systems. You will need a biofilter to get enough surface area for beneficial bacteria. (Nelson & Pade 2008, 54-59.)

4.2 Raft

Figure 4 Raft system uses several floating rafts that can be moved along in the row according to the age of the plant. (popularwoodworkingprojects)

A raft system (Figure 4.) uses floating beds for plants. All water in the system is recirculated constantly from the fish tank through filters and large water-filled shallow tanks. The raft system is commercially viable. The large volume of water provides a buffer, and in a commercial system it’s easy to move rafts around according to the age of the crops. There is also lots of base data available. It does however require daily and periodic filter cleaning, and utilises lots of components. (Nelson & Pade 2008, 48-53)

4.3 Media bed

The word “media” describes the “substrate” that’s placed inside the grow bed. In biology substrate is defined as “…a natural environment in which an organism lives, or the surface or medium on which an organism grows or is attached.” (Aquaponicsworld n.d.)

A media bed system is the cheapest system to build, and is a good choice for a small-scale or home production system. It works well for multiple crops and garden style aquaponics. The media bed works as a biofilter. The grow bed is filled up completely and then drained on a timed basis. The media bed will need complete cleaning occasionally as there isn’t solids removal. It also has the lowest production level from three system types. The media in the system is prone to eventual clogging as organic matter decomposes, which can lead to anaerobic zones that can slow growth and may even kill plant roots. The rule of thumb for the depth of a media bed is 30cm. A range of 18-30cm is common. A 30cm deep bed has an advantage in being able to support a greater amount of beneficial bacteria that converts ammonia to nitrates. A deeper bed doesn’t have to be emptied as often as a shallow one, as solids break down and go to the bottom of the tanks. . (Nelson & Pade 2008, 59-64; Aquaponicsworld n.d; Backyard aquaponics 2012.)

There are many different types of growing media that can be used for an aquaponics system. It is preferable that the rock or particle size of media is between 8-16mm. If media is a lot smaller then there isn’t much space for air between the media once it’s in your media bed. If the media is a lot bigger, your surface area reduces considerably and planting becomes a lot harder. Expanded clay (LECA) pebbles are relatively smooth, making them easy on hands and sensitive roots. Expanded clay pebbles have a very high surface area which supports a great amount of beneficial bacteria, making it an effective biofilter. It’s also pH neutral, drains freely and aids in this way to oxygenate the plant roots. Lava rock is used widely in some areas due to good availability and low cost. It can be described as natural version of hydroton (expanded clay pebbles) as it is light weight and porous. You do however need to make sure that there aren’t any impurities or chemicals present in the media. Lava rock isn’t as easy to work as hydroton due to its irregular shape. It may initially float, but will settle down with time. River rock or pea gravel isn’t as easy to work with as the other alternatives. River gravel is cheap, has higher density and so it can support taller plants than clay pebbles. Gravel is very heavy, has less surface area than hydroton and it doesn’t hold water well. You need to test the gravel to make sure there aren’t impurities. You can test the media by adding vinegar and observing if it reacts with the stone. It shouldn’t react, and a reaction means that there is lime in stone, which will affect the pH of the system. Perlite/Vermiculite/Sand/Coir/Glass beads have been used either as a complete grow media or as an addition with one of the main types of media. You will find that perlite and vermiculite are relatively small, thus they can cause clogging in your system and may have an impact on how freely water is flowing in the growbed. Coir can cause discolouration in the water.

As such, due to the varying properties and effects each type of media can have on the system, it is important to do your research about the media you are going to use, and make sure there aren't any impurities or lime. Choosing the wrong media can cause large problems when you are setting up your system. (Japan aquaponics n.d.)

4.4 Siphons and plumbing

Research has shown that the flooding, and then rapid draining of the growbeds, provides for excellent access to nutrients for the plants, and high oxygenation for the plant roots. The rapid draining draws oxygen down fully into the roots and this is vital for good growth. At its simplest, the siphon is a mechanism for moving water from one reservoir to another, lower reservoir. The benefit of the siphon is that it is capable of raising water over a barrier – and this makes it distinctive, and a practical benefit to aquaponics.

A loop siphon is probably the simplest type of siphon. This siphon can be mounted inside or outside of the growbed. As the name would suggest, this siphon is quite simply a loop of tubing. However, it could be made from solid PVC piping, in which case it may be called a U-bend siphon. The tubing comes out of the growbed and forms a loop. The loop will determine the maximum height that the water rises to inside the growbed. As the water rises inside the growbed, it will also rise inside the tube until eventually it starts to trickle out. The flow of water will increase until eventually all the air has been expelled from the tube and at that point water will start to rapidly drain. This will continue until the water level in the growbed drops enough to allow air to re-enter the tube and so stop the siphon. Maximum level of water in the growbed can be easily changed by varying the height of the loop or U-bend. As a rule of thumb, diameter of the tube should be larger than the piping that brings the water to the growbed so that it can drain faster than the rate that the growbed is being filled.

Figure 5 Bell siphons are ideal for using flood and drain system.

In a larger, let's say 500 liter growbed, you will be looking at filling and emptying approximately 200 liters of water in each cycle. Let's assume that you will be using an 800-liter fish tank to support this growbed. This means we are probably looking at approximately 4 cycles every hour, with a Flood and drain cycle of about 20 minutes. Your pump and plumbing need to be able to handle this capacity.

- You will need to work backwards from the volume of the water in fish thank. This volume has to be recirculated at least once every hour. You can therefore work out the minimum setting for your pump – the setting that at a minimum will recirculate the entire volume of the fish tank.
- This setting will now give you the minimum amount of water that will be entering into your growbeds at any given time. You can increase this mount, but not decrease it, as your siphon has to be able to start with this minimal amount of water coming into the growbed.

A bell siphon (Figure 5.) is comprised of a few simple components. The media guard can be either drilled or cut depending on your preference of the tools that you have available. As your growbed fills up with water the water will rise within the bell siphon until it reaches the top of the standpipe. At this point the water will start flowing over the top of the standpipe and exiting the growbed. If there were no bell siphon this would continue to overflow continuously and the water would stay at that height in the growbed. This is because the air pressure acting on the water in the growbed is equal across the whole system.

When we add the bell siphon over the standpipe, then something different happens. As the water flows over the standpipe, if the siphon is set up properly, then eventually all of the air will be sucked out of the bell siphon, and at that point. Because of differences in air pressure acting on the water, a siphon will be formed and the water will be rapidly forced out of the growbed. This will continue until the level in the growbed reaches down to the gaps at the bottom of the bell siphon and air will enter the bell siphon. This will cause siphon to "burp" and stop. Once the bell siphon has stopped then the growbed will simply fill up with water as before, until it reaches the top of standpipe and the siphon automatically starts again. This process is repeated for as long as the water is entering the growbed. This type of siphon is called an auto-siphon, because as long as water is flowing into the growbed, the siphon will start and finish automatically. (Japan aquaponics n.d)

4.5 Pumps

When you are planning your system, you need to think if you will be running a one pump or a two pump system. In a one pump system you raise the water from the lowest point of your system to the highest, and let the rest of the water flow back via gravity. A one pump system uses less power than a two pump system, and if one of the pumps fails it doesn't pump the whole system empty….The two pump system however doesn't require as much height difference between the highest and lowest points.

There are two different types of pumps that can be used for an aquaponics system. One is a traditional water pump and the other is an airlift pump. A water pump is more convenient in systems where water has to be lifted high. An airlift pump has its advantages when the height of the required lift isn't much. An airlift pump is an air pump that pumps air underneath the water. The air and water is directed into a vertical pipe where air pushes the water up and aerates it at the same time. The rule of thumb is that an airlift pump can lift 40% of depth of your tank. This means that with 1m deep tank airlift pump could lift water about 40cm over the fish tank. (Nelson & Pade 2008, 65.)

5 INPUTS IN AN AQUAPONICS SYSTEM

An aquaponics system provides possibility to grow fish and plants in a closed cycle. Following chapters will give an idea about what type of crops can be grown in an aquaponics system, fish species and what can be fed for the fish. Choosing right species of fish to fit your climate can save trouble later on. Many things can be grown in aquaponics system, anything from herbs, leafy greens and vegetables to even small fruit trees. The type of fish depends on personal preference, market price and climate. Be sure to choose species that suit your location as introducing invasive species to new areas isn't a good idea.

5.1 Common fish species for aquaponics gardening

As you can't grow plants without nutrients, you need fish. Once you add fish to a tank you will see the ammonia level begins to rise. After 7-10 days, the ammonia level will begin to fall and nitrite level begins to rise. In another 7-10 days, nitrite levels will begin to fall and nitrate level will begin to rise. This happens by natural microbial processes. Ideally, you should only stock your fish tank by less than 20% of the total biomass that your system can support, by means of fish weight. This reduces fish mortality and allows the bacteria population to get established. It also leaves room for fish to grow and gives the possibility for adding some more later. (Nelson & Pade 2008, 105.)

There are many different fish species that can be grown in an aquaponic system (Table 1), anything from ornamental fish like goldfish to edible fish like tilapia, trout and different types of perch. Here's an introduction of some possible fish species. You should always make sure the regulations that are specific to your area. Climate and diet requirements do vary according to the breed of fish. There are mainly two types of fish: omnivorous and carnivorous depending on the diet. Some fish do better in cooled climate than others, for example barramundi does well in warm waters, while trout or zander prefer cooler climate while some fish are meant to swim in salty water while others require fresh water. Fresh water fish are the most common way to go as it supports a greater variety of plants. Salt water aquaponics is also possible, even though less common as it limits what plant species can be grown in the system.

Table 1 Common fish species that can be used for an aquaponics system.

Fish species	Tilapia	Channel catfish	Barramundi	Jade perch	Silver perch
	Tilapiine cichilid	*Ictalurus punctalus*	*Lates calcarifer*	*Scortum barcoo*	*Bidyanus Barcoo*
Diet	Omnivorous	Aquatic insects, crayfish, small fish, frogs and also some filamentous algae. Also accepts pellets.	Carnivovous, accepts pellets. Requires high protein diet.	omnivorous	Omnivorous
Temperature	17-32°C	21-32.2°C	25+ Will stop eating at 16c. Prolonged exposure to 15°C will result in death.	18-32°C	12-26°C
pH	7-8	7.0-8.5	7.0-8.5	6.5-8.0	6.5-8.0
Growth	2.5 pounds in 6 months in ideal conditions.	1 pound in 5 month season. Harvest 1.25 pounds.	Plate size 400-800g. Main market is for larger fish (2-3kg)	12 months to plate size	12 months to plate size 500-600g.
Special notes	Noxious fish in NSW waters	Likes to live at the bottom of tank.	Territorial, will cannibalize.	World's highest omega-3 content.	Slow growth, but very hardy.

Tilapia

Tilapia (*Tilapiine cichlid*) is the most commonly raised fish in aquaponics. Tilapia is very hardy, grows rapidly and is a popular food fish. They do well in temperatures of around 23.5°C, which suits most vegetable crops one would consider in an aquaponic system. Tilapia is also the fastest growing and most dependable. Tilapia's tolerance to varying water quality conditions makes them an excellent option for aquaponics cultures. In some locations there are restrictions on non-native species so it is important to check with your local fisheries department to see which species are available and legal in your location. Tilapia are listed as a Class 1 noxious fish in all NSW waters under the Fisheries Management act 1994. It is illegal to possess, buy or sell tilapia in NSW. (NSW department of Primary Industries n.d; Nelson & Pade 2008, 68-72.)

Barramundi

Barramundi (*Lates calcarifer*) are native to the South East region, including northern Australia. In South-East Asia barramundi is known as Asian sea bass. Research into the culture of barramundi began in Australia in the mid 1980's. Studies were carried out by the Queensland Government.

Jade perch

Jade perch (*Scortum barcoo*) are a native Australian freshwater fish that have incredible fast growing qualities. They also possess the world's highest natural omega-3 content in their flesh and fat pouches in their body cavity. Jade perch is a hardy, omnivorous species, capable of achieving rapid growth rates on relatively inexpensive diets. Jade perch is an exceptionally good species for aquaculture production.

Silver perch

Silver perch (*Bidyanus bidyanus*) are usually silver-grey in the adult stage but they can be greenish, brown or golden. Silver perch is native to Australia and occurs naturally in freshwater. Silver perch adapt to recirculating cultures and will accept commercial feed. Since 1990, silver perch has received increasing attention as a candidate for finfish aquaculture in Australia.
(Nelson & Pade, 2008; Aquaponics how to n.d.)

Trout

Rainbow trout, brown trout and brook trout are all being used in an Australian aquaponics systems. Rainbow trout prefers cooler water temperatures, with optimum around 13-17°C but they can tolerate temperatures as low as 3°C and as high as 24°C but not for extended periods of time. Trout can be grown all year round in areas that have cooler seasons, or as a winter crop in locations where temperature fluctuations are wide between the seasons. Trout have a quite fast growing rate, and are species of salmonid. (Aquaponic gardener n.d.)

5.2 Fish feed

You can feed your fish at least once a day, but can also feed them more often for faster growth or additional nutrients for plant beds if required. Commercial aquaculture operations can feed their fish as often as once an hour. You need to be careful not to overfeed the fish. The best rule of thumb is to feed your fish only what they will eat within five minutes. After five minutes, remove remaining food from the tank. Automatic feeders are ok, but if your fish decide not to eat you won't notice that there could be something wrong with your system. Fish may stop eating for various reasons. Reasons might be change in water temperature, pH being outside tolerable range, too much ammonia and/or nitrites, not enough oxygen, stress or disease. Problems can be fixed if they are caught early.

Commercial fish feed is an excellent source of nutrients for your fish. You need to know if your fish are omnivorous or carnivorous, with biggest difference in the required protein content. Another thing you're looking at is the pellet size. Small fish eat small pellets, while bigger fish need bigger pellets. Fish feed includes proteins, fats, minerals, carbohydrates and other nutrients. One easy way to supply additional source of protein for your fish is to hang light over the fish tank to attract insects. Fish will feed on the insects that are attracted by the light.

You can grow your own fish food to give as a supplement, or even by producing their entire diet, you can save money and decrease your aquaponics systems' environmental footprint. Omnivorous fish can feed on duckweed, worms, black soldier fly larvae and kitchen and garden scraps. Duckweed is a fast growing aquatic plant, which doubles its mass every day. It is made up of more than 40% of protein (more than soybeans). You need to keep duckweed in a separate tank from your fish, otherwise they will eat all of it. Various different types of worms make excellent fish food, but the challenge is in growing enough for more than an occasional treat. Black soldier flies are associated with humanity by compost piles, manure producing facilities and poorly serviced toilets. A black soldier fly's grubs are considered beneficial scavengers in nature. They help to digest and recycle decomposing organic material. That organic material includes carrion, manure, fruits and decaying plant waste. (Bernstein 2011, 147-151.)

5.3 Crops to be grown in aquaponics system

You can grow a wide variety of plants in an aquaponics system. Almost anything that you would grow in soil can be grown in aquaponics. By words of Bernstein: "There is only one type of plant that I know that absolutely does not grow well in aquaponics and that is any plant that requires a pH environment much above or below neutral 7.0. Examples of this are blueberries and azaleas, which prefer acidic soil (below 7.0), and chrysanthemums, calendula and zinnias, which prefer basic soil (above 7.0)." Another example is root vegetables. Root vegetables will grow in aquaponics, but their final mature shape will be far from what you've used to. This is because your root vegetable, like carrot, has a hard time growing through gravel compared to soil. (Bernstein 2011, 153-154.)

At the early stage of aquaponics it was thought that the plant production was limited to leafy crops, like lettuce and herbs. However many types of plants can be grown in the aquaponics system. Tomatoes, cucumbers, melons, peppers and other fruiting crops will thrive. There has been experiments with plants ranging from dwarf banana trees to beans, corn, radishes, herbs and many other crops. This leaves choice for the gardener, backyard growers usually plant vegetables that they like to eat, while commercial growers must plant crops that bring the best return for the investment. Most often the most profitable plants are lettuce and herbs due to the stable nutrient demand of the plant, fast seed-harvest rate and consumer demand. (Nelson & Pade 2008, 87.)

Of note, mint (*menthe sp.*) can easily take over a whole grow bed as it's fairly invasive. It can also begin to grow in the pipes, thus possibly causing a blockage. Strawberries grow easily, but can't tolerate salt. Therefore if you need to salt the fish you might lose your strawberries while helping your fish. Salting fish helps them to produce more slime, making them more resistant to fungus infections. (Nelson & Pade 2008, 96; Anderson, interview 13.2.2015.)

6 RUNNING THE AQUAPONICS SYSTEM

Once you've managed to design and build the aquaponics system pumps can be turned on, plumbing and siphons checked. Following chapters will supply the information about how to start up the system, get enough good bacteria to take care of nitrification process and keep the system running. The first couple of months are critical and you will need to observe changes in pH, water temperature, amount of ammonia and many other things. One dead fish in the corner of a tank or power outage can cause a system crash. Maintaining an aquaponics system does take some observing and checking levels. Nevertheless once the system is running and stabilized it will run with little maintenance and observation and provide fresh crops and fish.

6.1 Starting up the system

Once the system has been built you can turn on the pumps, test your siphons and check if there is any leakages that need to be fixed. Making sure that everything is running smoothly at this point saves stress later when you have already your fish and plants in the system. The next step is to establish the nitrifying bacteria into the system. This can be done in two different ways: Either cycling the system with the fish, or without the fish. The cycling begins when you or your fish add first ammonia into the system. Ammonia is toxic for the fish unless the level is low, or it's been converted into less toxic form. There are two different types of nitrifying bacteria. The nitrosomonas will convert the ammonia into nitrites (NO_2), which is even more toxic than ammonia. After that nitrospira converts the nitrites into nitrates which are excellent food for the plants and generally harmless to the fish. When you detect nitrates in the water, and the ammonia and nitrite levels have both dropped to 0.5 or even lower. Your system is fully cycled. Usually cycling takes four to six weeks. You will need to monitor ammonia (NH_3), nitrite and nitrate levels, and not to forget the pH so you know when the system is fully cycled.

When you start up the system by using fish you add fish in your system on first day and hope that they make it through the cycling process. The challenge is to get the system cycling fast enough so the ammonia level drops to a safe level before it poisons your fish. S. Bernstein recommends that you stock your tank into less than half of the tank's full capacity. For this purpose you can use even gold fish from a pet store, as they are fairly tolerant to ammonia, rather than the type of fish you will eventually be using. These fish shouldn't be fed any more than once a day and even then only in small amounts. Fish produce ammonia, and without dilution, removal or conversion to a less toxic form it will build up in the fish tank and kill the fish. Ammonia (NH_3) changes to ammonium (NH_4+) and vice versa depending on water temperature and pH, the lower the pH the more of the nitrogen is in toxic ammonia form. If ammonia levels exceed levels on the chart you should replace 1/3 of water with fresh, de-chlorinated water in order to get the water diluted back to a safe level. As the system is cycling with the fish you should keep the pH level around 6.0-7.0. The fish prefer slightly alkaline water, while ammonia toxicity is more likely above in pH 7.0. When you adjust the pH it has to be done slowly as changing pH fast creates more problems than having it out of range. As a rule of thumb changing pH by 0.2 per day should be safe.

Nitrite behaves on fish like carbon monoxide does with air breathers. The nitrite will bind with the blood, taking the place of oxygen causing "brown blood disease" that will kill the fish. In case the nitrite levels in your tank rise above 10ppm while you are cycling your system. You need to do a partial water change and adding salt to the system will help protecting the health of the fish. Use non-iodized salt, preferably cheap pool salt or water softener salt. Dissolve salt in water before adding it in the system. The quantity should be at least 1 part per thousand (1kg of salt per 1000 liters of water). Stop feeding the fish until nitrite levels drop below 1.0 and make sure you have plenty of oxygen in water.

S. Bernstein recommends that you should add plants into your new aquaponic system as soon as it begins to cycle. When plants are transplanted there might not be seen new growth for a few weeks as plants establish their root system into the new environment. Seeing yellowing or dropped leaves is normal. Adding plants in straight away allows them to get through rooting progress early and gets them ready to begin moving nitrogen-based fish waste as soon as possible. You can use seaweed extract to engage root growth as its primary used as a growth stimulant.

Cycling the system takes usually four to six weeks, but there are couple of ways to speed up the progress. You can add bacteria from an existing aquaculture or aquaponics system, or from a pond nearby or buy your bacteria from a commercial source. Bacteria from existing system can be introduced from different sources, for example media, ornaments or filter material, not to forget rocks from the nearby pond that has some fish in it. Water temperature has also its effect on the cycling speed. Optimal temperature is 25-30°C. At 18°C the growth rate is decreased by 50%. At 8-10°C it decreases by 75% and stops at 4°C. Bacteria will die below 0c or above 49°C. (The aquaponic source 2011.)

There is another way to cycle the system: that's called fishless cycling, which means that the ammonia comes into the system from another source than fish. This is less stressing as there isn't fish that have to stay alive during the process. You can be less concerned about pH as it has to be in range for cycling, but not for the fish. You can also elevate the level of ammonia a lot higher, thus it enables you to cycle the system faster, usually in about 10 days to 3 weeks and have the system ready for full stocking once the cycling has completed instead of having to increase stocking rate carefully when cycling with fish. There are many ways to introduce ammonia into the system. Liquid ammonia, known as clear ammonia, pure ammonia, 100% ammonia or ammonium hydroxide is old cleaning product that can be used if it's found in form that has only ammonia, do not use anything with any additives like perfumes, colorants or soap. Ammonium chloride, known as crystalized ammonia is crystallised version of liquid ammonia. Human urine, also called "humonia" can be used to get the system cycling, as a disadvantage it takes time before urine will convert to ammonia, thus it's suggested that you should keep it in a sealed bottle for a few weeks. There is no way of measuring how much potential ammonia has been introduced into the system, meaning that one day readings are very low and next day levels climb too high. As another concern when using human urine is that there might be bacteria or germs in the digestive system that could be harmful for the fish. A bit of dead fish can be used to introduce ammonia into the system as it decays. There is a chance that it might introduce something unwanted into the system, plus the possibility of it attracting flies and other insects.

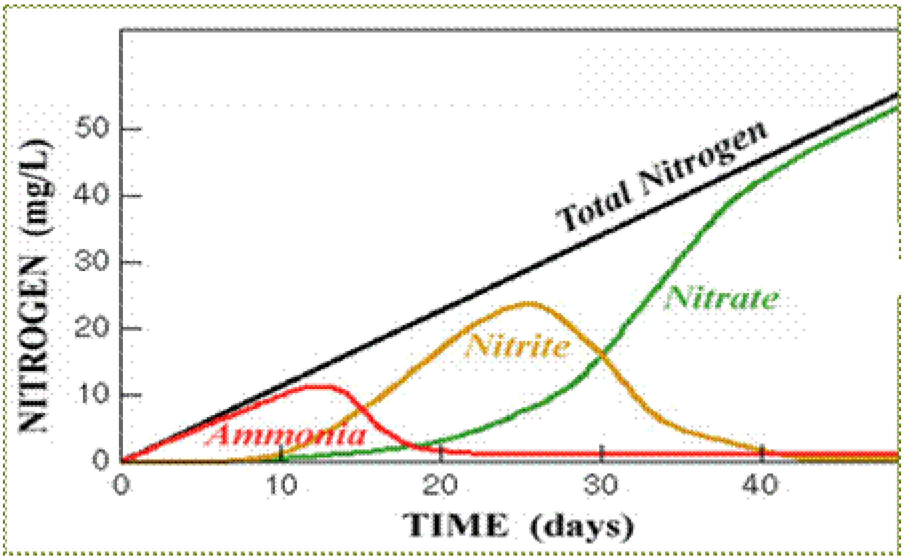

Figure 6 Nitrogen cycle transfers ammonia into form that's usable for plants.. (The aquaponic source 2013.)

When you know your choice of ammonia you add ammonia to your fish tank until you reach 2-4ppm. If you found out that you added too much ammonia (more than 6ppm) drain some of the water from fish tank and add some fresh water for diluting remaining water in the tank. If the test doesn't show any reading it is possible that there is way too much ammonia in the system and the test couldn't handle it. If your fish tank is under 378 liters add only half a teaspoon or less of ammonium chloride at a time. If your fish tank is bigger than 757 liters you can add more than one teaspoon of ammonium chloride at a time. If you are using powdered ammonia, let the powder mix in the system for a couple of hours before re-testing.

Every day until your system has cycled fully you need to test your system for ammonia, nitrites and pH levels, and keep record of them. You also need to keep pH 6.8-7.2. In case of ammonia level drops you need to add some ammonia back to 2-4ppm. Drop in ammonia level means that nitrifying bacteria is beginning to do its work (Figure 6). When you see measurable amount of nitrites you can begin to measure nitrates as well. As soon as the levels of ammonia and nitrites drop close to zero and there is enough nitrates to show on test. The system has cycled and you can add your fish into the system. Once you've added fish into the system you don't have to add any more ammonia as fish will produce ammonia in their waste. (The aquaponic source 2010b & 2012.)

To speed up the process you can add media and water from someone else's fully cycled system, even squeeze from filter material can be good way to introduce the bacteria, instead of waiting the bacteria to arrive in the system you add existing bacteria. For this purpose you can also use water from pond or river, even if it does introduce a risk as you can't be sure what else comes into your system. (The aquaponic source 2010a.)

6.2 Maintaining the system

There are many things to observe in an aquaponics system. Aquaponics systems run mostly pretty well once the plumbing is connected, fish are happy and seedlings have been planted. Sometimes everything looks fine until something goes wrong and leads into suddenly your fish are dying. Everything was fine yesterday, today you found dead fish, tomorrow another one.

Water quality is essential. Good filtration ensures good water quality. Check the water for off smells. Uneaten food will decompose at the bottom of the tank, causing ammonia build up in the system. Therefore uneaten food has to be removed from the bottom of the tank. If the level of impurities in your water rises too much, the water gets a cloudy or murky colour and gets a frothy surface. Usually it's caused by over feeding. If this happens you need to stop feeding the fish and do a partial water change.

Requirements for water temperature and conditions vary slightly depending on the fish species. Every time you change a large amount of water you're adding stress for your fish. Especially if there is a sudden change in pH. It's a good idea also to avoid handling the fish to reduce stress. High ammonia levels are toxic for fish. A spike of ammonia can be caused if your system is new, or hasn't been cycled properly, or fish have been overfed, especially when the temperature is higher than normal. High nitrate levels won't kill your fish, though they will feel it by the time the nitrate levels reach 100ppm, especially if the levels remain there for some time. This makes fish more sensitive to diseases. When you see a high nitrate concentration you should either reduce the number of fish or add more plants to use up the nutrients. A balanced aquaponics system has low or no nitrate readings. Algae will grow in nitrate levels as low as 10ppm.

Table 2 Water quality tolerance for fish, hydroponic plants and nitrifying bacteria. Parameter for aquaponics. (Water quality in aquaponics n.d.)

Organism type	Temp °C	pH	Ammonia mg/litre	Nitrite mg/litre	Nitrate mg/litre	DO mg/litre
Warm water fish	22-32	6-8.5	<3	<1	<400	4-6
Cold water fish	10-18	6-8.5	<1	<0.1	<400	6-8
Plants	16-30	5.5-7.5	<30	<1	-	>3
Bacteria	14-34	6-8.5	<3	<1	-	4-8
Aquaponics	18-30	6-7	<1	<1	5-150	<5

The ideal pH level for aquaponics is between what's ideal for fish, and what's ideal for plants (Table 2). Fish prefer pH 7-7,5 while plants prefer mid 6's. A pH level of between 6.4 and 7 is ideal to keep both the fish and plants happy. A salt bath is a common way to shock and kill parasites that might be lurking on the fish and de-stressing fish. Stressed fish excrete minerals into the water. Salt loss can be fatal for fish. If this condition persists for an extended period of time. By adding a small amount of salt into their water, the survival rate of your fish increases. Mineral excretion is directly linked to the concentration of salt in the water, and so increasing the water salinity reduces salt excretion and stress for the fish. The recommended salinity level to dose the fish is in the range of 0.5-3ppt. Adding too much might kill your fish and plants, where for example fish doesn't tolerate levels beyond 3ppt.

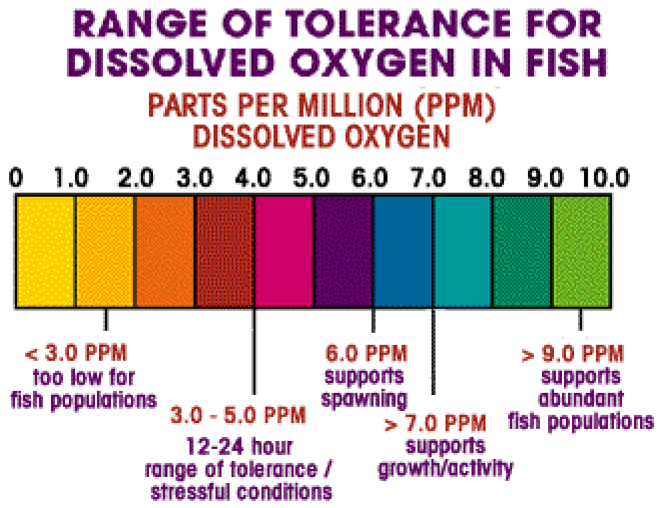

Figure 7 Range of tolerance for dissolved oxygen in fish, oxygen is essential for fish. (Ecofilms 2010b.)

Fish need dissolved oxygen in water to survive (Figure 7.). Low oxygen levels will result in chronic stress and fish deaths. Low oxygen levels makes fish "breathe" faster than they would normally, even gasping air on the surface of the water when the oxygen level is critical. Different fish require different levels of dissolved oxygen. As an example, trout needs 6ppm of dissolved oxygen, while other more "hardy" fish require less. Warm water is more difficult to saturate, therefore making sure that there is an adequate dissolved oxygen level is even more important during the summer months. (Ecofilms, 2010b.)

6.3 Water quality and nutrients

Water quality is essential for maintaining the system. Levels of pH (figure 8), nutrients and ammonia + nitrite + nitrate are the things to test and keep an eye on. The amount of dissolved oxygen is essential for the wellbeing of fish and therefore the whole system.

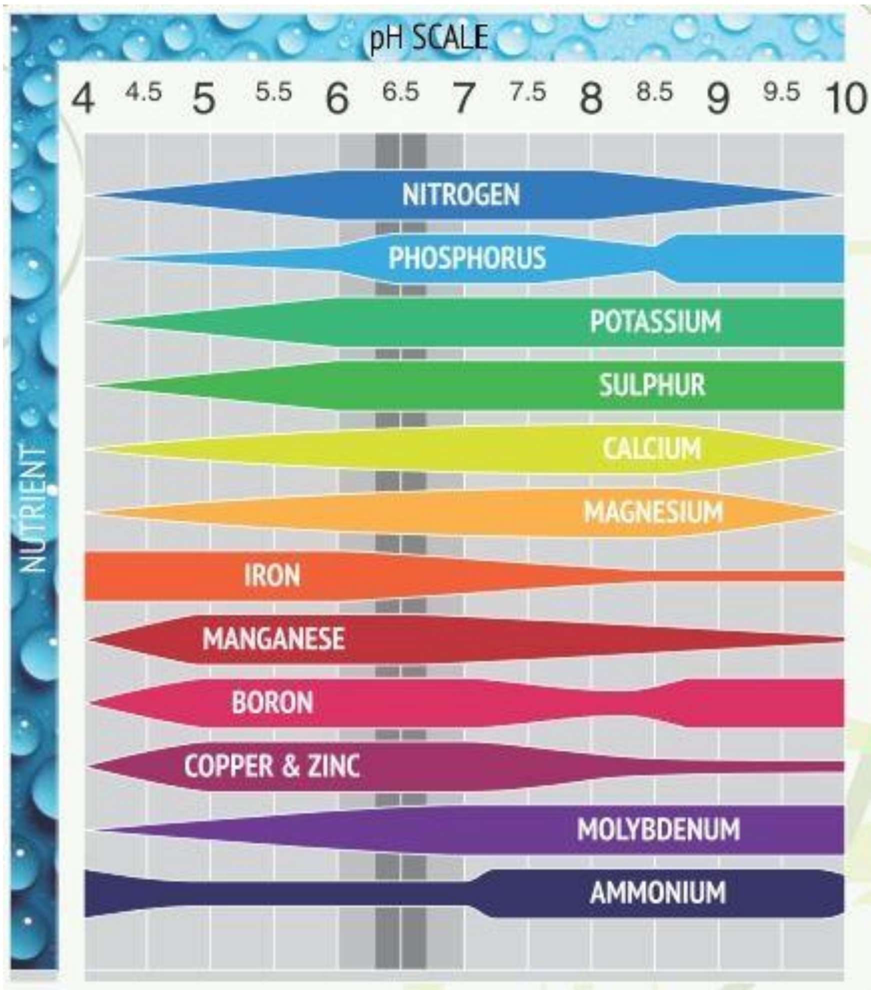

Figure 8 Plants ability to absorb nutrients according to the pH level (backyard aquaponics 2012).

There is nothing worse in aquaponics than to see your fish suddenly go belly up and die without any apparent reason. One point that people overlook in aquaponics is the relationship between ammonia levels, water temperature and pH. There is a relationship between these three factors that is hardly ever noticed by most people and their inter-relationships are not well understood, which can lead to impending disaster.

All fish give off ammonia which is toxic to fish. It comes off their gills and in waste. Uneaten fish food also turns into ammonia as it breaks down. If it’s left to build up over time without nitrifying bacteria to convert it to nitrates that plants ingest, it will cripple your system and kill your fish.

The nitrogen cycle takes care of ammonia. Bacteria turns ammonia into nitrates that the plants use. For a new aquaponics system, it can take up to six to eight weeks in winter, or a couple of weeks in summer before the system is said to have cycled and is all in balance.

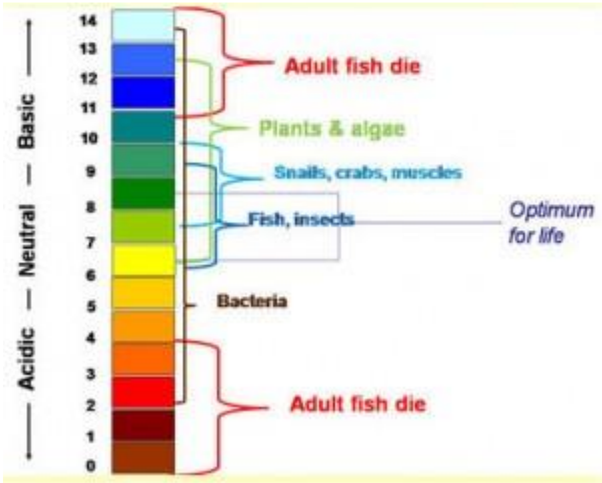

Figure 9 The pH chart shows pH levels that support healthy aquaponics system. (Ecofilms 2010a.)

The pH is a measure of hydrogen ion (H^+) concentration in the water. The pH scale ranges from 0-14 with a pH of 7 being neutral. A pH below 7 is acidic and pH above 7 as basic. An optimal pH range for aquaponics is between 6 and 7, and can vary slightly depending on fish species (Figure 8).

Ideally your ammonia level should be near 0 but there will always be a trace level being emitted constantly from the fish. It gets more complicated if you stock your system with a heavy fish load. (Ecofilms 2010a.)

Table 3 Total ammonia readings that fish can tolerate. (Ecofilms, 2010a.)

Total Ammonia Nitrogen (TAN) - ppm
Use this table to find out when ammonia levels will start to become toxic to your fish

Temp (°C)	pH										
	6.0	6.4	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4
4	200	67	29	18	11	7.1	4.4	2.8	1.8	1.1	0.68
8	100	50	20	13	8.0	5.1	3.2	2.0	1.3	0.83	0.5
12	100	40	14	9.5	5.9	3.7	2.4	1.5	0.95	.61	0.36
16	67	29	11	6.9	4.4	2.7	1.8	1.1	0.71	0.45	0.27
20	50	20	8.0	5.1	3.2	2.1	1.3	0.83	0.53	0.34	0.21
24	40	15	6.1	3.9	2.4	1.5	0.98	0.63	0.4	0.26	0.16
28	29	12	4.7	2.9	1.8	1.2	0.75	0.48	0.31	0.2	0.12
32	22	8.7	3.5	2.2	1.4	0.89	0.57	0.37	0.24	0.16	0.1

This table (Table 3) shows the level of ammonia you can tolerate in your fish tank before it affects the fish. You can see that at very warm temperatures a small amount of ammonia can be toxic to your fish. The cooler the water, the higher the ammonia levels that the fish can tolerate. This applies also for dissolved oxygen. Cold water can store more dissolved oxygen than the same amount of warm water.

Understanding the relationship between ammonia and water temperature will give you control over how well you can manage your system and avert danger if your water temperature suddenly climbs during the summer and the fish begin to look weak and stressed.

If problems occur you should

- Make sure the system had cycled enough before introducing the fish
- Stop feeding the fish when ammonia levels are high
- Bring pH down to the mid to low 7's over a number of days. The fish will tolerate the lower pH better.
- Do a partial water change (about a third) to reduce the amount of ammonia in the system over the next few days.

(Ecofilms 2010a.)

7 EXPERIMENTAL PART

As the subject was new for everyone who's been participating in the project, lots of time has been used for research and designing the system. The idea of the thesis was first to build the system and observe how it runs, changes in the nutrient levels etc. As time went by and more and more effort was put into the background research and designing of the system, it was realised that building and observing the system will play a smaller part in the project. There are many different ways of building system for one. There are different ideas, different equipment available and different expectations at every place where one or more of these systems is built. The research about aquaponics still isn't finished, as new ideas keep coming up while knowledge about the system spreads around the world.

It's great to be part of a project that is still searching for new ways of doing things. It's been interesting to notice how few people know what aquaponics means, and at the same time to see the excitement on people's faces when they hear what the system is about. How much simpler can it sound? A farmer feeds the fish, fish waste feeds the plants and plants clean up the water back to the fish. A simple idea, with various different ways of getting around it. Managing to build a balanced small scale eco-system by just recirculating water through different components is definitely interesting, and also challenging at the same time.

7.1 The farm

The farm is a 900ha cattle farm in Krambach, NSW, Australia.
The main line of production is beef cattle. Cows roam at pastures all year round with a bull. About 500 headed cattle is run according to a holistic management grazing program. That means that they are moved every couple of days to new fenced areas while most of the farm gets to rest and grass gets time to recover from the animal impact. The farm has 7 horses, and

from those 4 are brumbies, Australian wildhorses that came from Guy Hawkes National park 2013.

There is always numerous building projects underway. Timber for building comes from dead trees that are found from the property, and is cut with a portable Lucas sawmill and chainsaws. The farm relies on rain water and uses lots of solar energy to run fences and even some of the buildings at the farm. (Koolombach n.d.)

7.2 Building and documenting aquaponics system for Australian farm

The farm started looking into setting up an aquaponics system for the farm in 2013. The project was due to begin winter 2013, but was delayed by unexpected circumstances. This opened the possibility of using the project as a subject for the thesis.

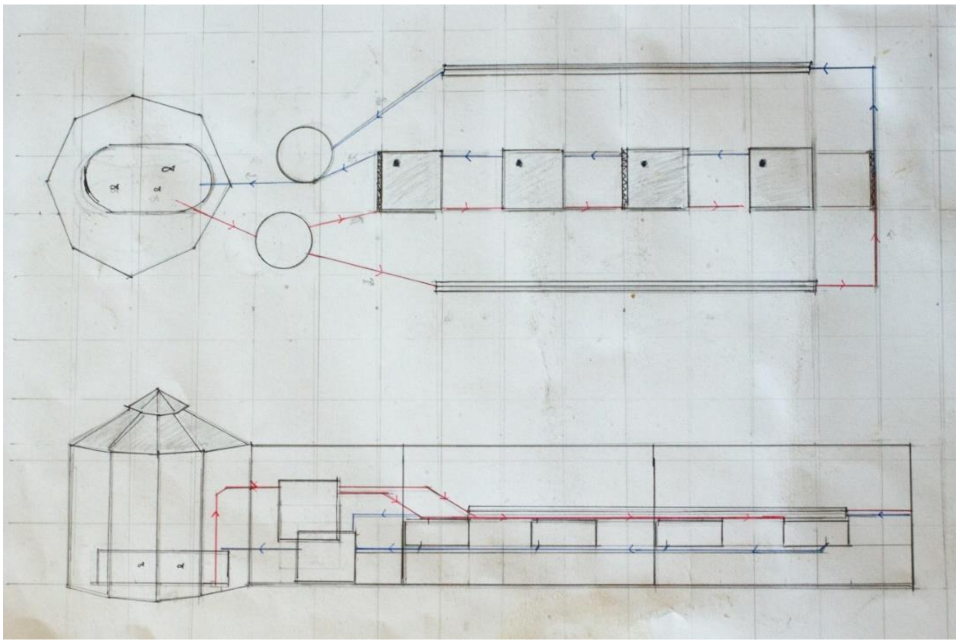

Figure 10 Drawings of the first version. Media beds in middle, NFT pipes on sides. Shallow fish tank under pergola. Red colour represents water going right, blue returning water that flows to the left.

The project was begun by doing lots of research about the subject. Research and gathering of material continued from 2013 to 2015. Lots of time has been put into research about different parts that you can put in the system. The plan has been changed multiple times.

The first plan (Figure 10) was to have four media filled beds and 4-6 NFT pipes with a fairly shallow 1000 liter fish tank, 500 liter swirl filter and 600 liter sump. The fish tank was to be under a pergola and plants under old garden hoops, covered with clear roofing sheets. As we were setting up the housing we realized that we wouldn't have much space to walk around the system, place electrics, manage seedlings and so on. Therefore we changed the plan. We'll have two media filled beds and four nutrient film technique pipes, as one of them was damaged on transport and another one broke on construction site.

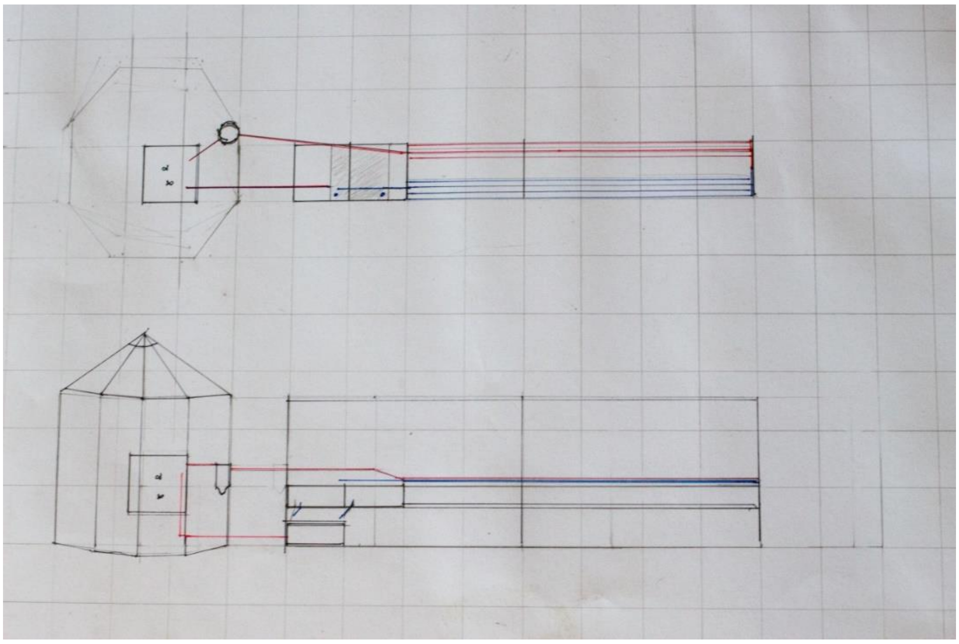

Figure 11 Drawing of second version. IBC fish tank under pergola, 2 media beds and NFT pipes in line.

Due to the possibility of high winds, the frame and pergola were concreted into the soil. Deciding how to build the roof over the frame that covers the plant took some planning as we had two options; garden hoops that were bought for the system that were aesthetically better, or build one from a top hat that would have more space, and thus be more practical but not as aesthetical. We chose to go for garden hoops as the building is at the front yard.

Our design is a combination of NFT and media-filled beds (Figure 11). This way we should be able to grow a greater variety of plants in the system. Leafy greens and small rooted plants will do well in pipes, but bigger plants might be too heavy, and cause the system to crash due to roots clogging up the pipes. There for it is a good idea to put larger plants in media beds. Our media beds are IBC tanks (1000 liter, 1m x 1m) that we cut down to 0.35m. In the media beds we have bell siphons. Our standpipe is 40mm wide, and about 27cm high. Each bell siphon is about 30cm long, with a 65mm pipe with cap on it. We drill a hole in the middle of the cap and attach a small breather hose to make sure water stops flowing through the siphon when required. The last piece for the siphon is a media cover that is just a bigger piece of pipe that lets the water through, but not the media.

Figure 12 The flowform is aerating the water. The green sieve is breaking the water flow more and this way supplying more oxygen.

Aeration is essential for the wellbeing of the fish. Our fish tank is 1000l. I've come to the conclusion that a minimum for our system would be a pump that can pump 10 grams of oxygen per hour. To leave space for error and later expanding it would be a good idea to go for slightly larger pump. To minimise risk, adding a spray bar for extra aeration is a good idea. Spray-bar will keep adding some oxygen into the system even if the air pump fails one day, and by doing so provides more time to react. Never the less during the research we found out that required water pump is smaller than the ones on the market, therefore we came to conclusion to use beehive flowform (figure 12), that makes water circulate, thus aerating it without consuming power. There has been an oxygenation research carried in New Zealand, 1987 and 1988 about how different types of flowform design affected the water. The test was carried out by The Hawkes Bay Regional Council water board scientist and Rob Dewdney using dissolved oxygen meter and the Winkler test. 13°C bore water with high levels of calcium was run once through a flowform cascade with 12 *Beehive* models, which are 4 and 5 chambered "lung" designs with extra vortical chambers. This was repeated 20 times to receive average readings. The oxygen reading at the beginning was 1.4 parts per million (ppm) and the end 7ppm, showing an increase of 5.6 ppm over distance of 4.8 meters. Each *beehive* model unit increased dissolved oxygen by an average of 0.465 ppm. Similar testing was carried out with flowform Järna model, which is of a "kidney" shape that emphases mixing and polishing, it showed an average increase per unit of 0.2 ppm. (Flowform n.d.)

An airlift pump is the alternative to using a water pump. An airlift pump uses air to move water, replacing a water pump and aerating the water at the same time. Air lifts can be used in smaller systems, as generally they are not used in large commercial systems due to limited lifting capacity. Airlifts lose efficiency (pump less water) the higher you lift the water compared to your total water depth at the airlift. They work best when you lift water only a small percentage higher than your total depth, which makes it unfortunately not suitable for the system we are building. Therefore we had to use water pump that pumps 1000 liters of water per hour to make sure water rises high enough with sufficient flow.

As stated by Nelson and Pade, “The deeper the water depth compared to the lift, the better” (Nelson & Pade 2008, 65.)

Building the system has taken a lot more time than first thought. As an operating farm, there is always other projects, daily and seasonal jobs that have to be also taken care of. Travellers have changed many times during the project, and all of them have different skills. The housing is a pergola, and garden hoops that are covered with plastic and shade cloth. Under the pergola we have a 1000 liter IBC tank as a fish tank, under that we have a 300 liter sump, that has been cut down from a full sized IBC tank. From fish tank the water flows to the swirl filter that is constructed from a 19 liter water bottle. From the filter the water flows to four NFT pipes that can carry 24 plants each, which makes 96 plats in total. From the NFT pipes the water is gathered up again and guided into three media beds that are made from cut down IBC tanks, each carries about 300 liters, that would be 200 liters of scoria and 100 liters of water as an estimate. Every media bed has a bell siphon that empties the bed from water when the water level reaches the height of the stand pipe. Maximum water level should be about five centimeters under the scoria, to avoid drowning of the plants and algae growth when the water gets exposed to the sun. As the siphon goes on it flushes the water in pipe that guides the water to the sump that makes sure the water level in the fish tank doesn’t alter too much, thus reducing stress in the fish. From the sump the water gets pumped back to the fish tank completing the cycle. As sunlight encourages algae growth in tanks, we’ve painted all tanks from outside to block excess sunlight and at the same time protecting the tank from UV light, thus extending the life of the tanks.

The levels for gravity feeding… A lot of effort and time was put into thinking of the heights of the tanks to get the gravity feeding working and still being able to access the tanks easily. The information on how much higher everything has to be compared to the other tanks as the information just doesn’t seem to be available easily. Thinking through how to get the water to leave from the bottom of the fish tank, still having fish tank on height that we can access and getting it to flow high enough to gravity feed down to the rest of the cycle was a challenge as the writer doesn’t have any previous experience from plumbing. Finally I came across a solution, a standpipe that leaves from the bottom of the fish tank, reaches up over the tank, and a vertical pipe that leaves horizontally from the top of the fish tank. This makes it possible to lift the solids from the fish tank towards the filter while still having the outlet on top of the tank so the tank doesn’t empty itself in case something fails.

7.3 Testing the aquaponics system

Finally after lots of research we got the pipes up and water running in the system. We were able to begin cycling the system to see how everything holds together and if the levels were right. First challenge we came across was our media, it had a lots of fine dust and sand that would have to be washed out of the system before adding the living organisms in the system. During testing we found out that the standpipes in the bell siphons were too big compared to the flow rate that was achieved with gravity feeding, therefore standpipe was changed to one with smaller diameter to ensure siphoning begins. During the test run we came across another problem: Size of the sump isn't sufficient to carry three media beds as we were afraid. When all media beds were almost full, the water level in the sump tank went too low, making the pump run empty and water stopped running. Eventually this would result in failure of the pump and total system crash, so we had to get back to the drawing board. As a guttering we used first top hat that we eventually changed to roofing gutter as the material was available.

Testing the siphon went well, we cut some horizontal slots on siphon pipe, that wasn't enough for sufficient amount of water to flow through thus causing siphon not to begin properly and breaking too early. After first test we made the slots bigger, allowing more water to go through. Second test was successful with bigger slots, siphon started when water level reached height of the standpipe, and stopped when water level was down to first slot on standpipe. During testing we wanted to experiment with the siphons, and ended up changing the media cover around the siphon to bigger pipe because working inside 100mm diameter pipe was challenging. The bigger pipe made the siphons easier to access and maintain. Scoria we chose to use has required lots of washing, as there was a lot of fine dust and sand that did cause our first pump to fail. We ended up placing a piece of stocking to the end of the pipe that comes from the media beds to gather sand and small stones so they wouldn't get in the pumps. We continued testing with one 24volt pump that was moving about 600 liters of water per hour running the system during the day and turning it off for the nights. We fixed the leakages we found from the guttering. We built a filter for the inlet pipe of the pump as we got a couple of small stones inside it. Tests were carried out with 2x 12volt batteries joined together to get 24volts. Never the less, as we begun to wire up the batteries that we are using for running the final system we noticed that it would be easier to do wiring for 2x 12volts, instead of 24volts so we had to change the water pump. We had 3 small water pumps in stock. We begun to run the system with one small pump, but it didn't give enough water flow to the required height. With a timer and bucket test we found out that the pump was doing only a bit over 200 liters per hour. That wasn't sufficient to run the system. We added a second small pump and repeated the test with bucket and timer and received a flow rate of about 600 liters per hour, which was much better, but still not 1000 liters per hour, but was enough to launch siphons and get the water flowing through the system. We came to the conclusion that as we had small pumps already in stock we would run three small pumps continuously as it would still use less power than running one bigger pump, and in case of a pump failure other pumps would still keep running the system with less water flow, giving time to replace or fix the failed pump without crashing the system.

One of the critical issues with the system occurred to be the size of the sump. When all of the media beds filled up the same time. The sump tank ran empty, causing water pump to suck air, and would eventually cause the system to fail. The 300 liter sump would be sufficient to carry two media beds even if they would be full at the same time, but it wasn't sufficient to carry three media beds if all of them would fill up the same time as there wasn't enough space for error. Thus the sump tank has to be replaced with a bigger one, or joined to another back up tank before finally running the system with living organisms. Later on a new fish tank was built from a food grade IBC tank, it was insulated to prevent sunlight getting in and to minimise temperature fluctuations. The old fish tank was refurbished with a new frame and dug underground under the fish tank to get back to the same height than we had before. The filter was eventually replaced with slightly bigger blue barrel. Inside the barrel we inserted a wall to force water to go under it, and thus leaving the bigger solids on the bottom. The old filter was letting too much sunlight in, and was growing algae on sunny days. The guttering had to be covered with timber later on, due algae growth.

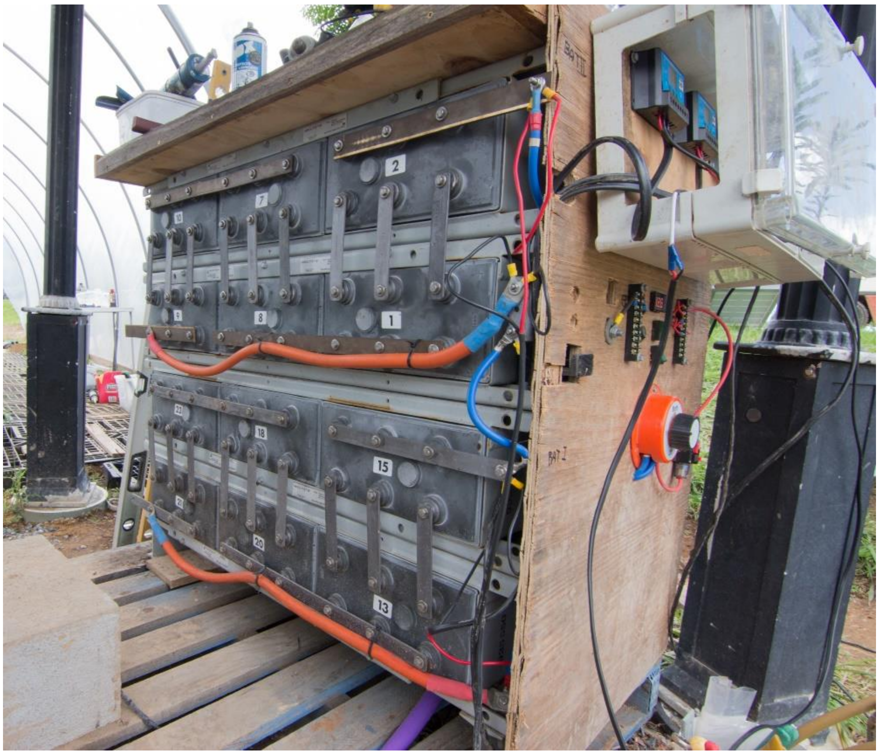

Figure 13 The power bank. The batteries are charged by several solar panels. The wires are brought to the switch board on the side.

On 10th of October the plastic was lifted over the garden hoops. Batteries (Figure 13) are beginning to charge up with solar panels. The solar panels are hooked up to regulators, regulators are wired up to the batteries and the pumps are connected to the regulator to begin with. Later on we came to the conclusion that the regulator was too clever, and it was trying to balance the incoming and outgoing current when sun begun to go down, not giving enough power for the pumps and causing them to struggle. Thus the wires for the pumps were moved to run straight from the batteries, bypassing the regulators. This did make a clear difference on how the pumps were running when it was cloudy and when the sun was down. We are experimenting with potting material, some of the parsley pots are filled with scoria, some of them with scoria and coconut fibre that's out of an old mattress, and one of them with only coconut fibre.

7.4 Cycling the system

On Sunday 11th of October I found out that the fish has already been in the system for a couple of days as the farmer found out that someone was going to throw away 40 goldfish from the dam and they were put in our system. One fish didn't survive transport. At this point we didn't have the testing kit so we dug out parsley that we had a lot in the garden and added it in NFT pipes to filtrate the water. We added two shallots in the middle media bed to see if they survive. The system is running at this point only during the day, and turned off for the nights as the sump is still too small and would cause the pumps to fail if left unattended for too long. The water is still really grey from the dust that got in the system when scoria was introduced so all I could do was to trust that there really was some fish in as they could not be seen. We added Charlie Carp fertilizer to the system to help the bacteria build up and give the plants better chance of surviving while system is beginning to cycle.

On 14th of October the parsleys that were added to the NFT pipes are still alive, even some of the bottom leaves are yellowing as expected due transplanting stress. Four pots of oregano and basil were added into the NFT pipes. Smallest one of the oreganos died, and one of the bigger ones didn't quite recover, but basil recovered quick and looks healthy. Pumps have been struggling as the water level in the sump has gone very low couple of times and dust has been blocking the filters. In the evening the water wasn't flowing through the system and the fish tank was overflowing. The reason was a fish that found its way in the pipe and didn't fit all the way through to the filter. This was the first time I saw a fish and it confirmed that there was fish in the system. The fish that caused the blockage lost some scales and was missing one eye, it has been possibly missing already earlier. This means that even there was something at the beginning of the pipe to stop the fish getting into the pipes it must have fallen off. This will be fixed once the fish tank will be changed. The fish tank is IBC tank with wooden pallet bottom, that's sitting on top of another tank. Wooden pallet begun bending under the weight of the water so changing the fish tank is necessary.

Figure 14 The new fish tank on the top, and the sump tank has been buried in the ground.

On 15^{th} of October we received the API freshwater master test kit, the results are followed up in figure 12. So far the system has been running with the fish for about a week as I still can't be sure what day the fish went in. All the tests were carried without having any fingers over open end of test tube to make sure the test results are correct. The tests were made 6pm from the top of the fish tank using API freshwater master test kit. First test was pH, 5ml of water from the top of the fish tank was added to a test tube. Three drops of test solution was added to the sample, holding the dropper bottle upside down to ensure uniformity of drops. The test tube was capped and inverted several times. The result was 7.6, which is the highest reading on the chart. Therefore a high range pH test was carried. 5 ml of water from the top of the fish tank was added in the test tube. 5 drops of high range pH test solution was added to the sample, holding the dropper upside down to ensure uniformity of drops. The sample was capped and inverted several times, keeping fingers out of the open end of the test tube. Result was 8.2, which is too high for the plants to consume all the nutrients. Ammonia test was carried by taking 5ml of water from the top of the fish tank. 8 drops of test solution from ammonia test bottle #1 was added to the sample, and 8 drops of solution from ammonia test solution #2 was added to the sample. Test tube was capped and shaken vigorously for 5 seconds. 5 minutes was taken to let the colour develop. Ammonia reading was 1ppm. Reading is safe for fish and ammonia is present, level will drop lower once the nitrification bacteria establishes. Nitrite test was carried. 5ml of water from top of the fish tank was added in test tube. 5 drops of nitrite test solution was added to the sample, holding the dropper bottle upside down to ensure uniformity of the drops. The sample was capped and shaken for 5 seconds. 5 minutes was taken for the colour to develop. The result was 2ppm, meaning it's still in safe level as the system is still cycling it will probably drop down during the time. The nitrate test was carried. 5ml of water was taken from the top of the fish tank into test tube. 10 drops of test solution was added to the sample from test bottle #1. Test was capped and inverted several times to mix solution. Test tube #2 was shaken vigorously for 30 seconds before adding 10 drops to the sample. The test was capped and shaken vigorously for one minute to ensure test mixes up properly. 5 minutes was taken to for the colour to develop. Test result was 20ppm, meaning nitrification bacteria is present and establishing. The bacteria might have been present in the creek water that was used for the system, or it might have been established in the first week of having the fish in. Tests were carried out of IBC tank that was used to add water to the system. pH level was 7.6, ammonia reading 0-0.25ppm. Test results show that the system has begun to cycle, and nitrification bacteria is present. pH level is too high, that might be due the scoria that we used for the media beds or from Charlie Carp fertilizer. The pH level should come down during the time due nitrification process but has to be kept an eye on and lowered if it doesn't drop to ensure the health of the system.

16th of October a small amount of potassium that was separated from citrus fertilizer was dissolved in the water and added to the system. The pumps have been struggling and had to be restarted several times to get water flowing. In the evening the system was turned off again, like every evening and the fish begun to swim around the tank near the surface, looking healthy. Small headlamp was added over the fish tank to attract bugs.

17th of October the system had stopped during the day, pumps were clogged up and didn't transfer water.

18th of October the sump tank and swirl filter were flushed and 300liters of creek water was added to the system as the sump was running dry when the media beds were full. The API freshwater master tests were carried again. As measured from the top of the fish tank high range pH level is still 8.0. Ammonia reading has dropped to 0.25ppm, nitrite was 5ppm and nitrate reading was only 5ppm. We repeated the tests from the bottom of the fish tank as there was possibility that water wasn't properly mixed up in the tank. Results were 8.2 on high range pH, 0.25ppm on ammonia, 2ppm on nitrite and 20ppm on nitrates. The pH level is still high, even 8.0 reading wasn't as clear as in last test. Ammonia level has gone down, that could be resulted from the nitrification bacteria establishing, and replacing some of the water in the system might have changed levels also. In the evening as the system was turned off the fish came up to the surface again. They were offered some goldfish flakes and begun to feed.

19th of October the sump was running dry again, so 150 liters of creek water was added to the system.

20th of October I turned the system on and the morning, checked the siphons and heard something fall. One goldfish took a leap of faith over the edge of the fish tank and landed on the ground. It was returned back to the fish tank. 3pm the tests were carried again from the bottom of the fish tank. Water temperature was 27°C. High range pH was still 8.2. Ammonia 0-0.25, nitrite 2ppm and nitrate 40ppm. Due high pH reading we added 3 capfuls of Alaska mor-bloom fertilizer, diluted in 5 liters of water. 21st of October I added another 3 capfuls of alaska mor-bloom.

Figure 15 Three mediabeds and four NFT pipes after one month of cycling the system. The plants are growing well.

22th of October added one silverbeet in media bed and 6 basils in NFT pipes. Testing 3.30pm. Sample taken from the bottom of the fish tank. High range pH 8.3. Ammonia 0.25ppm. Nitrite 0ppm. Nitrate 20ppm. The pH level is way too high and climbing. On sample pH from the top of the fish tank was 8.2. We cleaned up NFT pipes and filter. We've taken sample from the scoria in water glass to see if high pH is caused by the media. High pH might be also resulted by beginning nitrification process. Once bacteria has established the pH should come down. Media sample was put in glass jar with just enough water to cover the sample, pH at this point 7.2. Mesh was added to the top of the fish tank to prevent any more fish jumping over the edge. Fish didn't come to eat, possibly due to having the mesh on top of the tank.

23rd of October pH of the media sample is 8.2. This means that the scoria is causing the high pH level. By a change there happened to be a bottle of pH down hidden in the shed. While I was returning to the system something wasn't right. Fish tank was overflowing. We had another fish stuck in the pipe. Fish got rescued in time and returned to the fish tank after being in salty water for short time to encourage production of protective slime. A piece of chicken wire was pushed down to the pipe to prevent more fish getting in the pipes. Active component is 850g/l of phosphoric acid. The amount to lower pH by 1.0 is 1ml per 50l. That makes 10ml per 500L. 20ml per 1000l, and 30ml per 1500l. For safety of the bacteria and the fish we'll begin with 10ml. Our water quantity in the system is 1300-1500l. 1pm High range pH had fallen to 8.0. More plants added in the system. Lots of oregano, sage and two catnips to NTF pipes and eggplant to the media bed. One of the media beds was closed off the cycle to see if it helps bringing the pH level down. Fish weren't keen to eat, they might be scared of the mesh that was added to the top of the tank to prevent them jumping out of the tank.

24th of October the system has been running overnight for the first time. The pumps seem to run better in cold. Tests were carried again 8.30 am. High range pH 8.2 again… Ammonia 0ppm. Nitrite 0ppm. Nitrate 5ppm. According the results the plants have consumed most of the nitrates. As pH was up again we've added 15ml of aqua down. The pH level has dropped to 7.8 by 12am. We added another 5ml of aqua down.

25th of October 9am pH has increased back to 8.0, we added another 15ml of pH down. The pH level had dropped to 7.8 4pm, but was still fairly high so we added 4ml of pH down.

26th of October 1pm pH has climbed up to 8.1, added 10ml of pH down. 5pm we did API freshwater master tests, as a result pH 7.6, ammonia 0ppm, nitrite 0ppm and nitrate 5ppm. Nitrates have stayed down even fish have been eating well for last two days. This means that we have enough plants to use up the nutrients, as the plants grow we might end up not having enough nutrients unless fish will begin to eat better when the weather warms up.

27th of October begun by emptying the fish tank, catching the fish and emptying the sump. We have 31 healthy goldfish, two of them were fairly big. The sump tank has been too small to carry three media beds, so we changed the old fish tank as a bigger sump and built a new fish tank (figure 14), and as we had to take pipes out we re-built the clarifier filter, as the old one was a bit too small, and due to the high amount of sunlight getting through the walls it was growing algae. Most of the water was saved and pumped back to the system, and 1000liters of fresh water was added to the system. As we had to dig the new sump down to have same level for the pipes we found some worms that were fed for the fish while they were waiting in temporary tank.

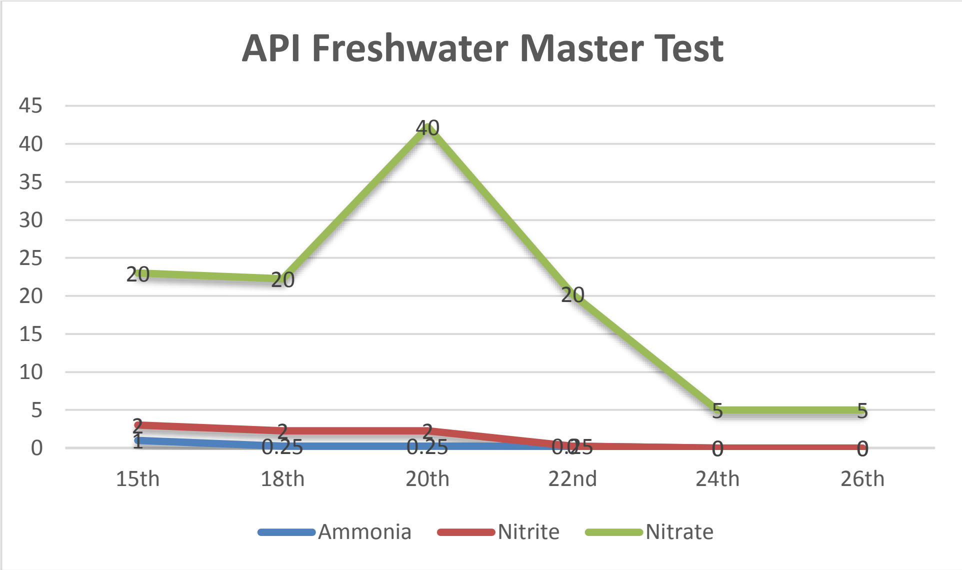

Figure 16 Water quality test results on chart. Table includes results for ammonia, nitrites and nitrates. Fish has been in for about a week before test kit arrived, and the water from a creek has already some of the bacteria in, therefore cycling the system has already begun and at the end of chart nitrification bacteria has been established. Differences in nitrate levels are from time the system was running as it was off for the nights until the pumps and siphons were running without any bigger problems, and batteries were charged up. Biggest difference came from running the system continuously and adding plants to the system.

28th of October the tests were carried again. The pH level is 8.0 at the bottom of the fish tank, and 7.8 at the top of the fish tank. Ammonia 0ppm, Nitrite 0ppm and Nitrates 0ppm, meaning that the plants have consumed all the nitrates, or it could have been result from the big amount of water that was added to the system a day before. We added 10ml of pH down and 20ml of mor bloom fertilizer. 29th of October pH has dropped to 7.6 as a result from pH down and mor bloom from the day before. Some of the basil is showing yellowing in fresh growth. Charlie carp foliant spray given to weaker looking plants.

2nd of November Tests were carried again after writer was away for a couple of days. During these days there has been Charlie carp fertilizer added to the system, causing a lot of algae blooming in the gutters. More plants were added to the system, a lots of different types of lettuce, rainbow chart, kale, silver beet, two tomatoes, two cucumbers and zucchini was added to the system. The plants look healthy. The pH level 8.2, ammonia 0ppm, nitrite 0ppm nitrate 5ppm. 15ml of pH down added. The algae has been cleaned out of the pipes.

4th of November pH level is 7.9, meaning that the nitrification process is finally beginning to lower the pH level. More foliant spray added to the plants. Cleaned up more algae from the guttering. The new pumps finally arrived and were installed. The system is running now with 4 pumps and filters for the pumps were uprated. Difference in water flow rate is noticeable, and as a result bell siphons are running more stable. The media beds took about 20 minutes to fill up and 4 minutes to drain.

5th of November the tests were carried from the bottom of the fish tank. The pH level was 7.9, ammonia 0.25ppm, nitrite 0ppm, nitrate 5ppm. From the top of the fish tank pH reading was 7.8. Changes in levels happen faster on the top of the tank. The pH level is finally coming down as a result of the nitrification process. Levels are looking good, the fish are eating and the plants are doing well (figure 15). As an observation the writer hasn't ever seen leaves of basil (figure 19) grow as big and parsley that was planted first as a sacrificial plant has bolted. We've been adding the foliant spray for the freshly introduced plants. We've came to conclusion that nitrification bacteria has been established, pH level is coming down and system is running well. We've added timber to protect the gutters from sunlight to prevent algae growth. We are still waiting for another pump to be tested. The gutters were covered with timer to prevent sunlight getting to prevent the algae growth.

7th of November the new brushless DC pump arrived and it was installed. This pump should deliver 2800l of water per hour, which is a lot more than required. The flowform is cycling well with the new pump. 10ml of mor-bloom added for the plants as some of them are showing yellowing on the leaves. Added Charlie Carp foliant spray on the plants that are showing deficiency. Rosella and two different types of dragonfruit was sown, 5 seeds of each in the mediabeds, and 5 seeds of each in seedling pots.

8th of November the tests were carried again. High range pH was 7.9, ammonia 0ppm, nitrite 0ppm, nitrate 5ppm, added 5ml of Charlie carp fertilizer and 5ml of pH down.

9th of November we topped up the water level with 250 liters of rain water, we cleaned up the filter and 12ml of mor-bloom was added in the system. The connections for the filter were replaced with bigger ones to increase water flow, as the new pump caused the fish tank to overflow. 15ml of pH down added to the system as the pH level still didn't come down.

10th of November the tests were carried again. High range pH was 7.8, which is still high. Ammonia 0.25, nitrite 0, nitrate 30. Nitrate reading shows that the plants haven't used up all the nitrates this time but the level is still in a good level. More action was taken to bring the pH level down by adding 30ml of pH down. As an observation one of the cucumbers has two flowers. More solarpanels were installed on the roof of the pergola and we've been working on the switch board to get the wiring under control. The fish begun to eat lettuce to bring variation into their diet.

Figure 17 The goldfish are looking healthy after cycling the system for one month.

We will continue bringing pH level down, by November 12th pH level has been brought down to 7.5-7.6. We assume that the scoria in the mediabeds is buffering the pH level, thus every change will require a greater action. The switch board is getting finished. We will bury another IBC tank in the ground next to the system to collect rain water for topping up the water level in the system. We'll keep the system running, after the first month the plants and the goldfish (figure 17) are growing.

We've had to add fertilizer to supply enough nutrients. The pumps have shut down couple of times due problems with the wiring, but the only losses have been couple of plants in NFT pipes. The basil grew well, and ended up blocking up the NFT pipes with its roots, therefore it was transplanted to the media beds. 22nd of November we added spawning mop to the fish tank, and by the next morning there was goldfish eggs on the mop. 26th of November we added hatchery tank to the system, and 27th small fish begun to hatch. 29th of November we received 41 silver perch and 5 crayfish (figure 19), they were added to the system. It took couple of days before silver perch begun to be brave enough to come to the surface of the tank for feed. The pH level settled down to 7.2.

Figure 18 System after it's been running for two months

On 3.12 we find out we have a problem. The sump tank has gone empty during the night because of blockage that was caused by zucchini that was fed for the crayfish that were living in the filter. Causing the system not to cycle. The sump was topped up with 800 liters of water. Cages were built for the crayfish and they were moved to the bottom of the fish tank. One crayfish disappeared, and it was found from the fish tank 5 days later. The goldfish are enjoying the system, as there was more eggs in the spawning mop. 6.12 We bought more plants that were added to the system, 2 capsicums, 7 lettuce of different varieties, 1 climbing spinach and 2 truss tomatoes. The goldfish eggs begun to hatch. The zucchini has been producing deformed zucchini's, that might be result of inconsistent supply of nutrients, or failing of the pumps. The first lettuces are producing. The kale has been unlucky and it's been attracting insects. Cucumbers are beginning to produce. Goldfish fry are fed with hard-boiled egg yolk, after it has been dissolved in water. Silver perch have been fed grated carrot in the hatchery, therefore it was added to the diet of the fish. The fish are enjoying grated zucchini and carrot. Peeled peas are good addition to diet of the goldfish to prevent constipation. Floating pellets were introduced for the fish also, as an option for the fish flakes. Plants are growing. By comparing figures 16 and 18 there is no doubt that there has been a lot of growth.

Figure 19 41 silver perch, 30 goldfish and 5 crayfish in the fish tank.

We will continue maintaining the system, and watching how the goldfish are growing. After more fish has been added to the system it is really important to observe water quality more carefully so nitrification bacteria can keep up with waste. The pH level has gone down, and seems to have stabilized.

The farm is building an aquaponics system to raise the farm's sustainability. The farm hosts travellers from around the world, and having fresh vegetables growing on the farm would cut the cost of food. Getting into a project that will be beneficial to everyone is great. There are always projects on the farm going on, and aquaponics became one of them. The Australian climate can be tough for growing vegetables in a garden, with a hot and dry summer, storms, and wildlife all giving their own challenges for gardening. The farm is growing oranges, mandarins and bush lemons for own use, though too often flying foxes and birds collect the crop before they ripen enough to collect. I planted some strawberries in a fenced garden in 2014, and in the first year most of them died for lack of water while I was away. The second year (2015) plants that were left begun to make fruit, but animals got into them first even though the garden is fenced with chicken wire. Never-the-less parsley keeps flourishing in the garden year after year. It's been self-seeding and tries to take over the rest of the garden. Watering the garden doesn't always happen as not everyone knows where the garden is, and there are many other jobs. The farm grows beef cattle, so most of the meat has been grown on the farm. Chickens take care of leftovers and give eggs as change.

Figure 20 Basil, grown in our aquaponics system. The plant has established massive root system.

7.6 Water flow rates

Knowing something about water flow rates when planning an aquaponics systems is important. Knowing what size of piping is required to achieve sufficient water flow through the system is important when building a system. The fish stocking density determines how fast the turnover rate of water that goes through the fish tank is required. The higher the density, the more turnover is required. Water turnover rate should be at least half of the fish tank volume if the stocking density is less than $15kg/m^3$. One fish tank volume per hour should be turned over when the stocking density is higher. When planning a commercial aquaponics system one fish tank volume per hour should be a minimum design criteria. This water turnover rate ensures that dissolved waste, for example ammonia, doesn't build up to toxic levels and the amount of dissolved oxygen will be adequate. Going to high turnover rates does introduce danger of having too high water velocity for certain fish species. Having too high water velocity means that the fish would have to swim against the current, and sometimes it can affect negatively on fish health. If the water velocity is too slow, the fish might not swim enough and it can affect negatively on their health. Having sufficient water turnover rate of one fish tank per hour ensures that water quality requirements of the fish will be met.

When building a system, the amount of water that has to be turned determines minimum size of piping (table 4.) and pump that has to be be used to achieve sufficient water turnover rate. The pipes should be oversized by 30% to ensure sufficient water flow even when solids build up in pipes over the time. (Aquaponic Solutions 2012.)

Table 4 Water flow rates for different pipe sizes using Hazen Williams Formula – S.I. units. (Harlan Bengtson 2011.)

Pipe material is PVC. Hazen Williams Coefficient, C is 140. Pressure drop over the pipe length, DP is 140 kN/m²

Pipe Length m	Water flow rate, m³/hr							
	Pipe diameter, mm							
	12	20	25	40	50	65	75	100
1	5.6	21.5	38.6	133.0	239.2	477.0	694.9	1481
2	3.9	14.8	26.6	91.5	164.5	328.1	478.0	1019
4	2.7	10.2	18.3	62.9	113.2	225.6	328.7	700.5
6	2.1	8.2	14.7	50.6	90.9	181.3	264.1	562.8
12	1.5	5.6	10.1	34.8	62.5	124.7	181.6	387.1
30	0.9	3.4	6.2	21.2	38.1	76.0	110.7	236.0

Hazen Williams Equation as used in this spreadsheet:

$Q = (3.763 \times 10^{-6})\ C\ D^{2.63}(DP/L)^{0.54}$

Q is the water flow rate in m³/hr

D Is the pipe diameter in mm

L is the pipe length in m

DP is the pressure difference across pipe length L in kN/m²

Australia experiences extreme heat during summer, and heavy winds can do structural damage if buildings aren't properly secured. During winter the temperature drops, and may cause the fish to begin hibernating. That might cause insufficient nutrient flow for plants. Droughts are a problem most years, and bush fires can also happen.

Finland on the other hand faces very different environmental issues. While Australia is hot and dry, in Finland it get dark and cold. The long Finnish winter means that the system requires proper housing and heating. Additional light is also required for the plants to grow in dark winter months. Therefore keeping the system running will require a lot more energy and thus considerably bigger power bill when compared to Australia.

The force of nature will bring its own challenges in both countries, as an aquaponics system is fragile, and if for some reason or another the system stops running the fish won't live long without oxygen and filtration. Therefore a backup energy supply is essential in both countries to avoid a system crash.

Differences between fish breeds and plants and their requirements have to also be taken into consideration.

I visited two different types of aquaponics farms in Australia. The first was a fairly big NFT system in Brisbane. After doing lots of research, by coincidence I found out that there was another system that was located in the same town as the farm where we were doing our project.

Case farm: Kevin Krambach.
Kevin has had his main system (figure 21) running for 14-16 months, since he moved to the village. Kevin's system is small hobby scale with a 200L bathtub as a fish tank, and one 260L media bed. The system floods and drains about every 15mins, 4-5 times per hour.

Figure 21 A small media bed system in Krambach.

As media in media beds Kevin used blue stone. There were some white lime dots in the media, which are not recommended as they can cause a pH problem in the long run. If he would do the system again he would prefer to use river stone as it’s easier to handle due to the rounded shape. In the fish tank he had about ten silver perch and about a dozen of local gambusia (figure 22). The fish were still fairly small, and are of varying ages due to losing some of them during the first months. The fish get a small capful of fish pellets. He has two different sized pellets for the different sized fish. He’s feeding about 5g of bigger pellet twice a day and about 1g of small pellets.

Figure 22 Silver perch and gambuzia.

The system has been covered with a dark shade cloth to protect the plants from excess sun and to prevent the media from getting too hot, as high temperatures could burn the roots of the plants in summer. Heating is supplied during winter by running water through a round of black pipe that heats up in the sun. The round of black pipe is enough to increase the temperature in his system by 5 degrees in winter. As a pump he has a 2500l/h pump which is big for a system that small, though that is because he already had it from another project.

The system is growing different types of chillies, cayenne pepper, jalapenos, celery, capsicum and basil. Kevin adds about 45 liters of water each week to the system. Water has been collected from the morning hue that gathers up on the roof. The system has stabilized, pH is 6.8 and it hasn’t changed in a couple of months. He doesn’t do any regular testing now when the system is stable. General observation has been enough to identify possible problems. He’s been adding some Iron Chelate Fe 13% EDTA every 1-1.5 months for the plants.

Figure 23 Biofilter system with yabbies.

Kevin's second small system had only yabbies with a biofilter (Figure 23). The biofilter has layers of different materials that give beneficial bacteria sufficient surface area to grow. Layers in the 60l bio filter are made from scourers, plastic hoops, expanded clay balls and expanded foam rings. The yabby system didn't have any plants. (Anderson K, interview 13.2.2015.)

My first aquaponics farm visit was to John's farm in Brisbane. He has an old system which had been a one pump system that grew strawberries (Figure 24). One winter a hailstorm caused a system crash, and system wasn't operating as plants had died and some parts collapsed. Having only one pump might cause the fish tank to overflow if something fails. The media bed material was scoria.

Figure 24 Old system with strawberries. Crashed due hailstorm in Brisbane.

New system is a big NFT system with 2 pumps (Figure 26). One pump runs to the fish, and other pump runs for the plants. There was 12 NFT pipes, each of them was two six meter pipes joined together, thus being 12 meters.

Figure 25 Fish tank in Brisbane system is covered with shade cloth to prevent fish jumping out of the tank.

The system in Brisbane has several different filters, and several fish tanks (Figure 25) for different aged fish and yabbies. As filters he has a solids separator in the first tank, filtration material in the second, and a biofilter and aeration in another IBC tank. Everything flows back to the sump.

Seedlings are done in separate pots, where they are moved into the system later. The mixture in the pots is roughly 3 parts perlite and 1.5 vermiculite. Plants are taken to farmers' markets. The difference between plants that have been at market, and those that haven't is huge. Plants suffer when they are pulled out of the system for day. The greenhouse can be sprayed to give plants additional humidity. Worms eat solids, but they make more and finer solids that can be a problem. Use only worm urine for adding nutrients to aquaponics system. If the nitrate level goes up solids need to be taken out of the system. When calculating the number of bio balls required for biofiltration more the better: "you can't have too many" by words of John.

When a system is started it has to be seeded. Urine, rotten fish, and fish food can be used to get bacteria growing. It is a good idea to let bacteria build up for a month or so before adding the fish. Plants don't eat all of the nutrients. As time goes by the media bed will eventually clog up due to solids build up as the years go by. If the media bed is blocked you need to either wash the media or replace it. If the media doesn't get cleaned, you might end up with a nutrient explosion. The water temperature reflects nitrification. During summer opening doors and turning fans on keeps the system cool. In winter additional heating is required. One problem was that the visit to the farm was in winter time. The fish didn't eat so there weren't many nutrients going to the plants. Due to the low temperature the fish went into hibernation. An ideal temperature would be 21-22°C.

Banana peels can be added to the system for additional potassium. Sea shells can be added to the system periodically to adjust pH. Temperature and pH have been the only problems with the system. Small plants love nitrogen, while bigger plants don't. There has to be 70-75% dissolved oxygen in the system. Insulating tanks helps to handle temperature differences during different seasons. Its' very important to get the system stabilized. The farmer has done a great spreadsheet for calculations. Lots of work has been done for the calculation sheet. I will be able to use his spreadsheet to design the system, but it shall not be shared forward. The spreadsheet works for systems under 20 000l.

Figure 26 NFT system in Brisbane. Greens are taken to the farmers markets.

8 CONCLUSIONS

The project has shown the many different details you need to consider when you are building an aquaponic system. The amount of research behind every part that goes into the system without previous experience involved in construction work is huge. I’ve spent several months on finding the information that’s required to understand how every part in the system works. Will the airlift pump work in our system? Good question, airlift pump systems are still so new that there aren’t answers available. As such the only way to find out is through trial and error. The specialists can give you an idea on how big a pump should do the job, but there are no statistics available on how much water and how high airlift pumps can transfer and lift water. There isn’t only one way to build a system, as there are many different ways in how to set up a system. Size, setup, fish, plants; everything can be changed to suit each individual system. Too often I wound myself trying to think too much of every individual part, or getting caught by trying to work out how high each component in the system should be to get it flowing by gravity. Some of the answers were found from the books and internet sources, and some of the answers from the people who were passing by. One of the keys that came from the travellers was from a plumber, as a rule of thumb, for gravity feeding was that for each meter of pipe, descent should be 1cm. This information finally summed out and made the system finally work.

The project has been a true learning process. Many parts were changed during the first month of the system running. One of the challenges has been also to convince people on your ideas and plans, especially if they know something about building or aquaponics. Some parts were made to suit ideas of the builders, and were changed later back to the original idea. There has been also many good points of view that came from the people who were included in the project. A big part of the information that I’ve received didn’t come from the books, there has been the learning curve of trial and error, searching out many possibilities, why something didn’t work and something that was “due to fail” worked better than we expected. One of the comments on the design was from the farmer about the size of the sump, he thought 300 liter sump was too big, and waste of space. By calculations it was very tight measure. Eventually running the system proved that size of the sump wasn’t sufficient and had to be replaced. After researching the filter possibilities, I came to a conclusion that a filter with baffle would be easiest to build, but a plumber thought that it didn’t work well, so it was changed into swirl filter. During the first weeks of testing we ended up taking the swirl filter apart, pipe by pipe as it was restricting the water flow, and getting the right angle was challenging. At the end we ended up rebuilding the baffler filter, and upgrading it to a slightly bigger one. None of the books mentioned that when the system is starting the pH level can be fairly high until the system settles. We were searching the reason from the system itself, and after spending hours and hours on discussion forums there was people with similar experience. Their solution was to keep eye on the system and let the bacteria bring the pH down. Having pH up at 8.2 was sure distressing, even the fish were alive and plants were growing as eventually it would lead to deficiencies in the plants as pH level determines what nutrients are available for the plants. We did lower the pH with phosphoric acid, but it only lowered the pH level for short period of time. After running the system for about a month, it was a relief that the pH level was beginning to come down by itself. The algae growth could have been one of the reasons for the high pH level according to the discussion forums. The pH level is gradually coming down, and further actions will be made. We managed to get the algae growth under control by covering the gutters with timber to keep the sunlight out. The plants are growing well, as an observation especially basil is growing really well. The farm never had any luck with basil, but in the system it's thriving. There has been fertilizers added in the system, and we did not follow all the guidelines on how to cycle the system, but all of the fish are still alive, and growing, and so are the plants. There was a couple plants that didn't make it when we begun cycling the system, that were transferred when they were small, and the system was still turned off for the nights. Finding the right pumps was another story itself. First we begun by running the system with multiple small pumps that were transferring barely enough water to get the siphons work, and after all we ended up running an oversized pump that had to be used with a dimmer switch to regulate the power so the system doesn't over flow. Fish are enjoying the system, as they begun to breed. Cucumber that was planted in the garden died, and the ones planted in the system are thriving.

Trying to work on with paperwork at a working cattle farm brings its own challenges. One day you were planning to do paperwork, but end up mustering cattle or fix up a fence they smashed before they get moved to a different section. Days go by easy, days change to weeks and the group of travellers changes and you find yourself doing the introduction of where everything is at the farm or keeping them lesson on how to tie bowline or truck knot for fencing jobs. Another day you sit down, already open the document and receive a phone call: another farmer nearby needs a hand with something that takes rest of the day. There would have been easier way to build a system, as we used materials that we already had, and we had to make some of them fit the system. Choosing to make a hydrid system as the first system instead of making a simple system brought its own challenges. The amount of work and research would have been enough for a couple of students.

The project has been never the less a good choice for thesis. I've probably used lot more time for research than would have been required for the whole thesis. Lots of information can be found from discussion forums and Youtube videos from private people who've been experimenting with their own backyard aquaponics system for everyone who has the interest. Lots of people have built their systems based on Youtube videos successfully. It's great to see something that you've been planning and preparing for a long time to finally begin to stand up through levelling the base, concreting, cutting the fame with grinder, driving around the paddocks with four wheel drive cars to find a clean IBC tank. Driving it down to the creek to be washed on back of the truck. Overcoming the challenges on how to secure the garden hoops on top hat in way that the building will manage its own weight and the great winds. There's been times when there hasn't been much process to be seen, and then suddenly the frame is up and you are lifting the roof up with travellers from all the way across the world. Australian, Italian, Austrian, German, Korean, Japanese, French, English and many others. Travellers, friends, locals, students from the other side of Australia. All the different skills, ideas, cultures have made the project a great experience. The project continues, even the thesis finishes.

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CHECKLIST FOR PLANNING THE SYSTEM

1. What are you expecting from your system? Are you going to build a home system for you and your family, or are you planning to go commercial?

2. What comes into planning a system? Determining the size of the system is the first step.

3. What type of fish do you wish to grow? Decorative or edible? Ones that you wish to eat, or ones that give you the highest prize at market?

4. What type of plants do you wish to grow? Assortment of different greens for your family or greens to give you the best profit?

5. One pump or two pumps? Water pump or airlift pump. Sump or no sump? What’s your lowest point?

6. How many and how big are the fish tanks you need?

7. Where are you going to build the system, is there any space limitations? Accessibility to water and electricity for pumps is critical. A media bed, raft or NFT system, or perhaps combination of them is possible to achieve.

8. Consider what challenges your climate brings, as your system might need additional heating or cooling, according to seasonal changes in temperature.

9. Do your research on materials that are available locally, as prizes do vary.

10. Will you build the system yourself, or does buying a package system serve your needs better? Building an aquaponics system does take time and effort. You can get an aquaponics system that is ready to start cycling or build your own, building a system from materials that are available does save money, and makes the system unique.

Once you’ve considered what you are expecting from the system building can begin. Once the system is cycling you need to just remember to keep eye on the water quality and overall health of the system. Do your research and don’t count too much on your luck, there has to be a backup system in case of power outage as your fish won’t live long if your pump stops working, therefore having a backup pump ready is a good idea. A media bed system can support a good variety of different vegetables, while an NFT system has its benefits when you are planning to grow lettuce and herbs. You need to be aware that if you have as many fish as the size of your water tank can handle, there might not be much space for error. For example, as a rule of thumb 1kg of fish needs 10l of water, this means 1000l fish tank should be able to support 100 fish. Sounds good? It does as long as everything runs perfectly, until 1 case of failure when you have only a couple of minutes to get the system cycling before your fish begin to stress. It's better to put less fish in to give more time to react to possible problems, for example having 25-30 fish for 1000L is a lot safer to begin with.

It's a good idea to check the local regulations on possible crops and fish species as having noxious species running to wild is a real threat that can already be seen in Australia in form of runaway garden plant lantana that has taken off and takes over the valleys. Charlie carp is a company that uses European carp to make fertilizer, this way cleaning Australian water ways from invasive species. You've probably heard what happened with rabbits that were brought to Australia? Introducing invasive species to a new area is not a good idea. Wildlife is rich as it is. There are many species that are only native to Australia, like most species of gum trees, also known as Eucalyptus and well known koalas and kangaroos.