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PRESTUDY FOR A SMALL-SCALE AQUAPONICS IN BOVIERA IN NORRTÄLJE

Sammanfattning

A prestudy exploring three different aquaponics systems that could be implement in Boviera in Norrtälje, where the dwellers are interested in having aquaponics as recreational activity.

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Project for Brf Bovieran Norrtälje

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Detta dokument har genomförts inom ramen för det LEADER-finansierade projektet ”Akvaponi i Roslagen” Projektet är finansierat av LEADER Stockholmsbygd samt Jordbruksverket. Roslagens sparbanksstiftelse har finansierat bygget av en akvaponisk demoanläggning på Utvecklingscentrum för vatten/Campus Roslagen i Norrtälje. Huvudsakligt syfte är kunskapsspridning kring akvaponi, ett recirkulerande odlingssystem som möjliggör förlängd odlingssäsong, ökad konkurrenskraft hos företag, mer lokalproducerade livsmedel, samt tekniska system som gör minsta möjliga påverkan på miljön.

Sveriges nationella livsmedelsstrategis övergripande målsättning är en konkurrenskraftig livsmedelskedja där livsmedelsproduktionen ökar, samtidigt som nationella miljömål uppnås. Detta för att bidra till en hållbar utveckling i hela landet. Strategin nämner en ökad livsmedelsproduktion som svarar mot konsumenternas efterfrågan. På detta sätt når man en högre självförsörjningsgrad av livsmedel och sårbarheten i livsmedelskedjan bör minska.

Livsmedelsstrategin har utpekat tre strategiska mål för att nå målen

1. Regler och villkor
2. Konsument och marknad
3. Kunskap och innovation.

Projektet Akvaponi i Roslagen har huvudfokus utifrån strategimål 3 i livsmedelsstrategin.

Denna rapport presenterar olika typ av system som kan byggas hos Boviera i Norrtälje, utan dimensionerar dem.
Det har tagits fram av Oscar Vandromme, student i miljöteknik och hållbar infrastruktur i KTH.

Introduction:

This paper is divided into several parts. First, a small introduction will be done. Second, several scenarios will be presented.

Aquaponics is the combination of hydroponics (culture of vegetable with root directly in water) and aquaculture (fish culture). The main principle is to create a circular system where the metabolic waste from the fish is used as nutrient for the plants. The fish are fed, their dejections are then transformed from ammonium produced by the fish into nitrite and then nitrate through the nitrification process. In most of the cases, a biofilter is used for the nitrification process. The nitrate is one of the main nutrients for plants, that will capture the nutrients after the biofilter and grow. Aquaponics normally has a production of fish and vegetables (Somerville et al. (2014)).

It is important to understand that an aquaponic system has for objective to recreate an ecosystem As all ecosystems, this system will have to be monitored closely since changes can affect the whole system. In this project some variables will be assumed , and the scenario will have to take them into account. For example, the already existing pond will most likely be used as the equivalent of the fish tank in a normal system. This will represent a constraint since the dimensions are therefore already given. This also means the temperature will be hard to control and that the eventual sun radiations will reach the fish tank (Not advisable in aquaponics due to the creation of algae).

In an aquaponics system, some variables have to be changed to adapt to the situation, once the design is done. The number of fish, the amount of food given, the type of vegetable in the vegetable tank are an example of those variables. This means that even if a system is not perfectly dimensioned, it is possible to change some parameters to make it fit most adequately. This also implies that this system will evolve in time and that monitoring and adaptation are keys to reach a good aquaponic system.

Aquaponics systems usually have a high starting cost (Somerville et al. (2014)). The several scenarios will try to take this into account by having a system that could be less costly using the available resources. Using the available resources also means that some uncertainties will increase or appear. Indeed, it is easier to create a system from the beginning as it is then possible to design every piece of the system. Some scenario may be more about leisure than real productivity. In this project, optimal productivity will be hard to achieve due to the initial parameters: variation of temperature, the limit of space, no artificial lamp, …

The different sketches done in this project report are only done for visual support. They can give an idea of designs. They are not at the right scale, and a combination of the different plan or variation of them is possible. The purposes of these sketches are just informative and don’t correspond to reality. There is still a lack of information and data to be able to design precisely a plan of the system. Design can vary tremendously depending on the money available and the objective of the system.

Scenario 1, Deep Water Culture:

Type:

The first scenario is inspired by the basic scheme received. This will be a typical deep-water culture (DWC) system.

Design:

The DWC consists of 3 mains parts: The fish tank, the biofilter and the vegetable tank. In a DWC system, the vegetable tank consists of water with vegetable on it. The roots of the vegetables are directly in the water.

The water coming from the fish tank will go through the biofilter, that will replace the filter already in place and will most likely be bigger than the filter already in place. Some biofilter can still be small and very efficient. Several designs can be chosen for the biofilter, this mainly depending on the main objective of the system (production, educational, recreational, ...) and the budget. One of the efficient biofilter is the moving bed technology using Bioballs® for example.

Table 1, Characteristics of different types of moving beds (KTH course, Water and Wastewater Handling, AE2304)

Name	Material	Shape	Size [mm]	Specific effective carrier surface area $[m^2/m^3]$
LINPOR	Polyurethane (PU)	cube	14×14×14	1000
Kaldnes K1	Polyethylene (PE)	cylinder with a cross on the inside of the cylinder and fins on the outside	Ø 10, lenght: 7	500
Kaldnes K2			Ø 15, lenght: 15	350
Biolox	Polyethylene (PE)	cylinder wtih fins on the inside of the cylinder	Ø 14, lenght: 8	640
Bioflow 9		cylinder with a cross on the inside of the cylinder and fins on the outside	Ø 9, lenght: 7	800
EvU-Perl	Polyvinyl acetate (PVA)	cylinder wtih fins on the inside and outside of the cylinder	Ø 5, lenght: 8	800
Natrix	Polyethylene (PE)	cylinder	Ø 60, lenght: 50	310
FLOCOR-RMP	Polypropylene (PP)	cylinder	Ø 15-20, lenght: 20-30	160

The table presents the different designs of biofilm carriers and the variable that will change. This technology is typically used in wastewater treatment to optimize the biological processes. The benefit of this technology is the documentation available, its efficiency and the limited space it takes. However, it requires some energy for aeration.

Other types of technologies exist. The demonstration version from our facility is not Bioballs® and could also be considered.

Once the water flows to the biofilter, it will go to the vegetable tanks. There, two options are possible, either split the water in three or have the same flow of water go to the first then the second and finally the third tank.

Scheme of the first system:

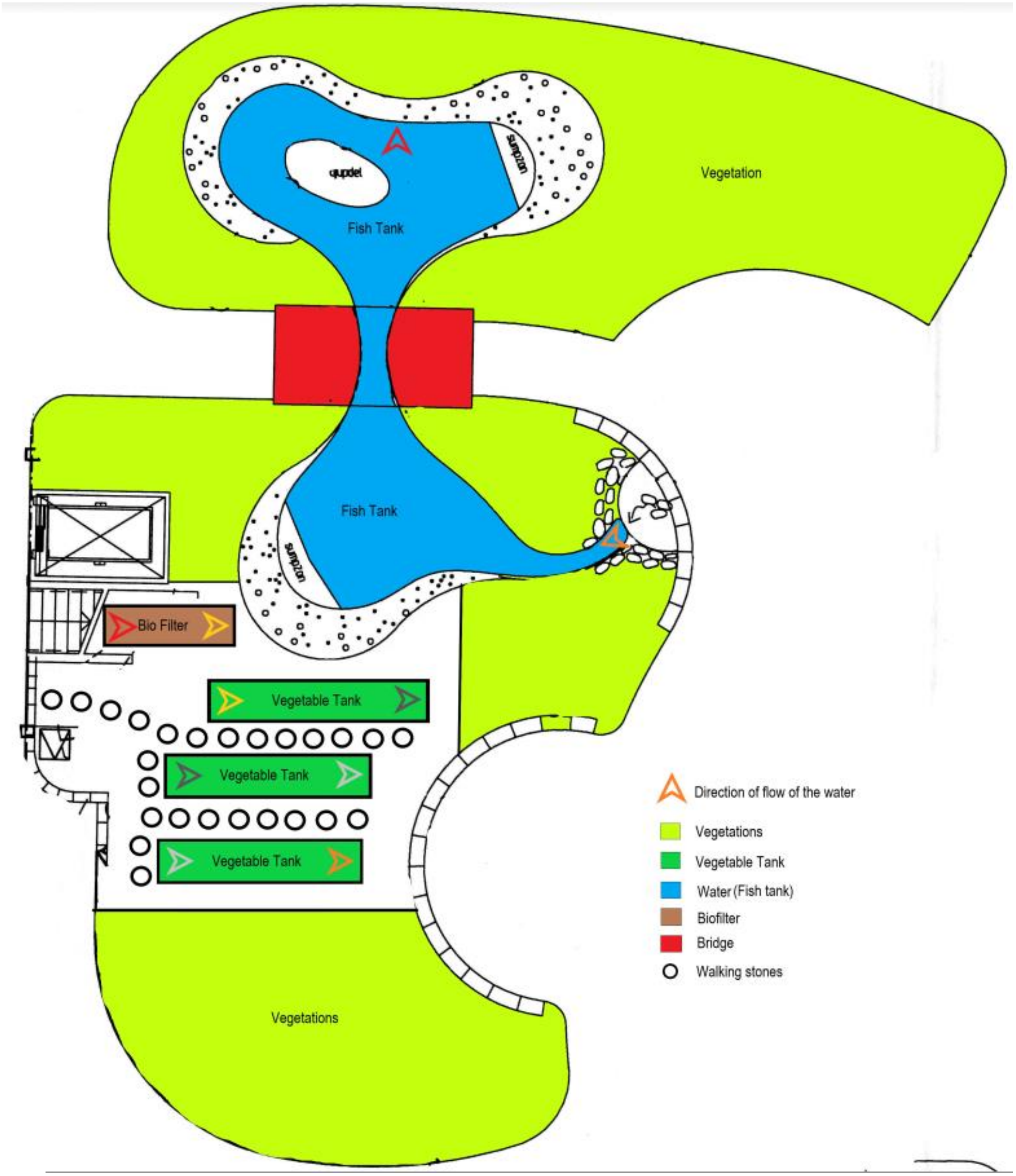


Figure 1, Design 1 DWC system.

Here is the scheme for the project. As it is possible to see, the arrows of the flow of water show that the same water goes through the three tanks. This is important to take into consideration. Indeed, if there is only one stream of flow, the water will be more and more depleted from nutrients. The water from the last tank will probably be depleted. This should particularly be looked when choosing the vegetables. The more nutrient demanding plants should go in the first tank while the plant that can thrive with limited nutrient should go into the last tank. As a positive feature, this solution would allow cultivating different vegetable in the same system.

How to size up a system?

Several techniques can be used for dimensioning a system for the first time. One of the most common is based on the Feed Rate Ratio. This formula allows us to know the size of each part of the system, knowing one variable. In this project, the amount of food given by days could be calculated as the tank size is already known. Once the amount of food necessary is calculated, it is then possible to calculate the surface of the vegetable tank (depending on the type of vegetable).

FRR= food given to the fish per day/ growing surface. FRR ranges are known for leafy or fruity vegetables.

The feed rate ratios will provide a balanced ecosystem where each part is coherent with the other. However, this method can only be used for estimations and should not be the only method used.

Fish:

Koi carp could be kept as the type of fish for the fish tank. This has several throwbacks. Koi carp are more ornamental than for food. This means that the fish tank will not produce food for human and are not harvestable. It can be considered in some case to sell some nice-looking specimen.

The temperature from the pond is proper for Koi carp. Koi carp water temperature can range from 1 to 35° C.

You cannot feed your koi when the temperatures drop below 11°C. The ideal temperature is between 11°C and 28°C. A higher temperature will decrease too much the water saturation in oxygen (Neaves, s.d.).

The main benefits of keeping the koi carp are: very limited time to wait for the fish to be mature enough, no initial cost for buying the fish, limited impact on the local environment.

If the intent is to grow eatable fish, the koi carp should be removed, and typical aquaponics species should be added. Several options for the types of fish are possible.

The initial plan was to grow local fresh fish species. Trout seems like promising. However, trout only survive in water temperature between 10 and 18°C (Somerville, 2014). In this first scenario, the pond is kept unchanged. The temperature in that pond varies from 10 to 23-25°C which makes it unsuitable for trout. Trout can be considered in other scenarios where the pond is not used or if the temperature stays between the boundaries.

The best species for this scenario would probably be the Common carp. The ideal temperature for common carp is between 25-30°C. This means that they will never reach the perfect temperature for maximal growth in this scenario. However, they can survive to temperatures between 4-34°C which make them still suitable for this specific pond (Somerville, 2014). The typical growth rate of common carp in aquaponic system is 600 grams in 9–11 months. The growth rate will probably be lower due to the low temperature of the pond.

Tilapia is also a typical fish species for aquaponic system. They can survive to temperature between 14-36°C. They thrive in water temperature between 27-30°C. In an unchanged situation, this species could not be considered as in winter they would die. However, it could be considered to add a heating pump that is only turn on when the temperature goes below 16°C. The adding of a heating pump will increase the cost of the system (for the initial cost and the electricity cost during the year).

Vegetables:

The benefit of using a DWC system is that vegetables can be easily changed or adapt to the situation. Not knowing the amount of ammonium produced by the fish right now, it is impossible to select the adequate vegetable accurately. If the Koi carp are kept in the fish tank, sample from the water of the pond just before reaching the filter would be interesting to analyze.

Nevertheless, some vegetables are typically more adapted to aquaponics than others.

I would advise when the system is starting to use basic vegetables that do not ask many structures or nutrient to grow. Lettuce and basil are typical species that thrive in aquaponics systems. The first few years, this should be the main vegetable use. Once the system is well regulated, it would be probably possible to use other, more demanding vegetables. Cucumber and tomatoes are an example of high demanding nutrients species that could be added. I would advise, especially in a system with one single flow to have these vegetables in the first tank.

It is important to know that heavy plant are not suitable fora DWC system. Typically, eggplant, pepper, beans, head cabbage, … are not adapted for DWC.

The density of the vegetable is important as it will partly define the amount of nitrate needed. The density will be defined by the type of vegetable used and the amount of nutrient available. I would advise starting with a low-density system at the beginning. Once the system is well set up, and the amount of nutrient is known, the system can increase its density.

The last concern is temperature. Type of vegetables will have to be adapted to the situation. The big advantage is that vegetable usually take only a few months to grow. This means that adaptation to the temperature can easily be made. Moreover, even if this concern is only minor in aquaponic systems, rotation of different vegetable can be advice to decrease the risk of disease. As an example, basil take 5–6 weeks to grow, it can be then either be harvested or it is possible to take leaf when needed. The temperature should be between 18–30 °C, and its optimal temperature is at 20–25 °C (Somerville, 2014). Schedule of the vegetable rotation should be done to plan the new material needed.

Different design:

These designs will only be different in their layout, the type of system and the information above are still relevant.

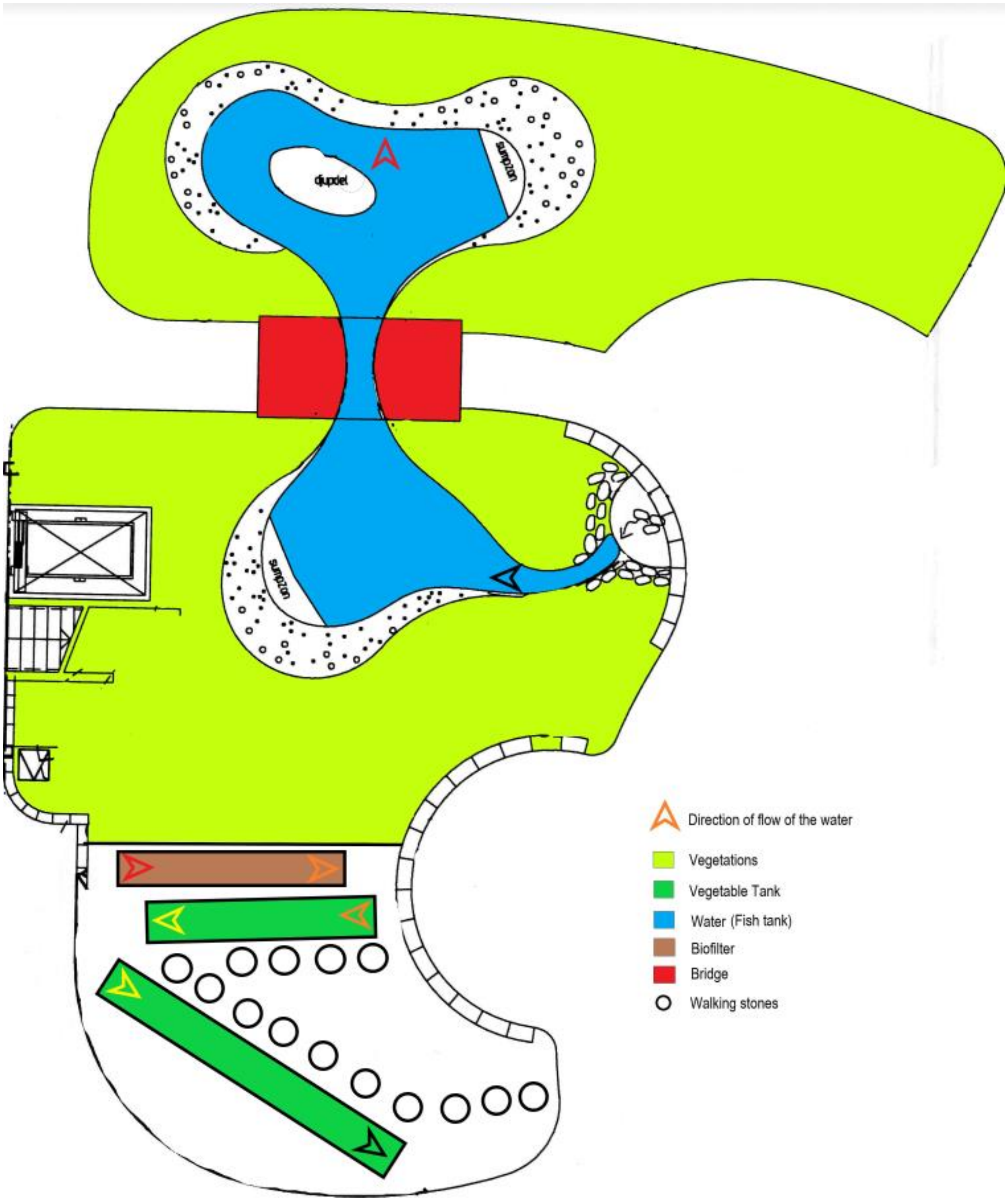


Figure 2, Design 2 DWC system.

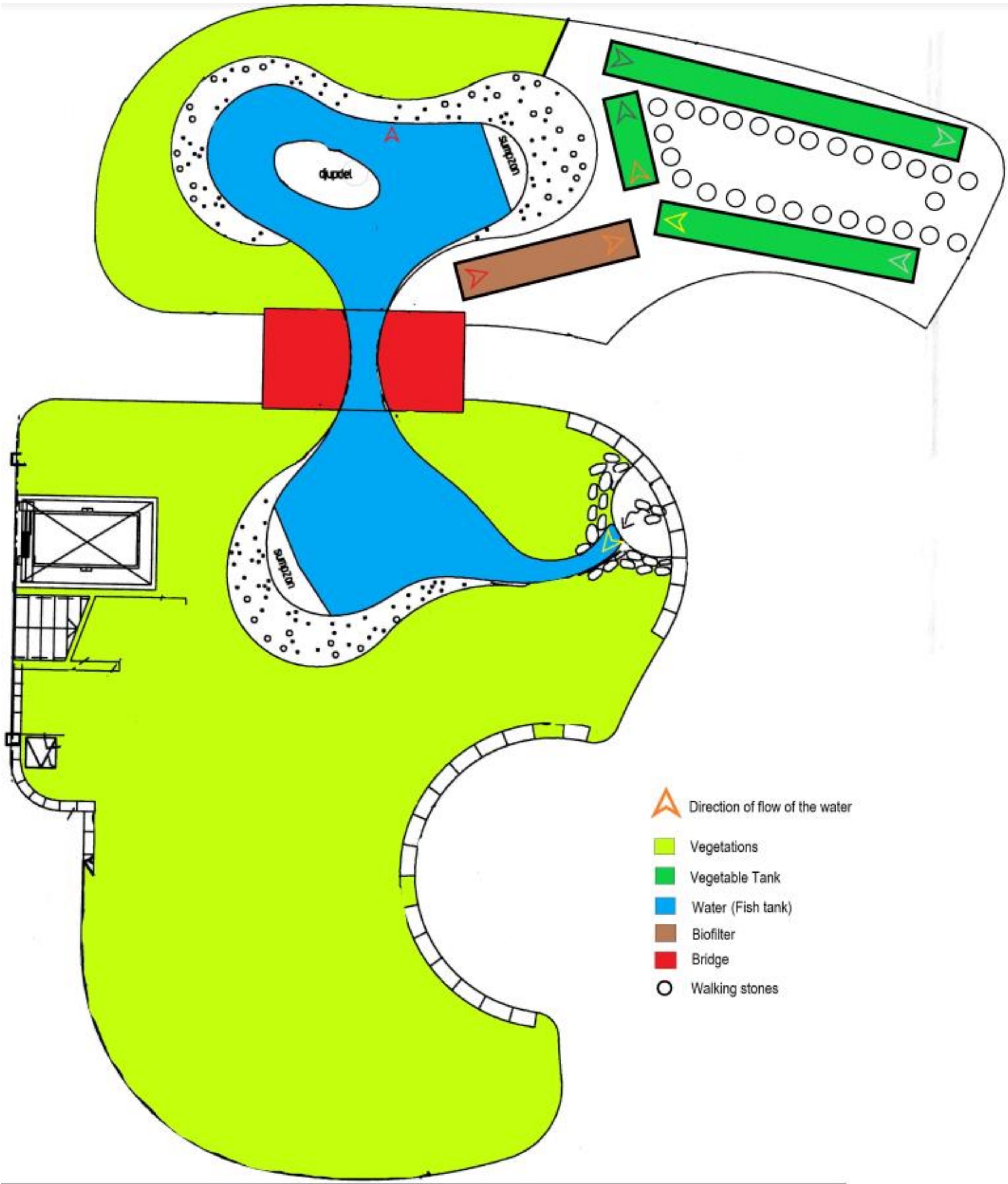


Figure 3, Design 3 DWC system.

Scenario 2, Media bed system:

Type:
Media bed (flood-and-drain techniques)

Design:
Media bed, using the flood-and-drain techniques, can be considered as a system for this project. It is considered as the “most popular design for small-scale aquaponics” (Somerville, 2014, p54). Somerville also mentions that “These designs are efficient with space, have a relatively low initial cost and are suitable for beginners because of their simplicity.”(Somerville, 2014, p54). However, it can be more complicated to control each part of the system as they are mixed. Here is a scheme of how a media bed system works:

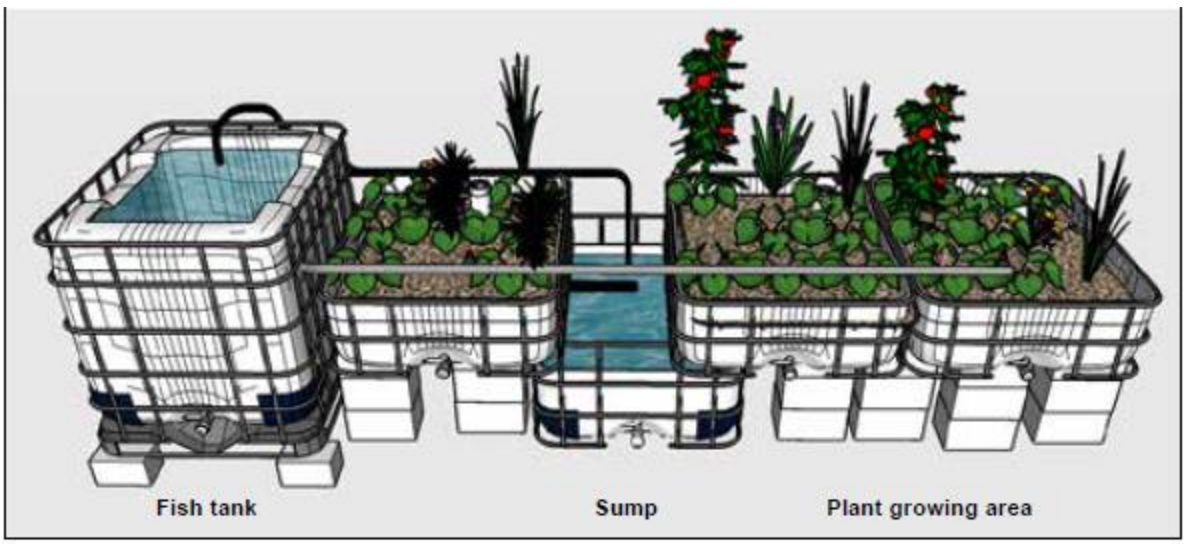


Figure 4, "Illustration of a small media bed unit" (Somerville, 2014, p55)

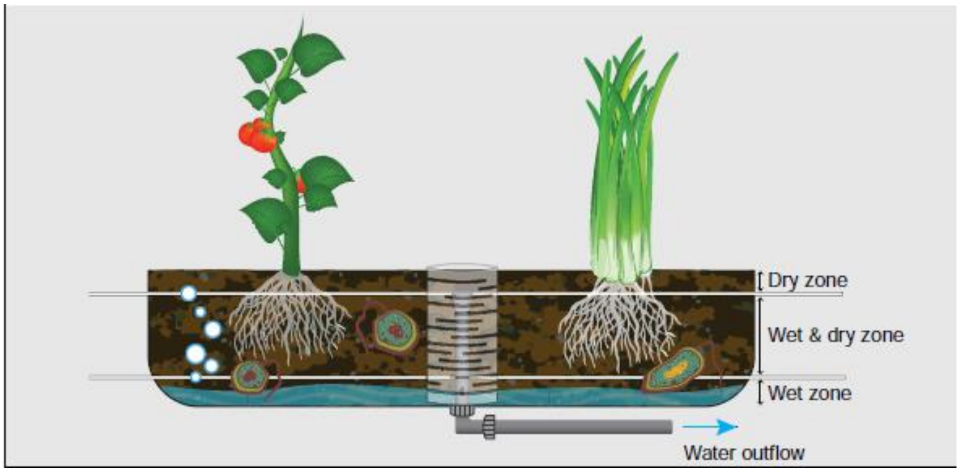


Figure 5, "The three zones of a media bed during the drain cycle" (Somerville, 2014, p60)

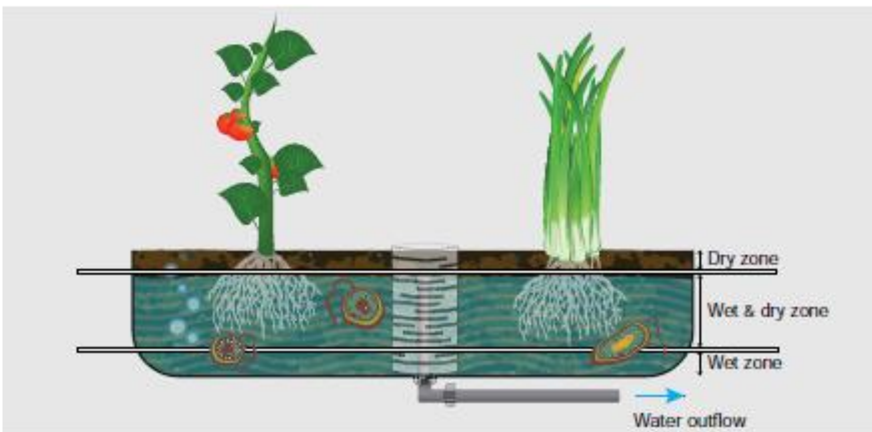


Figure 6, "The three zones of a media bed during the flood cycle" (Somerville, 2014, p60)

In this system, there is an inert media. The media bed is constituted with three parts: From top to bottom there are the dry zone, the wet and dry zone and the wet zone. The dry zone works as light barrier by preventing the light from hitting the water directly which can lead to algal, it also helps to minimize evaporation.
The wet and dry zone is beneficial for both moisture and aeration since it is intermittently wet and dry. This zone is mainly used for the transformation of the ammonium to nitrate by the bacteria. It is also where the plant will absorb the nutrients. The wet zone is constituted of heterotrophic bacteria and other micro-organisms. This zone has for main functions to break down the waste into smaller fractions and molecules. Systems can exist where the water is not drained, but where there is a constant flow.

In this project, the flood-and-drain techniques could be used. It would avoid the need for a biofilter. However, this is much heavier. It is also probable that a tank containing water should be added to prevent drastic level change during the flooding of the bed period (vegetable tank). Because the system is very heavy, the tank will have to be on the soil. This means that the management of the vegetable cannot be done standing. If the management is done by elderly persons, this can be inconvenient.

Fish:

The choice of fish is the same for media bed and DWC. For more details, I will refer to the fish part of the DWC scenario (scenario 1).

Vegetable:

One of the benefits of using the media bed technique is the ability of the system to be able to have denser vegetables. Because there is soil, it is possible to maintain vegetable with a heavy base. Systems like that can have, for example, banana trees as the main crop.

Typical crops for media bed: cauliflower, Eggplant, peppers, beans and peas (Somerville, 2014).

These vegetables are usually high demanding crop. It will probably not be possible to grow this kind of vegetable during the first years. As in the DWC, the types of fish, the amount of fish and the food of fish will influence the amount of nutrient available for the vegetable.

<u>Different designs</u>

Because the media bed system requires intermittence between flooding and flushing, the system cannot be too big as it would require to much water.

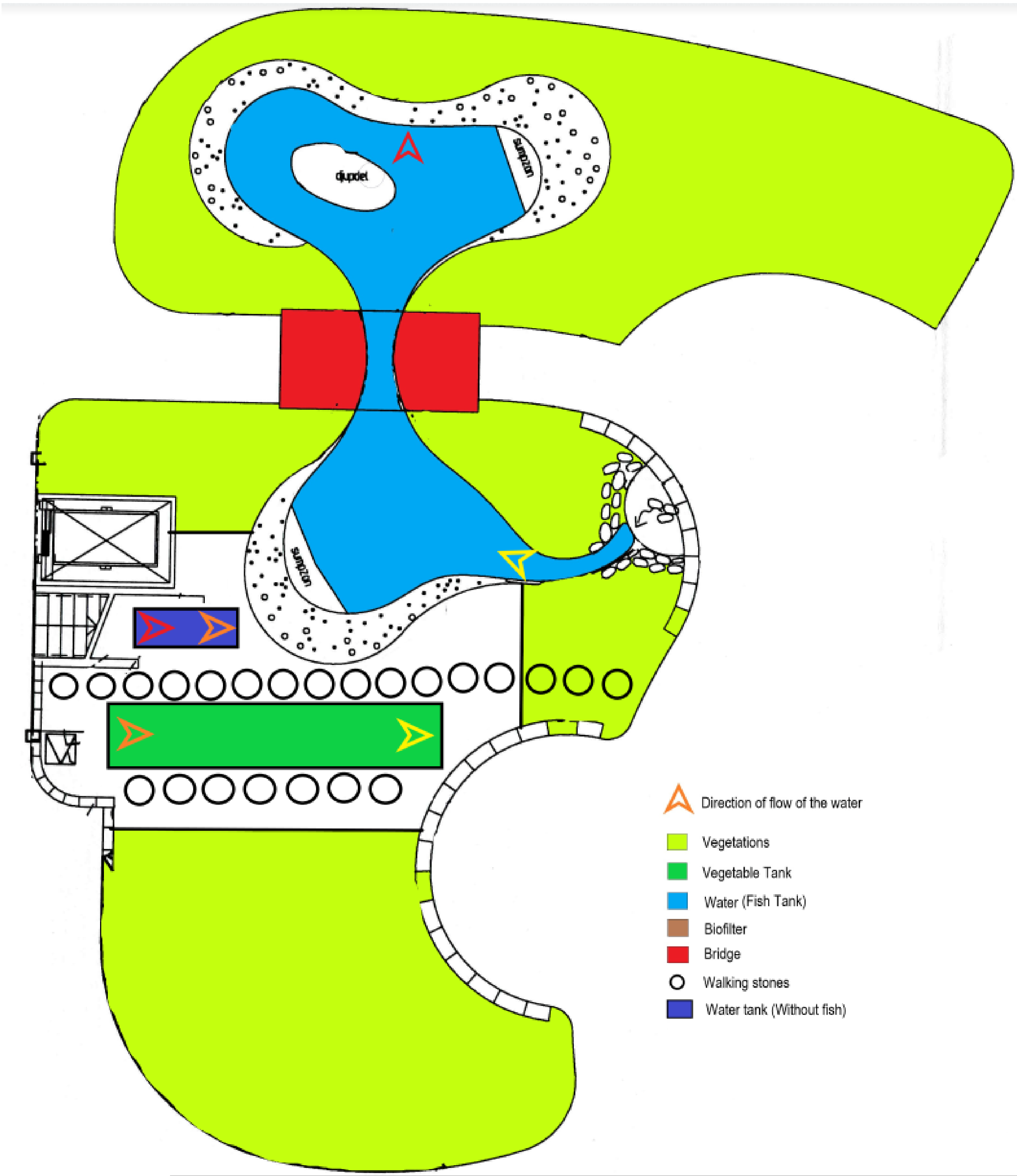


Figure 7, Design 1 Media bed system.

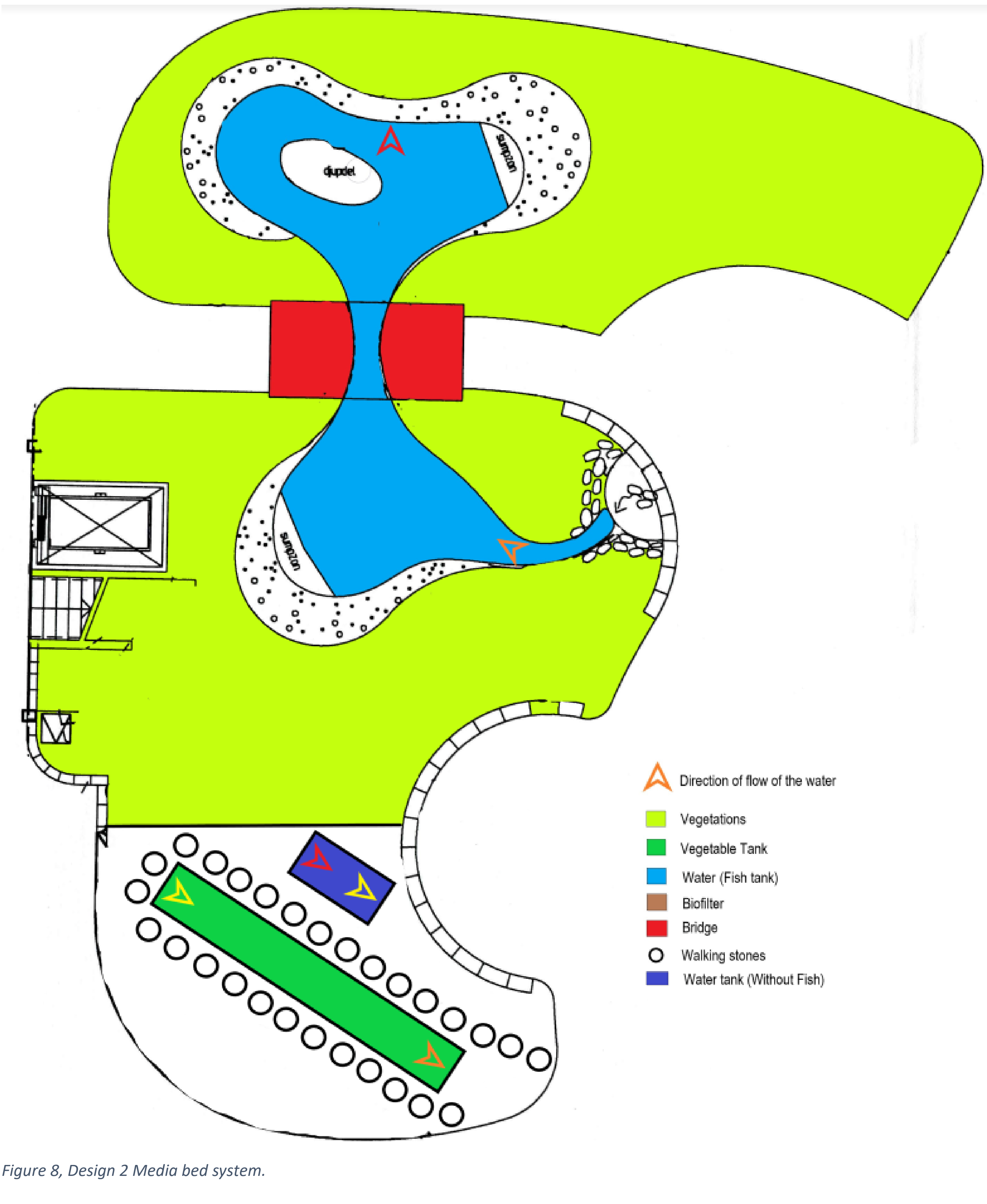


Figure 8, Design 2 Media bed system.

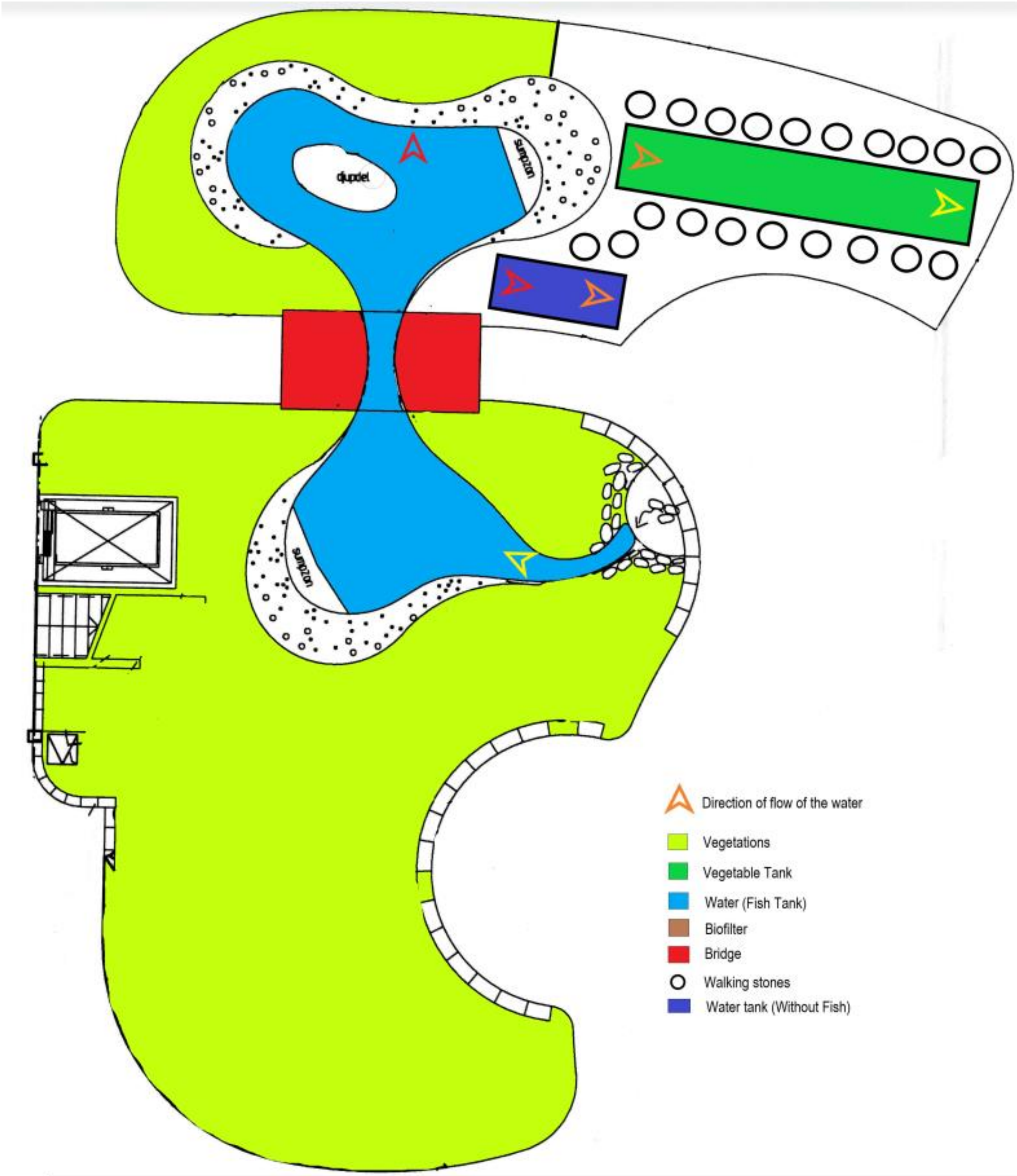


Figure 9, Design 3 Media bed system.

Scenario 2.1, Media Bed system with constant flow:

This chapter will present an alternative to the classical media bed system. This is directly related to the aquaponic project of Bjorn Oliviusson. If more information is needed, I would advise to referred to him as he has a lot of experience n the aquaponics field and in the system, I will present in this chapter.

Type:

Media Bed.

Design:

The design of this system is pretty similar to the one of scenario 2. However, there are major differences that will influence greatly the system and the management.

This system is a classical media bed system with a constant flow. This means that unlike the flood-and-drain technique, there is a constant flow of water in the media bed. This makes the system easier to manage. Moreover, there is no need for an extra water tank that is necessary to not decrease the level of the fish tank to much.

One of the inconvenient of this technique is the fact that not all of the media bed surface in the vegetable tank is used. Moreover, this technique is less used and has less material related to it.

Fish:

The fish are he same as in any system. Bjorn Oliviusson uses tilapia with piranha. The piranha are used as a natural compost. Indeed, tilapia need specific food and are quite selective. Piranha are used to transform the unprocessed food into food that tilapia eats. This can be advantages as it would decrease the amount of specific food necessary for the tilapia and decrease the amount of waste of the Bovieran system. Old bread and vegetable waste can be put into the system and be processed by the piranha.

Vegetable:

In this system, perennial plants are use. Because a certain temperature needs to be kept inside the "greenhouse", it could be possible to use tropical perennial species. Bjorn Oliviusson has several different types of plant that could be suitable for the Bovieran case.

I consider that the temperature inside Bovieran system is between 10°C and 28°C. This estimation comes from the measurement of the temperature of the pond during the year that should be pretty similar to the average temperature of the air around the pond.

With this temperature banana trees could be considered as a perennial plant for the system. Indeed, the ideal temperature for a banana trees range from 25-30°C depending on the species and the sources (Haifa Group. (2020), Birgit Bradtke. (n.d.)).

Table 2, Key temperature parameters for banana growth (Calberto et al., (2015), p268)

Temperature (°C)	Effect of temperature on banana growth
47	Thermal danger point, leaves die
38	Growth stops
34	Physiological heat stress starts
27	Optimum mean temperature for productivity
13	Minimum mean temperature for growth, field chilling
6	Leaf chlorophyll destruction
0	Frost damage, leaves die

In this table 2, we can see that the Bovieran facility could be suitable for banana trees. Banana trees have also the advantage of growing very fast.

Other perennial trees could be considered like papaya trees. Papaya trees have an optimal growth temperature between 21–32°C. The trees can survive at lower temperature with a decrease growth. Below -0.6°C the trees will have permanent damage or die (Crane, (2013), p2).

Those 2 plants are example of what could be use in a system like this one. The perennial plant needs less management and can produce considerable amount of food.

Sustainable Development Goals:

Figure 10, Sustainable Development Goals (United Nation, (n.d.))

The growth of world population increases the stress on land, water and natural resources in general. There is a need to find new ways to produce food sustainably and reliably (Goddek et al. (2019)). In this context, aquaponic is a promising alternative that can be linked to several Sustainable Development Goals (SDG). The goal (2) No hunger, is directly related to the production of food and the potential of aquaponics. Other goals as sustainable cities and communities (11), Responsible consumption and production (12), climate action (13), life below water (14) and life on land (15) can all be associated with aquaponic. Indeed, the production of fish in tanks allows to decrease some pressure of fishing and could decrease overfishing in natural water bodies.

The production of food at a local level could also decrease the carbon footprint of food and in turn, have an impact on climate change (13). In the case of Bovieran we could directly see the impact of using the greenhouse to produce tropical food which would decrease the carbon footprint of the boverian inhabitant. The transport impact of tropical food is very consequent and would be reduced if it is produced directly in Sweden.

Bovieran facilities are an example of the creation of small communities. These communities could become more sustainable by producing some of their food and this would also have an impact on the social life of the community. The goal (11) on sustainable cities and communities is referring to that. Aquaponics system could emphasize human interaction and activities that require man labour. Moreover, this system could also include an educative part that could be first for the Bovieran inhabitants and second for external people if the system is successful.

For the same reason as the goal (14) life below water, the production of vegetable will decrease the food demand of the community and could decrease the pressure of agriculture on land. This would have an impact on life of land (15).

Achieving these goals will depend on every human being and every initiative toward sustainability counts. Aquaponics could be one of this initiatives. However, aquaponics needs to be correctly managed to have benefic impact. Badly managed aquaponics systems can have adverse effects. Aquaponics developed in the past decade at a very rapid rate, but there are still some main challenges that are not properly addressed (Goddek et al. (2019)). However, aquaponics systems are usually a cycle which limit pollution and input in the system, which leads to more sustainability (Li et al. (2018)). On the other hand, the energy efficiency of an aquaponic system is still a challenge to reach sustainability (Goddek et al. (2019)).

Conclusion:

Several different scenarios and designs have been presented. To be able to do a complete design, some information will be needed. The amount of water in the pond, the budget, the exact dimension of the place and the primary use of the system are an example of information needed. The nutrient film technique (NFT) has not been considered. This system mainly uses pipes as vegetable tanks. I consider it would not correspond to the criteria given at the beginning. Indeed, one of the criteria was to create a system that could fit into the scenery. NFT would not achieve that.

Media bed seems a promising option. As a personal opinion, I do not consider this system to be much easier than the DWC system.

The DWC system is the system used for the demonstration system present in “Utvecklingscentrum för vatten” office. This system is quite easy to manage and can give a good result. If the vegetable tanks are done in wood like in the demo version, the system could easily fit the scenery. It will also be easier for future advice if the DWC is chosen.

If the Koi carp are the fish kept for the aquaponic system, there will be no production of eatable fish in the system.

A media bed system with constant flow and perennial plants could strongly be considered. This system would fit the scenery. It would also allow the production of tropical fruit and require less management than a classical DWC system. As a specialist in Sweden has already implemented this system, precise help and data could be provided by Bjorn Oliviusson. In aquaponic systems, help from consultants that already have a working system is invaluable. As said before, an aquaponics system has a high number of variables to take into account and need adaptation. An expert of the system is then necessary in order to guide adaptation, especially at the beginning of the system implementation.

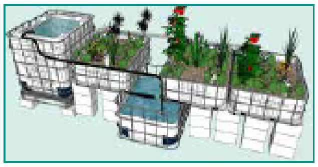
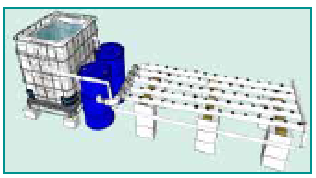
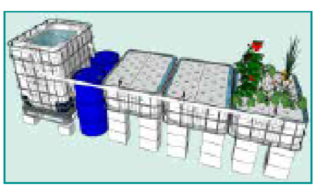
In conclusion, there are numerous options available for creating an aquaponic system. The fish, vegetables, dimension, type of biofilter, … are different criteria that can change and adapt to fit the system.

Annexes:

Annex 1: FAO table comparing the 3 systems

TABLE 4.2

Strengths and weaknesses of main aquaponic techniques

System type	Strengths	Weaknesses
Media bed units 	Simple and forgiving design Ideal for beginners Alternative/recycled parts can be used Tall fruiting vegetables are supported All types of plants can be grown Multiple irrigation techniques Many types of media can be used High aeration when using bell siphons Relatively low electrical energy Medium captures and mineralizes solids	Very heavy, depending on choice of media Media can be expensive Media can be unavailable Unwieldy at large scale Higher evaporation than NFT and DWC Labour-intensive to construct Flood-and-drain cycles require careful calculation of water volume Media can clog at high stocking density Plant transplanting is more labour-intensive as the media needs to be moved If water delivery is not uniform, plant performance may differ from bed to bed
NFT units 	More cost-effective than media beds on large scale Ideal for herbs and leafy green vegetables Minimal water loss by evaporation Light weight system Best method for rooftops Very simple harvesting methods Pipes spacing can be adjusted to suit different plants Well researched by commercial hydroponic ventures Smallest water volume required Minimal labour to plant and harvest	More complex filtration method Water pump and air pump are mandatory Cannot directly seed Low water volume magnifies water quality issues Increases variability in water temperature with stress on fish Water inlet pipes can easily clog Vulnerable to power outages
DWC units 	More cost-effective method than media beds on large scale Large water volume dampens changes in water quality Can withstand short interruptions in electricity Minimal water loss by evaporation Well researched by commercial hydroponic ventures Polystyrene rafts insulate water from heat losses/gains keeping constant temperatures Shifting rafts can facilitate planting and harvest Rafts provide biofilter surface area DWC canals can be fixed with plastic liners using almost any kind of wall (wood, steel frames, metal profiles) Can be used at multiple stocking densities	More complex filtration method Very heavy unit High dissolved oxygen required in the canal, and a more sophisticated air pump is required Plastic liners must be food-grade Polystyrene sheets are easily broken Tall plants are more difficult to support Large water volume increases humidity and the risk of fungal disease

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