THE DESIGN OF AN INNOVATIVE AQUAPONIC SYSTEM FOR THE CLIMATE CONDITIONS OF VAN CITY

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Assoc. Prof. Dr. Numan BİLDİRİCİ

PREFACE

The world is facing great uncertainty due to reasons such as global warming, climate change, soil pollution and environmental degradation. Unfortunately, all these developments have negatively affected the general food production situation based on agriculture in almost all countries. All these factors have created great challenges for science in terms of feeding the world and scientists are doing their best to develop technological and scientific innovations in terms of improving food production on a sustainable basis.

Aquaponic farming system is a combination of soilless plant cultivation integrated into fish production ponds to grow fish and plants that are rich in nutrients and human health. Aquaponic systems, if managed meticulously, can produce high-quality agricultural food without the use of pesticides and synthetic fertilizers, with efficient, biosafety levels and minimizing external contamination and disease risks.

An aquaponics system is an intensive, land-based food production technology that uses a combination of aquaculture, the growing of aquatic organisms, and hydroponics, soilless growing of plants. Water used to grow fish and plants is circulated through the system as fish waste is used as nutrients for plant growth. Aquaponics systems are intensive systems, requiring control of the environment in order to optimize growth of both the plants and fish.

Therefore, this study is focused on explaining the applicability, main concept, design models and components of different aquaponic farming systems to raise fish and plants together on a sustainable basis for the Design of An Innovative Aquaponic System Suitable for The Climate Conditions of Van City, inspired by the European Union project we carried out in partnership with Van, Netherlands and Slovenia on Aquaponic Systems between 2018-2021.

This book intends to bring more insights for the understanding of agricultural entrepreneurship in order to cultivate interest in youth into this field. In addition, the book will support the young farmers in order to open up their horizon and change their prejudgment against agriculture and the opportunities that agriculture offers. Moreover, through this book the opportunity will be given to young people to be active in the field of agricultural entrepreneurship and more specifically, in the field of aquaponics. I believe that this book will also contribute to young people improving their agricultural competence and defeating the unemployment monster.

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INTRODUCTION

Agriculture, as we know it today, evolved through initiatives and activities at individual, collective and institutional level worldwide, and it is continuously evolving, providing benefits to all sectors of economy with great impact to natural and socio-economic frameworks. The Agricultural framework has a very important role in the economy of countries at global scale, and is the main source of food, income and employment to their populations.

Aquaponic systems can be examined under two parts. These are closed-circuit polycultural systems where fish and plants are grown together, which are formed by the integration of soilless agricultural systems into fish ponds, where fish are produced in the aquaculture part and plants are produced in the hydroponic part. Water contaminated with fish feces and waste used in fish ponds is continuously circulated in a closed-circuit flowing water system, so that the natural nitrogen in the water is filtered by plant roots and used as a natural nutrient source for plant growth, and the filtered and cleaned water is sent back to the pond. Aquaponics systems are intensive systems, requiring control of the environment in order to optimize growth of both the plants and fish.

Depending on how the water flows between the fish and the plants, an aquaponic system can be categorized as coupled or decoupled.
Coupled systems are designed such that the plants are used to clean the culture water before returning it to the fish tank(s). Decoupled systems are designed in such a way that the rearing water of the fish is only used for plant irrigation, but the water does not return back to the fish tanks. Both systems have their advantages as shown in Table 1.

Table 1. *Advantages of coupled and decoupled systems*

Advantages coupled system	Advantages decoupled system
Simplicity in the design and lower cost	Water parameters can be changed for optimal plant growth, without affecting fish (extra nutrients, pH, temperature)
Complete use of nutrients in the water (zero waste)	The system is less affected by harvesting of either fish or plants (reduction nutrients or reduction filter capacity)

Growing Plants and Fish

In order to manage an aquaponics system, a basic knowledge of fish and plant biology is necessary. For a farmer, plant and fish growth can be considered as the most important factor. This is because the shorter the growth period, the sooner money comes in and the less risk there is for something to go wrong. Growth can be maximized by selecting the fast-growing strains of fish and plants, improving nutrition and controlling the environment optimally. Selection for fast growth is done by carefully selecting reputable suppliers of fish fingerlings, fish eggs and plant seeds. Nutrition is optimized by choosing good quality fish feeds and by taking care that the plants receive extra nutrient supplementation in the water when needed. A good control of the rearing environment is achieved with good design, with good quality equipment, some water quality testing tools and plenty of technical knowledge and experience.

1.1. Fish Biology

The most efficient way of increasing fish growth is to feed more, with protein being the most important component (Somerville et al., 2014). Several water quality parameters have an effect on how much the fish eat and how efficiently they digest their food. Temperature, dissolved oxygen (DO), dissolved carbon dioxide (CO_2), nitrogen (N), pH and solids suspended in the water are among the most important factors influencing the health and growth of fish (Somerville et al., 2014; Timmons et al., 2018). Table 2 summarizes the water quality parameters for optimal growth and their limits for the culture of trout. When the limit is reached, the fish are in danger. The first thing to do is to stop feeding. System water should be exchanged for clean water and the cause of the problem should be addressed.

- **Temperature**

Temperature has a direct effect on the efficiency and the amount of feed that can be consumed (Timmons et al., 2018). The temperature range that fish can endure is species dependent. Within that range, the higher the temperature, the more feed can be consumed. Above the optimum temperature, feed intake and conversion will go down and will result in losing fish (Timmons et al., 2018).

- **Dissolved Oxygen (DO)**

Just like animals on land, fish need oxygen to survive. While there is plenty oxygen (O_2) in the air, dissolved oxygen (DO) is a limiting factor in the water. Because of this, regulating the oxygen concentration in the water is one of the most important parameters to control. Since air contains oxygen, it can be supplied to fish via air. However, with higher stocking densities, higher dissolved oxygen concentrations are required to maximize growth. This can be done by supplying pure oxygen into the system (oxygenation). Oxygen is needed for fish to move around and to digest feed. It has an influence on both the feed intake and feed conversion efficiency. The more feed is put into the system, the quicker DO depletes. If there is not enough oxygen in the water, fish can die within minutes. Temperature and salinity affect the amount of oxygen that can be dissolved into the water. With the use of pure oxygen, higher dissolved oxygen concentrations can be reached. Pure oxygen enables a farmer to increase the fish density by 4x.

- **Dissolved Carbon Dioxide**

When oxygen is consumed during respiration, carbon dioxide (CO_2) is produced. Since CO_2 levels in the air are low, it is easy to transfer CO_2 from the water to the air. Addition of oxygen with air (aeration) will automatically be enough to keep the CO_2 level in the water low. If pure oxygen is supplied (oxygenation), without gas exchange with the air, CO_2 levels can increase in the system. Increased CO_2 limits oxygen uptake by the fish and a device for degassing CO_2 is necessary (Timmons et al., 2018).

- **Nitrogen (N)**

Nitrogen is the main component of protein. Proteins from the feed are converted into fish body mass (fillets, bones, viscera). During this conversion, nitrogen in the form of ammonia (NH_4) is released. NH_4 is toxic for fish. Bacteria convert the toxic NH4 into less toxic forms, first NO_2- and finally NO_3-. This is visualized in Figure 1. Concentrations of NH_4, NO_2- and NO_3-should be measured regularly and kept within safe limits.

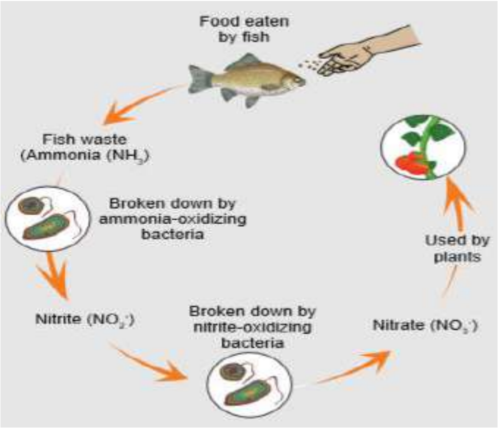

Figure 1. *Nitrogen cycle in an aquaponics system (Somerville et al., 2014).*

- **pH**

pH expresses how acid or basic the water is. Highor low pH can be stressful to fish. However, the way pH affects other water quality parameters is what generally harms fish in aquaculture. For instance, ammonia becomes extremely toxic with a pH above 8 (Timmons et al., 2018). To keep the pH within safe levels, the pH should be kept around 7.

Bacteria that convert ammonia (NH_4 to NO_3), lower the pH. Carbonate alkalinity (CO_3^{2-}) prevents the change of pH in the water. It can be bought for instance in the form of solid calcium carbonate ($CaCO_3$). Per kg of feed 225 g $CaCO_3$ should be added in order to keep the pH at a stable level (Timmons et al., 2018).

Rule of thumb:

To compensate for the alkalinity consumption of converting NH_4 to NO_3, 225g of $CaCO_3$ needs to be added per kg of feed

- **Solids**

After digestion of feed, solids are released into the water by the fish. This, together with feed particles, algae and bacteria contribute to the solid waste of the fish farm suspended in the water. Part of the solids sink and should be transported by water flow to the mechanical filtration. Smaller solid particles stay in the water column, forming the total suspended solids (TSS). When solids levels reach too high, solids can clog the gills of the fish (Timmons et al., 2018). Mechanical filtration, such as settling tanks and drum filters can remove solid wastes from the water.

- **Other Factors**

The above-mentioned parameters are the most important parameters to control good water quality. Besides water quality, there are other factors that influence the performance of fish. Light, crowding, noise, pathogens and feeding strategies are factors that can be important depending on which species is cultured.

Table 2. *Water quality parameters for culture of trout**

Parameter	Range for optimal growth	Limits
Temperature	9-15^{o}C	7- 18^{o}C
Dissolved O_2	6-9 mg/l	>5 mg/l
Dissolved CO_2	<20 mg/l	<30 mg/l
Ammonia (TAN)	<0.1 mg/l	<0.4 mg/l
NO_2	<1 mg/l	<3 mg/l
NO_3	<100 mg/l	<400 mg/l
pH	6-8	6 -8
TSS	<4.5 mg/l	<15 mg/l

***Source:** *Molleda, 2007; Molony, 2001; Timmons et al., 2018; Woynarovich et al., 2011*

When these parameters are kept within optimal limits, the feed intake and efficiency, thus growth, will be optimized and the fish stay alive. In aquaponics systems, the waste products of fish are used to culture plants by using the water from the aquaculture system.

1.2. Plant Biology

Like fish, plants grow using nutrients. However, unlike fish, plants take their energy from the sun instead of the feed. The mechanism for creating this energy is called photosynthesis. Photosynthesis consumes CO_2 and transforms this into glucose, which they use as energy. The glucose enables plants to use the nutrients in the water to grow. For growth, plants need mainly nitrogen (N) to build proteins. Besides nutrient (N) plants need phosphorus (P) for cell divisions, potassium (K) for transport of energy and other reactions and calcium (Ca) for cell walls. Magnesium (Mg) and iron (Fe) are used for chlorophyll, which is the molecule responsible for photosynthesis. Table 3 shows the essential nutrients of plants and their functions. Other parameters influencing plant growth are nutrient concentrations, temperature, humidity, light, pH and dissolved oxygen. An overview of the range for optimal plant growth is given in Table 5.

Table 3. *Functions of nutrients needed for plant growth*

Nutrient	Functions
Nitrogen (N)	Synthesis of proteins for growth
Phosphorus (P)	Cellular division, formation of energetic structures
Potassium (K)	Transport of sugars, formation of starch, stomata control, co-factor of enzymatic reactions, reduces susceptibility to plant diseases

Calcium (Ca)	Building block in cell walls, reduces susceptibility to plant diseases
Magnesium (Mg)	Part of chlorophyll molecule
Sulfur (S)	Synthesis of essential amino acids
Boron (B)	Cell wall formation, germination and elongation of pollen tube, metabolism and transport of sugars
Copper (Cu)	Influences the metabolism of nitrogen and carbohydrates
Iron (Fe)	Chlorophyll synthesis
Manganese (Mn)	Aides in photosynthesis
Molybdenum (Mo)	Component of nitrate-reductase and nitrogenase enzymes
Zinc (Zn)	Auxin synthesis

- **Nutrient Concentrations**

When there are more nutrients in the water, their uptake by the plants becomes easier. When the concentration is too low, plant growth will be reduced. Nitrogen (N)in the water can be in the form of NH_4, NO_2^- and NO_3^- as explained in fish biology. Plants are able to take up some NH_4, but the main form in which plants take up N is NO_3^-. Plants do well in an aquaponics system with NO_3 levels between 10 to 150 mg/l, with an optimum range between 40 to 80 mg/l of NO_3 (Sallenave, 2016).

Increasing nutrients does not always have a positive effect. When there is an abundance of one nutrient it might reduce the uptake of other nutrients. For example excess of P can reduce or block the absorption of K, Cu and Fe (Goddek et al., 2019). Relations of nutrients are shown in Figure 2. Different solutions are available that include all and balance the nutrients. Leafy greens need lower amounts of nutrients compared to fruiting vegetables. Electric conductivity (EC) is a measure of the total nutrient concentration, which is being used to express the total nutrient requirements. EC ranges from 1.2 to 3.0 dS/m for lettuce and tomatoes for instance.

- **Temperature**

Temperature regulates the rate of photosynthesis and thus the speed at which a plant can grow. Photosynthesis increases with increasing temperature up to around 25ºC. After this temperature photosynthesis comes to a stop and most plants will die (**Figure 3**).

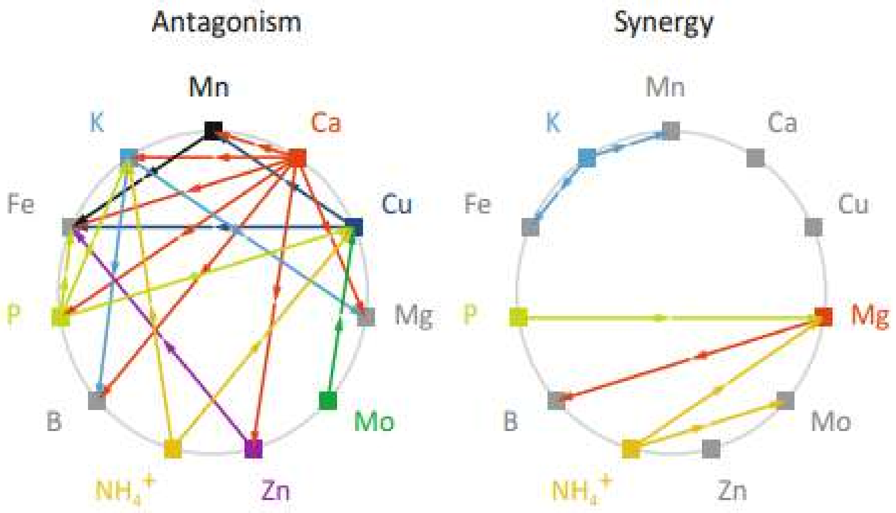

Figure 2. *Nutrients synergies and antagonisms amongst ions. Connected ions present antagonistic or synergistic relationship according to the direction of the arrow (Goddek et al., 2019).*

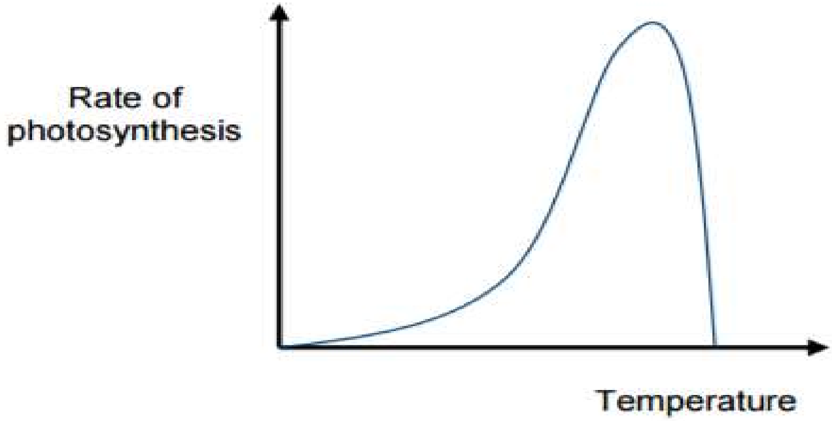

Figure 3. *Rate of photosynthesis with increasing temperature.*

- **Humidity**

Humidity has an influence on the speed at which water and nutrients can be taken up by the plant. When the water evaporates in the leaves, the water is taken up by the roots. There is an optimum speed at which the highest growth can be achieved. The humidity necessary for the right speed at which the water moves is dependent on temperature. On average a humidity of 60-75% is recommended. The humidity should be kept below 70-80% to prevent condensation leading to fungal problems (Baudoin et al., 2013).

- **Light (Wavelength and Intensity)**

Light has different wavelengths; this is visible by it having different colors. Photosynthesis can occur in a range between 400-700 nm. The major molecule responsible for photosynthesis, chlorophyll A, has an optimum at a wavelength of 440 and 675 nm. When using artificial lighting the light should be within this range or at these specific wavelengths.

Besides wavelength, light has certain intensity. When the intensity of the light is insufficient, the plant will not grow well. When the intensity is too high, the plant will not grow. Different plants have different light intensity requirements (Table 4). The light intensity should be between 3 and 18 mol/m^{2}d depending on the crop.

Table 4. *Preferred light intensity of different crop species*

Crop species	Light intensity (mol/m2d)	Natural example
Low-light crops	3-6	Cloudy day in winter (3-5 mol/m^{2}d)
Medium-light crops	6-12	Sunny day in winter (5-10 mol/m^{2}d)
High-light crops	12-18	Cloudy day in summer (10-15 mol/m^{2}d)
Very high-light crops	18	Sunny day in summer (20-30 mol/m^{2}d)

- **pH**

pH is important regarding the availability of nutrients. When the pH is too high, positive ions can bind as (hydr)oxides making them unavailable for plants to take up. Also, calcium can bind to phosphorus making both unavailable for plant uptake. When the pH is too low, sulfate can be reduced to sulfide, which in turn can bind to other elements. The effect of pH on nutrient availability is shown in Figure 4. pH should be kept below 7, with an optimum of 5.5 (Baudoin et al., 2013; Goddek et al., 2019).

A challenge in aquaponics is to find a balance between optimal pH. The optimal pH for plants is at 5.5 (Goddek et al., 2019), fish perform best at a pH of 7 and the bacteria in the biofilter at pH 7.2-8.2 (Timmons et al., 2018). There are two options to deal with this problem. One is to keep the system stable around a pH of 7, where plants, fish and biofilter can grow. This might result in a lower biofilter efficiency and lower plant growth. Another option is to keep the aquaculture system at a pH of 7-7.5 and to reduce the pH of the water with an acid before the water enters the hydroponics system. This ensures higher growth rates and plant quality (Timmons et al., 2018).

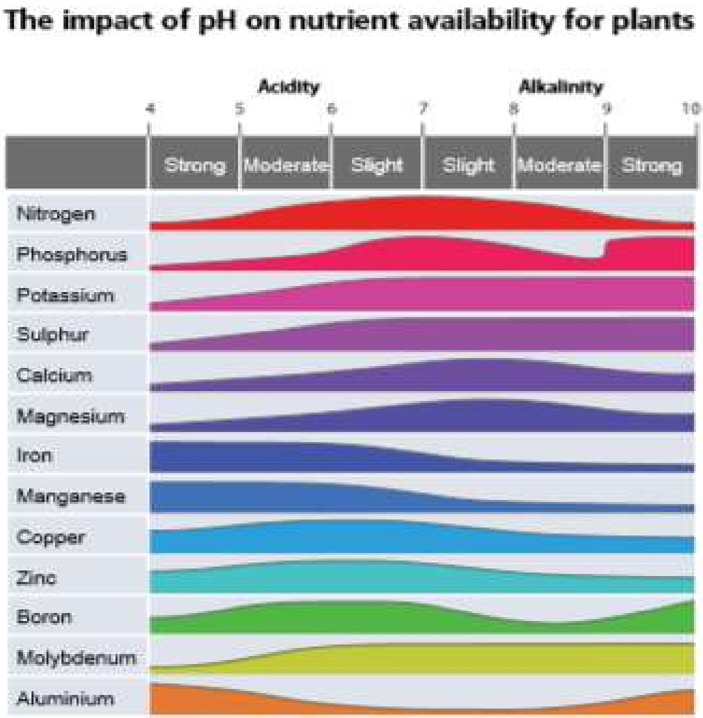

Figure 4. *Nutrient availability at different pH (Somerville et al., 2014).*

- **Dissolved Oxygen**

Dissolved oxygen is one of the fundamental requirements for plant growth in an aquaponics system as it influences nutrient uptake by the roots. DO levels of above 3 mg/l are needed within the system to prevent root-rot and enable proper nutrient uptake by the plant roots (Somerville et al., 2014).

Table 5. *Environmental parameters for optimal plant growth*

Parameter	Range for optimal growth
NO_3	40-80 mg/l
EC	Species dependent

Temperature	25°C
Humidity	60-75%
Light (wavelength)	400-700nm
Light (intensity)	Species dependent
pH	5.5-6.5
Oxygen	>3 mg/l

2. Components of An Aquaponics Farm

Besides biology, knowledge of the components of an aquaponics farm is necessary. A few options are given per type of component, including explanation of different hydroponic systems.

Fish Holding

- **Materials**

The material used for making tanks, pipes and other components of the system are important. Metals should be avoided because they corrode and may end up in the water. Plastic or fibreglass is an example of an inert, durable material with a long life span (Somerville et al., 2014). Lining wood with plastic or fibreglass makes it water resistant, thus providing a cheaper option that can also be used to make tanks for fish and plants. For plastics, polyethylene (PE) and polyvinyl chloride (PVC) are commonly used. They are welded and glued together respectively. The used glue should be friendly to fish, as some types of glue contain chemicals that may leach into the water and kill the fish.

Pipes made of PVC are preferred, because they are inexpensive, safe for fish and consumption of fish and fittings are easily accessible.

- **Growing Tanks**

When designing a farm, the number of growing tanks is dependent on the culture time of your fish and how often the fish can be stocked. The steps are explained by following an example for the culture of trout.

Example:

It takes 26 weeks for trout to grow from 10 to 400 gram. 100 trout of 10g need a smaller tank compared to 100 trout of 400 gram. In order to reduce the size of the farm, the trout will start in a single tank. When the trout is around 35 grams (6 weeks), they are put into 2 tanks. When the trout is around 125 grams (15 weeks), they will be put into 4 tanks until they reach a size of 400 gram. This is visualized in Table 6. A new batch of trout arrives every 9 weeks. The second batch will overlap with the growth cycle of the first batch etc. When the 5th batch arrives, the first batch is fully grown and harvested. At week 27, there are 4 different batches in the farm at the same time, occupying 11 tanks (4+4+2+1). This is the minimal number of tanks needed. This is also the moment most feed is fed to the fish, which is the maximum feed load. A system can be build based on this feed load, or the amount of fish per batch can be adjusted to the maximum feed load at this moment.

Table 6. *Production plan for the growth of Trout from 10 to 400 gram*

Week	1	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54
Batch 1	1 Tank			2 Tanks			4 tanks							Batch 5					
Batch 2				1 Tank			2 Tanks			4 tanks							Batch 6		
Batch 3							1 Tank			2 Tanks			4 tanks						
Batch 4										1 Tank			2 Tanks			4 tanks			

- **Quarantine Tanks**

Since all tanks are connected to the same filtration equipment, all the fish are connected through the water. If a new batch of fish arrives with an infection or parasite, this can spread to the other fish. It is therefore wise to observe the fish in a separate quarantine tank for a period of two to four weeks.

During this period the fish are monitored for parasites and diseases and treatment is provided when needed. If the fish pass through the quarantine period without any disease or parasite signs, they are introduced into the system, sharing the same water with the other fish.

- **Purging Tanks**

Within RAS systems there are certain bacteria that produce compounds resulting in an earthy or musty flavor. These compounds can accumulate in fish resulting in an off flavor. In order to reduce this flavor, the fish are “flushed”. This is done by putting the fish in a purging tank that is not connected to the aquaponic system. The water in this tank is not recycled, but constantly refreshed, thus purging the compounds out of the system. The water from these tanks can be used in the recirculating system, preventing excess use of water.

Water Treatment

- **Mechanical Filtration**

Mechanical filters are used to remove solids from the system. Solids control in RAS and aquaponics is very important, as solids accumulation results in a cascade of worsening water quality affecting the fish, the biofilter and the plants. The negative effects are mostly caused by fast growing heterotrophic bacteria that feed on the solids and consume oxygen (Timmons et al., 2018). In this report two methods of removing solids are proposed, a settling tank and a drum filter. These methods work in different ways. A settling tank (**Figure 5**) works by means of gravity. Water flows without pumping in the tank in such a way that there is no turbulence. The solids will sink to the bottom and remain there, while the clean water continues. Another type of mechanical filtration is by using a screen to filter (**Figure 6**).

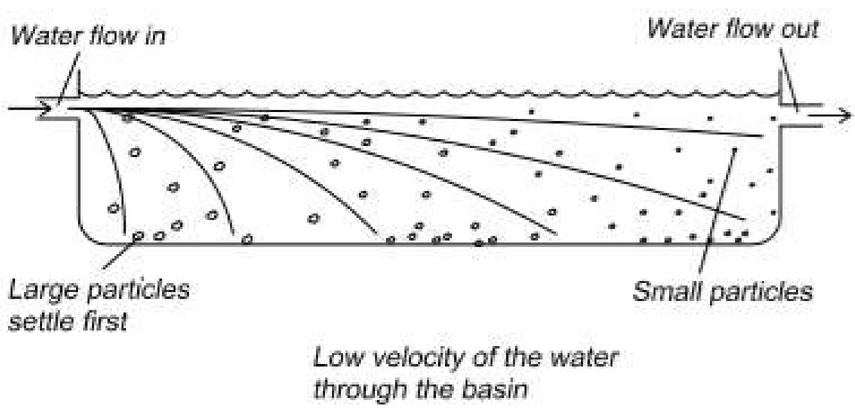

Figure 5. *A settling basin (Lekang, 2013)*

Larger particles compared to the screen are not able to pass the screen, while the water can continue. A drum filter (**Figure 7**) is an example of such filtration. The water passes the mesh, trapping the solids. When the mesh becomes clogged, there is an automatic system that cleans the mesh and removes solids from the system. The minimum size of the particles taken out can be adjusted. In general, a mesh of 60 µm is used.

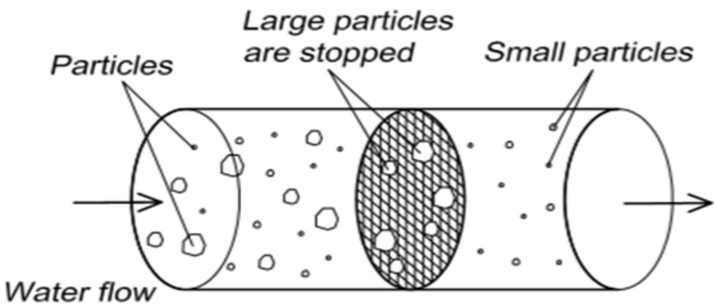

Figure 6. *A static screen (Lekang, 2013).*

Figure 7. *Inside view of a drum filter and backwash mechanism.*

- **Biological Filtration**

Fish excrete NH_4 as wastes. A system called biological filtration involves processes that turn this toxic NH_4into NO_2 and NO_3as explained in the in the fish biology section of this document. Examples of biological filtration are the moving bed bioreactor (MBBR) and trickling filter. In the presence of ammonia and oxygen, bacteria form naturally on any kind of substrate. This will happen not only in the biological filter, but throughout the whole system's surfaces. In order to promote this, biological filters apply techniques to increase the amount of substrate per volume.

The moving bed bioreactor (MBBR) works with media beads (**Figure 8**). These move freely in the water and keep themselves clean by bumping into each other. Air is supplied by for instance aeration stones, in order to keep the water moving and to supply oxygen. This results in favorable growing conditions for bacteria.

Figure 8. *Moving bed bioreactor and media inside.*

A trickling filter (**Figure 9A**) is a column full of media. The water is distributed evenly on the top and trickles down the media. In this way there is plenty oxygen for the bacteria to grow. When combined with a ventilation system, trickling filters can also be used for gas transfer (**Figure 9B**).

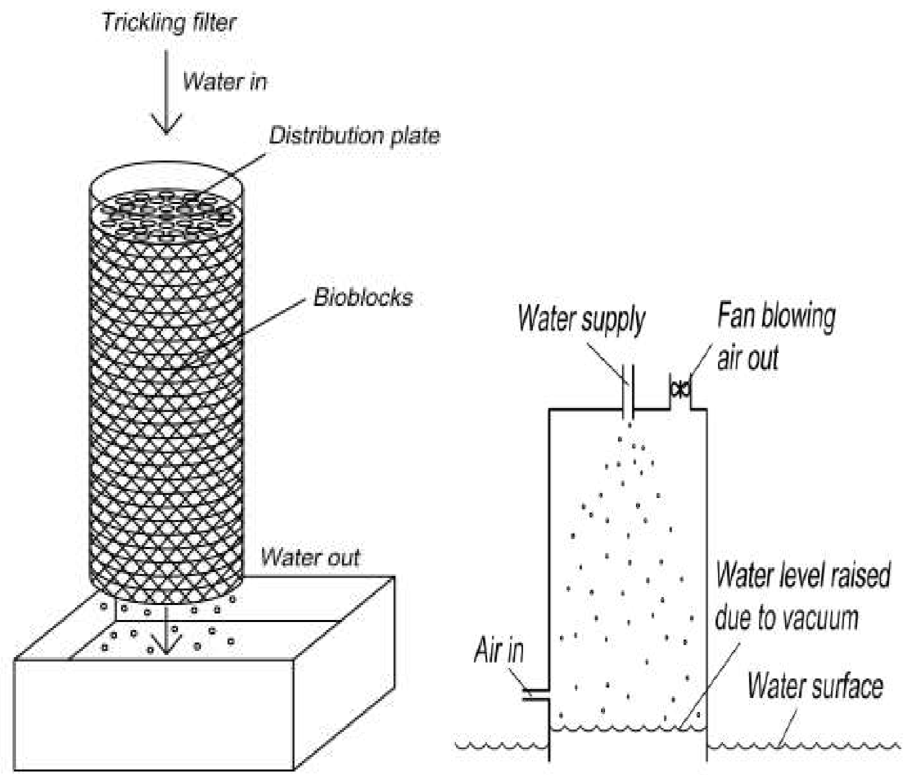

Figure 9. *Trickling tower and combination with gas transfer (Lekang, 2013).*

- **Gas Transfer**

Fish use oxygen and release CO_2in the water. This is compensated by a transfer of gasses from the water and the air. As explained at the point dissolved carbon dioxide in the heading Fish, removing CO_2 from the water is easier compared to adding O_2. When air is used to increase oxygen concentrations (aeration) CO_2 concentrations will be low. When pure oxygen is used to add oxygen to the water (oxygenation) a gas exchange with air is needed to remove the CO_2 from the water (Timmons et al., 2018).

Gas transfer happens everywhere where the air and water meet. To promote natural gas transfer, the water can be spread out over a larger area. This is what happens in trickling filters or CO_2 degassers (**Figure 10**).

Figure 10. *Top view of a CO_2 degasser*

Another way is to blow air or oxygen bubbles in the water by using for instance air stones. This method is however less effective (efficiency of 3-7 %) for transferring oxygen (Timmons et al., 2018) and when using air, can only be used up to 1.5 meter of depth. Below this depth also the N_2 in the air will transfer to the water, which is not desired.

An effective method of injecting oxygen gas in the water is by using an oxygen cone (**Figure 11**). Oxygen cones have an efficiency of 95-100 % reaching values of 30-90 mg/l (Timmons et al., 2018).

Figure 11. *Oxygen cone*

Besides trickling filters/CO_2 degassers, air stones and oxygen cones a common technique for adding oxygen to the water are low head oxygenators (LHO). LHO's combine the technique of trickling filters/CO_2 degassers with addition of oxygen gas. By using oxygen gas, the height of the column can be reduced. This is important for reducing pumping height or for using flow by gravity. An example with explanation of an LHO is shown in Figure 12.

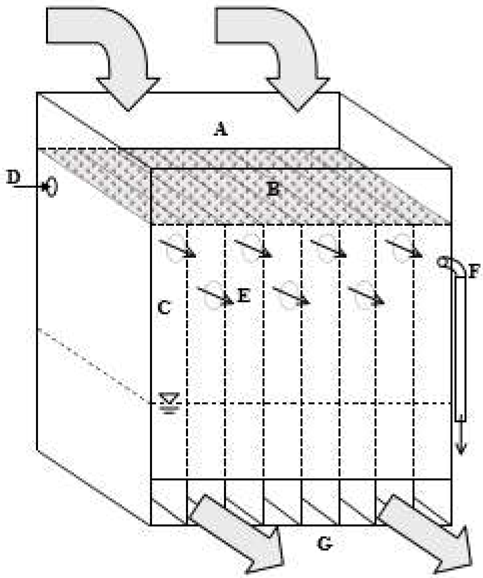

Figure 12. *Low Head Oxygen (LHO) unit. Water is flowing into a collection trough or plate (A), through a perforated distribution plate (B), and is oxygenated in the chambers (C), as gas flows from inlet gas port (D), through holes between chamber to chamber (E), to the off gas port (F), where excess gas is bubbled off under water. Water exits at the bottom of the unit (G) (Timmons et al., 2018).*

- **Fine Solids Filtration**

In recirculating aquaculture (RAS) and aquaponic systems, bacteria (including pathogens) and fine solids (<60µm) cannot be removed by mechanical filtration alone. Protein skimmers, ozonation and UV are techniques that can breakdown the fine solids and kill pathogenic bacteria that are in the water.

- **Sludge Treatment**

With mechanical treatment we collect the solids or sludge from the system. Sludge contains many nutrients that are essential for plant growth. Sludge contains P, K, Ca, Fe, Mg and Mn among others (Timmons et al., 2018). It is therefore a waste to flush the sludge in the sewer. Sludge can be used directly as fertilizer in agriculture using soil. Within the soil bacteria and worms will convert the sludge in such a way that plants are able to take up these nutrients. These processes can also be induced within aquaponics systems in order to make the nutrients soluble and available for plant growth in soilless agriculture. This process is called mineralization, and the reactor is called a mineralization reactor.

3. Example of A Recirculating Aquaculture System

An example of how the water, air and fish move in an aquaculture/aquaponics system is shown in Figure 13. Firstly, water of good quality will enter the fish tanks. Inside the fish tank O_2 will be consumed by the fish and ammonia, CO_2 and solids will be produced. The polluted water will flow to a mechanical filtration device (drum filter). This device will take out most of the solids from the water. After the mechanical filtration, the water will move to a biological filtration device (moving bed bioreactor). This device will convert the toxic NH_4 into the less toxic NO_3. For this reaction oxygen is necessary, which will be supplied with air compressors bubbling air into the water. After the removal of ammonia, the dissolved CO_2 will be removed from the water by a CO_2 stripper. The ventilation of the room is connected to the CO_2 stripper. From here the water will be collected in a sump. The sump is the lowest point within the system and has room for pumps. So far, the water has been moved by utilizing gravity. From here, the water can be pumped to a plant compartment for irrigation. Other additional treatment techniques include part of the water can be treated by a protein skimmers and ozonation to remove fine solids, or water chilling or heating. Before the water will be pumped to the fish tanks, an oxygen cone makes sure there is enough oxygen for the fish. In large farms, oxygen is stored in large cryogenic tanks commonly named LOX tanks.

New water from a borehole will first be heated to the optimal temperature and will enter the system directly after the fish tank. This ensures that the water will be properly mixed and prevents sudden changes in the water that will enter the fish tanks. Before harvest, fish will be put in an off-flavour removal tank. This is a tank where the water is not or minimally recirculated, in order to remove the muddy flavour.

Water from this system can be used to refill the transpired water from the fish growing system.

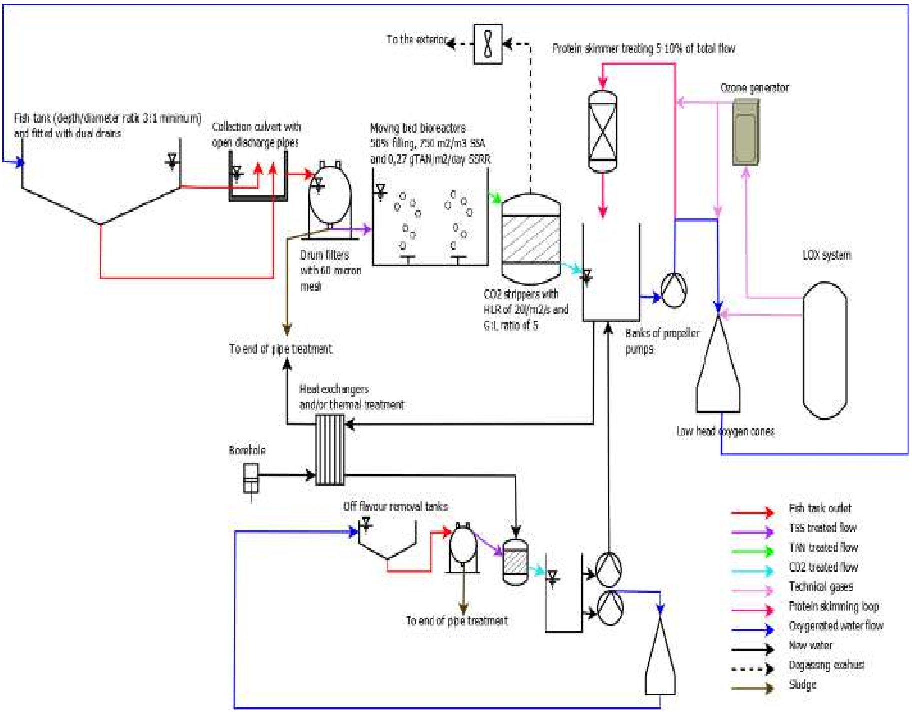

Figure 13. *Flow diagram of an aquaculture system (design by Landing).*

4. Hydroponic Systems

There are various hydroponics systems that can be used in aquaponics efficiently. The choice of which hydroponic system(s) to use in a certain situation will depend on the technical capability of the operators, level of investment, the type of crops (low or high nutrient), external environment (seasons, temperature fluctuations) and the level of intensity needed in relation to the available space. Common hydroponic systems are:

- Nutrient film technique (NFT)
- Floating raft technique
- Media based system
- Ebb and flow table system

Advantages and disadvantages of the systems are shown for each system in **Table 7**(NFT), **Table 8** (Floating raft), **Table 9** (Media based systems) and **Table 10** (Ebb and flow tables).

4. 1. Nutrient Film Technique

The nutrient film technique (NFT) is a common hydroponic system that is applied in aquaponics. This involves the suspension of roots in a channel (**Figure 14**) & (**Figure 15**) through which water with nutrients flow.

This maintains contact between nutrient rich water from the fish tanks and the plant roots. With a 1 or 2 % slope, water from the fish tanks flows by gravity from one end of the channel, passing all plant roots and is collected at the other end.

A flow rate of <57 litres per hour is recommended to ensure proper extraction of nutrients from the water by the suspended plant roots. To prevent that all nutrients are used up in the middle of the channel, length should be maximal 9 meters.

The channel should be covered against light to prevent growth of algae. Seeds can be planted in NFT systems using net pots/ grow pots (**Figure 14**) that contains media like coconut coir, pumice or rock wool.

Example:

A simple PVC NFT system can be made using 10 cm Ø PVC pipes with around 5 cm Ø holes, depending on the size of net pots.

The distance between the holes is dependent on the plant species and size, with an average distance of around 40 cm. Fruiting plants require more spacing because they need more light for fruit bearing (Somerville et al., 2014). A smaller pipe (5 cm Ø) at the start and end of the channels used to limit the flow rate.

The fish tanks and solid filter is building higher compared to the NFT channels, letting water flow by gravity from the fish section through the channels.

After flowing through the channels, water is pumped back and oxygen is supplied before returning to the fish tanks. The fish tank is aerated using a blower and diffusers.

Rule of thumb
The slope of NFT channels should be 1 to 2 %, a flow rate of <57 liters per hour and channel length < 9 meters.

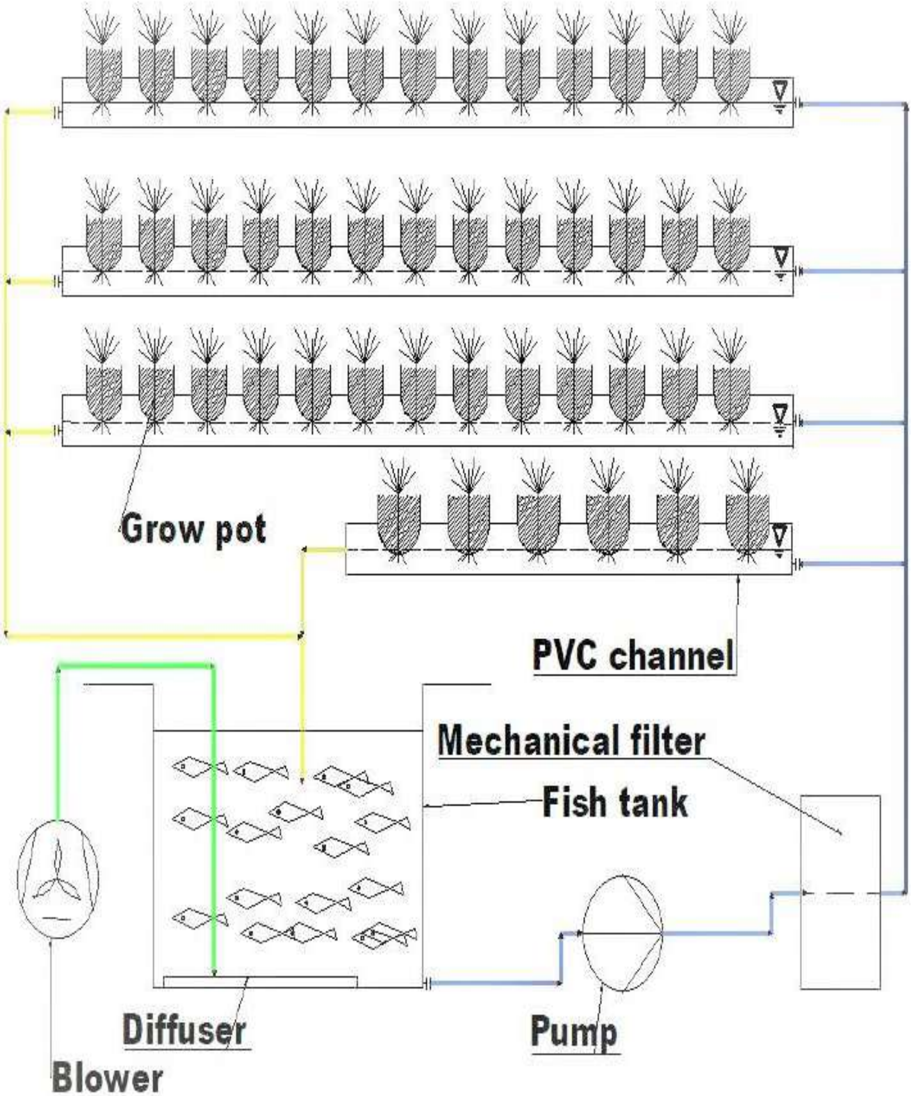

Figure 14. *Diagrammatic representation of the nutrient film technique.*

Figure 15. *Greenhouse NFT channels for lettuce (a) and a grow pot of one showing lettuce roots (Merwe, 2017).*

Table 6. *Advantages and disadvantages of nutrient film technique*

Advantages	Disadvantages
• **Small weight of the whole system** • **Can be constructed vertically** • **Low evaporation**	• Sensitive (difficult management) • Nutrient solution needs cooling during summer • Roots can block water flow through gutters • Need for good solid filtration

4. 2. Floating Raft Technique

Floating raft is the most common hydroponics technique employed in aquaponics due to the easy setup and operation (**Figure 16a**). The system uses floating rafts with holes. Plants are kept in the holes, with their roots submerged in the water column (**Figure 16b**). Young plants from nurseries are introduced into the raft system in net pots. Materials used for rafts are expanded polystyrene, plywood, foam and guttering pipes.

Figure 16*. An operational full raft aquaponics system (a). (b) Shows the roots of plants in grow pots with a raft lifted up (Nelson and Pade Inc.).*

Example:

Water from the fish tank flow through a settling tank. After the settling tank, the water goes through a mechanical filter and is pumped to the trough with floating rafts. This trough is 4x1x0.5m (lxbxh) with 4 rafts of 1x1m (lxb). Between all rafts, a diffuser provides oxygen to the plants. From the end of the plant compartment, water flows back by gravity to the fish compartment which is also aerated by a blower and diffuser (**Figure 17**).

Rule of thumb
Tanks should be at least 0.5 meter deep. Rafts should almost fully cover the water to prevent growth of algae.

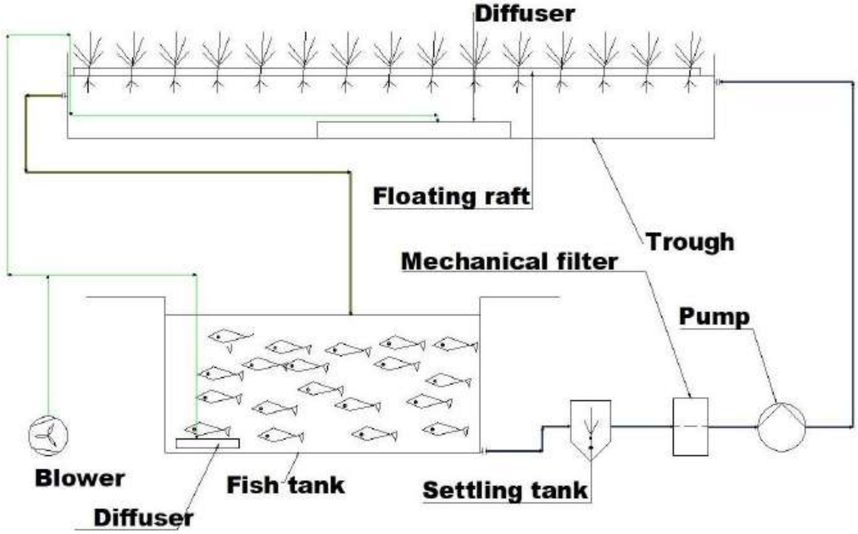

Figure 17. *Diagrammatic representation of the Floating raft technique.*

Table 8. Advantages and disadvantages of floating raft technique.

Advantages	Disadvantages
-Big water volume, no sudden changes in water quality and temperature. -Rafts can be moved around for easy planting and harvest.	-Big water volume, relatively less air/water exchange, more energy to maintain dissolved oxygen levels. -Plants are not on standing height.

4.3. Media Based Systems

Media based systems are the simplest aquaponics systems. Plants are grown in media beds that are supplied with nutrient rich water. The media provides area for the roots to attach as opposed to other systems where the plants float on water. The media to use in these systems are biologically inactive. Gravel, pumice stones and lightweight expanded clay aggregates (**Figure 18**) are often used as media. Gravel should be limestone free as this influences the pH of the system.

Figure 18*. An expanded clay aggregates media bed for aquaponics with various plants* (Castelo, 2019).

Example:

Water is pumped once every 2 hours from the fish tank into the media bed. After passing the media bed, water is flows by gravity back into the fish tank, leaving the media dry until water is pumped in again (**Figure 19**). The fish tank is aerated using a blower connected to diffusers in the tank. When the media bed is clogged by too much solids, the media is taken out of the bed and rinsed.

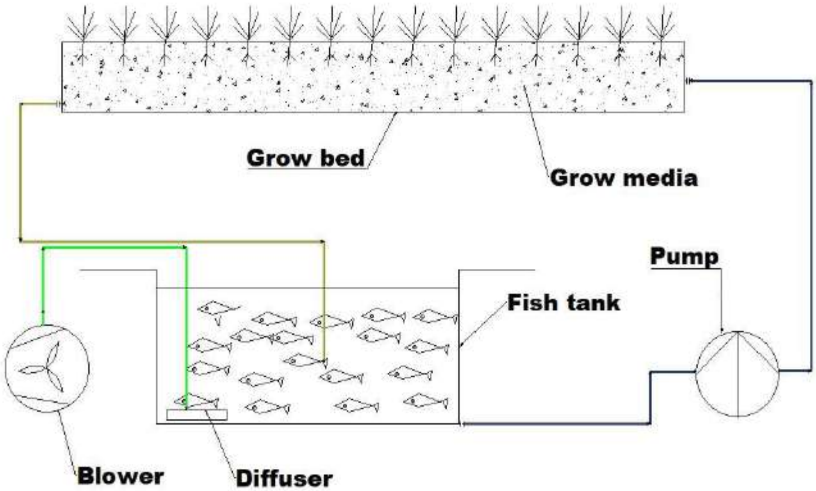

Figure 19. *Diagrammatic representation of a media-based aquaponics system.*

Rule of thumb
An ebb and flow watering system ensures sufficient oxygen for plants and bacteria.

Table 9*. Advantages and disadvantages of media-based systems*

Advantages	Disadvantages
-Easy to build -Can be of any size (big or small depending on one's choice) -Can support growth of worms in media which can be fed to the fish	-Buildup of anaerobic zones when there are too much solids in the media bed -Media needs occasional cleaning

4. 4. Ebb and Flow Tables

Ebb and flow tables are a hydroponics system where plants are cultured in pots. Plants in pots with media are placed on a growth table that is periodically flooded with nutrient rich water (**Figure 20**). During flooding; the plants are supplied with nutrient rich water, while after draining the roots are exposed to oxygen. The water is pumped on the tables for about 15 minutes every hour. There are drain channels in the table to ensure proper drainage. Tables are on standing height and can have a rolling system to reduce the farm size.

Figure 20. *An ebb and flow table for the growth of basil and mint (Fishglashouse, Rostock University).*

Example:

Water is pumped from the fish tank to the hydroponic area using a submersible pump placed in the fish tank and flows back by gravity. The pump is activated every 1-2 hours for 15 minutes (**Figure 21**).

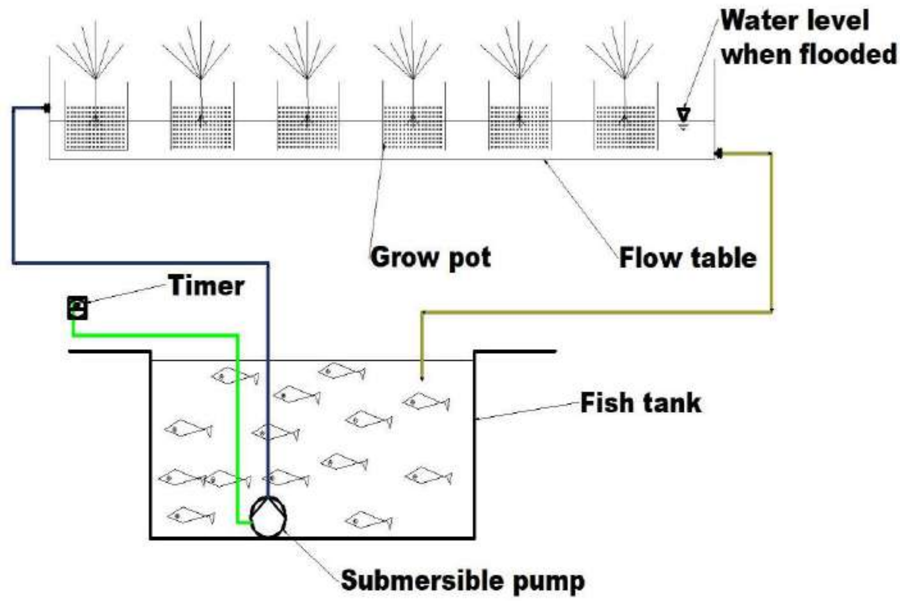

Figure 21. *Diagrammatic representation of ebb and flow table aquaponics system.*

Rule of thumb
About 15 minutes is needed for the plants to take up enough water before draining. Drain channels ensure proper draining.

Table 10. *Advantages and disadvantages of Ebb and flow tables*

Advantages	Disadvantages
• Easy maintenance • Comfortable working height • Plants are in pots for selling	• High technology costs (timed pumps) • Use of pots and media

5. A Set of Design Rules of Thumb for System Sizing and Design

Before a system can be designed, a production target and a production plan are made. The production target is based on a market study, a budget and/or the available space for production. After making a production plan, the total daily feed load can be calculated. Based on the feed load, the equipment needed to treat the water is determined and sized. When all the tanks and equipment is known, a technical drawing of all components, including piping, is made.

6. System Sizing/ Production Plan

6.1. Species Selection

In order to determine which species is cultured, there are a few things that must be considered:

• The sensitivity of the species and the experience of the manager

- The market demand for this species
- The compatibility of the species with your climate, or the capital investment needed for full climate control
- The source of fingerlings, seeds and feed
- Are they of good quality and can they be frequently supplied?
- Is there more than one supplier available?

- **Fish**

When planning an aquaponics system, the suitability of the fish forgiven aquaponics system needs to be considered. Various species of fish have been reported to be successful in aquaponics including; tilapia, common carp, catfish, trout, largemouth bass, barramundi and crustaceans like prawn(Somerville et al., 2014). Of all the fish species used in aquaponics tilapia is most adaptable due to its tolerance to a wide range of pH, temperature and other conditions. Hybrid striped bass is not a good fish for coupled aquaponics systems, because it cannot tolerate the high levels of potassium that are sometimes added to improve plant growth. Capital and production costs for making a system work should be considered.

Rule of thumb
Warm freshwater fish are best suited for aquaponic systems, since most plants prefer freshwater or around 25°C.

- **Plants**

Plant selection depends on the concentration of nutrients coming from the fish. This is regulated by the stocking density of the aquaculture system. Low stocking densities (<20 kg/m^3) can accommodate plants with low nutrient demands while high stocking densities (>60 kg/m^3) can support plants with high nutrient demand. Fruiting plants require higher nutrient concentrations compared to leafy greens. Examples of plants with low and high nutrient demand are given in Table 11.

Table 11. *Examples of plants demanding a low and high nutrient concentration*

Low nutrient demand	High nutrient demand
Spinach	Tomatoes
Chives	Cucumber
Watercress	Pepper
Lettuce	Cabbage
Arugula	Peas
Basil	Broccoli
Mint	Beans

Plant resistance to pathogens and their ease of control should be observed when selecting a good plant to use in an aquaponics system. To minimize diseases in a system, seedlings should be purchased from nurseries that have good disease prevention strategies.

Rule of thumb

Plants with low nutrient demand can be cultured with stocking densities <20 kg fish/m^3, culturing plants with high nutrient demand requires >60 kg fish/m^3 or addition of nutrients.

6.2. Stocking Strategy

In an aquaponics system, a stocking plan should be put in place. The stocking will make sure that at any given time there is enough fish to supply plants with the required nutrients. In the case of a coupled system there should also be enough plants to extract all the nutrients produced by the fish. For this, staggered production is the solution: Plants and fish of one size are put in groups in the system. Every few weeks a new group enters the system. In this way, there are always fish and plants that can be harvested. When one batch of fish is harvested, there are other batches of fish in the system providing nutrients for the plants. In turn, when one batch of plants are harvested there are still other plants to take up the nutrients provided by the fish.

6.3. Fish Growth Modelling

To determine the feed and size of the system, the growth of one batch of fish must be determined. Relative to their size, fish can eat and grow faster when they are young compared to when they become mature. By using a growth model, the time and feed required to grow a fish can be calculated.

Example:

Trout will take approximately 26 weeks to grow from 10 to 400 gram (**Figure 22**).

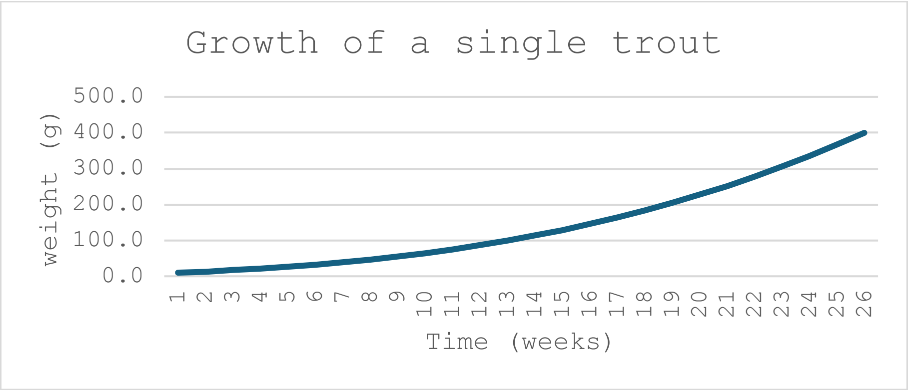

Figure 22*. Growth curve of trout from 10 to 400 gram.*

6.4. Feed Load and Production Terms

Based on the growth and feed intake, the feed load of a single batch of fish can be calculated. The feed load of the system increases as the fish grow.

Example:

When 1250 trout are stocked with a size of 10 gram, the total biomass of the fish is 12500 (1250*10) gram or 12.5 kg (12500/1000). These fish eat 1.5 % bodyweight, which is 0.19 kg feed per day (12.5*(1.5/100)). One week later, the trout are 13 g and eat 0.24 kg feed per day. Table 7 shows the amount of feed needed per week for a batch of 1250 trout. In Figure 23, the feed load of one batch of trout growing from 10 to 400 g is calculated per week.

***Table** 12. Feed load per week of a batch of 1250 trout growing from 10 to 400 g. Trout weight is the weight of a single trout; feed load is in kg feed per week for the total batch*

Week	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**
Trout weight (g)	10	21	39	64	99	146	205	278	366
Feed load (kg/week)	1,4	2,9	5,3	8,8	13,7	20,0	28,1	38,1	50,3

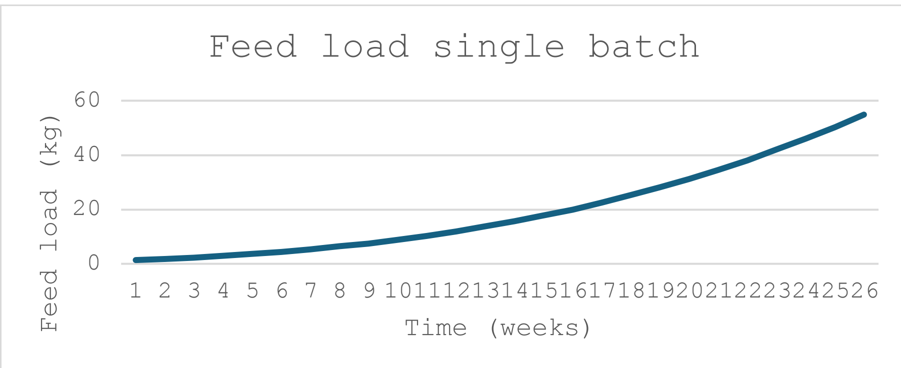

***Figure 23**. Feed load of a batch of 1250 trout growing from 10 to 400 g.*

With staggered stocking strategy, there are more batches of different sizes on the farm at the same time. Since the fish are connected via the same water, the feed load of these batches is added.

Example:

Figure 24 shows the result of stocking 1250 trout fingerlings (10g) every 9 weeks, resulting in a production of 2300 kg trout in the first year (no mortality) and 2900 kg in subsequent years. The feed load increases as the fish grow and as more batches are added (steeper growth). When a batch is harvested the feed load drops and increases again. The maximum total feed load of the system is 84 kg per week or 12 kg per day. The farm can be designed based on this information. If, for any reason, the farm is not able to handle the feed load, batch sizes or number of batches can be reduced. In general, more batches are preferred, as this reduces variation in the system. The supplier of fingerlings should be contacted to ensure the production plan is possible.

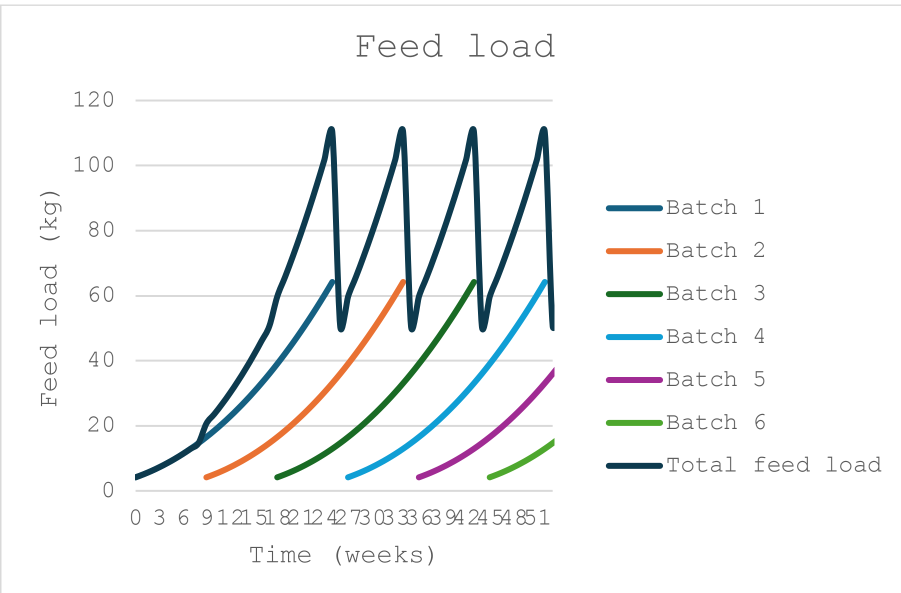

Figure 24. *Total feed load and feed load per batch for growing 1250 trout from 10 to 500 g.*

6.5. Plant Production-Plant Growth Modelling

The growth of plants can be modelled in the same way as the fish. The "Feed load" of plants is NO3 demand and is limited by the aquaculture production. As a rule of thumb, 30 g Ammonia-N is produces per kg feed. If all ammonia is converted by the biofilter, this will result in 30g NO_3-N per kg feed.

Rule of thumb
There is 30g N per kg feed in the water.

Example:

Continuing with the example of a trout farm producing 2300 kg of trout a year, the feed load is converted to NO_3-N production using 40 g N per kg feed. The result is shown in Figure 25. The average NO_3-N within the system is 2.25 kg N.

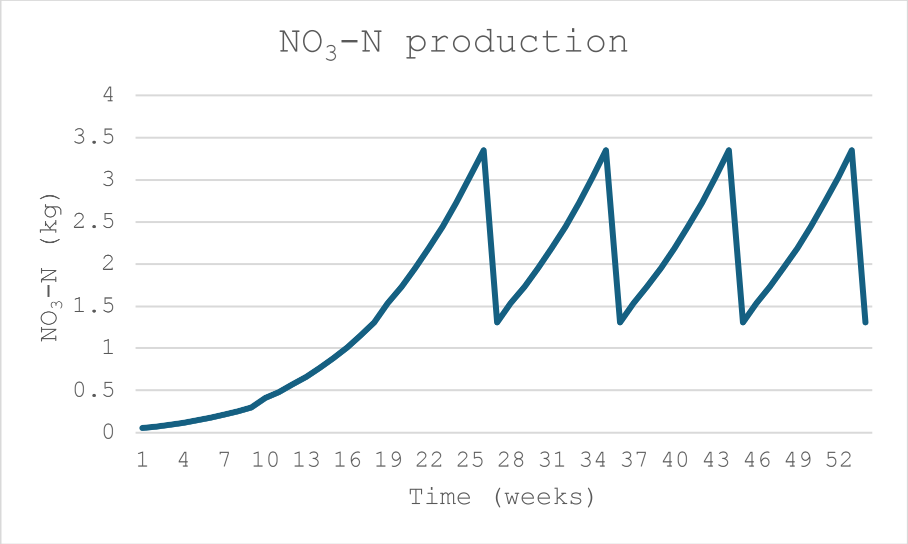

Figure 25. *NO_3-N production of a trout farm stocking 1250 fingerlings (10g) every 9 weeks, fed with 1.5 % BW.*

As a rule of thumb, for every kg of feed fed 17.5 m^2 of leafy greens can be fertilized in a hydroponic system (Rakocy, 1989). When fruiting vegetables are cultured, this area will be smaller. When nutrients are added, either from solution or by utilizing the sludge (see Sludge treatment); this area can become bigger.

Rule of thumb
17.5 m^2 of leafy green area is needed to remove the N of 1 kg fish.

- **Basil**

Basil production is divided in a nursery area and grow-out. Basil can be cultured in all hydroponic systems, with no differences in production between NFT and Floating raft technique (Walters and Currey, 2015).

In the nursery, seeds germinate and grow to seedlings in 7 days. Density of seedlings can be up to 40 plants/m^2 (Somerville et al., 2014). After this period the seeds are transplanted to the grow-out area.

In the grow-out area the seedlings are grown for 5-6 weeks in which they can either be continuously harvested (starting from when they are 15 cm) or sold as a plant. When basil is fully grown there should be no more than 8 plants/m^2 (Somerville et al., 2014).

Example:

To prevent depletion of all nutrients, the hydroponics area (excluding nursery) will be 1050 m^2, this is calculated based on a feed load of 60 kg fish feed (60 kg*17.5 m^2). As an example, basil is grown on ebb and flow tables. When stocking every 3 weeks, 3 sets grow-out tables are needed (Table **13** 13). Each set will have a size of 350 m^2 (1050/3) and have 2800 basil plants (350m^2*8 plants/m^2). The nursery area will be 70 m^2 (2800 plants/ 40 plants/m^2).

Table 13. *Stocking strategy of basil*

<table>
<tr><th>Week</th><th>0</th><th>3</th><th>6</th><th>9</th><th>12</th><th>15</th><th>18</th><th>21</th><th>24</th><th>27</th><th>30</th><th>33</th><th>36</th><th>39</th><th>42</th><th>45</th><th>48</th><th>54</th></tr>
<tr><td>Table 1</td><td colspan="3">Batch 1</td><td colspan="3">Batch 4</td><td colspan="3">Batch 7</td><td colspan="3">Batch 10</td><td colspan="3">Batch 13</td><td colspan="3">Batch 16</td></tr>
<tr><td>Table 2</td><td></td><td colspan="3">Batch 2</td><td colspan="3">Batch 5</td><td colspan="3">Batch 8</td><td colspan="3">Batch 11</td><td colspan="3">Batch 14</td><td colspan="2">Batch 17</td></tr>
<tr><td>Table 3</td><td></td><td></td><td colspan="3">Batch 3</td><td colspan="3">Batch 6</td><td colspan="3">Batch 9</td><td colspan="3">Batch 12</td><td colspan="2">Batch 15</td><td colspan="2">Batch 18</td></tr>
</table>

- **Mint**

Just like basil, mint can be harvested continuously. When pruned and harvested correctly, there is no need to replace the plant. Mint seeds are not reliable, new plants can be grown by using a cut from another plant (Bradley and Ellis, 1992). The selection of mother plant is important, since the cuts will produce clones. An area can be made in order to produce the most potent mother plants.

Example:

1050 m^2 of ebb and flow tables are used to produce mint plants in pots. The mint plants are continuously harvested and pruned. Part of this area is used to produce and sell whole plants depending on market demand. 100 m^2 is dedicated to produce better mother plants and start new cuttings.

7. Design of The Farm

When the feed load of the farm is determined, all components can be sized according to the maximum feed load. In this section, a set of sizing rules are provided.

7.1. Equipment Sizing

- **Fish Tanks**

A properly designed fish tank should be able to mix the water and remove the solids produced by the fish. In rectangular and squared tanks, corners may create zones where solids accumulate and water is not properly mixed. Solids in the system should be cleaned to prevent consumption of oxygen and production of toxic substances such as ammonia (Somerville et al., 2014). The consumption of oxygen by these bacteria and the products which they can produce reduce the growth of fish and may be harmful. In order to reduce "dead zones" round or octagonal tanks are recommended (**Figure 26**).

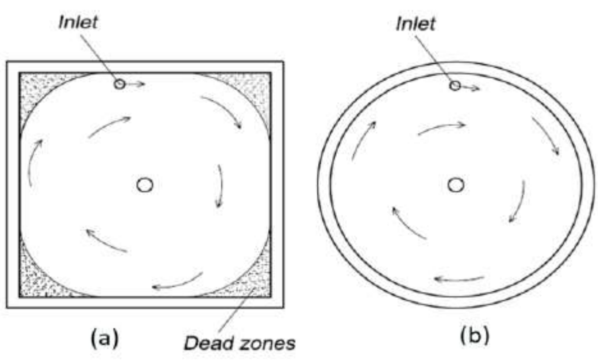

Figure 26. *Effect of rectangular tanks on water mixing (a) as opposed to circular tanks (b) (Lekang, 2013).*

These tanks reduce dead zones by maintaining a circular flow to ensure even distribution of influent water into the tank. To ensure the removal of solids within the tank and optimal use of the space by the fish a ratio of diameter: depth of 3:1 is advised. The size and number of the tanks is dependent on the fish production.

- **Size and Number of Tanks**

The amount of fish that can be held within a single tank can be expressed in fish/m^3 or kg/m^3. For each commonly cultured species a maximum density can be found in literature. Densities are usually expressed in kg fish/m^3 and vary depending on size. Our ability to supply the fish with oxygen will determine the stocking density. For intensive trout culture where pure oxygen can be supplied, fingerlings can be held at a density of 45 kg/m^3, juveniles around 80 kg/m^3 and grow-out at densities of 100 kg/m^3. As mention in ***Error! Reference source not found.*** and Gas Transfer, when no pure oxygen is supplied the maximum density is 4x less. Sizes for the different life stages and an example are given. An overview is shown in Table 14.

Because fingerlings have less weight, more small-sized fish can be stocked in a tank compared to bigger fish. The number of fish/m^3 in a tank is reduced when fish grow as the amount of kg/m^3 increases with growth. To give an idea of stocking densities, an example of three sizes of trout is given.

- Fingerling trout starting from 10g
- Juvenile trout starting from 35g
- Grow-out trout starting from 100g

Example:

1 batch of 1250 larval trout (10g) can be put into a single tank of 1 m^3. They will grow to 35g in this tank, resulting in a stocking density of 1250 fish / m^3 or about 45 kg / m^3 assuming no mortality. When the fish become 35g they will need more space. The fish are therefore split into 2 tanks of 1m^3 until they are 100g, resulting in a final density of 625 fish / m^3 or 62.5 kg / m^3. For the final stage the fish can be put into 4 tanks of 1 m^3 for growing until a harvest size of 400 g. This is a density of 250 fish / m^3 or 100 kg/m^3.

This data shows the maximum amount of fish that can be cultured assuming the water quality can be maintained. Increasing density and decreasing water volume will always increase the difficulty of operating the system. This also regulates the amount of variation allowed and the speed at which you will lose fish. It is therefore advised to start working with higher water volumes and lower fish densities, before increasing production.

Table 14. *Overview of stocking densities of trout Fingerling, Juvenile and Grow out sized trout with and without pure oxygen supply*

				Without pure oxygen supply		**With pure oxygen supply**	
Size class	Size of the fish (g)	Size of the tank (m^3)	Number of tanks	Density of the tank **(fish/m^3)**	Density of the tank **(kg/m^3)**	Density of the tank **(fish/m^3)**	Density of the tank **(kg/m^3)**
Fingerling	10-35	1	1	312.5	11.25	1250	45
Juvenile	35-125	1	2	156.25	20	625	78.125
Grow out	125-400	1	4	62.5	25	250	100

Rule of thumb

Based on an average density of 15 kg fish/m^3, the system volume increases with 4.44 m^3 per kg feed. With oxygen the average density can be increased up to 60kg fish/m^3resulting in a system volume of 1.11 m^3 per kg feed.

7.2. Flow Requirements

In order to remove the solids from the fish tanks, a turnover of 2x the tank volume per hour is necessary. Running the system on 2.5-3x the tank volume allows room for starting up the system and room for variability without affecting fish. All equipment should be sized accordingly to reach safe water quality.

7.2.1. Flow Water Treatment

In order to reuse the water coming from the fish tanks, the water needs to be treated. This process involves filtration of wastes from the water and the transfer of gases (O_2 and CO_2).

There are two types of filtration (mechanical and biological) used in aquaponics systems of which examples have been given (Water treatment). Advantages and disadvantages of mechanical and biological filtration are given in Table 15 and gas transfer methods in Table 16.

__Table 15__. Advantages and disadvantages of biological and mechanical filtration methods that can be applied in aquaponics

	Method	Advantages	Disadvantages
Mechanical filtration	Settling tank	Low technology	High surface area, labor intensive, smaller particles remain in the water
	Drum filter	Filters specific sizes of particles, area efficient Small surface needed	Expensive
Biological filtration	MBBR	simple and flexible, self-cleaning	Less resilient to changes
	Trickling filter	Biological and CO_2 filtration in one	Water must be pumped high, if solids accumulate within the filter efficiency will drop rapidly

***Table 16.** Advantages and disadvantages of gas transfer methods that can be applied in aquaponics.*

	Method	Advantages	Disadvantages
Gas transfer	Trickling filter	Biological and CO_2 filtration in one	Water must be pumped high, if solids accumulate within the filter efficiency will drop rapidly
	CO_2 stripper	Efficient way of stripping CO_2, especially when integrated with the room ventilation	Water must be pumped high
O_2 addition	Aeration stones	Easy to move, turn on and off	Low efficiency
	Oxygen cone	Very efficient	Difficult to engineer, can block if water flow is not sufficient
	Direct injection of oxygen	No need for a separate device	Less efficient
O_2 addition and gas transfer	Low head oxygenator	Good for large volumes of water, low height, both O_2 addition and CO_2 stripping	Depending on engineering O_2 may not be used efficiently and CO_2 stripping may not be sufficient

Sizing of filtration devices is done by using single pass efficiency. Calculating with a flow of 2x turnover of the system and a volume of 1.11 m^3 per kg of feed, the minimum sizes of each filter is calculated in Table 17.

An explanation of the filters is given in the heading water treatment.

Table 17*. Sizing of the filtration per kg of feed with relevant information*

	Increase in size per kg feed added	**Other information**
Mechanical filtration		
Settling tank	2 m^2	Filters only particles >100µm, solids should be cleaned/ removed manually; design should be such that there is no turbulence within the tank. Depth is advised to be kept at 1 m.
Drum filter	1.2 m^3/h	Drum filters are sized by flow capacity.
Biological filtration		
MBBR	0.3 m^3	50% fill with media of 750m^2/m^3 height of 1 meter is advised.
Trickling filter	0.35 m^3	Media of 200m^2/m^3, trickling filter should be increased in height
CO_2 filtration		
Trickling filter	When an air flow is ventilated through the trickling biofilter CO_2 is removed from the water. Measure the total volume of the room or building where your system will be located, multiply that volume by 2. That volume ventilated per hour, through the	

	trickling filters (using fans), will be enough to keep CO2 under control.	
CO_2 stripper in combination with MBBR	0.03 m^2	The efficiency of the CO_2 stripper is dependent on the height of the tower and air coming through. Ventilate 2X building volumes through a stripper column that 2m tall.
O_2 addition		
Oxygen cone	Height: 0.36*Feedload^0.5 Base diameter: 0.16*Feedload^0.5	The size of the cone is given by a formula. The water flow should be high enough to ensure all gas will be taken up. When the water flow is not sufficient a gas bubble will form in the cone blocking the system.
Low head oxygenator	0.02 m^2	As a rule of thumb, the LHO should be 0.5m high. Additional CO_2 stripping is needed dependent on stocking density.

7.2.2. Pumps and Pipes

Water transport and flow around an aquaponics system is much dependent on the choice of pumps and pipes used around the farm.

- **Pipes**

It is advised to use bigger pipes and avoid a lot of connections when designing an aquaponics system. Bigger pipes may appear more expensive but become cheap in the long run as they create less friction, making water movement easier and pumping costs lower.

Example:

Rearing tanks with a volume higher than 7 m^3 need a80mm diameter pipe to properly supply water from the sump over a height of close to 1.2 m (Timmons et al., 2018). A small aquaponics system with a volume of 1m^3 should have a minimum pipe diameter size from the pump to the rearing tank of 20 mm up to 50 mm depending on the height the water has to move (Aragon, 2019).

Elbows increase the friction, thus the energy needed to move the water. Pumping energy can be reduced by having as less pipe connections as possible in the system. Friction can also be reduced by using elbow sweeps/ bends instead of regular elbows as their angles are less sharp (**Figure 27**).

Rule of thumb
Smaller pipe size = Less cost, but more friction in pipes
Bigger pipe size = Larger cost but alleviation of friction in pipes

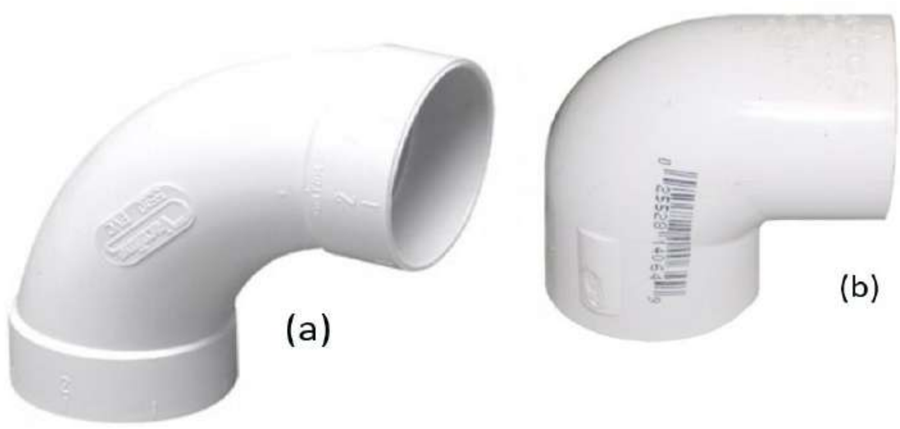

Figure 27. *90-Degree elbows. (a) is an elbow sweep/ bend and (b) is the normal 90-degree elbow.*

In all systems, there is a chance that poor pipe sizing can lead to flooding of the plant beds when the rate at which water enters the beds is higher than the rate at which it leaves. Flooding is avoided by having a bigger pipe coming from the beds as compared to the pipe that brings water to the beds.

Rule of thumb
In hydroponics systems using beds, the pipe removing water from the beds is always bigger than the pipe taking water into the beds.

- **Pumps**

The pump should be strong enough to move water around the aquaponics system but at the same time economical. The choice of pump depends on both the quantity of water transported and the height the water is moved. A good pump should be able to circulate the entire system water at least every two hours.

Example:

In an aquaponics system with a total water volume of 50,000 liters one would require a pump that will be able to move at least 25,000 liters per hour. Cheap pumps are liable to wearing out easily, which may crash the whole system. Using two durable pumps at half capacity ends up being the better option to use. When one pump fails, there will be another pump that can keep the farm running. A new pump should be installed as soon as possible.

Centrifugal pumps are the most common pumps for moving water around an aquaponics system, while submersible pumps are used to draw water from for instance underground wells (Lekang, 2013). Submersible pumps are also used to transport water from a sump.

The pumping costs in an aquaponics system can be reduced the more gravity is used. This depends on the system design of the fish tanks in relation to the plant section. Most small aquaponics systems would target a flow of water by gravity from the fish tanks into the plant system and pumping of water from the plant system. To achieve this fish tanks are set slightly above the plant level. The height of fish tanks will depend on the pressure needed to achieve the required flow rate into the plant section. However, a large difference in height may lead to high pumping costs.

Equipped with information about the flow needed and the height between the lowest and highest point of the system, the right pump can be selected. Flow and height (Total Dynamic Head) of the pump are given in the performance chart set by the manufacturer. However, the friction losses in pipes should also be considered and this increases with both the distance and the number of fittings used. More information about the height and flow can be obtained from the manufacturer manual or the pump supplier.

Example:

The graph below shows pump height against gallons per minute (GPM) for various pump series by a manufacturer (**Figure 28**). A system needs a pump to move 25.000l per hour at a height of 2 meter. This is 416l per minute (25.000l/60 min) or 110 GPM (416/3.785) at a height of 6.56 foot (2 m*3.281). The pump L3-120-AQ can pump 110 GPM only 5 foot; therefore the L3-160-AQ is needed. A pump above your pumping requirement is always preferred. To reduce the risk of losing fish when the pump fails, it is advised to install two pumps. In this case the flow requirement per pump is 55 GPM (110/2) and two L3-100-AQ pumps can be used. To continue feeding when one pump fails, two L3-120-AQ is preferred.

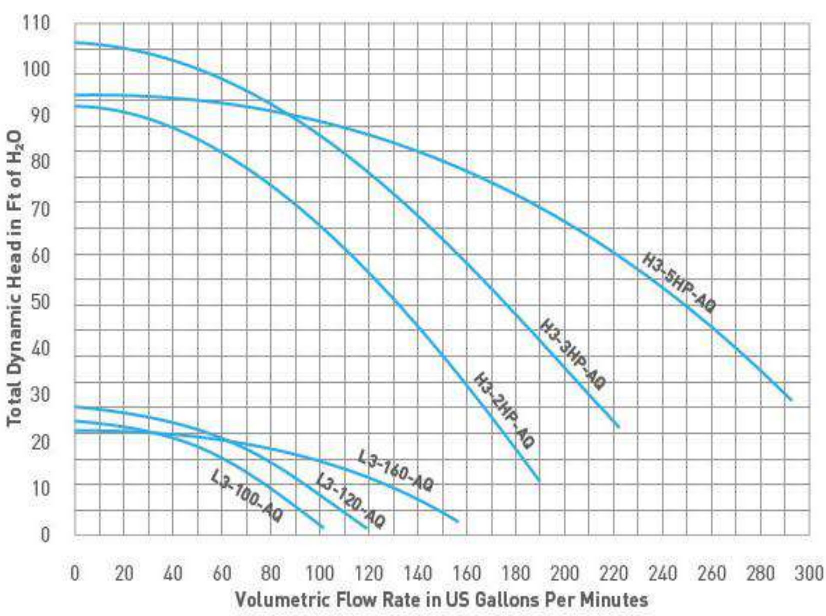

Figure 28. *Performance curves of L3 and H3 series pumps (Pentair Aquatic Ecosystems, 2018)*

For proper pump maintenance a pump should be placed in a position that enables it to be flooded with water before it is turned on and this is usually done by placing the pump slightly below the surface of the water being pumped. This prevents the pump from running dry which damages the pump. In other cases, a non-return valve is placed just before the pump to prevent water backflow when the pump is turned off ensuring that the pump is under water when switched on.

Rule of thumb

Water pump should circulate the total water volume every 2 hours

7.3. Enclosure of The Farm

The type and need for enclosures are dependent on the climate. When temperature and light are optimal for fish and plant growth throughout the year, only minimal enclosure is needed to protect against wind and rain (Somerville et al., 2014). All water in the system should be shaded to prevent growth of unwanted algae. However, when temperature fluctuates throughout the year, insulation is necessary. When light intensity fluctuates greatly, artificial lighting is needed. The consistency artificial lighting and temperature bring, will improve production and product quality. In regions with a lot of sun, solar panels can utilize the energy the sun brings. Next to the climate, electricity and a water source should be available. Fences can protect the system against theft, vandalism, animal pests and food safety.

In the case of an insulated building, ventilation is important. As a rule of thumb, 2x the volume of air within the building should be ventilated in order to control humidity and CO_2 in the air. Humidity control is necessary for hygiene and efficiency of gas exchange. CO_2 control is necessary for general work safety and efficiency of gas exchange.

Rule of thumb
2x the air volume within the building should be ventilated for humidity and CO_2

7.4. Heating and Heat Losses

Depending on enclosure, air and water temperature, the need and costs for heating can be calculated. Because heat losses are highly variable depending on environment and system, no rules of thumb can be given. Instead, only the factors that influence heat losses and the costs for heating will be discussed.

Since water in RAS is recirculated, the heat is also recirculated and stays within the system. Heating costs will be for:

1) new water and air entering the system
2) heat losses via the walls, floor and ceiling

Water exchange rates are dependent on the density of the fish and filtration capacity of the system, with values below 10 % of the system volume per day (Timmons et al., 2018). Ventilation should be 2x the air volume of the building per day. Depending on the difference in temperature between the system and the environment (air and water source) a certain amount of energy is needed to heat the new air and water coming in.

Besides new water and air, the building will lose heat through its walls, floor and ceiling. The rate of heat loss is dependent on the isolation of the building, difference in temperature and wind speed along the building. For all commonly used isolation methods, variables for heat loss can be found and heat losses can be calculated.

When summers are hot, cooling is equally important. Costs for cooling are calculated in a similar way. The only difference being that cooling can only be done with electrical power and is more expensive.

8. A Brief Description of The Costs Involved in The System

Costs involved in producing fish and plants are highly variable depending on production. Increasing production will increase the costs but decrease the costs per kg production.

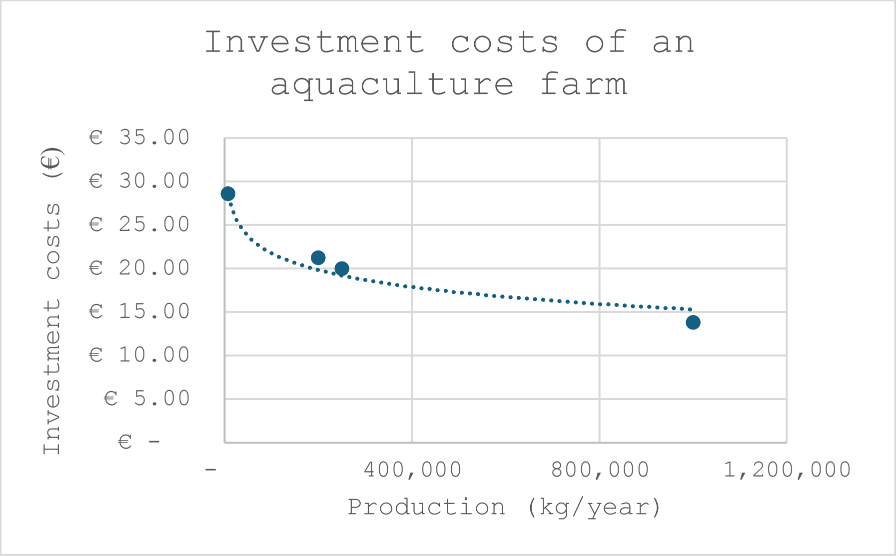

Figure 29. *Investment costs of an aquaculture farm. Landing aquaculture.*

A fish tank will need probes to measure water quality. Increasing the size of the tank will increase the costs of the tank but uses the same number of probes. As an example, Figure 29 shows that the investment costs decrease from €29 per kg to €15 per kg when production is increased from 7.000 kg/year to 1million kg/year. Besides being variable based on production, location will greatly influence the costs of a system. Land and labor costs are different in Turkey compared to Switzerland for instance. An overview of capital and operating expenses is given in order to get an idea of what needs to be considered. A relative contribution to the total costs is given to clarify the importance of each of these factors. Costs can vary greatly depending on the local circumstances. An economic feasibility studies should be done before constructing a system.

8.1. Capital Costs

Capital expenses (CAPEX) are the costs that are not being depleted for production. It consists of equipment, building and land costs. An example of costs with their relative contribution are given in Table 18.

Table 18. *Relative capital expenses of an aquaculture farm*

Component	Relative contribution (%)
Tank costs	**32%**
Grow-out tanks, pumps	
Oxygen and CO2 control units	
Electronic controller	
Feeders	
Biofilter	

Quarantine, hatchery/ fingerling tanks	**Relative contribution (%)**
Other Equipment	**18%**
Backup generator	5%
Monitoring system	2%
Ice machine	1%
Feed storage	2%
Harvesting system	2%
Water heating system	2%
Waste catchment unit	1%
Ventilation system	1%
Water wells (2)	1%
Fish handling equipment	1%
Building costs	**48%**
Quarantine area	1%
Laboratory and office	1%
Building space	46%
Septic/ restroom	0%
Land costs	**2%**

Source: *Timmons et al., 2018*

For a hydroponics system think about building costs, climate control system, irrigation, lighting, electricity and grow beds.

8.2. Operating Costs

Operating expenses are the costs that are concurrent for production. This includes feed, electricity, water and labour. In aquaculture systems 50% of total operating expenses are feed costs. However, due to the technical difficulty of operating aquaponics systems, the costs of labour are increased. Compared to any fish growing system, feed costs of aquaponics are low in relation to the total biomass output, because fish and plants are produced using the same input of feeds. Relative operating costs of the aquaponics and hydroponic compartment of an aquaponics farm are shown in Figure 30 and Figure respectively.

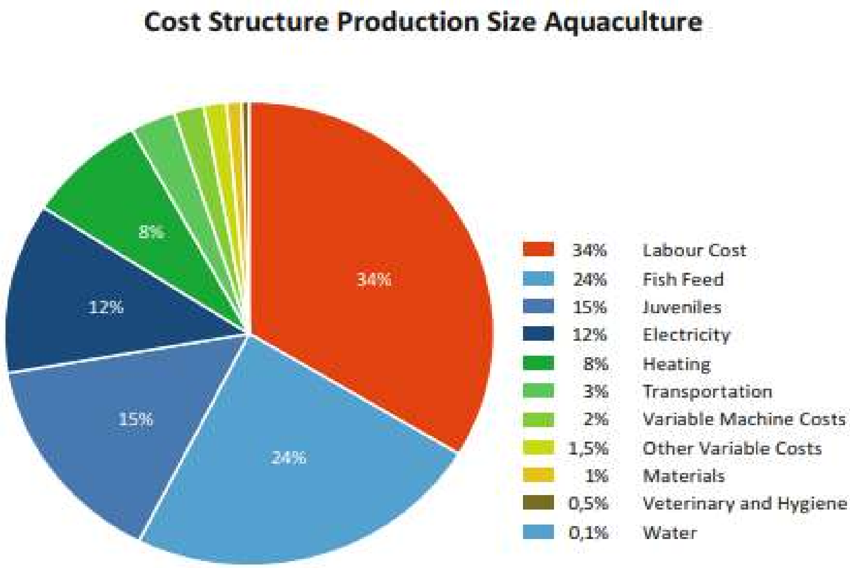

Figure 30. *Cost structure for aquaculture side of an aquaponics system, hypothetical model from technical data from the pilot plant of the University of Applied Sciences of South Westphalia (Morgenstern et al. 2017; Goddek et al., 2019).*

8.3. Start-Up Costs

When starting a business, it is important to keep in mind at what moment the first sales will be made. In this production plan 4 batches of fish are stocked before harvesting the first batch. Feed, electricity, water and rent bills will have to be paid before any return of investment is seen from the aquaculture side. It is common that the first batches of fish are lost due to management and start-up problems. Enough funds should be available in case this happens. Plant revenues can be attained much quicker. A simple 30m x 10m aquaponics system started with an investment of €21.500 has the ability to produce close to 120 kg of basil per month after one year of operation(Burgess, 2019).

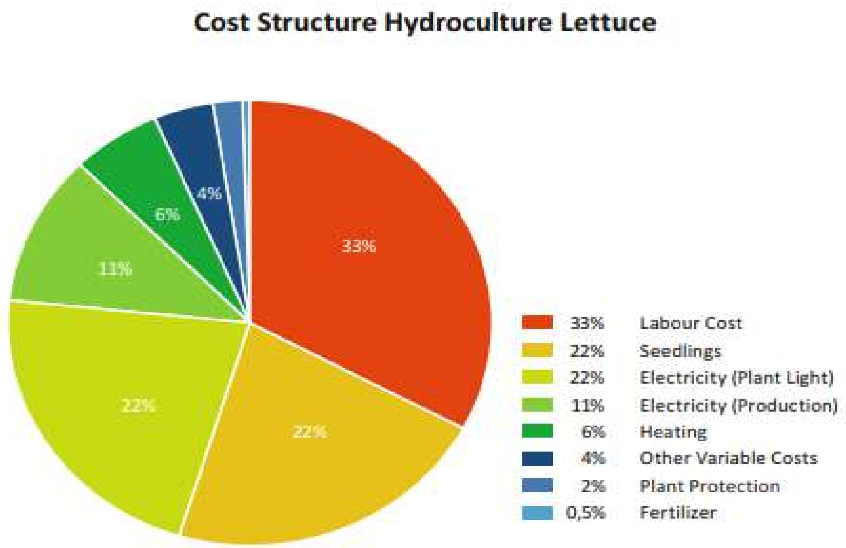

Figure 31. *Costs structure for hydroponics side of an aquaponics system, hypothetical model from technical data from the pilot plant of the University of Applied Sciences of South Westphalia (Morgenstern et al. 2017;* Goddek et al., 2019)

9. Equipment Suppliers

Choosing the right equipment is one of the ways of minimizing unnecessary costs in an aquaponics venture. After determining which equipment is needed and what size the equipment should be, various options are available from numerous suppliers. A good price/ quality ratio is important. Appendix 1 shows a list of suppliers for major equipments used in aquaponics. These suppliers serve as examples only.

10. Conclusions Regarding The City of Van

Van Province is located between 42º 40 'and 44º 30' east longitudes and 37º 43 ' and 39º 26' northern latitudes. Located in the closed basin of the Upper Murat-Van Lake in the Eastern Anatolia Region, Van is the 6th largest province of Turkey with an area of 19.069 km². The city has an average height of 1,726 m above sea level.

The region is generally affected by the typical continental climate. Summers are hot and dry; winters are hard and cold. Long-term climate data of the provinces of the region were analyzed (**Table 19**).

Table 19. *General meteorological status of Van Regional provinces.*

Meteorological Data	Bitlis	Hakkâri	Muş	Van
Maximum Temperature °C	38.0	38.0	41.6	37.0
Minimum Temperature °C	-22.0	-23.4	-34.4	-24.8
Average Temperature °	9.47	10.29	9.67	9.3
Average Total Annual Precipitation (kg/m²)	941.1	742.2	773.2	382.
Average Number of Rainy Days	119.4	99.4	114.9	98.7
Average Sun Time (hour)	5.86	7.86	7.21	7.98

Source: Van Meteorology Regional Directorate, 2017, July

The surface area of the inland water resources in the Van Region is 9,200 km2. Eastern Anatolia is one of the richest regions in terms of the number of lakes and water volume. Lake Van, the largest lake in Turkey (3,713 km^2), is located in the Van Region (DAKA, 2014). It is a volcanic barrier lake formed by the water accumulated in the crater as a result of the eruption of the volcanic Mount Nemrut between the borders of Bitlis and Van provinces. However, Lake Van only allows the pearl mullet to live due to its soda water feature. In addition, the Van Region has an important potential for aquaculture. Because, as it is known, the main sources of the Tigris River are supplied with water taken from the high mountains of our region.

Lake Van cannot be used as a water source for plant production. Because the waters of Lake Van are bitter, salty and soda. In addition to being the world's largest soda lake, it also has salt water characteristics. A different water ecosystem is seen in Lake Van than both freshwater and seawater ecosystems. The salinity rate is 0.224% and the pH value is 9.52. This situation does not allow the growth of cultivated plants.

Aquaculture, hunting and aquaculture are carried out in the Van Region. With a hunting area of 3,713 km2, Lake Van, which is the largest lake in Turkey and constitutes a large part of its surface area, is the pearl mullet fishery. 9,037 tons of pearl mullet are caught annually, 8,400 tons of which are in Van and 637 tons in Bitlis.

This situation allows approximately 15,000 people living around Lake Van to make a living from pearl mullet hunting. In addition, Lake Erçek, which shares the same characteristics as Lake Van, has a high pearl mullet potential and may be opened to hunting in the coming years (DAKA, 2014).

When we look at cultured fish farming in the Van Region, rainbow trout, which is easy to grow and open to the market, is preferred. There are a total of 72 trout farms (active and semi-active) in the region with a total production of 4,115 tons, and a large part of this is consumed within the region.

There are different types of freshwater fish in the lakes, ponds and streams in the provinces of the Van region, and some of them are Cyprinus carpio (Tin Carp), Tinca tinca (Velvet), Leuciscus cephalus (Freshwater Mullet), Barbus plebejus (Catfish), Capoeta tinca, Cobiti taenia, Vimba vimba, Alburnus alburnus Gobio species (DAKA, 2014).

Since Van has a continental climate, temperature control is needed for production with the aquaponic farming system. Cold water culture type is recommended due to long winters. When considering suppliers and market demand, which species to grow is an important factor. Since trout is a relatively resistant cold water species, it will be a good option with established suppliers and market demands.

Considering the many studies conducted in the ecological conditions of the city of Van, it is recommended that aquaculture be preferred for aquaponic systems (Bildirici, 2019). Since the aquaculture system will be operated with a high pH (>7), it is necessary to add acid before transferring the water to the hydroponic system. This will lead to a high-quality crop. Plants should be selected according to their resistance to cold water. If hot water crops are selected, a heat exchange should be established to use the heat as efficiently as possible. Since the heat of the sun will be sufficient in the summer months, seasonal crops can be grown without the need for heat exchange.

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Appendix 1

Table 20. *List of major aquaponics equipment suppliers*

Section	Equipment	Possible suppliers
Plants culture	Net pots	Hydroponics growshop (UK & I) (https://www.hydroponics.eu/ Nitriculture (UK) (http://www.nutriculture.co.uk/) Organic growshop (GR) (https://www.organic-growshop.gr/)
	Rafts, channels and liners	Hydroponics growshop (UK & I) (https://www.hydroponics.eu/ Mad greenhouse products (USA) (https://www.madgreenhouseproducts.com/) Organic growshop (GR) (https://www.organic-growshop.gr/) Pentair Aquatic Ecosystems (USA) (https://pentairaes.com/) Viscon (PL) (https://www.visconhydroponics.eu/)
	Ebb and flow tables	General Hydroponics Europe (https://www.eurohydro.com/) Hydroguru (https://hydroguru.shop/) Mad greenhouse products (USA) (https://www.madgreenhouseproducts.com/)
	Seeds	**Vegetables** Anamas seeds (TR) https://www.anamastohum.com/en/ Hydroponics growshop (https://www.hydroponics.eu/) Kucukciftlik (TR) (https://kucukciftlik.com/)
		Herbs Aeroponic hydroponics (GR) (https://aeroponic.gr/)

		Kucukciftlik (TR) (https://kucukciftlik.com/)
		Fruits Aeroponic hydroponics (GR) (https://aeroponic.gr/) Anamas seeds (TR) https://www.anamastohum.com/en/ Bursa seeds (TR) (http://www.bursaseed.com/) Kucukciftlik (TR) (https://kucukciftlik.com/) United genetics (TR) (http://unitedgenetics.com/)
		Flowers Aeroponic hydroponics (GR) (https://aeroponic.gr/)
	Growth media	Aeroponic hydroponics (GR) (https://aeroponic.gr/) Amazon (DE) https://www.amazon.de/) Hydroponics growshop (https://www.hydroponics.eu/) Nitriculture (UK) (http://www.nutriculture.co.uk/) Organic growshop (GR) (https://www.organic-growshop.gr/)
	Fertilizers and Pest management	Hydroguru (https://hydroguru.shop/) Zeruva (TR) (http://zeruva.com/tr/)
	Irrigation and drip nozzles	Hydroguru (https://hydroguru.shop/) Seomak technology (TR) (http://www.seomak.com.tr/)
Fish	Feeds	Aller Aqua (DK) (https://www.aller-aqua.com/) Alltechcoppens (NL) (https://www.alltechcoppens.com/) Aquasoja (PT) (http://www.aquasoja.pt/)

		Biomar (DK) (https://www.biomar.com/) Cargill (TR) (https://www.cargill.com.tr/) Dibaq Aquaculture (ES) (http://www.dibaqacuicultura.es/en/) Gumusdoga (TR) (https://www.gumusdoga.com.tr/) Le Gouessant (FR) (http://www.aqua.legouessant.com/) Skretting (TR) (https://www.skretting.com/)
	Automatic feeders	Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Aquacultur (DE) (https://www.aquacultur.de/) Aquaculture ID (NL) (https://www.aquacultureid.com/) Fish farm feeder (ES) (https://www.fishfarmfeeder.com/) Sterner (UK) (https://www.sterner.co.uk/)
	Tanks	Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Aquacultur (DE) (https://www.aquacultur.de/) Fatih polyester (TR) https://www.fatihpolyester.com/ Landing aquaculture (NL) (https://www.landingaquaculture.com/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/) Purewell Fish farming (UK) (https://www.purewellfishfarming.co.uk/)
	Fingerlings	Gumusdoga (TR) (https://www.gumusdoga.com.tr/)

		Trout lodge (NL) (https://www.troutlodge.com/) River Gwash trout farm (UK) (https://www.rivergwashtroutfarm.co.uk/)
Mechanical filtration	Bead filter	Air-aqua (NL) (https://www.air-aqua.nl/) Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Aquaculture systems technologies (USA) (https://astfilters.com/) Sibo fluidram (NL) (https://sibo.nl/)
	Drum filter	AGK Aquakultur -Teich (DE) (https://www.agk-kronawitter.de/) Air-aqua (NL) (https://www.air-aqua.nl/nl/) Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Faivre (FR) (http://www.faivre.fr) Hex (DK) (http://www.hexfilter.com/) Hydrotech(SE) (http://www.hydrotech.se) MAT Aquaculture Filtration (TR) (https://mat-ras.com/) Sterner (UK) (https://www.sterner.co.uk/) Timex (TR) (https://timex.com.tr/)
Biological filtration	Trickling filters	AGK Aquakultur -Teich (DE) (https://www.agk-kronawitter.de/) Air-aqua (NL) (https://www.air-aqua.nl/nl/) Aquaculture ID (NL) (https://www.aquacultureid.com/) Aquaculture systems technologies (USA) (https://astfilters.com/) Landing aquaculture (https://www.landingaquaculture.com/)

	Moving bed bio reactor	Landing aquaculture (https://www.landingaquaculture.com/) Aquaculture systems technologies (USA) (https://astfilters.com/) MAT Aquaculture Filtration (TR) (https://mat-ras.com/) Timex (TR) (https://timex.com.tr/)
	Biofilter media	**Random packing** AGK Aquakultur -Teich (DE) (https://www.agk-kronawitter.de/) Air-aqua (NL) (https://www.air-aqua.nl/nl/) Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Aquacultur (https://www.aquacultur.de/) Aquaculture ID (NL) (https://www.aquacultureid.com/) Pall ring company (UK) (https://www.pallrings.co.uk/ RK Bioelements (DK) (https://en.rkbioelements.dk/) Smallbox special plastics (CN) (https://www.mbbrfiltermedia.com/)
		Structured packing AMACS (NL) (https://www.amacs.com/) Coolmdeck (IN) (http://cooldeckin.com/) Enexio (UK) (https://www.enexio.com/) Matala USA (USA) (http://www.matalausa.com/)
Gas transfer	Blowers	Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Aquacultur (DE) (https://www.aquacultur.de/)

		Blowtac (TW) (https://www.blowtac.com.tw/) Busch (NL)https://www.buschvacuum.com/ Pentair Aquatic Ecosystems (US) (https://pentairaes.com/) Ratz Aquaculture (DE) http://www.ratz-aquaculture.com/ Sjerp &Jongeneel BV (NL) (https://www.sjerp.nl/)
	Air compressors	Aquacultur (DE) (https://www.aquacultur.de/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/)
	Oxygen generator	AirPro gas solutions (IE) (https://www.airpro.ie/) Innovative gas systems (IT)http://www.igs-italia.com/ MAT Aquaculture Filtration (TR) (https://mat-ras.com/) Oxymat (DK) (https://www.oxymat.com/) Sterner (UK) (https://www.sterner.co.uk/) Sysadvance (PT) (https://www.sysadvance.com/)
	CO_2 degasser	**Random packing** Alvestad (NO) (https://alvestad.com/) Landing aquaculture (https://www.landingaquaculture.com/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/) Pall ring company (UK) (https://www.pallrings.co.uk/) Sterner (UK) (https://www.sterner.co.uk/)
		Structured packing

		Landing aquaculture (https://www.landingaquaculture.com/) NP Innovations (SE) (http://www.npinnovation.se/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/)
	Diffusers/ air stones	AirPro gas solutions (IE) (https://www.airpro.ie/) Aquacultur (DE) (https://www.aquacultur.de/) Ratz Aquaculture (DE) (http://www.ratz-aquaculture.com/) Sterner (UK) (https://www.sterner.co.uk/) Sibo fluidram (NL) (https://sibo.nl/)
	Oxygen cones	Fatih polyester (TR) (https://www.fatihpolyester.com/) Linde group (DE) (https://www.the-linde-group.com/) SDK (PL) (https://www.sdk.com.pl/)
Water transport	Pipes and fittings	Agru (AT) (https://www.agru.at/en/) Akansu group (TR) (http://www.akansu.com/) Aquaculture ID (NL) (https://www.aquacultureid.com/) Kuzeyboru (TR) (https://www.kuzeyborugroup.com/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/) Sibo fluidram (NL) (https://sibo.nl/) Vink (NL) (https://www.vinkkunststoffen.nl/)
	Pumps	Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Apexpumps (UK) (https://www.apexpumps.com/) Air-aqua (NL) (https://www.air-aqua.nl/nl/)

		Aquacultur (DE) (https://www.aquacultur.de/) Calpeda (IT) (https://www.calpeda.com/) Distrimex (NL) (https://www.distrimex.nl/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/) Sibo fluidram (NL) (https://sibo.nl/)
	Flow meters	BMeter metering solutions (IT) (https://www.bmeters.com/) Sibo fluidram (NL) (https://sibo.nl/)
Water quality monitoring	PH, oxygen, redox, temperature, hardness, conductivity	Aquacultur (DE)(https://www.aquacultur.de/) Aqualabo (FR) (https://en.aqualabo.fr/) Bluelab (NZ) (https://www.bluelab.com/) HACH (USA) (https://www.hach.com/) Hanna instruments BV (NL) (https://hannainstruments.nl) LaMotte (USA) http://www.lamotte.com/ Oxyguard (DK) (http://www.oxyguard.dk/) Sterner (UK) (https://www.sterner.co.uk/) Yokogawa (TR) (https://www.yokogawa.com/) YSI (USA) (https://www.ysi.com/)
	Nitrate, nitrate and ammonia test kits	Aquachek (USA) (https://www.aquachek.com/) Aquaforest (PL) (https://aquaforest.eu/) Aqualabo (Fr) (https://en.aqualabo.fr/) Bluelab (NZ) (https://www.bluelab.com/) Hanna instruments BV (NL) (https://hannainstruments.nl)

		Lamotte (USA) (http://www.lamotte.com/) YSI (USA) (https://www.ysi.com/)
	Software and monitoring systems	Arowana automation (https://iurbanfarmer.com/) Aquacheck smart app (https://www.aquachek.com/) Bluelab connect (https://www.bluelab.com/) Osmobot (https://www.osmobot.com/) Smart ponnod (http://smart.ponnod.com/) YSI (USA) (https://www.ysi.com/)
Green house	Lighting	Certhon greenhouse solutions (NL) (https://www.certhon.com/) Hydroponics growshop (https://www.hydroponics.eu/ Mad greenhouse products (USA) (https://www.madgreenhouseproducts.com/)
	Light measurement	Hansatech (UK) (https://www.hansatech-instruments.com/) Harvest Agri (UK) (https://harvestagri.co.uk/) LI-COR (USA) (https://www.licor.com/) Spectrum technologies (USA) (https://www.specmeters.com/)
	Thermometer	Aquacultur (https://www.aquacultur.de/) Sibo fluidram (NL) (https://sibo.nl/) Sterner (UK) (https://www.sterner.co.uk/
	Cooling and ventilation	Certhon greenhouse solutions (NL) (https://www.certhon.com/)
	Covering materials	Agrimec (It) (https://en.agrimec.it/)

		Certhon greenhouse solutions (NL) (https://www.certhon.com/) Seomak technology (TR) (http://www.seomak.com.tr/)
Others	Full system design	Landing aquaculture (https://www.landingaquaculture.com/) MAT Aquaculture Filtration (TR) (https://mat-ras.com/) Smart farmers (BE) (https://smartfarmers.eu/) Sterner (UK) (https://www.sterner.co.uk/)=
	Tools and equipment	**Fish graders, stunners and scoop nets** AGK Aquakultur -Teich (DE) (https://www.agk-kronawitter.de/) Aquacultur (DE) (https://www.aquacultur.de/) Aquaculture ID (NL) (https://www.aquacultureid.com/) Faivre (FR) (http://www.faivre.fr) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/)
		Clothing and foot-ware Artkins (IE) (https://www.atkins.ie/) Wellpath (CN) (http://www.waderfactory.com/)
		Disinfectants Halamid (FR) (http://www.halamid.com/) Sanosil (CH) (https://www.sanosil.com/)
	Water heating	Akuakare Aquaculture Equipments (TR) (http://eng.akuakare.com/) Microwell (https://www.microwell.eu/) Pentair Aquatic Ecosystems (US) (https://pentairaes.com/)
	Consultations	Dutch greenhouses (Nl) (https://dutchgreenhouses.com/)

		Landing aquaculture (https://www.landingaquaculture.com/) Ponnod internet of greens (SL) (http://smart.ponnod.com/) Smart farmers (BE) (https://smartfarmers.eu/)

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