Outdoor Aquaculture Pond for Pike-perch Fingerlings Production at a Biogas Plant

Preliminary study and design

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Bachelor's thesis

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EXAMENSARBETE

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Utbildning och ort: Environmental Engineering, Vasa
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Titel: Utomhusbassänger för odling av gösyngel vid ett biogasverk

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Abstrakt

Syftet med detta examensarbete har varit att analysera vattenkvaliteten från grundvattenkällor kring Stormossen för att sammanställa information om en lämplig miljö för att odla gös, från infångandet av avelsbestånd (vild, äldre fisk), till produktionen av yngel. En modell för en utomhusvattenbruksbassäng, lämplig för alla skeden av projektet, har även designats.

Examensarbetet, som är utfört som en del av gösyngelodlingen vid Stormossen, analyserar vattenkvaliteten från den grundvattenkälla som ställts till förfogande av Stormossen med syftet att närmare undersöka möjligheterna för fiskproduktion med hjälp av grundvatten från ett avfallshanteringsområde. Arbetet belyser även de krav på vattenkvaliteten som gösodling ställer.

Examensarbetet är teoretiskt baserat, och välgrundade antaganden har gjorts genom arbetsprocessen.

Sammanfattningsvis bistår examensarbetet med att skapa en tillfredsställande insyn i vattenbrukskonstruktion med ett fokus på gösodling, och vattenkvalitetens betydelse för regleringen av fiskarnas hälsa poängteras. För att lyckas med projektet rekommenderas en kontinuerlig testning av vattenkvaliteten.

Språk: Engelska Nyckelord: Gös, utomhusbassänger

BACHELOR'S THESIS

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Abstract

The aim of the thesis was to analyze the water quality data from the groundwater source in Stormossen for compiling necessary information about the appropriate environment to grow pike-perch juveniles from the beginning of catching the broodstocks (wild parents fish) to production of juveniles and design a pilot outdoor aquaculture pond suitable for all stages of the project.

The thesis, carried out as part of the Pike-perch juvenile farming in Stormossen, analyzes the water quality data from groundwater source provided by Stormossen to investigate the possibility of fish production with groundwater source in a waste treatment area. It also highlights the guidelines for water quality requirement to grow pike-perch.

The thesis is theoretical-based, and assumptions are made throughout the process of conducting this thesis.

In conclusion, the thesis provided a sufficient insight to the aquaculture construction and pike-perch farming including the importance of water quality in governing the health of fish. It is also recommended a retesting for new water quality data is necessary to ensure the success of this project.

Language: English Key words: Pike-perch, Aquaculture pond

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Abbreviations

DO	Dissolved Oxygen
FAO	Food and Agriculture Organization of the United Nations
Lx	Illuminance (1 lux = 1 lumen/sq meter)
VASEK	Vaasa Region Development Company

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1 Introduction

1.1 Circular economy Korsholm

Pike-perch juvenile farming in Stormossen is a small-scale project created by the Ostrobothnian Fisheries Association (Österbottens Fiskarförbund) with the assistance of VASEK. The project is a prototype idea contributing to a larger project created by VASEK called the Circular Economy Korsholm with the vision of creating “a foundation for the cluster of circular economy companies in Vaasa regions” [1]. By rethinking the entire production cycle and circulating material flows and value of products, the project hopes to attract novelty ideas, growing new businesses and emerging industries in this field for the region.

Promoting the current recycling-based circulation of materials is the focal point in the first step of the project starting with companies within the waste treatment and recycling sector in the Korsholm industry area. Since Vaasa region is so-called the Nordic Energy Capital [2], their consistent focus is especially on utilizing the waste materials and surplus energy in the waste-to-energy industry through the opportunities provided by the circular economy.

To encourage to the goal of the City of Vaasa - “to be carbon neutral, waste-free and globally sustainable consumption by the year 2050” [3] not only the plan focusses on recycling waste but also aims for the circular economy model where zero waste is created throughout the life-cycle of a product. Of course, there are no absolute solutions in creating such products that are waste-free. However, according to the circular economy model principles, there is no such thing as ‘waste’ [4], it can be treated as a by-product material that can be utilized to manufacture new products with the goal to maximize the product value and conserve resources.

The benefits brought by circular economy are a high added value potential for the Finnish economy plus significant environmental and social opportunities. However, the transition from a linear economy to circular economy require changes and adaptation from businesses and industries from all sectors to have an open-minded cooperation and the boldness to take risks and actions [5]. By implementing recent research results and practical and cost-effective business opportunities with circular economy, the project will also improve the sustainability of fish stocking and production.

1.2 Pike-perch resource in Finland

Pike-perch or zander (Latin name: *Sander lucioperca*; Finnish name: kuha; Swedish name: gös) is a freshwater species that inhabits in turbid, eutrophic and brackish habitats when reaching to their adult years. They can be found along the coasts of Archipelago Sea and the Gulf of Finland and they also have been caught in large amount in recent years in the Gulf of Bothnia. The mature pike-perch is preferably caught when it is is between four and eight years old. Catch sizes in different regions vary depending on the reproduction of the stock [6]. In Finland, pike-perch is among the most valuable delicacy fish species for both commercial and recreational purposes. Over-exploitation threatens the Finnish pike-perch stocks particularly due to both growth-overfishing and recruitment over-fishing. Growth-overfishing relates to exploiting young fish before they can grow to a reasonable size, while recruitment overfishing occurs when the parent fish stock is reduced to the extent that not enough juveniles are produced leading to fish stock depletion in a region [7]. As shown in Figure 1, the total catch of pikeperch stock in the coastal and inland water has a steady rise, starting from about 1000 kilos in 1980 and increased fourfold the amount in 2015 although there were some minor downfalls along the way.

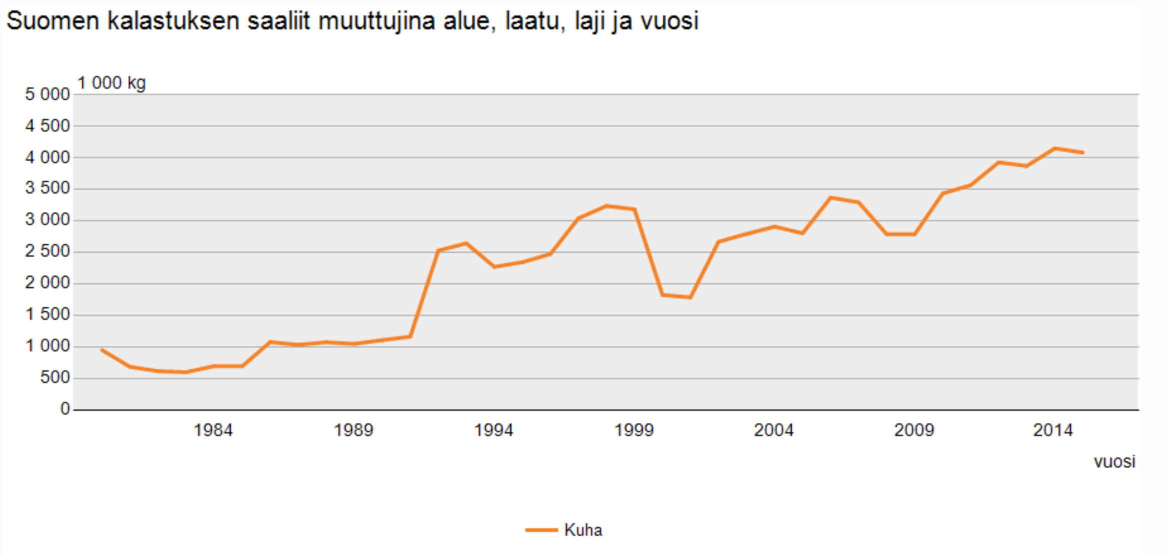

Figure 1. Total amount of pike-perch catches in Finland based on sea and inland water areas including both ways of commercial and recreational fishing from 1980-2015 [8].

There are numerous management measures of pike-perch populations, including re-stocking program and fishing restrictions carried out to mitigate the effects of over-fishing and enhance the production of pike-perch fingerlings [9]. However, pike-perch is constantly getting attention as a Finnish food delicacy, having a rise from 0,27 to 0,38 kg/person/year in the period of 2011-2016 as shown in Figure 2. In addition, Figure 3 demonstrates that the value in pike-perch price are considerably higher than other fish, even salmon in recent years, since salmon can be produced in commercial farms while pikeperch are mostly wild-caught. However, there are positive recognitions that Finnish fish farmer have started to take small steps in adopting recirculating techniques to raise pike-perch, for examples, the Savo Lax Oy has been producing pike-perch for the food market with their recirculating farm built in 2009 [12].

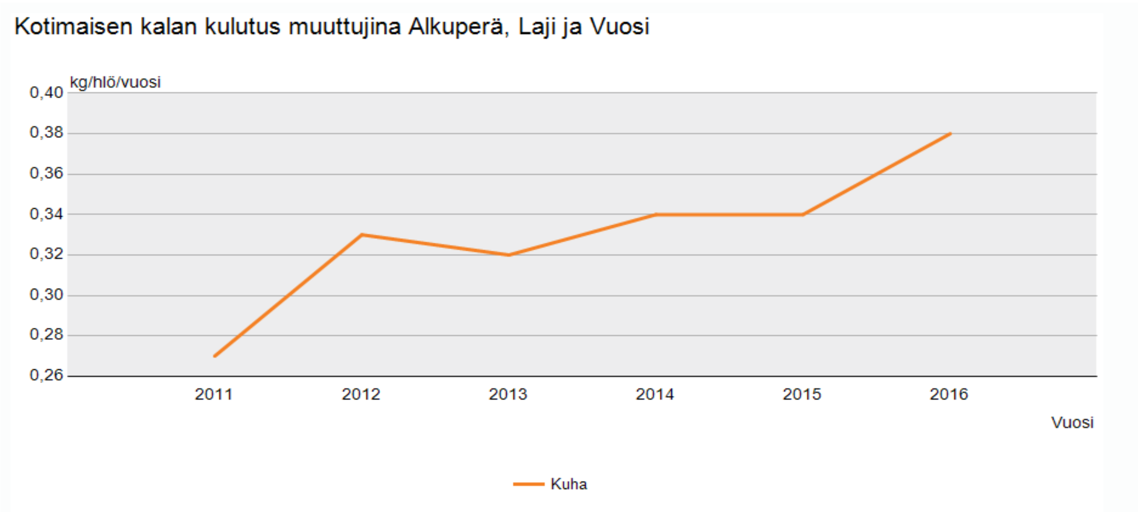

Figure 2. Pikeperch consumption in Finland from 2011-2016 (kg/person/year) [11].

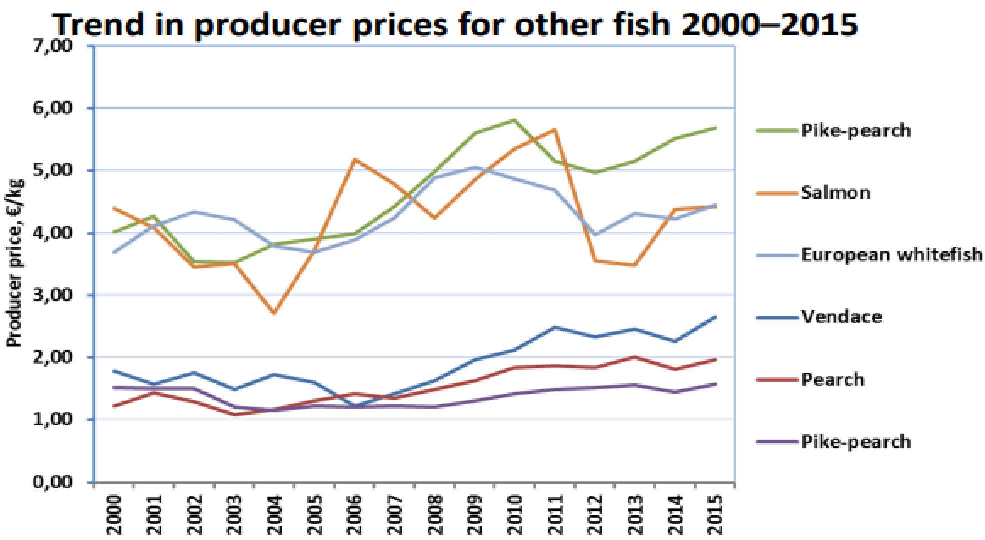

Figure 3. Trend in producer prices for other fish 2000-2015 [12].

1.3 Project details

According to the Ostrobotnian Fisheries Association (personal communication, November 2017), the supply of pike-perch fry for stocking is at limited in Ostrobothnia. Although there are some wild stocks of pike-perch that are used in fisheries management, most of them are reared in the middle of Finland (Tampere and Jyväskylä), where there are natural ponds with an acceptable water quality. Summer pike-perch juveniles are transported to the Ostrobothnia coast by car from the middle of Finland in water filled tanks with added oxygen. The amount of pike-perch transported each time is about 80-100 kg/1200 L water, depending on the temperature.

To have continuity and to increase the fish stocks along the Ostrobothnia coast, the fishery management must improve the local stocks. However, there are few natural ponds that are suitable for pike-perch farming in this area. The "Stormossen Pike-perch Farming Project" is an innovative project coordinated by the Ostrobothnian Fisheries Association and partnered with VASEK and Stormossen, hence considered as an important business opportunity.

It was also mentioned that the need for annual pike-perch was large as shown in Figure 4. The local water owners' interest in the fingerling stocking has increased year by year, and in 2017 the Ostrobothnia's Fisheries Association has been making orders of approximately 180,000 pikeperch juveniles in the area between Kristinestad (Finnish: Kristiinankaupunki, a town about 100 km south of Vaasa) and Karleby (Finnish: Kokkola, a town situated in Central Ostrobothnia about 120 km from Vaasa). Until now, the supply of pike-perch fingerlings is from Central Finland. However, the supply is very limited and only a third of the demand has been fulfilled at a maximum. Other disadvantages are the environmental impact as well as economic impact of long shipping distances which may cause stress and death for the small fries. These risks would be irreparable since the supply has already been too limited. The costs for 180,000 pike-perch fingerlings including transporting are around 50,000 € / year (personal communication, November 2017).

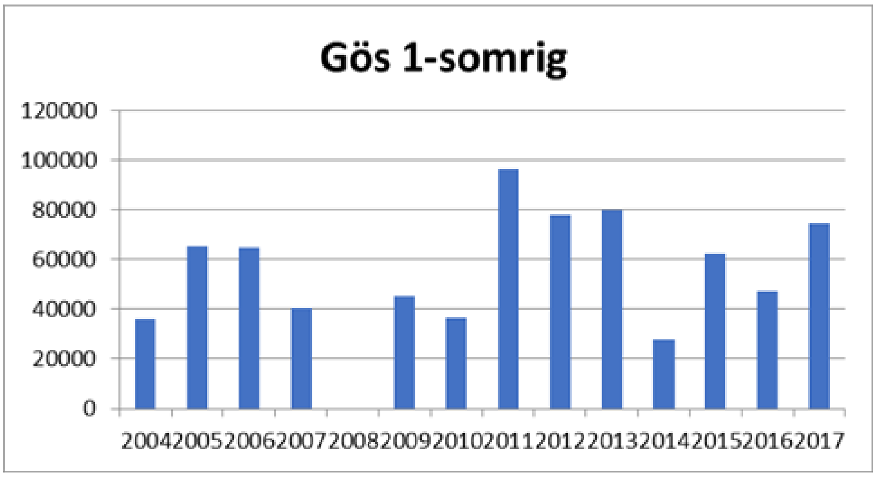

Figure 4. Exploitation of pike-perch in the Baltic Sea 2004 – 2017 [personal communication, January 2018].

The Association have been considering about a method in Kyrönjoki that can be used to collect the small fries from wild parent fish. Pike-perch is relatively fast-growing species, and for that reason, from the beginning of June to seedling in September, soon after the fingerlings can grow up to about 8 cm, they will be ready to be released to the sea.

The objective of the project is to investigate the possibility of pike-perch fingerlings production in Ostrobothnia. It aims to test new cultivation techniques for pike-perch for both in-season and out-of-season production. A pilot aquaculture pond will be done to test different bottom materials, heat regulation, feed control (plankton) testing for crop optimization and controlling other related issues concerning pike-perch growth rate. Different stages in the project will be tested and controlled daily from breeding, egg-hatching, feeding to maintain a healthy growth fish batch. All stages include uncertainties and the project strives to master all stages for a cultivation success. The fish stock will be added to the Kyrönjoki. The long-term goal is to strengthen the natural stock of pike-perch in the Kyrönjoki and increase the availability of fish stocks along the coast for commercial fishing purpose. Although there will be many risks and uncertainty related to pike-perch production processes, the project expectation is gaining the knowledge and experience on the aspects of technology and economy and creating new opportunities for the fishing industry and related-businesses in Ostrobothnia.

The duration of the project is almost two years, from 01.04.2018 to 31.10.2019. The cultivation season is expected to be from June to September in both years.

1.4 Project partners

1.4.1 VASEK

In 2003, Vaasa Region Development Company (VASEK, Finnish acronym) [13] was established by seven Ostrobothnia municipalities including Vaasa, Mustasaari, Isokyrö, Korsnäs, Vöyri and Laihia. VASEK plays the key role in supporting the development and competitiveness of regional economy. They provide business services for entrepreneur from the beginning of how to start up a company to the management of a business. Concerning about foreign trade and establishments, VASEK offers a variety of international services such as export and import investments or network for recruiting from abroad, which helps connecting specialists, local or foreign companies and investors together according to their needs and requirements.

VASEK has been partnered together with other organizations in several projects contributing to the energy technology business in Vaasa Region. For examples, the EnergySpin project [14] was created by VASEK, Merinova Technological Center and EnergyVassa, which is a company-specific training program offered for startup companies in the energy sector or other fields related to the energy technology, e.g. smart grids, IoT, renewables energy. The project has been receiving a great deal of interests and been partnered with big companies such as Wärtsilä, The Switch, Danfoss, Vaasan sähkö, and so on.

In summary, VASEK has been assisting start-up companies and new projects grow by connecting the right partners and investors and providing supports in both knowledge and investments needed. They spearhead projects on behalf of the municipalities that own it and other local players, and that is the role VASEK plays in the growth of various sectors in the region, including fisheries management.

1.4.2 Österbottens Fiskarförbund

The Ostrobothnian Fisheries Association was founded in 1930 and is comprised of 99-member organizations; currently involves 50 water owner associations, 43 fishery associations and six fisheries regions. The organization is under the Federation of Finnish Fisheries Associations. The region includes the coastal municipalities from Kokkola in the north to Kristinestad in the south. Their main objective is to promote the fishing industry so that a continuity production of fish in the fishing grounds is secured, profitable methods are developed for the procurement and utilization of fish production and the consumption of domestic fish is increased.

They provide services for the involved member organizations relating to water and fish stocks management as well as issues related to the Fishing Act. Their fisheries journals "Fiskarposten" and "Fiskeritidskrift för Finland" are the main channels to communicate with other fishing members including fishermen and private water owners. In recent years, fisheries courses in maritime safety, hygiene, fish processing, current fisheries legislation, fisheries monitoring, and fisheries management were organized to educate and exchange knowledge as well as experience not only for members but also publicly, in schools. They also arrange an annual fish market, 'The Fishery Day', which is a popular summer event in Vaasa with about 10,000 visitors annually. The aim of the event is to inform and educate the public about fishing in general, and to promote the consumption of domestic fish [15].

1.4.3 Stormossen Ltd

Stormossen Ltd is a regional waste management company, managed by six subregion municipalities – Vaasa, Isokyrö, Korsholm, Vörå, Malax and Korsnäs, with a total of approx. 107,000 inhabitants. Their main waste disposal center is in Kvevlax, Korsholm, which is 15 km driving from Vaasa. Stormossen Ltd has been a pioneer in the waste sector in the Ostrobothnia region, whose mission is to be a cost-effective and high-level waste mangement company that is also compatible with sustainable development.

Stormossen Ltd plays the key role to attain good outcome for the "Stormossen Pike-perch Farming Project" due to the fact that they provide most of the basic resource needed in the project such as land use, energy, water and wastewater treatment [16].

1.5 Aims of thesis

The aim of the thesis is to analyze the water quality data from the groundwater source in Stormossen for compiling necessary information about the appropriate environment to grow them from the beginning of catching the recruiters (wild parents fish) and design a pilot aquaculture pond suitable for growing pikeperch juveniles outdoor. The thesis should familiarize the reader of the scope of information related to the construction of aquaculture pond and process as well as suitable environments to raise pike-perch and freshwater warm fish in general.

1.6 Limitations

Content of thesis is only theoretically study and most of the resource is extracted from the Food and Agriculture Organization of the United Nations (FAO). Another limitation is the extremely high level of the total ammonia nitrogen - TAN (Ammoniumkväve mg/l) index in Stormossen groundwater in recent years which is toxic for the fish if in the form of Nitrate (NH_3). Therefore, it is important to have the groundwater retested for further investigations to support the continuity of the project.

1.7 Chosen location

The project cooperates with Stormossen Ltd., which helps setting up an area for the cultivation basins and monitoring the water temperature in the pond. The aquaculture pond will be constructed with a total area of approximately 440 m^2 (21 m × 21 m). However, no state of authority is neccessary, partly because it is a small-scale low-tech construction and the water from the cultivation will run through Stormossen's wastewater system. It is placed in a same area which is used for compost treatment and covered with asphalt as illustrated in Figure 5.

In this area, there is enough heat from sunlight and water is pumped out of the nearby groundwater canal, which is suitable for the regulation of heat in the ponds. It is assumed by Leif Kaarto, a fish expert from the Ostrobothnians Fish Organization, that the groundwater should possibly contain appropriate nutrients added to plankton production that later will be feed to the pike-perch larvae. The aquaculture system is required to be an open ground borne pond that can maintain a temperature of 16 – 22 °C.

Figure 5. The blue rectangle is demonstrated where the pilot pond will be constructed. [Google Map]

2 Theoretical background

2.1 Pike-perch

Figure 6. S. lucioperca. [Image: Gösta Sundman]

Pike-perch – *Sander lucioperca or Stizostedion lucioperca (S. lucioperca)*, is a large, freshwater species belongs to Perches – Percidae family. The average weight is between 2-5 kg and length reaches 50-70 cm. Figure 6 illustrates its biological features with a elongated and slender body with pointed snout and fairly large, dark and protruding eyes. It has two dorsal, in which the first one is spiny while the second one has soft rays. The colour varies from greenish-grey or brown on the back from head to tail and becomes lighter on the lower sides and white on the belly. Figure 7 demonstrates the common production cycle of pike-perch including different methods and ponds for extensive and intensive puproses. The first phase of the project plan will start with catching and breeding the broodstock spawners from the wild. Next, different methods for hatching fish larvae are tested including keeping eggs in spawning nests or using egg incubation systems, depending on the budget and the availability of equipments. The fry after 3-5 days old will be transferred to nursery/culture ponds for weaning and rearing until they reaches 8 cm and then be released to the sea.

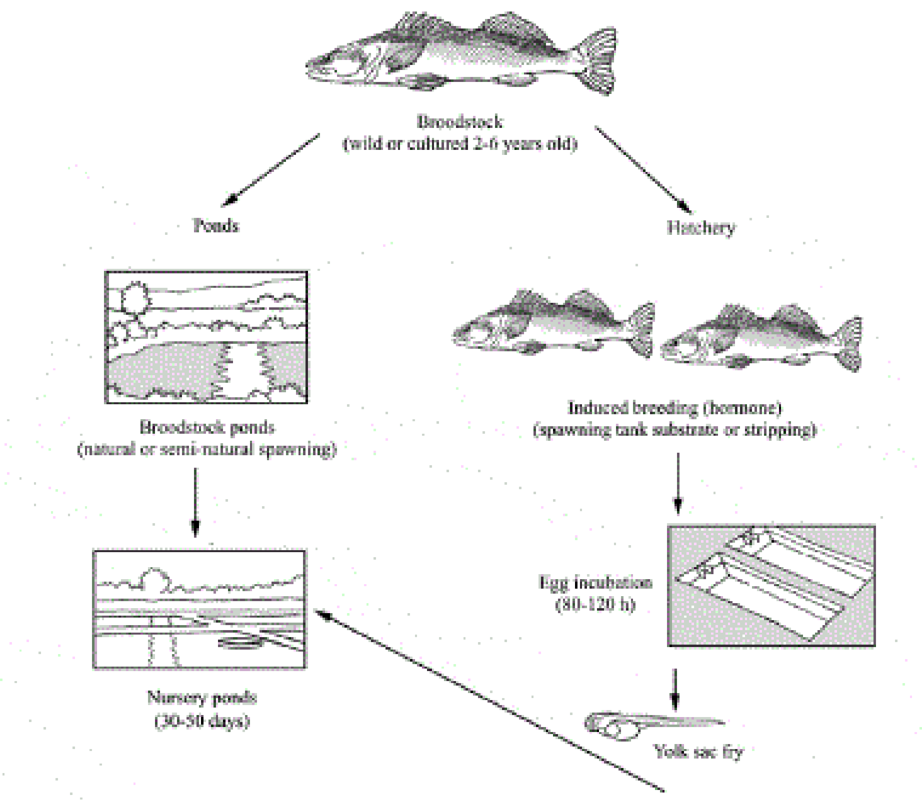

Figure 7. Production cycle of pikeperch [17].

2.2 Assessing water quality

The choice of source water for the aquaculture pond is to be filled with the spring water extracted from nearby canal. One problem with the available water analysis data provided by Stormossen is the uncertainty of the exact location where the tested water source is taken from, if it is from a surface canal (spring water) or straight from a groundwater well. This information can be worth mentioning because spring water might have different results from well water. It can be more likely to have phytoplankton, other microorganisms and plants presented and be exposed from air temperature, photosynthesis, other physiological processes and human impacts which later can have profound effects on pond water quality. However, spring and well ground water both share the same advantages, which is a constant temperature and less contaminated and disadvantages of low concentrations of dissolved oxygen and high concentrations of other dissolved gases (e.g. nitrogen, ammonia, carbon dioxide) and/or metals in the water source [18]. Therefore, this assessment of Stormossen's water quality data cover some important water parameters that later hope to support the next suggested water inspection.

In general, for optimum fish growth and production, it is important to know about the factors affecting the water bodies such as temperature, pH, DO levels, alkalinity, hardness and metals [19]. These quality issues need to be identified to determine that the water quality is suitable for fish farming and does not cause any negative effects to human health when consuming fish products. Until now, there is no specific directive developed for the water quality standards in pike-perch farming. However, there is a traditional method that raise pike-perch in a polyculture environment with common carp [20], a cyprinid species since they are both freshwater species and additionally, cyprinids are reported to be the main prey species for pike-perch in central Europe [21]. Therefore, it is presumed that the water environment suitable for cyprinid would also be applicable to pike-perch. In Table 1, the parameters from the Directive 2006/44/EC for the quality requirement of fresh water for protection and improvement of either salmonid and cyprinid would be applied on the required water environment for pike-perch.

Table 1. List of parameters extracted only information for Cyprinid [22].

Parameters	Cyprinid waters	
	G (Guide)	I (mandatory)
1. Temperature (°C)		10 – 28 °C
2. Dissolved Oxygen (mg/l O_2)	50 % ≥ 8 100 % ≥ 5	50 % ≥ 7
3. pH		6 – 9
4. Suspended solids (mg/l)	≤ 25	
5. BOD_5 (mg/l O_2)	≤ 6	
6. Total phosphorus (mg/l P) 7. Nitrites (mg/l NO_2)	≤ 3	
8. Non-ionized ammonia (mg/l NH_3)	≤ 0.005	≤ 0.025
	In order to diminish the risk of toxicity due to non-ionised ammonia, of oxygen consumption due to nitrification and of eutrophication, the concentrations of total ammonium should not exceed the following:	
9. Total ammonia (mg/l NH_4)	≤ 0.2	≤ 1
10. Total residual chlorine (mg/l HOCl)		≤ 0.005
11. Total zinc (mg/l Zn)		≤ 1
12. Dissolved copper (mg/l Cu)		≤ 0.04

2.2.1 Temperature

In aquaculture practices, water temperature is a critical water quality parameter influencing the fish stock survival, growth rate, health and reproduction. Each fish species has its tolerance range and optimum water temperature range where the fish population thrives. Therefore, if the water temperatures are outside the optimum range, it will have effects on fish body temperature which can cause stress, susceptible to infectious disease [23] which later results in a decline population. Moreover, there are researches showing that temperature is closely correlated with the growth rates and feed conversion rates of pike-perch [24] and also its puberty [25]. This means that the optimum water temperature required for each stage of pike-perch life such as egg incubation, growth of fish larvae and juveniles would be different and require closely monitoring. For examples, mean daily water temperature for spawners (parents fish) is 8 - 9°C, while the temperature for highest growth rate for rearing fry is 22°C [26]. In addition to the outcome of water temperature change, it can alter the solubility of gases in water, e.g. as temperature increases, the DO level decreases [27] and also the reaction rate of chemicals such as ammonia. Hence, the management of water temperature should be noted when design and monitor the aquaculture environment.

The spawning season is expected to occur in summer when the temperature is warm enough. For Figure 8, it is apparent that the chosen period has the warmest temperature raising in the year and would be the best condition to begin the reproduction process. However, the temperature is still too low for the fish stock to adapt and grow, therefore, it is neccessary to consider an appropriate methods or equipments for generating heat as well as controlling temperature. This issue will be later discussed in Chapter 4.1.

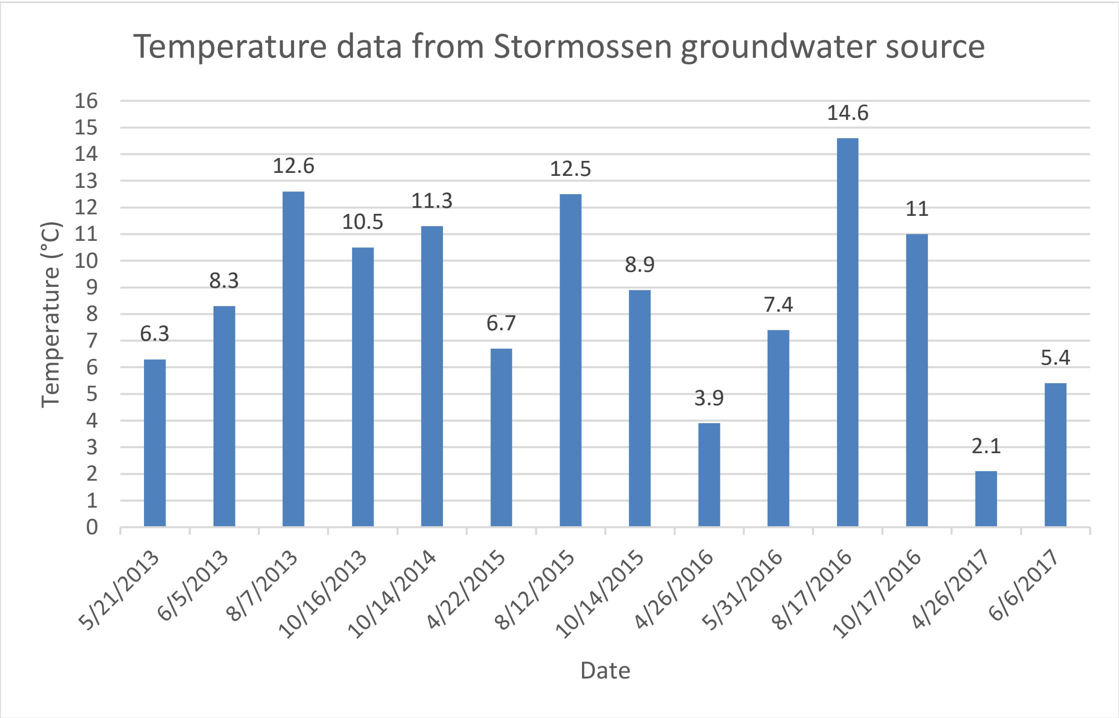

Figure 8. Temperature data from Stormossen groundwater source from 2013-2017 [Values in Appendix 1].

2.2.2 Light and vision

Light is an another necessary factor that heavily affects the fish life and also the fish living environment. Unlike other fish species that are not directly affected by the water transperancy level, pike-perch has a distinctive eye feature, which is *tapetum lucidum* [28], which helps improving vision during low light conditions or having good night vision. However, it is also an disadvantage which cause pike-perch vulnerable with intensive bright light, such as sunlight, especially at the start of their lives. According to the manual of the artificial propagation of warm-water finfishes, direct sunlight can also disturb pike-perch larvae equilibirium making them blind and affecting their ability to locate prey [29]. There area numerous of research shown that both juveniles and adult pike-perch prefer low light conditions and eat more effciently in turbid and night time conditions [30]. For examples, Luchiari, A. et. al. suggested that pike-perch should be reared under very dim light condition and that the behaviors of both 0+ year-old juvenile and 1+ year-old pike-perch age groups showed a preference for the lowest available light intensity (testing light intensity is from 1-50 lx) [31]. Moreover, the study of Kozowski also agreed and added that under such conditions (< 45 lx) pike-perch juveniles will thrive which make it possible to shorten the rearing period and lower production costs [32]. Detailed value can be found in Table 2 with examples of outdoor illumination (light levels) from natural sources, it is visible that the level of light intensity for pike-perch would be the same the condtion of twilight. The issue with low light preference in pike-perch, especially at larvae stage can be settled by either have them raise indoors only at that particular time and then transfer them to the hatchery and fingerlings pond, or by shading materials and increase the water turbidity. In Chapter 4.3, these methods will be explained in more detail.

Table 2. Common light levels outdoors from natural sources [33].

Condition	Illumination	
	(ftcd)	*(lux)*
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

2.2.3 Dissolved oxygen

Oxygen is vital for all the organisms on Earth, including aquatic animal. Therefore, dissolved oxygen is one of the most important parameters of water quality on aquatic life. Dissolved oxygen is dependent upon photosynthetic and respriration processes of phytoplankton, fish and submerged plants, and also the degradation of organic matter by microorganisms [34]. Moreover, these processes as well as the solubility of oxygen are influenced by temperature. Figure 9 shows the inverse relationship between temperature and oxygen solubility. As the dissolved oxygen was at high level, the temperature was at low degrees and vice versa. This held true excluding an irregularity on 26th April, 2016 and 26th April, 2017.

According to table 1, the recommended dissolved oxygen requirements for Cyprinid (or freshwater fish in general) are equal to or greater than 5 mg/l (100% saturation) and 8 mg/l (50% saturation). However, as previously mentioned, it is obvious that the concentration if dissolved oxygen from the groundwater source would be too low and could have major effects on fish growth, e.g. causing stress, disease susceptibility [35] and even suffering fatalities if the concentrations reaching below 2 mg/l [36]. If the fish start showing signs of ”unusual lethargic and stop feeding”, the cause could be from oxygen deficient water [37]. Other noticeable signs would be fish gasping for air at surface level and gathering at the inflow or aeration devices where oxygen levels are higher [38]. This problem can be solved by increasing DO concentrations with mechanical aeration, such as vertical pump, pump sprayer, and paddle weels even if the concentration of dissolved oxygen level was already sufficient. Consideration for a appropriate aeration system is influenced by various aspects, for instance, size, depth and shape of a pond, power source availability, need (emergency or long-term), efficiency, seasons [39]. In contrast to low dissolved oxygen level, a supersaturated oxygen or gas level in general can also cause gas bubble disease in fish and other aquatic organisms [40].

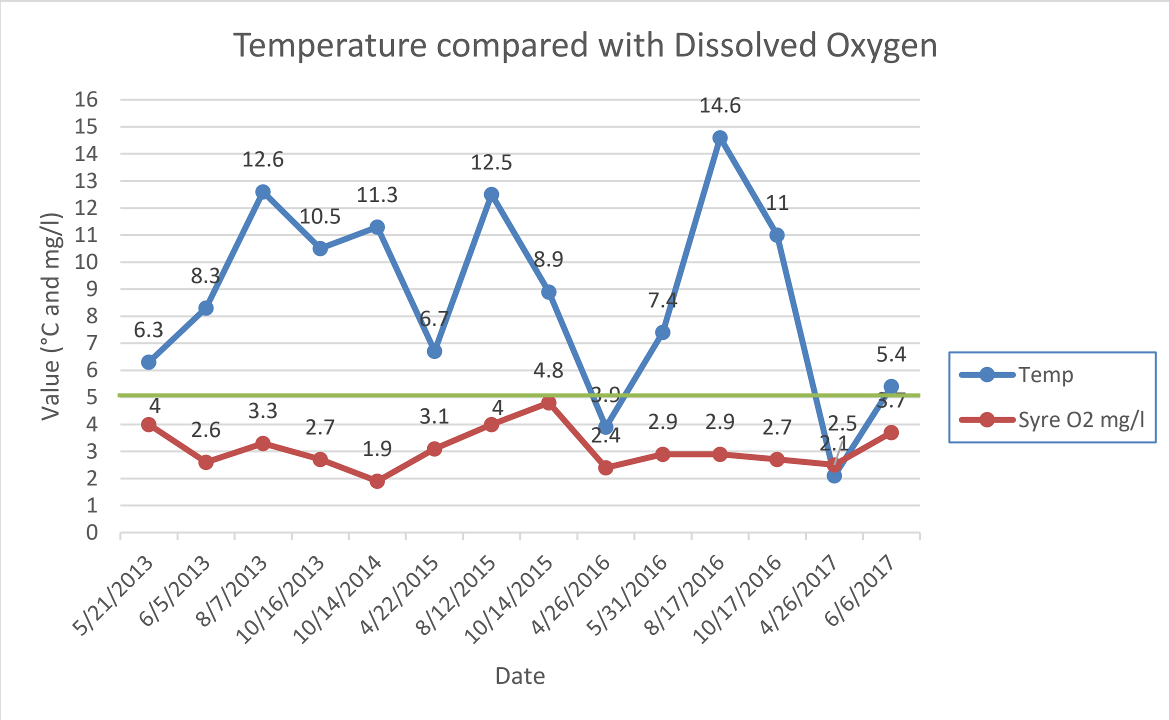

Figure 9. Temperature compared with Dissolved Oxygen from 2013-2017 [Values in Appendix 1].

2.2.4 pH and alkalinity

Water pH is the paramater representing the quantity of hydrogen ions in water with a scale ranging from 0 (strongly acidic) to 14 (strongly basic or alkaline) while the value of 7 corresponds to neutrality. A desirable range for pond water pH is recommended between 6.5 and 9 as demonstrated in Table 1 and the result from the tested groundwater data [Values in Index 1] shows an average pH level of 7, which is ideal for pike-perch growth and production. The water pH level will later change depending on a number of factors such as water source, aquatic life within the pond and their performance, stocking density of culture fish, feeding rate and sludge formation in pond bottom. It is important to monitor a stable pH range because the parameter has adverse effects on both survival and optimum growth of fish stock if the levels are out of desirable range as demonstrated in Table 3. Furthermore, pH has indirect effects resulting from the interactions with other chemicals parameters creating toxic compounds in the water system [41], e.g. when pH increases 1 unit, un-ionized ammonia – toxic form of ammonia (NH_3) increases by a factor of 10 [42].

Table 3. pH tolerance levels and its effect on warm water pond fish [43].

pH levels	Effects on warm water pond fish
< 4.0	Acid death point
4.0 – 5.0	No production
6.5 - 9.0	Desirable range for fish production
9.0 - 11.0	Slow growth
> 11.0	Alkaline death point
Source: Lawson 1995, Tarazona and Munoz 1995	

Total alkalinity measures the quantity of base (bicarbonates and carbonates) presented in water that indicates the pond's ability to resist large changes in pH. At low alkalinity level, the water pond pH level is less stable and more changeable which might cause stress, poor growth and even death of the cultured fish. In addition, the production of phytoplankton and plants is indirectly affected since certain nutrients can be unavailable in low alkalinity concentration [44]. Total alkalinity is usually expressed in two ways 1) in SBV units and 2) mg/l of equivalent calcium carbonate ($CaCO_3$). 1 SBV unit is equal to 50 mg/l $CaCO_3$. For examples, the measurement of total alkalinity in SBV unit is 3.6, this is equivalent to 3.6*50 = 180 mg/l $CaCO_3$. Table 4 expressed how total alkalinity along with carbon diocide can make impact on water pH level and fish farming general.

Table 4. Total alkalinity and the potential effects in fish farming [45].

Alkalinity and fish farming		
Total alkalinity of water		Potential for fish farming
in SBV units	in $CaCO_3$ mg/l	
<0.1	< 5	Very low: water strongly acid, unusable for fish breeding
0.1-0.5	5- 25	Low: water pH variable; carbon dioxide supply low for plant photosynthesis; danger of fish mortality
0.5-1.5	25- 75	Medium: water pH variable; carbon dioxide supply medium
1.5-3.5	75-175	High: water pH varies only between narrow limits; carbon dioxide supply optimal for plant photosynthesis, especially phytoplankton
> 3.5	> 175	Medium to low: water pH very stable; carbon dioxide supply decreases as alkalinity increases; fish health not endangered; calcareous deposits may form on surfaces

In the groundwater data as shown in Figure 10, there is no available unit for total alkalinity. If the measurement is in mg/l, these values would be too low and impractical to use for fish production. On the other hand, if the measurement is in SBV units, the results seems to be more positive since the acceptable total alkalinity range for ponds would be more than 20 mg/l and less than 400 mg/l [46]. In general, the values in recent years (2015 – 2017) are quite stable, which the lowest value is 2.2 in August 2016 and at highest (3.7) two months later. The variations are sufficient enough for aquaculture purposes.

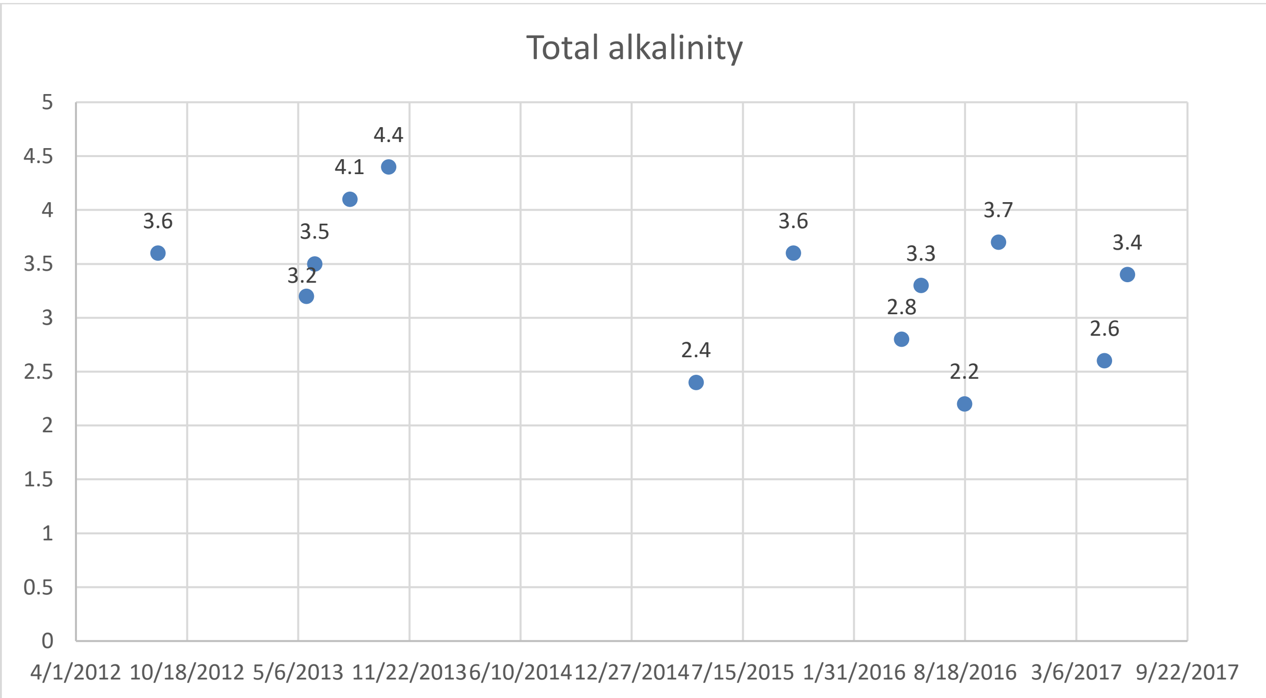

Figure 10. Total alkalinity concentration of groundwater [Value in Appendix 1].

2.2.5 Ammonia Nitrogen

In groundwater, nitrogen is presented as dissolved organic nitrogen, NO_3, NO_2, or NH_4. Ammonia nitrogen or ammonium (NH_4-N) is the dominant form commonly found in groundwater as a results of anaerobic decomposition of organic matters and also anthropogenic activities, e.g. wastewater discharge, landfill leachates [47]. Total ammonia nitrogen is the amount of nitrogen in the forms of ammonium and ammonia. The toxicity of TAN is dependent on the proportion of un-ionized ammonia NH_3. This proportion can be increased correlated with high temperature and high pH, shifting from right to left in equation (1). As previously mentioned, when pH increases 1 unit, un-ionized ammonia – toxic form of ammonia (NH_3) increases by a factor of 10.

$NH_3 + H_2O$	Û	$NH_4^+ + OH^-$
Low temperature and low pH	Þ Ü	High temperature and high pH

(1)

Furthermore, high level of ammonium NH_4+ is found out to be indirectly toxic to tilapia due to harmful metabolites derived from it, such as nitrites and chloramines and an increase of chloramines leading to water acidification [48]. High concentration of ammonia can cause ”gill damage, reduce the oxygen-carrying capacity of blood, increase the oxygen demand of tissues, damage red blood cells and the tissues that product them” [49]. Table 1 indicates that the requirement for total ammonia should not exceed 0.2 (guide) and 1 (mandatory) mg/l NH_4. However, the graph in Figure 11 shows that the groundwater well in the study area contain excessively high levels of ammonium, at its peak in 2014 with 540 mg/l and in 2017 with 230 - 350 mg/l. This measurement should be retested and analyzed as it is one of the most important water quality parameter that would highly affect fish health in general.

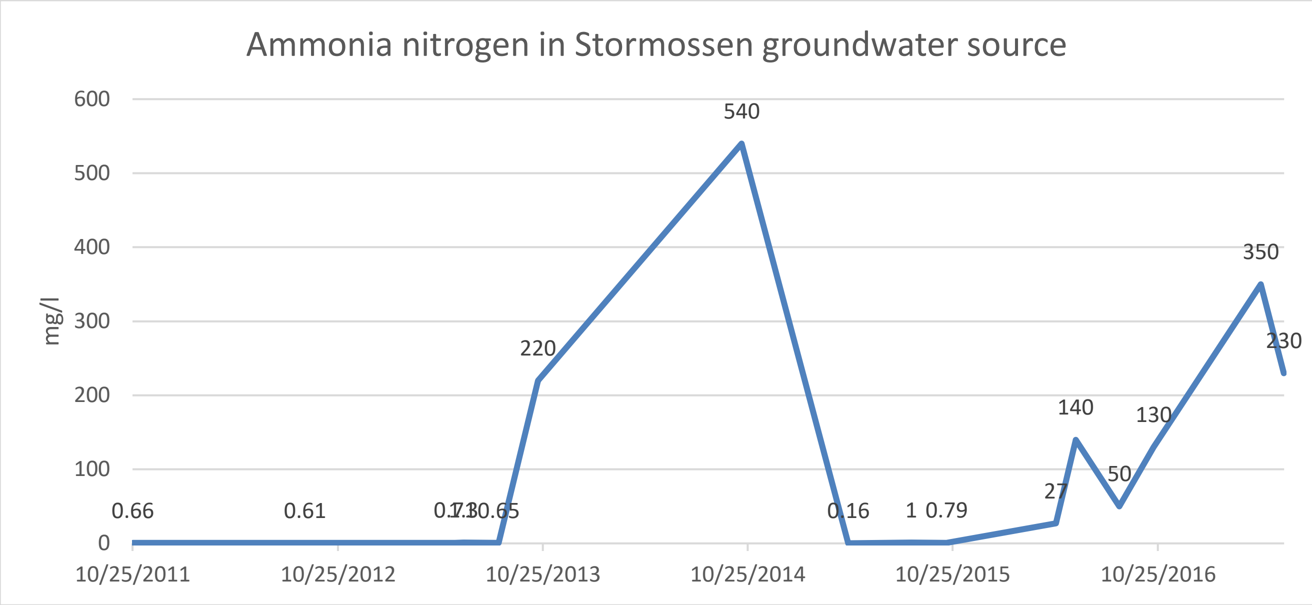

Figure 11. The amount of ammonia nitrogen in groundwater [Value in Index 1].

3 Suggestions for tackling water problems

3.1 Water heating methods

The problem with low temperature can be resolved by several heating technologies implementing in aquaculture, either by using energy source (electricity, oil, gas) to heat up the water such as heaters or by utilizing the available energy sources supply to meet the heating demand [50]. Waste heat from industry and renewable energy sources such as geothermal energy, solar energy, hydropower, biomass, wind or tidal energy are considered as potential energy usage in aquaculture. The original plan of this project was to recover the excess energy of thermal effluents or waste heat from the waste treatment plant as the heating source, which is the foundation of the Circular Economy plan. However, for the reason that this is a pilot project involving many risks and uncertainty factors and is budget-friendly and low-tech for trials and experiments, installation of heat/water pipeline and heat exchanger is considered to be unnecessary and expensive.

As for now, to control the water temperature controlling, simple methods would be heating up the water temperature by using black PVC tubes (heat absoprtion from solar radiation) and pond shading. Chapter 3.6.3 will provide more details about pond shading. The reason for choosing dark plastic materials would be to utilize the thermal conductivity effect, and reduce the construction and energy costs [51, 52]. Nevertheless, factors such as solar radiation, air temperature, seasonal change, geographical location, thermal stratification can make an impact on the competence of these methods. On the other hand, one advantage of an artificial pond is that the temperature change in small water bodies with depth about 1 – 2 meter will be minor between the surface and bottom water [53]. Moreover, aeration system can also be used to keep the pond in a continous circulation and prevent the temperature difference [54]. In another scenario, if these proposed techniques are ineffective in raising and maintaining the temperature demand, installation of heaters or a heat recovery system would be other suggestions to assist the system.

3.2 Light sensitivity and pond shading

One problem with outdoor fish pond in the Stormossen is the high number of birds and seagulls living and feeding in this area. Protection bird nets was the first idea to prevent the bird from attacking, feeding on the fish and also protect them from the birds contamination (salmonella). However, bird nets would not be able to provide an dim-light environment for the larvae to grow. To solve the problem, the proposed idea is to use black heavy duty PVC fabric to cover up the pond. The black PVC materials can utilize the thermal conductivity effect to heat up the pond water temperature. Rings are attached to the tips of the fabric and then tied to 4 sticks at the corner of the ponds as illustrated in Figure 12 and and Figure 13.

Another solution is to provide shelter or hiding spots for fish to retreat in safety escape predators or avoid the sunlight. Pond plants or coverage foam can be extra camouflage and cheap solution in this case. Although these approach are easy and inexpensive, the purpose of this project is aim to be a pilot of commercial fish farming, unneccessary elements should not be considered in the system to avoid changing the physiological effect of the pond.

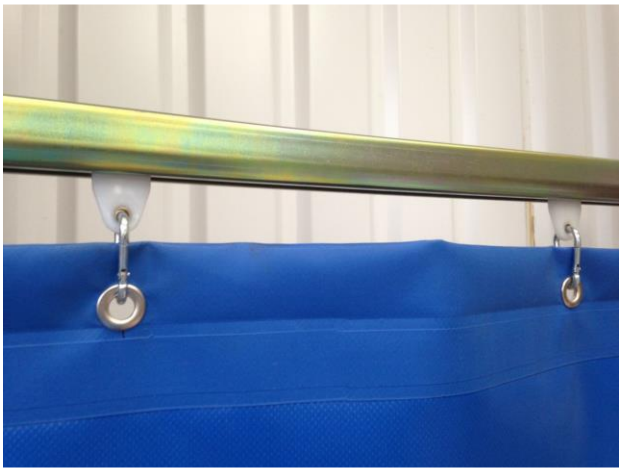

Figure 12. Making rings on the PVC fabric for sun blocking [Image: Google].

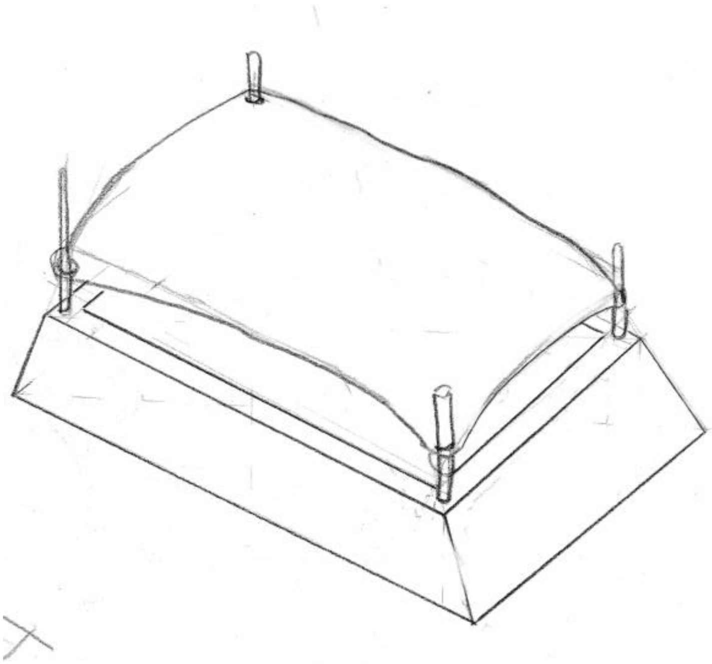

Figure 13. Pond shading design [Image: Nhi Tran].

4 Pike-perch aquaculture pond

The requirements of the project to build an outdoor aquaculture system consist of:

a) The pond is used for all the phases starting from pike-perch spawning to raising pike-perch fingerlings;

b) Temperature need to be controlled at different phases of ongrowing fish;

c) Light source should be kept at minimum since the larvae prefers dim light.

The reference material in the FAO Training Series on pond construction [55] is used throughout the design phase.

The design pond is determined to be a embankment pond lining with PVC plastic pond liner and the water is pump-fed from nearby canal that receives the pumped groundwater directly. Embankment pond as shown in Figure 14 is created by building a dam or embankment above the ground level to collect and hold water. They are usually drainable and fed by gravity flow of water or by pumping. The reason for the embankment pond is based on an economical budget by utilizing the surplus soil in Stormossen. There are four ponds for experimenting different spawning and feeding methods. The purpose of dividing into four ponds is for fish selection in size to minimize the rate of cannibalism and for easy water environment control.

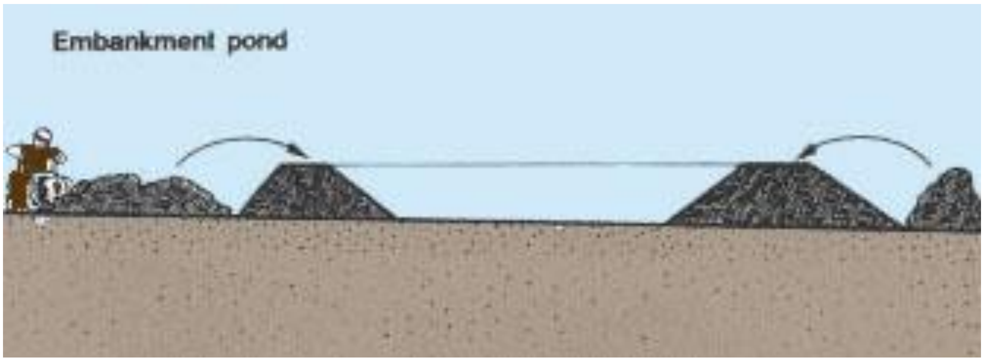

Figure 14. Embankment ponds [56].

The initial idea was to construct 4 embankment ponds with individual pond walls. The pond wall can resist the water volume and pressure from the pond water depth and should be high enough to keep the water in. However, through calculations, the area of the dikes for four ponds including 0.5 m-wide road would take up such enormous land area. Therefore, another alternative would be to build brick walls as dividers that would take less space and still provide strong walls to resist water pressure as demonstrated in Figure 15.

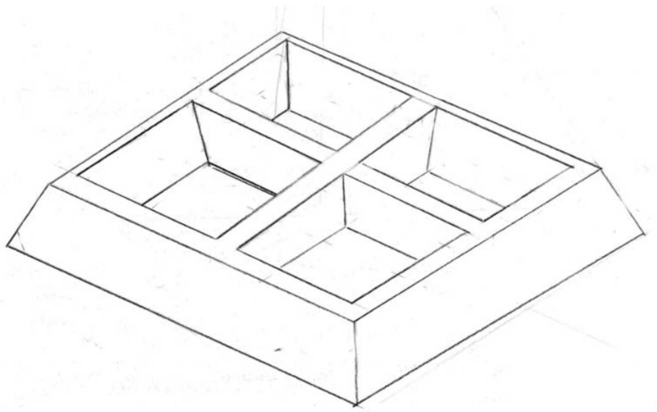

Figure 15. Proposed pond design [Image: Nhi Tran].

4.1 Construction height

To calculate the height of the pond walls, there are other parameters shown in Figure 16 that need to be considered. First, it would depend on the water depth (WD). Secondly, the freeboard (upper part of the pond wall – FB) could be kept between 0.25 – 1 m. Finally, depending on the compression and settlement of soil material, the pond wall could be lost during soil settlement. As a consequence, the settlement height (SH) would be accounted for

5 – 20% of the height of the wall. The formula of the construction height is demonstrated as follows:

$$CH = \frac{DH}{\frac{(100 - SA)}{100}}$$

where CH is the construction height, DH is the design height and SA is the settelement allowance.

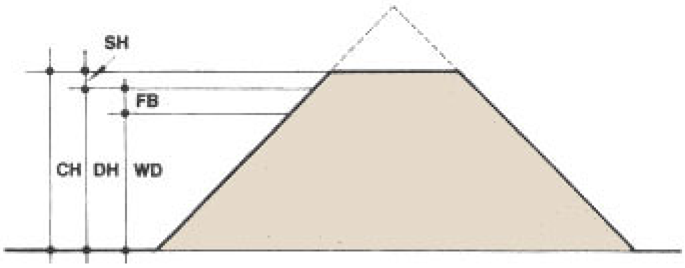

Figure 16. Pond wall measurements [57].

The requirement water depth for pike-perch spawning ranges from 0.5 – 3 m and for pike-perch juveniles should be greater than 40 cm [58]. If the chosen depth for the fish pond is 1 m and the free board is 0.3 (for pond size 400 m^2), design height will be 1.3 m. If the settlement allowance is estimated to be 15% (for firm, compact soil), the required construction height will equal

$$CH = \frac{1.3\ m}{\frac{(100 - 15)}{100}} = 1{,}53\ m$$

4.2 Thickness of pond wall

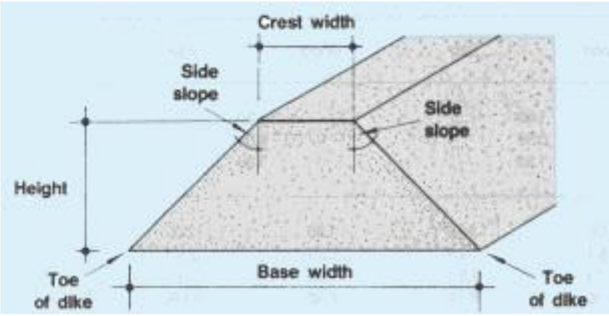

Figure 17. Dike's measurements [59].

In Figure 17, the thickness of the pond wall is controlled by the creat width and the slope of its two sides. Crest width is determined according to the water depth and it should be wide enough for tranportations. However, since transportation is unnecessary for this small pond, the chosen crest width is 1 m, enough space for 1 person to walk at ease.

Calculation for the width of pond wall base:

$$Base\ width = Crest\ width + (CH\ x\ Dry\ side) + (CH\ x\ Wet\ side)$$

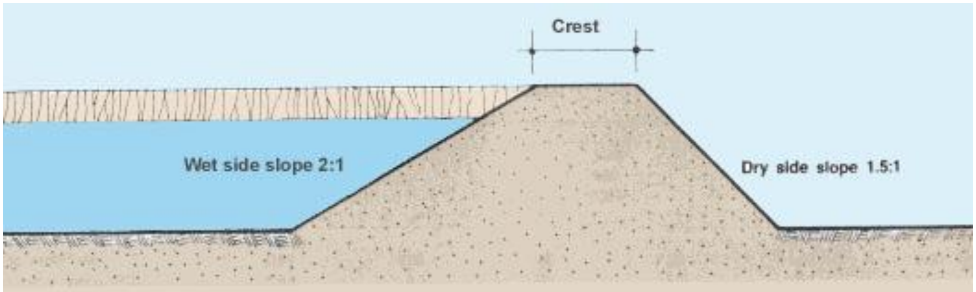

Figure 18. Determine wall slopes [60].

$$Calculated\ base\ width = 1 + (1.53 \times 2) + (1.53 \times 1.5) = 6.35\ m$$

Pond walls have two sides, the wet side inside the pond and the dry side or external side. The ratio between wet side slope and the crest is recommended to maintain at 2:1 and for the dry slope, the ratio is 1.5:1 as demonstrated in Figure 18. The slope should not be steep since the sand can lose its strength and decrease the height [61].

4.3 Estimated data

The calculated data as demonstrated in Table 5 is based on assumptions of multiple requirements for a pike-perch production. For examples, the pond height is established on the requirement water depth. Two factors determine the pond dimension and volume are fish stock density and the area required for spawning nests.

According to Lappalainen's collected data [62], it is reported that the fecundity of female pike-perch on average is between 150 and 400 eggs per 1g of female. Piestsch and Hirsch [63] also address that females can provide 1000,000 to 200,000 eggs per kg of body weight.

Assuming a female fish would lay 200,000 eggs on average with survival chance is 50% depending on different factors, e.g. cannibalisms, disease, stocking density, environment, feed (estimated by Leif Kaarto from the Ostrobothnia Fisheries Association) and 6 female fish (BW = 2 – 3 kg) will be used as breeders, the number of survival fish stock estimation is 500,000 – 600,000 fries. A study about the effect of fish size and stocking density on the weaning success of pond-cultured pike-perch report that at a density of 8 fish (total length = 40 – 42 mm and body weight = 0.42 – 0.55 g) per litre can ensure effective production of pike-perch juveniles. Based upon these conditions, a volume of 15.625 – 18.75 m^3 is required.

There have been numerous data addressing the size and shape of pike-perch spawning nest. Schlumpberger and Schmidt [64] recommended for a large spawning nest with surface area 1.26 m^2 with a dimension of 1.8 (L) x 0.7 (W) m. In natural reproduction, the mean diameter of natural pike-perch nests is 0.5 m [65]. Furthermore, a square nests of 0.42 m^2 with the side length of 0.65 m should be sufficient for the females to lay eggs [66]. In addition, a data cited from Lappalainen describes that in natural reproduction, because of the territorial behavior of male fish, it circles with a distance of 1 m around the nests [67]. However, there are no official information in Lappalainen et. al. journal about the exact distance, the review only mentioned that the male can be aggressive and attack other males while guarding the eggs [68]. However, in case of an exact number is required, it is assumed that a pond with ground dimensions 4 (L) x 4 (W) m should be adequate for two spawning nests. In total, three out of four ponds will be used as broodstock ponds.

The total land use and the measurement of pond liners and underlays are calculated based on simple mathematics.

Table 5. Calculated data for pike-perch pond

Measurements	**Units**
Water depth (WD)	1 m
Construction height (CH)	1.53 m
Crest width (CW)	1 m
Base width (BW)	6.35 m
Ground dimensions per pond (L × W)	4 m × 4 m
Water volume per pond (V)	17,63 m^3
Total land use	21 m × 21 m
Pond liners and underlay areas	500 m^2

4.4 Pond Materials

4.4.1 Pond liners

In the purpose of retaining the water from permeating through the soil and leakage, pond liners would be a suitable solution for fish pond in general. Moreover, pond liner can prevent erosion from heavy rainfall and maintain the pond shape. Another benefit from pond liner is that contamination from soil cannot affect the water pond. In today's market, there are many types of pond liner materials to meet different requirements for aquaculture ponds or decorative ponds. Some common materials are made of synthetic rubber such as methylene propylene diene monomer (EPDM) and plastics such as polyvinyl chlroide (PVC), high-density polyethylene (HDPE), polypropylene (PP) or thermosplastic polyolefin (TPO). However, they all share the same purpose of providing heat, cold, UV and weather resistance. Each has their ownadvantages and disadvantages and the price also varies for each product and also depends on manufacture companies. Depending on the need of the customers, consideration for different characteristics should be based on the 1) lifespan, 2) thickness and weight (for easy transportation), 2) flexibility (stiff or flexible), 3) cost, 4) puncture and tear resistance, 5) chemical degradation, UV and weather resistance and 6) if it contains any harmful chemicals for fish or plant. The underlay, which acts as a a barrier between the pond liners and the ground surface, can be a necessity to protect the liner from rocks and rough edge stones or potential risk of damage by rodents. In addition, it helps preventing the liner from shifting about due to ground movement.

4.4.2 Spawning nest materials

Materials for spawning nests can made from artificial grass mats as shown in Figure 19 or flat wooden frames filled with natural substrates (juniper or pine branches, bushy willow roots or sedge roots, rice hay) or synthetic materials, e.g. wool. Figure 20 and Figure 21 illustrates two types of nest for spawners, (1) re-used old fishing net and (2) flat wooden frames secured with wires and filled with roots of water plants. These nests will be fixed on the ground surface and attached with buoy for easy handling.

Figure 19. Artifical grass spawning nest with pikeperch eggs settling on it [69].

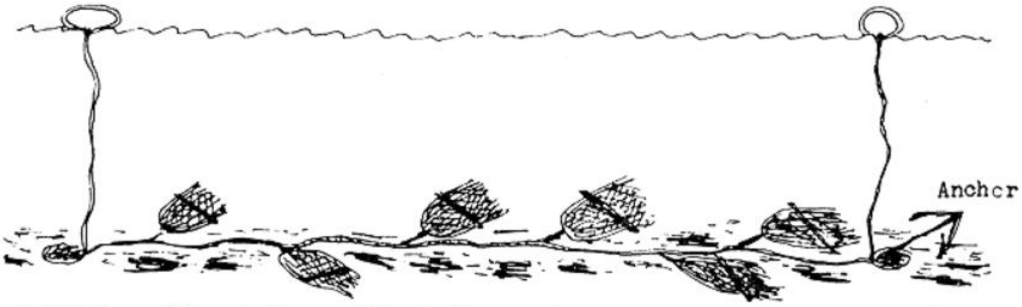

Figure 20. Old fish net spawning nests [70].

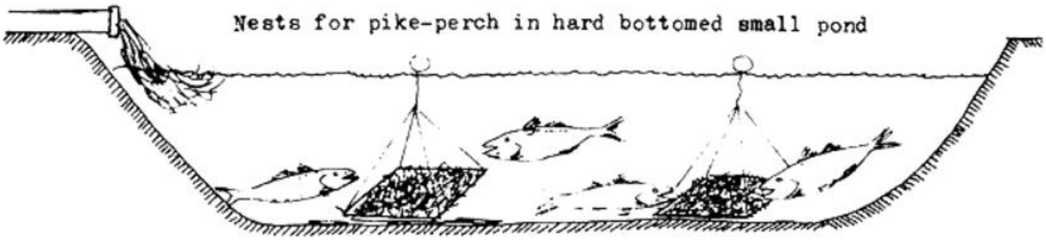

Figure 21. Spawning nests made of wooden frame filled with natural materials attached with buoy [71]

Figure 22 shows a real-life repopulation project of pike-perch in Danube Detlta, Romania.

Figure 22. Danube Delta, Romania: Repopulation of lake Razelm with pikeperch fertilized eggs [72].

These nests will be checked for signs of spawning every 2 or 3 days and those with clumps of eggs are removed for controlled incubation or transferred to the hatchery. These double-shelled eggs can be easily transported in boxes or baskets, taking care to keep them moist throughout [73].

5 Conclusion

The implementation of this project in circular economy is still vague since it is only one of the first of many steps in this roadmap. The purpose of this project that need to be fulfilled is to produce an adequate summer pike-perch juvenile stock to suit the demand in Ostrobothnia region and open business opportunities for the fishery industry. This preliminary study attempted to define and understand some physical water conditions and special environment affecting pike-perch life in an outdoor land-based aquaculture pond. The results from the study indicated the importance of water quality in governing the health of fish.

Firstly, in consideration on the water temperature, this would be the most important element for optimal fish growth and high yield rate that need special attention from the farm practitioners. At each stage of life, pike-perch has shown different preferences for water temperature range and it should be noted that for the a maximum growth of pike-perch fry, the optimum temperature should be kept at 22°C. Moreover, the changes in water temperature can alter the chemistry of water bodies, especially the reaction rate of amonnia. The temperature data was shown at a relatively low level which might not be suitable for the pike-perch standards. From this point of view, it is suggested to practice some methods for efficient water temperature control or apply different heating technologies to meet the temperature requirements.

Secondly, the level of dissolved oxygen in the groundwater source was too low and considerations for aeration and oxygenation system would be required. Next, the water pH level is at neutral state which is desirably suffice for both survival and optimum growth of fish stock. However, the value of total alkalinity was considered to be skeptical since the information was insufficient to determine if the water is acceptable for aquaculture purposes. Finally yet importantly, the amount of ammonia nitrogen was shown at an excessively high level which is 300 – 500 times higher than the recommmended tolerance level for aquatic organims in general. This parameter is crucial in affecting the survival rate of the fish. It would be recommended to restest and analyze the water parameters to ensure the success of this project.

With a distinctive eye feature (tapetum lucidum), pike-perch is considered to be a light sensitivity species which requires a very dim light condition (1 – 50 lx) to grow, especially for the 0+ year old juvenile and 1+ year-old pike-perch age groups. The recommendation in this case would be to build the incubation systems and hatchery ponds indoors to control the light intensity environment. However, due to the limitations of the project, the pond was required to be constructed outdoor which would make the fish exposed directly to sunlight. One simple solution would be pond shading method. By using black heavy duty PVC covering up the pond, this fabric could protect the fish from exposing to sunlights and predators and also absorb and convert the light energy into heat which might help increasing the pond temperature.

The overall conclusion is that although the pond design is calculated based on assumptions and can be changed in actual practice, the methods for calculation and collection information would be sufficient enough for the operation of the practical project.

Recommendations

The study provided a sufficient insight to the aquaculture construction and pike-perch farming. However, there are many aspects that have yet to be covered in this thesis and should be later studied and developed. For a further step in the circular economy road map, some studies on utilizing wastewater use as fish feed and fish waste utilization would be interesting to continue in this field. One example would be the implementation of fish waste in biogas plant, fish pond advancement into aquaponics and RAS system. Recently, the aquaponics and RAS technologies have been received attention because they are considered as innovative ideas in promoting a sustainable aquaculture industry. These technologies could be another potential approach for a further development of this project.

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Appendices

Appendix 1. Groundwater sampling data at Stormossen.

S&HM 461/2000 Kvalitetskrav Hushållsvatten		5/21/2013	6/5/2013	8/7/2013	10/16/2013	10/14/2014	4/22/2015	8/12/2015	10/14/2015	4/26/2016	5/31/2016	8/17/2016	10/17/2016	4/26/2017	6/6/2017
	Temp	6.3	8.3	12.6	10.5	11.3	6.7	12.5	8.9	3.9	7.4	14.6	11	2.1	5.4
	Fast substans mg/l	<4	<4	5	4	<4		<4	5	<4	<4	<4	<4	27	<2
250 mS/m	Ledn.förmåga 25C	97	100	110	120	120	92	100	120	86	96	100	110	78	95
250	Klorid mg/l	34	35	41	48	29	24	31	41	26	10	26	44	22	37
	pH	7	6.9	6.9	7	7	7	7.1	7	7	7	6.9	7	7	7.1
5	COD-Cr mg/l	<40	<40	<40	<40	16	18	29	34	27	30	43	26	17	21
	BOD7	<2	<2	<2	<2	<2	2	<2	<2	<2	<2	<2	<2	<2	<2
	Ammoniumkväve mg/l	0.71	1.3	0.65	220	540	0.16	1	0.79	27	140	50	130	350	230
	Kväve mg/l	1.7	1.8	1.3	0.89	2.8	3.8	2.1	1.8	1.7	2.7	7.6	2.2	1.7	1.6
	fosfor ug/l	59	16	50	37	35	24	82	52	17	15	48	20	52	31
	Syre O2 mg/l	4	2.6	3.3	2.7	1.9	3.1	4	4.8	2.4	2.9	2.9	2.7	2.5	3.7
	Alkalinitet	3.2	3.5	4.1	4.4		2.4		3.6	2.8	3.3	2.2	3.7	2.6	3.4