STORMWATER FLOATING ISLANDS

Case study INNOHULE

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Abstract

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Abstract

Stormwater management faces many problems and challenges. One of these challenges is the nutrients and pollutants that accumulate in the stormwater and are discharged into the water bodies like rivers and lakes, which negatively affect the environment, water quality, and ecosystem of the water bodies.

This thesis discusses the importance of enhancing the work of wetlands by adding Stormwater Floating Islands (SFI) and thus helping to reduce the nutrients and pollutants before the outfall.

An experiment project INNOHULE has been carried out to obtain preliminary results regarding nutrients removal and data on native plants that have the ability to adapt to the new submerged condition and the ability to survive the extreme low temperature winter.

Also, water tests were conducted to ascertain the efficiency of the SFI concept for the following nutrients: Phosphate PO_4^{3-}, Nitrate NO_3^-, Nitrite NO_2^-, and Ammonium/Ammonia NH_4^+ / NH_3.

Finally, the concept of SFI found that it can be applied in Finland, as well as a good variety of native plants that can tolerate the new submerged condition in a SFI. The concept of SFI can help mitigate nutrients and pollutants from stormwater wetlands.

During the INNOHULE project; recycled materials were used to build the SFIs, and many designs succeed to achieve the purpose role.

Keywords

Stormwater pollution, Nutrient removal, Floating island, Recycling

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Tiivistelmä

Hulevesien hallinnassa on monia ongelmia ja haasteita. Yksi näistä haasteista on ravinteiden ja epäpuhtauksien kertyminen hulevesiin ja niiden pääseminen vesistöihin, kuten jokiin ja järviin, mikä vaikuttaa negatiivisesti ympäristöön, veden laatuun ja vesistöjen ekosysteemiin. Tässä työssä käsitellään kosteikkojen työn tehostamista lisäämällä niihin hulevesiä puhdistavia kelluvia saarekkeita ja siten pyrkiä vähentämään ravinteiden ja epäpuhtauksien määrää hulevesissä ennen niiden vesistöihin pääsyä.

INNOHULE-kokeiluhankkeen ”Innovatiiviset kokeilut hulevesien puhdistuksessa” tavoitteena oli saada alustavia tuloksia ravinteiden ja epäpuhtauksien poistamisesta kelluvien kasvillisuussaarekkeiden avulla, tietoja kotoperäisten kasvien kyvystä sopeutua uusiin olosuhteisiin kelluvissa saarekkeissa ja niiden kyvystä kestää alhaisia lämpötiloja. Kokeilun aikana tehtiin mittauksia /veden laadun monitorointia joiden tavoitteena oli alustavasti selvittää, miten kelluvat kasvillisuussaarekkeet vaikuttavat ravinteiden määrään kasvatusaltaissa. Työssä tutkittiin seuraavien aineiden pitoisuuksia. fosfaatti PO_4^{3-}, nitraatti NO_3^-, nitriitti NO_2^- ja ammonium / ammoniakki NH_4^+ / NH_3.

Saatujen tuloksien ja havaintojen perusteella voidaan todeta, että kelluvia saarekkeita voidaan käyttää soveltaen Suomessa. Lisäksi huomattiin, että on runsaasti erilaisia kotoperäisiä kasveja, jotka pystyvät sietämään uuden kasvuympäristön, missä kasvin juuristo on veteen upotetussa tilassa kelluvissa saarekkeissa. Kelluvat saarekkeet voivat auttaa vähentämään ravinteita ja epäpuhtauksia hulevesi kosteikoista. INNOHULE-hankkeen aikana käytettiin kierrätettyjä materiaaleja ja useita malleja kelluvien saarekkeiden rakentamiseen tavoitteiden saavuttamiseksi.

Asiasanat

Hulevesien saastuminen, Ravinteiden poisto, Kelluva saareke, Kierrätys

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1 INTRODUCTION

Some studies and future scenarios predict - along with an estimate of the population growth - there will be increases in immigration from rural areas to cities. Accordingly, these cities are expected to become larger in population and area (Hendry 2016). This consequently means that the area of impervious surfaces that accumulate stormwater will also increase. Moreover, the development of Hennala area in the city of Lahti is a living example that reflects the population needs for new urban areas (City of Lahti 2016)

Human societies are currently trying to cope with climate change; we start to face some new phenomena that have strong impacts on nature and urban societies, such as droughts, floods, and hurricanes. Furthermore, we have recently witnessed how natural disasters cost lives and destroy urban spaces and communities (Munn-Venn & Archibald 2007). These negative influences also impose challenges on stormwater management, especially in the Nordic Countries, that will most likely face an increase in heavy rain events regarding quantity and density (Jylhä et al. 2009). Accordingly, a negative influence will present itself strongly in the future, especially with the predictions that there will be less snowfall, if not a total disappearance of it in some winters.

This thesis discusses the urgent needs to alleviate the negative impact of stormwater runoff. This stormwater runoff accumulates on hard surfaces, such as roofs and paved roads, carrying contaminants such as heavy metals and organic waste. If these contaminants find their way to lakes, river, or seas, they will adversely affect the ecosystem in these environments. They will also affect the health of humans and other species that come in contact with these contaminants directly, e.g., through drinking or swimming, or indirectly, e.g., by eating fish in which these contaminants accumulate (Abdel 1996; Campbell et al. 2004).

In high-density urban areas close to discharge outfall, a swale is not able to deal with the large quantity of stormwater. To deal with this problem, the City of Lahti constructed wetlands such as Kivipuro wetland in Karisto (picture1). A wetland helps to reduce the runoff speed, increase the percentage of water infiltrated into the ground, and reduce the negative impacts of the pollution in stormwater, by the help of natural aquatic plants (Aryal et al. 2010; Malaviya and Singh 2012; Mallin et al. 2002; Stanley 1996).

PICTURE 1 Kivipuro wetland in Karisto

Accordingly and taking into consideration the predictions of increased stormwater in the future in Finland, it is likely that wetland systems will continue to rely on heavily.

This study investigates whether adding Stormwater Floating Islands (SFI) makes the wetlands more efficient in eliminating pollutants in stormwater runoff.

A lectures review will be conducted, and preliminary experiment will be implemented to investigate whether some Finnish native plants could adapt the new aquatic condition and are able to survive the extremely low temperature of winter of Finland while the roots submerged in water. Moreover, during this experiment will also investigate the ability of SFI to reduce the nutrients in the water. Moreover, this research is also looking for the advantages and disadvantages of the wetland with SFI's system compared to the traditional wetland system. It is intended to test, how can the floating islands be built and deployed from the technical point of view.

Please note that; unless otherwise stated, all photographs are taken by the author.

2 BACKGROUND

2.1 The needs for wetlands

Wetlands can attenuate the potential stormwater flooding. As such, they are a low-cost form of infrastructure with a great performance in term of nutrient removal (Girts et al. 2012). Moreover, wetlands maintain and enhance the wildlife habitats and biodiversity by improving hydrologic connections (primarily surface flows) of functioning and/or degraded wetlands (Nakamura and Mueller 2008).

Furthermore, wetlands provide an interesting variety in the landscape and giving an example of sustainable resource management. And it is considered as physical and mental health enhancement of the community, through recreation and landscape benefits (Watson and Albon 2011).

Beside that wetlands have an effective ability to reduce the pollution carried by the stormwater prior to discharge distention such as lake or rivers (Girts et al. 2012), wetlands increasing the values of the neighboring property (Trust for Public Land 2010).

One of the important aspects of wetlands is that they lower energy consumption and maintenance compared to constructed closed stormwater systems, therefore, providing stormwater infrastructure and ecosystem at lower operation and maintenance expenses (Girts et al. 2012).

2.2 Wetlands in Lahti – Finland

Although wetlands in Finland perform a large task for stormwater management, they face some functional limitations as a result of the extremely low temperature during winter, when the aquatic plants die or enter into a state of dormancy around the beginning of the fall season. This means that the function of these plants as pollution eliminators stops from fall till the next summer (Stein and Hook 2003).

Overall, It was noted that:

The growing season of the aquatic plants is delayed, starting only after the water in the freezing wetlands melts, and the temperature begins to be warm enough and suitable for the aquatic plants to grow. However, large quantities of the contaminants accumulating during the winter in the snow or ice will find their way to water bodies such as lakes or rivers before the plants in the wetland grow and start to function and remove pollutants. During this short time, contaminants often exist as concentration peaks in the stormwater runoff (Liu et al. 2009; Meyer and Wania 2008; Westerlund and Viklander 2006). This period is very critical for the aquatic species, such as fishes, as it is the pre-mating period and the growth of these organisms will be affected negatively due to to the high pollution levels in discharge water. Moreover, the emergent plants of wetland start to grow under the water, and their growth will flourish after rising above the water level.

On the other hand, wetland banks, and shallow water areas are the places where the aquatic emergent plant colonies are found, and they gradually disappear in deepwater areas, where they might be replaced by submerged floating aquatic plants, and at deeper levels it is likely that even the floating, submerged plants might not exist (figure 1). Therefore, its function as a pollution eliminator is limited.

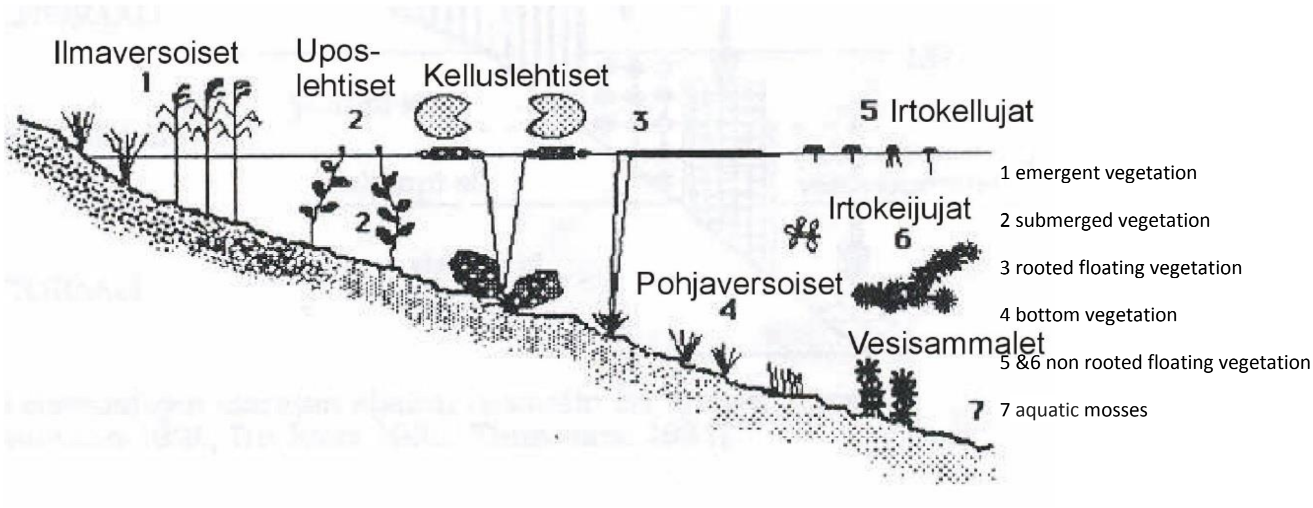


FIGURE 1. Aquatic plant locations (Southwest Finland Regional Environment Center 2005)

Furthermore, many stormwater wetlands are not natural, but constructed for stormwater management purposes. When constructed, these wetlands alter the habitats of many species which live or rely on these destroyed habitats in their life cycle.

One of the most important observations is that these aquatic plants, while acting as pollution absorbers, themselves will release the accumulated pollution and nutrients back to the water in their senescence stage, in addition to the organic mass they gained during their growth period. Such examples are found in the species *Phragmites australis* and *Typha latifolia* (Kroger et al. 2007).

2.3 Stormwater Floating Island System

A stormwater Floating Island (SFI) is an artificial floating structure planted with aquatic vegetation (figure 2). SFI allows the roots to immerse hydroponically in the wetland's water body. Therefore, the roots function of plants in the SFIs is similar to the natural ground-growth wetland plants regarding the intake of necessary nutrients for their growth, but precisely from the water body (Kadlec and Wallace 2009). The roots of the SFI vegetation not only take in the necessary nutrients, such as nitrogen and phosphorus, for their growth but also play a role as a foundation for biofilm growth and development, as the submerged roots provide a large surface area. This biofilm is the main contributor to the microbial process within the wetlands (Brix 1997).

Moreover, many studies suggest that a wetland system that includes floating islands is capable of eliminating nutrients (Gao 2008; Hubbard 2010; Li et al. 2010; Stewart et al. 2008; Tanner and Headley 2011). The nutrient removal efficiency of these systems could reach up to 96% of ammonium (NH_4^+) after seven days and 85% of dissolved reactive phosphorus after 14 days (Tanner and Headley 2011).

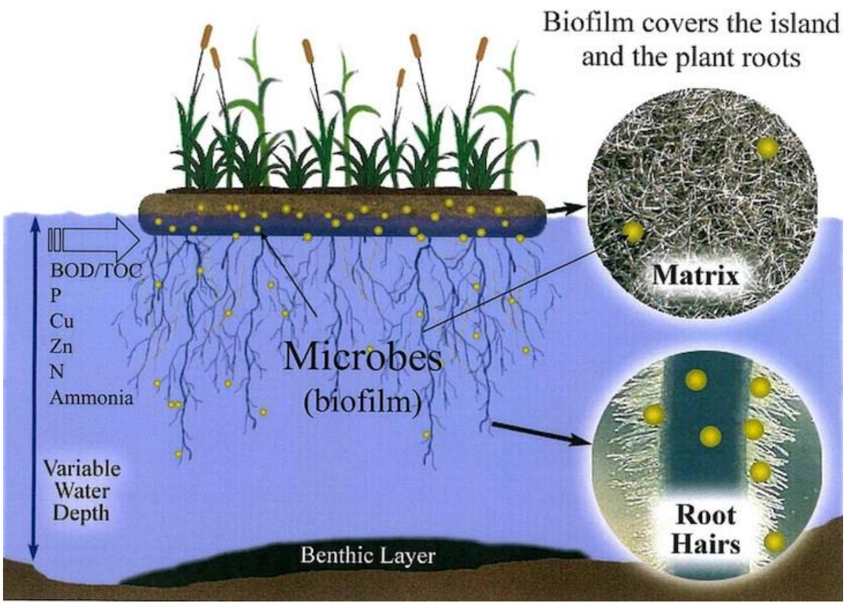
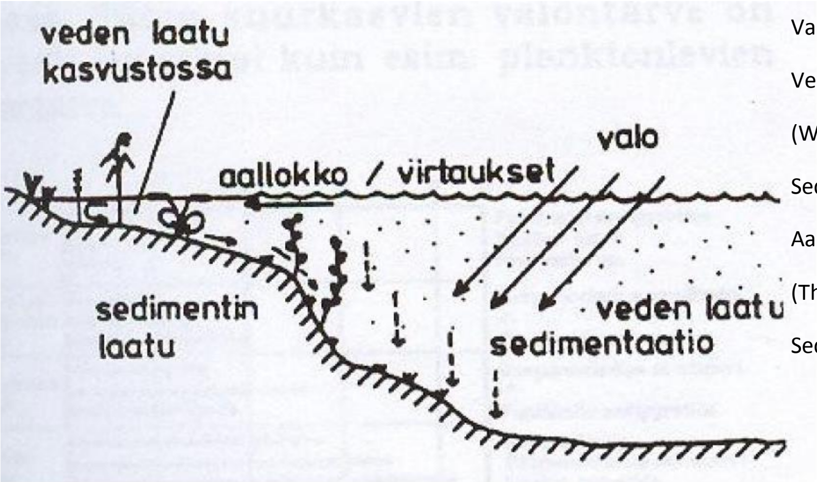


FIGURE 2. A cross-section of a floating island (Image courtesy of Midwest Floating Islands)

In addition to the benefits of an SFI in nutrient removal, it can be built from the low-cost material, including recycled materials. However, SFIs have another advantage over typical wetlands as they can be placed over a deep water area where no emergent aquatic plant colonies exist, as can be seen in (figure 3).



Valo (Light)

Veden laatu kasvustossa-

(Water quality in vegetation)

Sedimentaatio (Sedimentation)

Aallokko/virtaukset-

(The waves / currents)

Sedimentin laatu (Sediment quality)

FIGURE 3. Ecological factors affecting the occurrence of aquatic plants (Southwest Finland Regional Environment Center 2005)

Moreover, SFIs have the buoyancy and flexibility to make them suitable for wetlands or ponds with varying water levels (Faulwetter et al. 2011). Therefore, floating islands have been used in water remediation from stormwater, wastewater and agriculture and animal farms in different areas (Billore et al. 2008; De Stefani et al. 2011; Duncan 2009; Hubbard et al. 2004; Van de Moortel et al. 2010).

Furthermore, using SFIs helps in stormwater management, one aspect of this is the harvesting of the vegetation that has been installed on the SFIs. This practice is significant and essential to prevent the nutrients from being released back into the water body when the plants go into the senescence stage. Therefore, harvesting should take place at an early stage time (Kroger et al. 2007).

On the other hand, algal growth relies on both light and the dissolved oxygen, and when it reaches an excessive stage, algae begin to die and settle to the bottom, where the sediment bacteria start to consume and decompose it. This process leads to a depletion of oxygen due to a higher demand for oxygen from the sediment bacteria to survive (Lee & Lee 1995). This condition can suffocate aquatic animals, especially the immobile bottom creatures that most likely would die off as a result (Horrigan et al. 2002). Consequently, the SFI reduces the nutrients within the water body needed for the algae growth. An SFI will also reduce the amount of light by shading. As a result, SFI will control the algae growth and reduce the consumption of the dissolved oxygen (Van de Moortel et al. 2010).

2.4 Expected pollutant removal pathways by an SFI

There are several expected pathways for pollutant removal from the stormwater wetland with SFI system.

Pathway 1. Stormwater carries a large amount of organic or non-organic suspended particles. The roots of the plants on the SFI trap these particles on the biofilm that covers the roots' surface (Tanner and Headley 2011), which subsequently increases the clarity of the water. In some conditions, water bodies can be under conditions of high turbulence, which could cause some of these trapped particles, including the biofilm, to fall off the roots to the bottom of the water body, these falling particles could be returned to the water body after another high water turbulence event (Kadlec and Wallace 2009).

Pathway 2. In an aerobic environment, and over the roots surface of the SFI plants, such a condition can enhance the heterotrophic bacteria growth; these heterotrophic bacteria transform the organic molecules into basic nutrients that plants can absorb. These biochemical processes also produce nutrients that volatilize (Kadlec and Wallace 2009). There are also in these environments many species of autotrophic bacteria, such as Nitrosomonas, and *Nitrobacter*. These chemoautotrophic bacteria oxidizes ammonia to nitrite by Nitrosomonas which then *Nitrobacter* oxidizes the nitrite to nitrate (Kadlec and Wallace 2009; Gersberg et al.1986). Moreover, Stewart et al. (2008) report that floating islands enhance denitrifying bacterial growth and, as a result, induce denitrification leading to volatization to elemental nitrogen gas.

Pathway 3. Under the SFI and due to radial oxygen loss, along with the presence of oxidizing bacteria, iron hydroxides and manganese hydroxides are formed in low quantities on the surfaces of roots (Emerson et al. 1999, Batty et al. 2002). These metal hydroxides take up metals such as copper, zinc, or phosphorus (Ye et al. 2001; Batty et al. 2002). Furthermore, Phosphate is described to have sorption affinities with sediment particles or soil that contains Al, Fe or Mg (Vymazal 2008) therefore; phosphate can accumulate on the surface of sediment particles. Metals likewise have binding properties with organic compounds (Nierop et al. 2002), metal-organic compounds should be present below the floating island as a result of root death and the resulting exudates. Metals would settle to the bottom of the wetland after binding to organic matter.

Pathway 4. The main pathway of pollutant removal is the symbiotic system between the plants of the SFIs and the microbes. As the plant roots provide large surfaces for the biofilm, which in turn enhances the microbial growth. Plants will, in turn, be able to take the necessary nutrients after microbes break down the organic matter. This pollutant removal pathway relies on the availability of nutrients and organic matter within the water body, on the type of plants, on the period of the plants' growth and of course on temperature and light. For example, nutrient uptake will be higher during the flourishing period of the plants compared to the stationary stage when some plants, such as *Phragmites australis* and *Typha latifolia*, will start to release nutrients back to water (Kroger et al. 2007).

2.5 State of the art

Currently, there is increasing awareness around the world of the negative impacts of pollutants (e.g., nutrients and heavy metals) in the water on people's health in urban communities (Ladislas et al. 2010). Whether directly through drinking water or swimming, or indirectly through eating foods, like fish, that accumulates these pollutants, the pollutants come into contact with people in urban areas and impact their health. What makes matters worse is that the world is facing water scarcity problems. The Treatment Floating Island (TFI) concept came about to imitate the natural free-floating aquatic plants such as duckweed and water lily, but at the same time to allow a larger quantity and variety of plants to establish above these manmade floating islands while the roots are immersed in the water (Tanner and Headley 2011; Faulwetter et al. 2010; Tanner and Headley 2008). These immersed roots will provide a host for the microorganism which in payback would break down the organic matter, allowing the plants to absorb it for their growth necessities. The roots also play a role as a trap for the suspended materials (Nakamura and Mueller 2008).

2.5.1 Treatment Floating Island application

By employing the concept of floating islands, many experiments and projects have been carried out around the world (below several are described). These projects varied in their design and objectives. Although these examples are from different places and environments, they had a unique main purpose, and that is to remove or reduce the amount of nutrients and pollutants in water, including but not limited to lakes, sewage, and stormwater.

The application of the TFIs is divided into:

Wastewater

Wastewater lagoons are made to stabilize the manure slurries within the wastewater coming from e.g, poultry, beef, or swine farms; these manure slurries require treatments before they can be used on agricultural lands. However, within these lagoons and during the stabilization period, there is a low percentage of nutrient removal. Several studies have looked into the potential for nutrient removal and ways to minimize the bad odor by installing TFI to cover the wastewater lagoons' surface (Hubbard et al. 2004).

Hubbard et al. (2004) conducted a study to evaluate the TFI potential benefits at a swine farm located in Tifton, Georgia, USA. Three types of plants are used in their study in order to determine which plants are the best concerning the growth of the plants and nutrient removal. The plants were installed over mats floating on three tanks holding about 1.3 m^3 of wastewater. The plants used were *Juncus effuses, Panicum hematomon* and *Typha latifolia,* each plant was used in one of the tanks. The study found that *Typha latifolia* is the best plant among the three regarding the growth and nutrient removal. Moreover, the study found that one of the advantages of the TFIs is that they help reduce the odor of such lagoons. On the other hand, some studies point out that a disadvantage of TFIs for wastewater treatment is that there are limited aquatic species able to survive in high concentrations of nutrients (De Stefani et al. 2011; Hubbard et al. 2004; Tanner 1996).

Polluted lakes and rivers

With the increase in human activities, increasing waste and nutrients appear in the surrounding environment, whether it comes from people's daily life routine or agriculture and industry. Due to the expansion of cities and their constructed impervious surfaces, the stormwater runoff, carrying the waste, increases in quantity and speed and finds its way to the water bodies, such as lakes and rivers in many ways, including outlets, pipes, and ditches. These pollutants such as nutrients, toxic substances, and pet wastes will enter the water bodies around urban areas. Therefore, it is imperative to improve the water quality of these water bodies. Many studies evaluated the benefits of TFIs, and most of these studies are focused on nutrient removal from polluted water bodies. In Washington D.C a study by Hwang and LePage (2011) took the Anacostia River nearby the Diamond Teague Park as a testing field. Seven floating islands with a total area of 148.6 m^2 were installed in order to find out whether the floating islands would mitigate the pollution in the river. Although the surface area of the floating islands was relatively small, it provided a floating roots surface of 24,281.14 m^2, which reflected positively on the results with an annual removal of the 449.1 Kg nitrogen, 62.6 Kg phosphate, and 449.1 Kg ammonia.

Moreover, these floating islands not only enhanced the water quality, but also created valuable spaces for the wildlife and some aquatic species, and added an aesthetic factor to the urban community with relatively low cost. Billore (2007) evaluates the floating islands for treating the polluted water during his study on Kshipra River, India. The evaluation used a comparative method by taking water samples from under the floating island's mat, and other samples at a distance from the mat. In his study, the removal of many nutrients was between 40% and 50%. Both Billore (2007) and Hwang and LePage (2011) provide an evaluation of the benefits of floating islands on water quality in polluted rivers and lakes and show that the mechanism of the floating islands can be the best removal of many nutrients. Such nutrients removal would be directly from the polluted water body if a significant area of floating islands has been used.

Mine drainage

Acidic water drainage that comes from the mining process is one of the important environmental problems. This acidic water contains high amounts of sulfur, heavy metals, and many toxic substances (Johnson and Hallberg 2005). A number of methods can be used in the treatment of such acidic water, including chemical addition (adding limestone, for example), and biological ways which include using wetlands or mixed chemical and biological methods (Sheoran and Sheoran 2006). All these methods aim to change the acidity of the water. Wetlands, by uptaking the metals from the water body, produce a more alkaline environment. Most of the studies on the use of wetlands for treatment of the acidic mining drainage focus on land-based wetlands, and it has not been widely studying evaluating the floating islands benefits on such polluted water. However, floating islands would be a valuable factor if added to mining drainage wetlands, because the surface of the roots of the vegetation is colonized by microorganisms. These microorganisms contribute to metal precipitation by converting the metals to insoluble forms, such as metal hydroxides (Kalin 2001). Adding to that, TFIs offer an increasing coverage of vegetation that causes the uptake of more nutrients and metals. Moreover, the long-term stability of the toxic substances, metals, and nutrients which accumulate within the plants is uncertain, and these plants can be environmental hazards if not harvested and disposed of appropriately (Mays and Edwards 2001). Therefore, floating islands can be an answer to easy management for the removal and deployment of new vegetation.

Stormwater

Stormwater management widely relies on wetland systems in order to reduce stormwater runoff, flooding, and erosion. Most of these wetlands are constructed before the outfall into water bodies such as lakes or rivers. Within the wetlands, suspended particles that accumulate within the runoff over the impervious surfaces will start to settle into the sediment (Gallagher et al. 2011). However, large amounts of these suspended particles, especially the soluble contaminants such as heavy metals, nitrogen, and phosphorus will find their way out of the wetland to the water bodies like lakes and rivers. (Bishop et al. 1999). Accordingly, this suspended matter, when accumulating in the recipient water body can cause a high health risk, and undesirable water quality conditions, including hypoxia and algae bloom, which affect negatively both living aquatic species of these water bodies and human health (DeLorenzo and Fulton 2009). Adding floating islands to these wetlands or stormwater ponds would eliminate a significant amount of nutrients from the water column by the uptake process of the plants.

Moreover, with the help of microorganism attached to the floating root surfaces, floating islands would increase nutrient removal. Also, floating islands can deal with various water flow rates and levels due to their buoyancy (Tanner and Headley 2008). Furthermore, Chang et al. (2012) suggest that water depth has no significant impact on the effectiveness of floating islands for nutrient removal. Their study evaluates whether the depth of the water underneath the floating islands, besides the coverage rate, would affect the removal of the nutrients. Chang et al. (2012) have included eleven circular water tanks in their experiment. The tanks were of two sizes: 4000 liters and 18000 liters. A tank of each size was left without floating islands for control. Overall, the results show the removal of 53% total of Phosphorus, 73% of nitrate, and nearly 100% of ammonia within 15 days of the start of the experiment (Chang et al. 2012). Therefore, TFI can provide a solution for stormwater management concerning nutrient removal, regardless of the wetland's water level. Also what makes this solution applicable is the wide range of aquatic plant species suitable for the TFIs. However, there are only a few large-scale applications of TFI implemented and evaluated around the world (e.g., Borne and Fassman 2011; Duncan 2009; Tanner and Headley 2008), and that can be counted as a disadvantage.

2.5.2 Nutrient removal mechanisms by TFI

The nutrient removal processes by the floating treatment islands in wetlands are tightly bound to the main components of the wetland, which can be divided into three main constituents: (Sheoran and Sheoran 2006). These removal processes are classified into three categories: physical, chemical and biological. The chemical processes category includes volatilization, precipitation, and sorption. In volatilization, gases can be produced and released to wetland vegetation species, the soil, and substrate material and the water movement in the water body the atmosphere, for example, free unionized ammonia can be volatilized (Kadlec and Wallace 2009). While in precipitation, compounds are converted into insoluble particles that can be settled to the bottom of the water body (Sheoran and Sheoran 2006). The capacity of substrate sorption can be different due to the variety of contaminants and metals, (Kadlec and Wallace 2009).

The physical processes category includes filtration and sedimentation. During filtration, contaminants are entrapped within the roots of the plants, while in sedimentation contaminants settle to the bottom of the water body (Sheoran and Sheoran 2006).

Biological processes cover the uptake of the plants, plant decomposition, microbial degradation, and transpiration.

The submerged roots of the installed plants on the TFI are in direct contact with the water, and therefore it is taking up the nutrients directly from the water body. However, in certain times when the plants pass the maturity age, the plants will start to release the nutrients back to the water (usually in autumn). In addition to that, any dead part of the gained biomass will decompose into nutrients in the water again.

Moreover, in microbial degradation, the removal of contaminants takes place after the microorganism activity on submerged surfaces, such as the plant's roots and the floating island's material. These microorganism activities create a biofilm, allowing the dissolved contaminants within the water to be diffused to the stagnant water layer around the biofilm. Then it passes through to the plant's roots while performing a biochemical transformation by the microorganism (Kadlec and Wallace 2009).

Under the transpiration process, the water will evaporate through the stomata of the plants that came from the submerged roots (Kadlec and Wallace 2009). This is in addition to the evaporation that occurs from the water surface.

2.5.3 Performance of Treatment Floating Island

It is difficult to compare the results of projects and experiments that use TFI around the world because of the different design, locations, timing, climate, aquatic plants used within the various project (Chua et al. 2010), coverage of the TFI and water targeted for treatment. However, a summary was made of reviewed studies in (Table1) in (Appendix1) for referencing. It is worth noting that all studies reported positive results regarding phosphorous and nitrogen removal from the treated waters.

3 CASE STUDY: STORMWATER FLOATING ISLAND (THE INNOHULE PROJECT).

Referring to the conducted literature review, it was would be valuable to investigate and experience this concept in Finland, as the climate is much different to that of all the international research sites which reviewed within this study.

Päijät-Häme Regional Council supported this research by a total amount of Eur 14,275.00 including VAT (Appendix 2) under the project title INNOHULE “Innovatiiviset kokeilut hulevesien puhdistuksessa”.

3.1 Goals of research – INNOHULE

The INNOHULE project was established in order to find the answers to this research questions which are:

The main question:

- Does the SFI’s system improve the wetland’s water quality regarding nutrient removal (phosphate, nitrite, nitrate, and ammonium/ammonia)?

Secondary questions:

- How can the floating islands be built and deployed from the technical point of view?
- What are the advantages and disadvantages of the wetland with SFI systems compared to traditional wetland systems?
- How do SFIs cope with Finnish winter conditions?

This research is limited to the investigation of removal amounts of the nutrients phosphate, nitrite, nitrate, and ammonium/ammonia, as they are common contaminants in lakes and rivers internationally. Moreover, these contaminate are harmful to humans and the aquatic ecosystems either directly or indirectly. For example, the United States Environmental Protection Agency confirms that ammonia is very toxic for fish species (USEPA 1993). On the other hand, nitrate is toxic and can cause health issues for human life, for example, liver damage, cancers (Gabel et al. 1982; Huang et al. 1998). Furthermore, nitrite can form nitrosamines after reacting with amines, which are carcinogens (Sawyer et al. 2003). On the other hand, phosphate is not harmful to human life, but it has significant impacts on ecosystems and can damage those of rivers and lakes through eutrophication mainly (Ærtebjerg et al. 2003).

Actions of the INNOHULE project

The main tasks of this project are as follows:

- To design and build the SFI.
- Studying and collecting native species along with noninvasive common species and installing them in the SFI.
- Building the greenhouse and installing the growing ponds.
- Laying the floating islands and placing the vegetation.
- During the experiment period, water testing will be implemented on weekly bases from the growing ponds and at rainy events from the stormwater wetland (Karisto).
- The last stage was to combine the data and write the thesis.

The need for a greenhouse

- Due to project kick-off timing in October 2017, the weather was not suitable for the plants as the extreme low temperature months were ahead.
- The greenhouse would give the opportunity to find out which species are able to survive to be installed at early springtime in wetlands on the SFI, as the temperature within the greenhouse will be controlled as possible.

Water testing of the wetland at rainy events

It is important to test the nutrients within the stormwater wetland in order to simulate the water within the growing ponds.

3.2 Project finances

Table 2 shows a summary of monthly expenses during the project period that were claimed from the project fund.

TABLE 2. Summary of the monthly expenses during the INNOHULE project

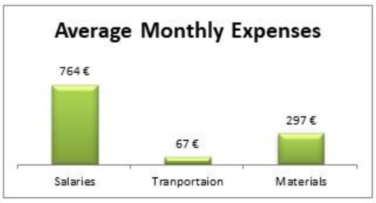
Project Name	**INNOHULE**
Done by	**Waseem**
Date of Analysis	**31/5/2018**

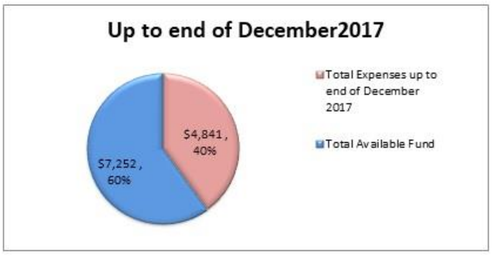
Inputs

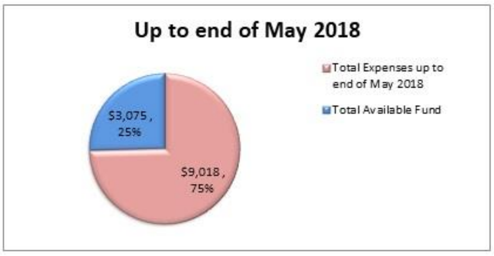
		Outstanding
Total Project Support including Tax	14,275 €	
Total Project Support without Tax	12,093 €	12,093 €
Total Expenses for October 2017	3,475 €	8,618 €
Total Expenses for November 2017	970 €	7,648 €
Total Expenses for December 2017	396 €	7,252 €
Total Expenses for April 2018	524 €	6,728 €
Total Expenses for May 2018	3,653 €	3,075 €
Total Spending	9,018 €	
Total Available Fund	3,075 €	

	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18
Personal Salary	1,416.00	780.00	396.00	0.00	0.00	0.00	288.00	3,228.00
Transports	106.29	144.99	0.00	0.00	0.00	0.00	110.00	174.00
Material Cost	1,953.14	44.69	0.00	0.00	0.00	0.00	125.76	251.12

Legend:
Outstanding
Paid
Estimated







Note:

Table 2 Covers only the expenses from the supporting fund by Päijät-Häme regional council. However, there were many other expenses which were covered by the author. Moreover, there are also recycled materials provided by some citizens of Päijät-Häme area such as but not limited to, polyurethane sponge and styrofoam sheets. As an example, (figure 1 in Appendix 3) shows a cost analysis of the item “cast on-situ concrete class C”.

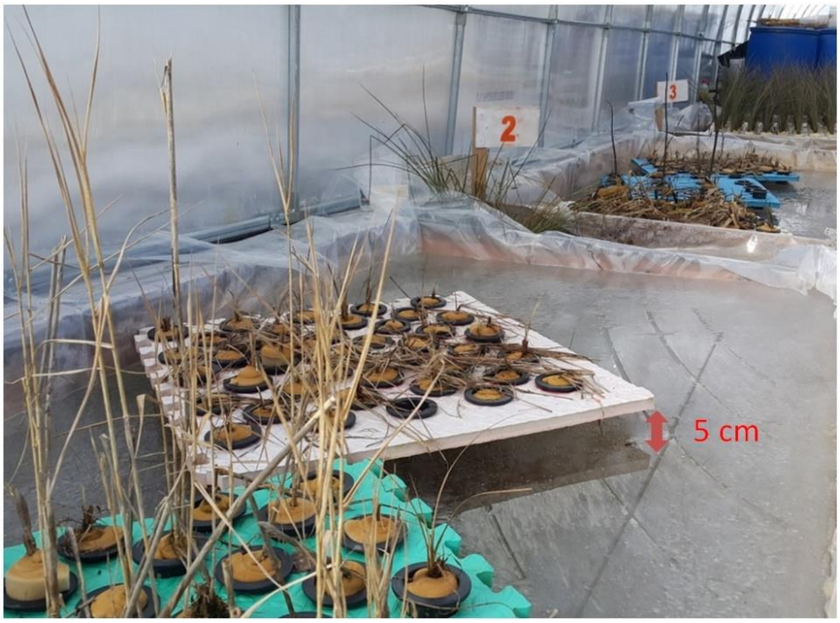
3.3 Project Plan

The original project schedule is shown in (figure 1 in Appendix 4). However, there were some delays in the project implementation as shown in (figure 2 in Appendix 4):

- A Delay of 11 days in October 2017 due to the weather conditions.
  - Heavy rainy days in October 2017 during fixing the greenhouse, which caused difficulties such as muddy ground (picture 3) and the inability to cast concrete in days when the temperature was below 5 degrees C.
  - Sudden frost occurrence (-12 degrees Celsius) delay pumping water to the growing ponds in the greenhouse (picture 2).
- Due to the death of some plants during the early warm spring, and for more variety plants investigation; it was estimated that the thesis draft would be ready in September 2018.
  - Early sunny spring caused the ice to melt and evaporate from around the roots leaving a loss of 5 cm in thickness (picture 4).
  - Also, it caused dehydration of some plants' leaves due to the warm air and lack of water supply from roots as the water was frozen (picture 5).

PICTURE 2. Sudden frost of the growing ponds after the summer experiment

PICTURE 3. Heavy rain caused very muddy conditions in which to work



PICTURE 4. Ice loss around the roots

PICTURE 5. Plants are dehydrated at early spring 2018

3.4 Design of the experiment

3.4.1 Location

The experiment was conducted in Nastola, Päijät-Häme, Finland, and the greenhouse was installed parallel to South-North (Latitude 61°00'13"N and Longitude 25°59'45") in a location where the nearest tree is about 35 meters away, to allow as much light as possible to go through the greenhouse. The greenhouse was located 10 meters away from the road for easy access and mobilization.

3.4.2 Structure

The greenhouse is a caterpillar tunnel type, of size 20 m x 3 m, and the structures made out of galvanized iron. The greenhouse cover is 4 mm thick polycarbonate (air gaped) sheets. The greenhouse was installed above insolated bricks and was fastened to the bricks with galvanized angles. The bricks are interlinked with dual steel bars of 6 mm dia and reinforced by concrete class C. Every 3 m, a steel anchor erected deep to the ground and fastened to the bricks-tie beam.

3.4.3 Growing ponds

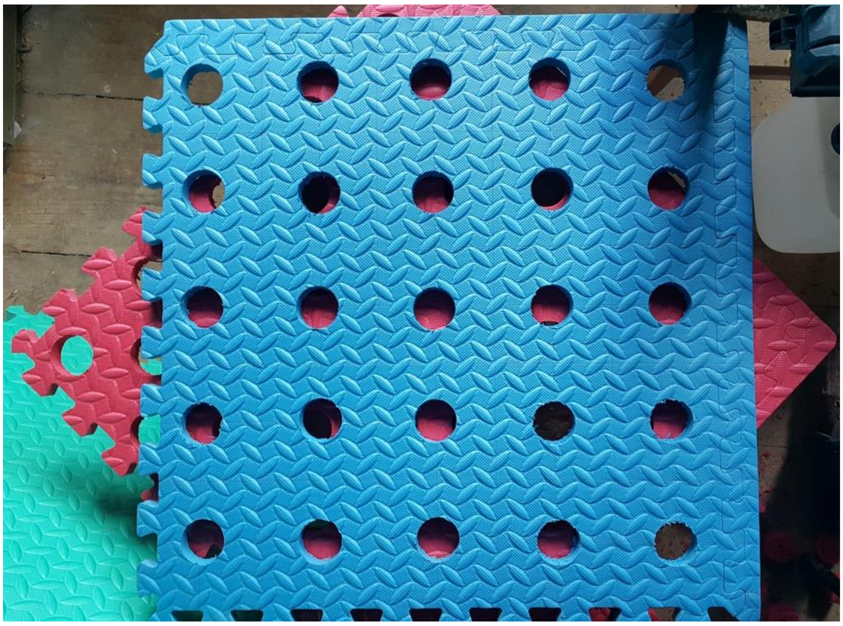
Twelve growing ponds were installed in two rows along the greenhouse. The growing ponds were made out of garden grow boxes of rectangular prism shape (114 cm x 228 cm x 22 cm). Construction plastic sheets (0.2 mm thick) were used for the liner (picture 6). A gap of 40 cm was left between the growing ponds for easy access during the installation of the floating islands, monitoring, and testing, for example when taking a reading of the water depth of each growing pond corner during the water testing procedure.

PICTURE 6. Growing ponds installed and water filling process ongoing

3.4.4 The design of floating islands

Many designs of the floating island with different materials were tested. However, as this idea is considered new in Finland, there are no ready-made floating islands available on the Finnish market, so the first step was to go around the markets and observe if any materials could be used to produce floating islands. Therefore, the first design was made of almost 85% new materials, and eventually, It was managed to build a floating island from up to 100% recycled materials

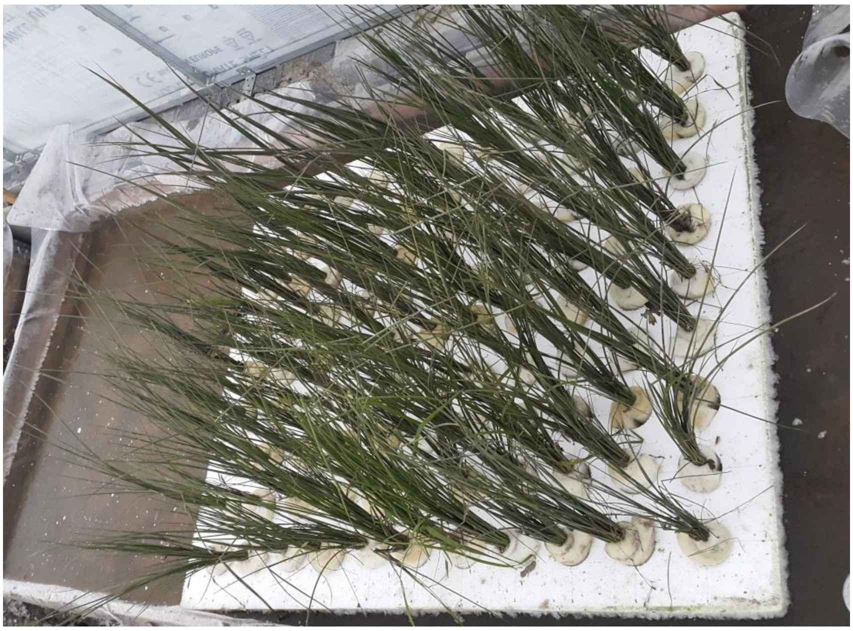
1) The first design was made out of a gym mat and by drilling suitable holes to fit the hydroponic net pots where the plants stem surrounded by a sponge strip to keep it in position and allowing the roots to grow in direct contact with the water body. This design was very stable, durable and the floating island can be easily enlarged and shaped as required by matching the gym mat with another one or by cutting it into another design shape. However, it is having some difficulties during the installation of the plants in the hydroponic net pots as the root of the plants might be larger than the hydroponic net pots holes. (picture 7 &8).



PICTURE 7. Process of building the 1st design of floating island (drilling holes)

PICTURE 8. Plants installed in hydroponic net pots and surrounded by a sponge.

2) The second design was made out of Styrofoam board by drilling suitable holes, in this design, hydroponic net pots were not used. Instead, a long stripe of sponge was used surrounding part of the roots and the stem to hold the plants in position within the hole in the floating island. This design showed acceptable stability and durability. Moreover, it is made out of 100% recycled materials (picture 9).



PICTURE 9. Plants installed over Styrofoam board.

3) The third design was made out of flower baskets trays that are usually disposed of as trash. It was managed to connect three pieces and support it with Styrofoam beam around, this allows to this design to float, carrying the expanded clay aggregate (ECA) and the plants. At the bottom of these trays, 6mm holes were drilled in order to let the plants' roots to grow freely in the water body (picture 10). The reason behind this design is that to find out if there is an opportunity to start the plants from seeds.

PICTURE 10. Setup a design of SFI out of flower basket trays

3.4.5 Heating and Lighting

The main heating source was the sun for the greenhouse during the experiment. However, there were two other systems. The first one was when the outside temperature was no less than -2 degree Celsius. The system was simply based on lighting four long-term burning candles. This system made it possible to bring the temperature in the greenhouse to above 1 degree Celsius and was used only to keep the greenhouse above freezing temperature during the nighttime up to the end of November 2017. After that, days became shorter and not much heat was stored inside the greenhouse due to the lack of sunlight.

The other heating system was a stove burning wood. The stove was built from recycled material, and the firewood were reclaimed wood (i.e., rotten wood, building leftover pieces). About 15 kg on average was used daily to heat the greenhouse and keep it above freezing temperature (picture 11). The temperature within the greenhouse was between +2 to +24 degree Celsius, while the outside temperature was between -12 and +4 degrees Celsius. This system worked until the end of December 2017 when it was challenging to maintain the greenhouse above zero Celsius; therefore, the heating process was turned off. It should be mentioned that there were additional water mass in barrels (5 barrels of 200 liters each) inside the greenhouse, to supply the growing ponds with water if needed, and as a mass that stores heat during the day and the heating hours.

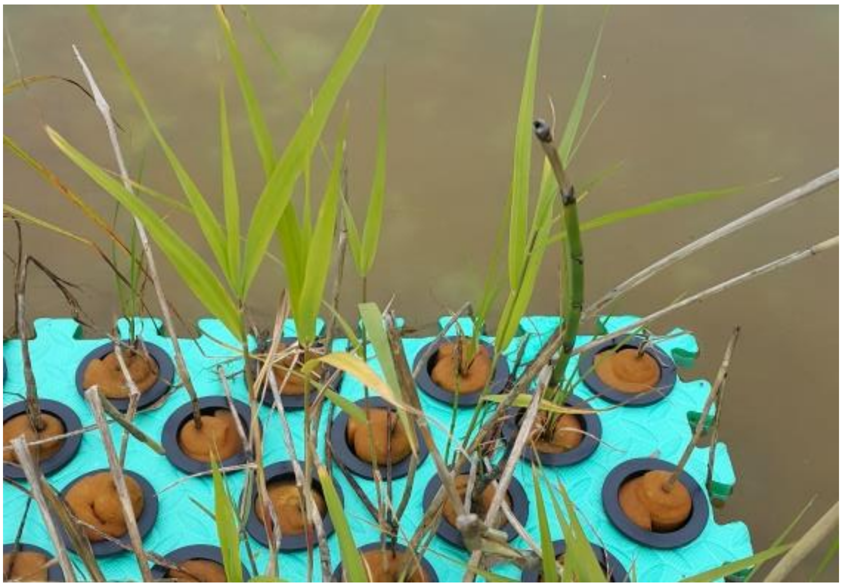
PICTURE 11. Stove in action in the greenhouse

3.4.6 Plants

Collecting of the plants started from June 2017, from Päijät-Häme region, focusing on Nastola, where the greenhouse is located. The search of the plants was focused on ditches, low lands, and marshals. The plants were then studied and classified. Non-native and invasive species were excluded (i.e., *Fallopia japonica*). The collected plants were installed on floating mats (summer growing ponds) in order to find out which could survive the SFI system. Some plants were unable to survive the aquatic environment (picture12). The plants showed varying adaptation shock periods, such as a slow growth period, as is the case with *Carex rhynchophysa* that returns to normal growth after 15 days (picture 13). On the other hand, *Phragmites australis* appeared to be severely affected, as it appeared to have completely died. However, *Phragmites australis* started to grow up again after 70 days (picture 14).

PICTURE 12. Many plants were unable to survive the aquatic condition

PICTURE 13. *Carex rhynchophysa* was able to survive on the SFI.



PICTURE 14. *Phragmites australis* grows back after 70 days

However, both native (not invasive species) and decorative gardening plants were used in this research. The plants used on the SFI in this study are:-

Native Plants

The native plants include*; Juncus effuses* (picture 15) (Figure 4)*, Phragmites australis*, *Carex acuta*, *Caltha palustris*, *Ranunculus repens*, *Saponaria officinalis*, *Rumex crispus*, *Avena sativa*, and *Scirpus sylvaticus*. Along with native plants pictures, there are figures showing the field observations of the species in Finland. Pictures of native plants along with field of observations can be found in (Appendix 5).

PICTURE 15. *Juncus effuses* in nature (Laji 2018).

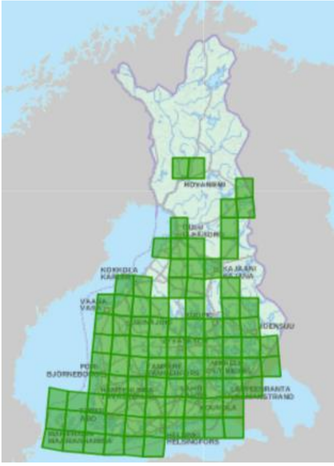


FIGURE 4. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

Gardening plants

The gardening plants that used on the SFI include; *Primula Vialii* , *Hemerocallis*, *Iris Pumila*, *Hemerocallis 'Lacy Doily'* , *Phalaris arundinacea 'pict* , *Hosta Sieb Blue Angel* , *Hosta Wide Brim*, *Sedum* and *Jacobaea Maritima*. Pictures of the gardening plants can be found in (Appendix 6).

3.4.7 Testing Methods

Weekly water testing was done for each growing pond. Two growing ponds were left without floating islands for control test purposes.

The water tests were done using TESTLAPMARIN produced by JBL Germany. It uses color charts to identify the nutrients level in the water. The gradient of the color charts have different levels and is limited between lowest and highest values as follows:

- PO_4^{3-} (Mg/l) [0.02, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.2, 1.8]
- NO_3^- (Mg/l) [0.05, 1, 5, 10, 20, 40, 80, 160, 240]
- NO_2^- (Mg/l) [0.01, 0.025, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1]
- NH_4^+ / NH_3 (Mg/l) [0.05, 0.1, 0.2, 0.4, 0.6, 1, 1.5, 3, 5]

3.4.8 Justifications

1. Depth of Water

The water depth in the growing ponds varied from 7 cm to 20 cm. The reason I did not choose deeper ponds due to the height of the growing pond frame which is 22 cm; in order to make the growing ponds deeper it required additional side supports of the grow box. Moreover, the greenhouse height is 210 cm, and due to the location of the growing ponds by the side of the greenhouse. It was preferable to have enough space for the plants to grow in order to prevent any contacts between the plants and the polycarbonate sheets of the greenhouse. Moreover, and based on the floating island experimental studies which reviewed, the depth of water columns does not have significant effects on the removal of nutrients (Chang et al. 2012)

2. Source of Water

The water used to fill the growing ponds came from a well located nearby the greenhouse. Two 1200 liter water containers were used to mimic the stormwater runoff with two different nutrients level. The first container contained water with high nutrients, and the other contained water with low nutrients. The nutrients including phosphorus and ammonia were added well mixed and dissolved before the water was discharged into the target growing ponds (picture 16).

Phosphorus pentoxide was added to the water as a source of phosphate and urea as a source of nitrogen. (figure 5) illustrates urea conversation into ammonium/ammonia, nitrite, and nitrate in water.

PICTURE 16. A container full of water with nutrients before discharge it to the growing pond

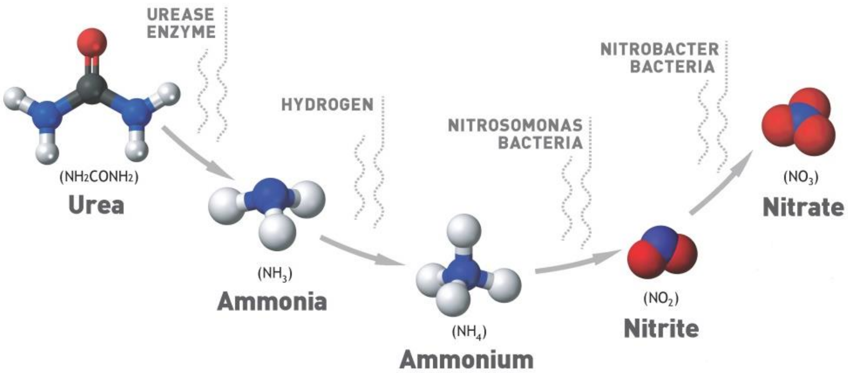


FIGURE 5. Nitrogen conversion process (Taurus 2018).

3. Shading

The percentage of the growing ponds surface area that was covered by the SFI varied according to the design of the floating island. Table 3 shows the percentage of the surface area covered by the SFI for each of the growing ponds.

TABLE 3. The percentage of the surface area covered by the SFI for each growing pond

Growing pond Number	Accommodation with SFI	Surface area coverage
1	Yes	28%
2	Yes	28%
3	Yes	46%
4	Yes	46%
5	Yes	46%
6	No (control growing pond)	0%
7	No (control growing pond)	0%
8	No	-
9	Yes	46%
10	Yes	24%
11	Yes	46%
12	Yes	14%

4 RESULTS

4.1 Coping with the aquatic condition and the Finnish winter

During the research, many plants were tested for their ability to survive the new aquatic condition on the floating islands and also tested for surviving the long freezing winter (lowest temperature reached in winter 2017-2018 in Nastola was -29 degree Celsius). Most of the plants coped well. The following plants (out of the list of the tested plants) had some adaptation impacts:

1) *Avena sativa*: Coped well up to 3 weeks from the time the seed was germinated and was installed on the floating island. Then the roots showed rotting signs. At this time the size of the plants reached between15-25 cm.

2) *Phragmites australis:* The plants were picked up in June 2016 from the shore of Lake of Ruuhijärvi. The sizes of the plants were between 50 – 70 cm with roots. The plants were greatly affected after the installation on SFI, and it looked like they died. However, the plants grew again after 70 days. However, during the experiment, *Phragmites australis* reached growth size between 40- 60 cm, which is smaller than the plant size found in nature.

The results of the surviving plants are summarized in Table 4.

TABLE 4 List of the plants installed on SFI and their surviving rates

S.N	**Name of the plants**	**Installation Survival Ratio %**	**Winter Survival Ratio %**	**Available in growing pond No.**	**Picture Reference Number**
1.	*Juncus effusus*	99	40	3,4,5 & 11	15
2	*Phragmites australis*	70	99	1	16
3	*Carex acuta*	75	99	1 & 2	17
4	*Caltha palustris*	80	90	2	18
5	*Ranunculus repens*	85	95	2,3,4 & 5	19
6	*Saponaria officinalis*	95	100	2	20
7	*Rumex crispus*	100	Not tested	2	21
8	*Avena sativa*	90	seed germinated	9 &10	22

9	*Scirpus sylvaticus*	100	99	2 & 12	23
10	*Primula Vialii*	100	Not Tested	8	24
11	*Hemerocallis*	100	Not Tested	8	25
12	*Iris Pumila*	100	Not Tested	8	26
13	*Hemerocallis 'Lacy Doily'*	100	Not Tested	8	27
14	*Phalaris arundinacea 'picta'*	100	Not Tested	8	28
15	*Hosta Sieb Blue Angel*	100	Not Tested	8	29
16	*Hosta Wide Brim*	100	Not Tested	8	30
17	*Sedum*	100	Not Tested	8	31
18	*Jacobaea Maritima*	100	Not Tested	8	32

4.2 Nutrient removal

Because nutrient removal is the main goal of the SFI, the following subsections discuss in detail the removal of each of the nutrients included in the study. It is important to note here that the removal of nutrients is compared between the SFI and the control test not only with respect to the amount removed by the end of the experiment period (42 days), but also taking into account the pace at which the removal took place. It is considered a better performance when the removal takes place at a higher rate at earlier stages, even though the overall removed nutrients after 42 days (i.e., the final result) is the same. A faster removal rate at early stages means that in the real life implementation of the SFI system in wetlands, water will contain less nutrients when it is discharged to the recipient water body. Having said that, the terms “performance” and “final result” are defined within the context of this study as follows:

- Performance: is the rate at which nutrient removal occurs; nutrient removal at a higher rate in early stages is considered a better performance
- Final result: the amount of nutrient removed by the end of the experiment (i.e., after 42 days), regardless of the rate at which the removal occurs during the 42 days.

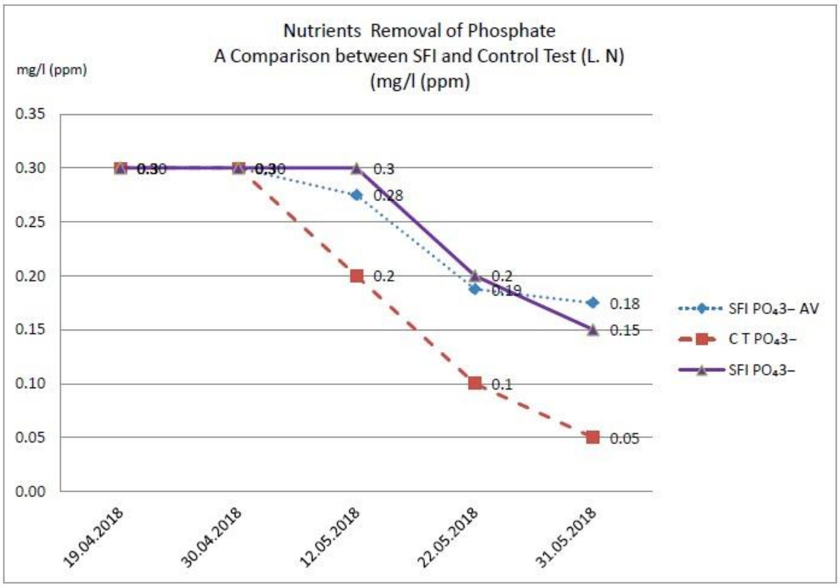
4.2.1 Phosphate PO_4^{3-}

Table 5 shows the results of the Phosphate PO_4^{3-} removal from the growing ponds. Besides the charts (figures 6-12), additional details are given about the conditions and factors (SFI area, water volume in the growing pond, the name of the plants) that might have affected the relevant growing ponds.

TABLE 5 Results of the Phosphate removal test from all growing ponds

	Phosphate mg/l (ppm)										
	With Floating Island							Average		Control Test	
	L.N	L.N	H.N	H.N	L.N	L.N	H.N	H.N	L.N	H.N	L.N
Date	G-P 1	G-P 2	G-P 3	G-P 4	G-P 5	G-P 11	G-P 12			G-P 6	G-P 7
19.04.2018	0.3	0.3	1	1	0.3	0.3	1	1.00	0.30	1	0.3
30.04.2018	0.3	0.3	0.5	0.4	0.3	0.3	0.5	0.47	0.30	0.3	0.3
12.05.2018	0.3	0.3	0.3	0.15	0.3	0.2	0.3	0.25	0.28	0.2	0.2
22.05.2018	0.2	0.2	0.2	0.02	0.2	0.15	0.2	0.14	0.19	0.2	0.1
31.05.2018	0.15	0.2	0.2	0.02	0.2	0.15	0.15	0.12	0.18	0.1	0.05
Removal amount	-0.15	-0.1	-0.8	-0.98	-0.1	-0.15	-0.85	-0.88	-0.13	-0.9	-0.25
Removal Percentage %	-50%	-33%	-80%	-98%	-33%	-50%	-85%	-0.88	-0.42	-90%	-83%

At low nutrients concentration, phosphate level started to reduce from April 30th from the control growing pond, unlike the one that was equipped with a SFI, including growing pond 1, 2 and 5 (figures 6, 7, 10 respectively), the phosphate started to reduce on May 12th. Moreover, the final phosphate test at the control growing pond was lower than the one equipped with SFI, so in growing pond 1 phosphate level at the final test was higher than the control growing pond by 0.1mg\l, and at growing pond 2 and 5 was higher by 0.15 mg\l.



Shading percentage: 28%

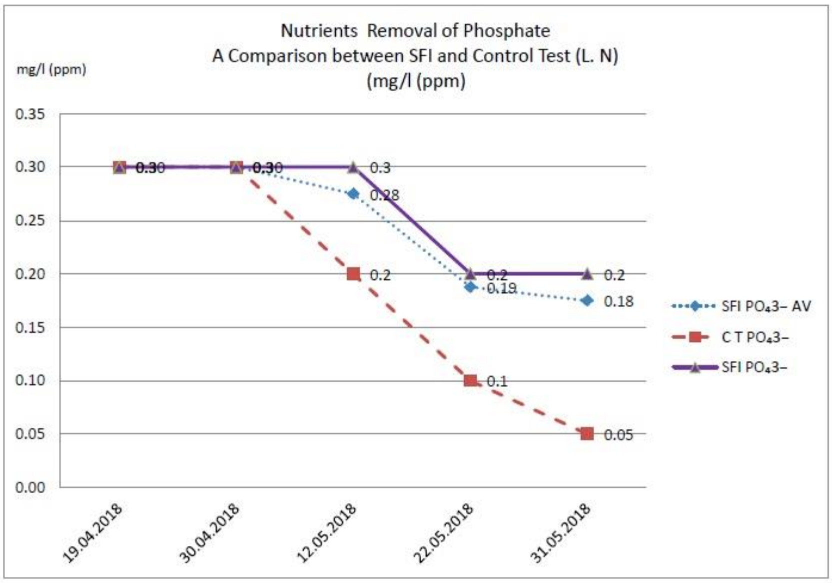
Water volume within the growing pond (m^3): 0.422

Plants:

1. Phragmites australis
2.Carex acuta

Growing pond 1 (Low Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same Low nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in Low Nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 1 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 6. Phosphate removal chart from growing pond 1



Shading percentage: 28%

Water volume within the growing pond (m^3): 0.413

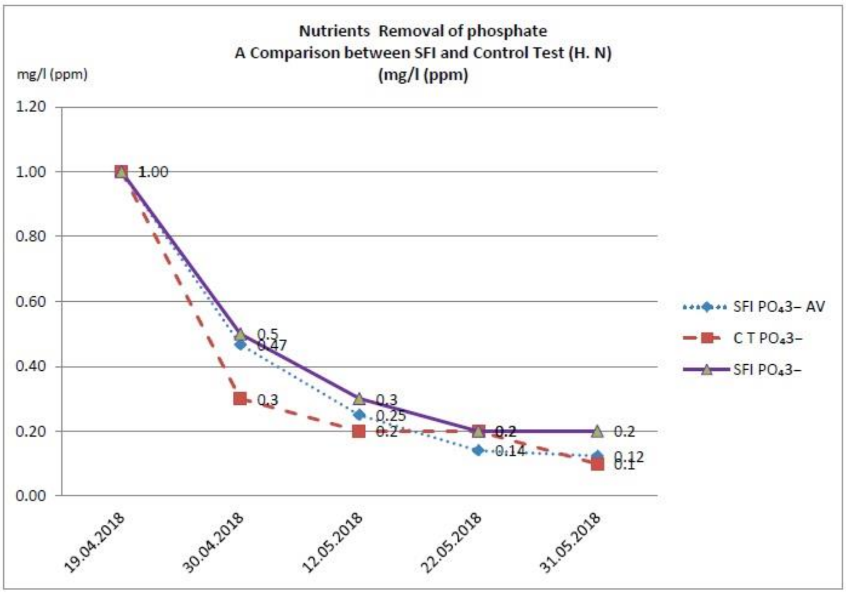
Plants:

1. Phragmites australis
2.Carex acut1.Carex acuta
2. Caltha palustris
3. Ranunculus repens
4. Saponaria officinalis
5. Rumex crispus
6. Scirpus sylvaticusa

Growing pond 2 (Low Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same Low nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in Low Nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 2 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 7. Phosphate removal chart from growing pond 2

In high nutrient concentration, the phosphate level in both control growing pond and the one equipped with SFI shows close results in the whole experiment (figures 19, 20, 23).



Shading percentage: 46%

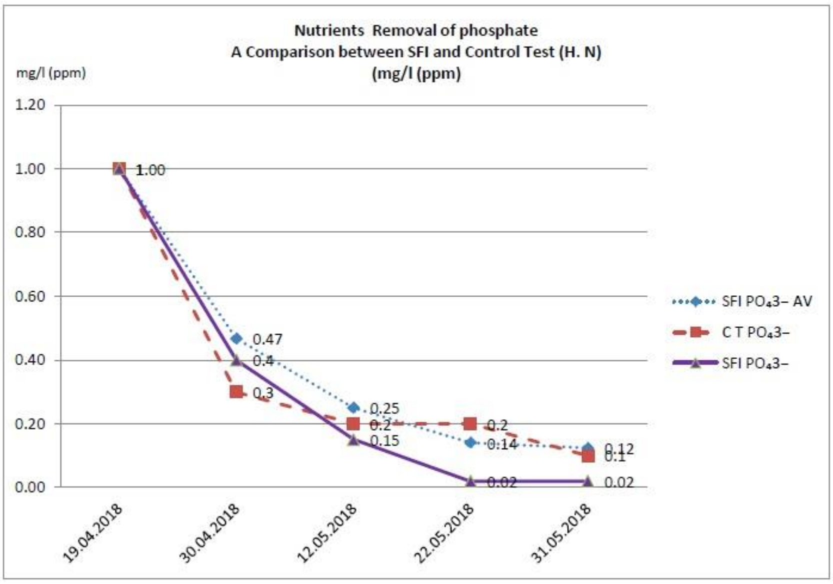
Water volume within the growing pond (m^3): 0.445

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 3 (High Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same high nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in high nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 3 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 8. Phosphate removal chart from growing pond 3



Shading percentage: 46%

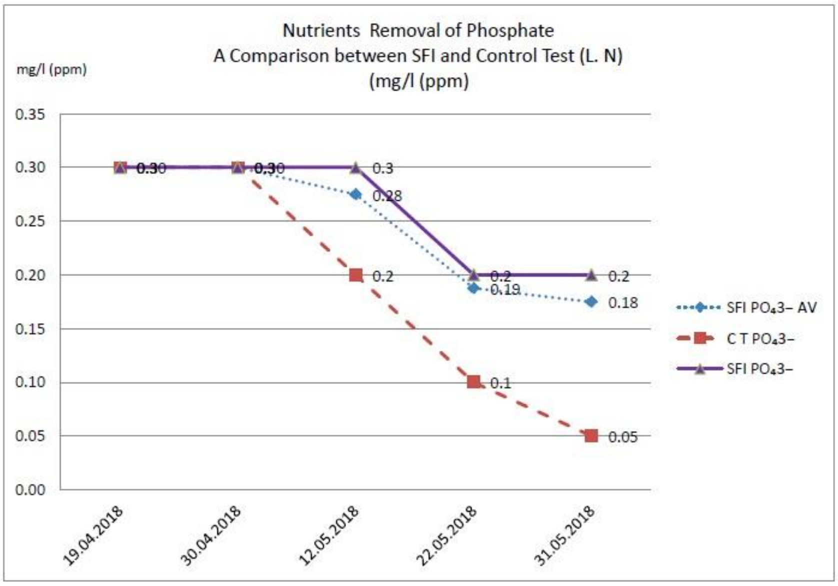
Water volume within the growing pond (m^3): 0.328

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 4 (High Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same high nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in high nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 4 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 9. Phosphate removal chart from growing pond 4



Shading percentage: 46%

Water volume within the growing pond (m^3): 0.289

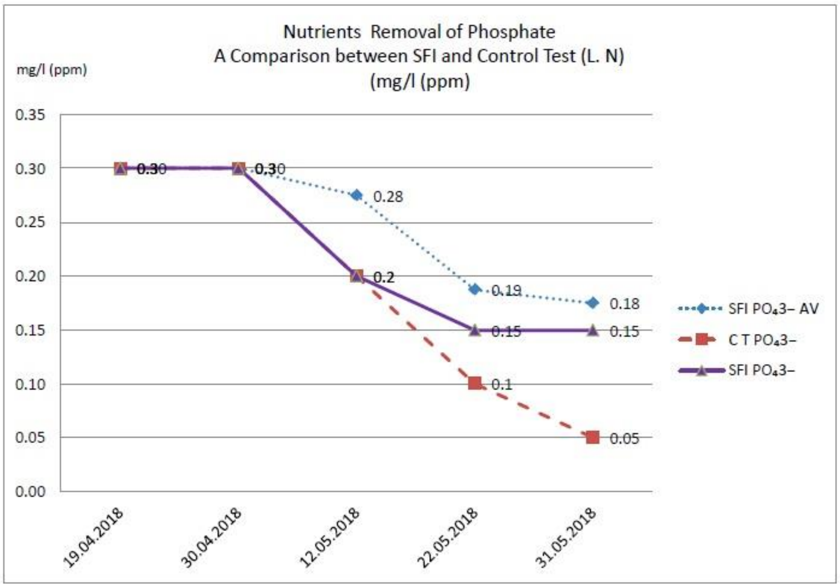
Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 5 (Low Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same Low nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in Low Nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 5 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 10. Phosphate removal chart from growing pond 5

At growing pond 11 where nutrients concentration is low, the phosphate level started to reduce in at same time as the control growing pond. However, the final test of the growing pond 11 was still higher than the control growing pond by 0.1mg\l (figure 11).



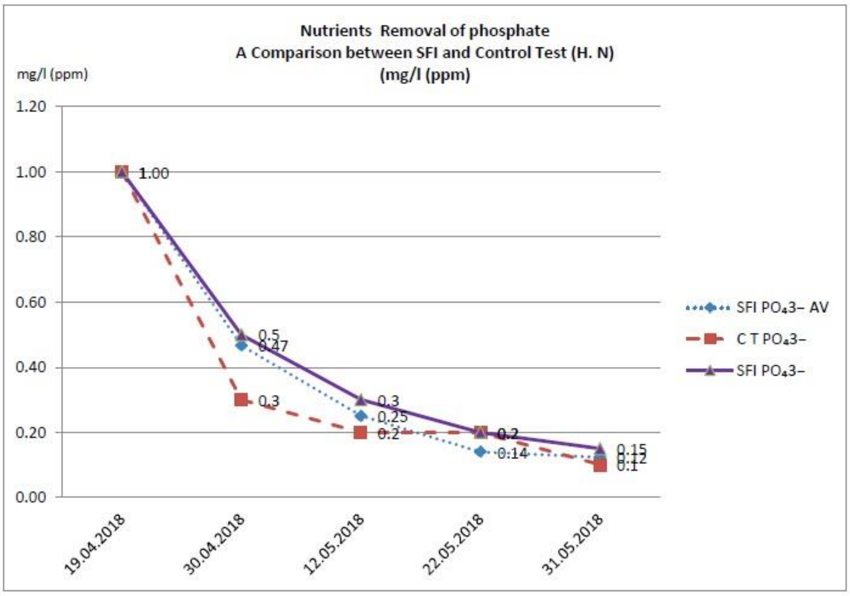
Shading percentage: 46%

Water volume within the growing pond (m^3): 0.461

Plants:
1. Juncus effusus

Growing pond 11 (Low Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same Low nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in Low Nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 11 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 11. Phosphate removal chart from growing pond 11



Shading percentage: 14%

Water volume within the growing pond (m^3): 0.435

Plants:

1. Scirpus sylvaticus

Growing pond 12 (High Nutrients)
SFI PO_4^{3-} AV: The average level of PO_4^{3-} between the growing ponds that has same high nutrients level
CT PO_4^{3-}: Level of PO_4^{3-} in high nutrients Control Test
SFI PO_4^{3-}: Level of PO_4^{3-} in growing pond number 12 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 12. Phosphate removal chart from growing pond 12

4.2.2 Nitrate NO_3^-

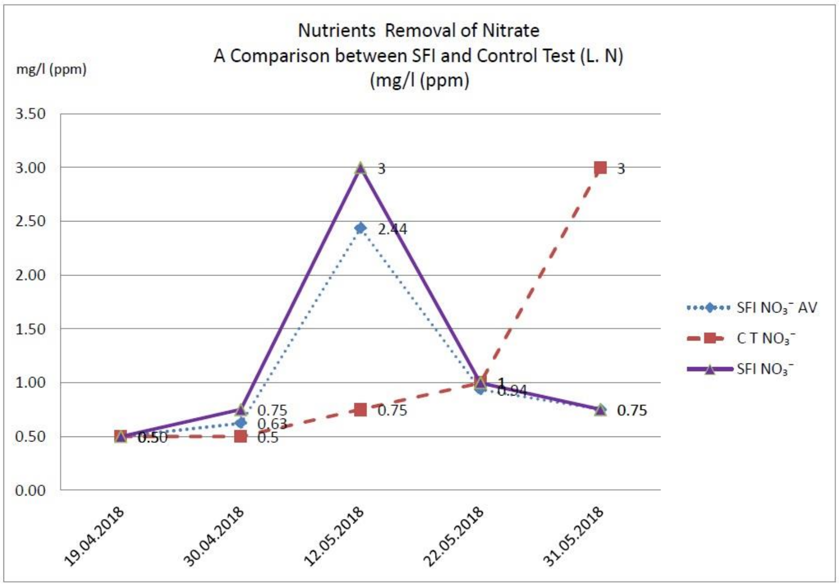
Table 6 Shows the results of the Nitrate NO_3^- removal from the growing ponds. Besides the charts (figures 13-19), additional details are given about the conditions and factors (SFI area, water volume in the growing pond, the name of the plants) that might have affected the relevant growing ponds.

TABLE 6 Results of the Nitrate removal test from all growing ponds

	Nitrate mg/l (ppm)										
	With Floating Island							Average		Control Test	
	L.N	L.N	H.N	H.N	L.N	L.N	H.N	H.N	L.N	H.N	L.N
Date	G-P 1	G-P 2	G-P 3	G-P 4	G-P 5	G-P 11	G-P 12			G-P 6	G-P 7
19.04.2018	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.50	0.50	0.5	0.5
30.04.2018	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.67	0.63	0.5	0.5
12.05.2018	3	3	5	10	3	0.75	3	6.00	2.44	3	0.75
22.05.2018	1	1	3	5	1	0.75	3	3.67	0.94	5	1
31.05.2018	0.75	1	1	3	0.5	0.75	1	1.67	0.75	3	3
Removal amount	0.25	0.5	0.5	2.5	0	0.25	0.5	1.17	0.25	2.5	2.5
Removal Percentage %	-	-	-	-	-	-	-	-	-	-	-

In growing pond 1 where low nutrients concentration, the final test results of the nitrate level on May 31st were lower than the final test of the control growing pond by 2.25 mg\l. However, there was nitrate peak formation on May 12th in growing pond 1, unlike the control growing pond where the nitrate level started to rise on May 22nd till the end of the experiment (figure 13). Similar results were observed in growing ponds 2, and 5 (figures 14 and 17).

Although, the final test for growing pond 11 was the same as for growing pond 1, the nitrate level did not form a peak on May 12th (figure 18).



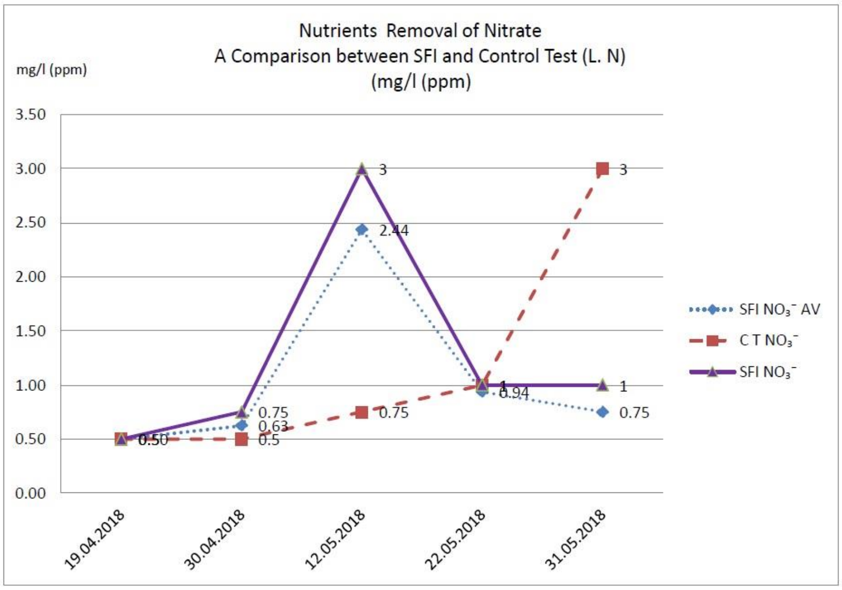
Shading percentage: 28%

Water volume within the growing pond (m^3): 0.422

Plants:
1. Phragmites australis
2.Carex acuta

Growing pond 1 (Low Nutrients)
SFI NO_3^-AV: The average level of NO_3^- between the growing ponds that has same Low nutrients level
CT NO_3^-: Level of NO_3^- in Low Nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 1 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 13. Nitrate removal chart from growing pond 1



Shading percentage: 28%

Water volume within the growing pond (m^3): 0.413

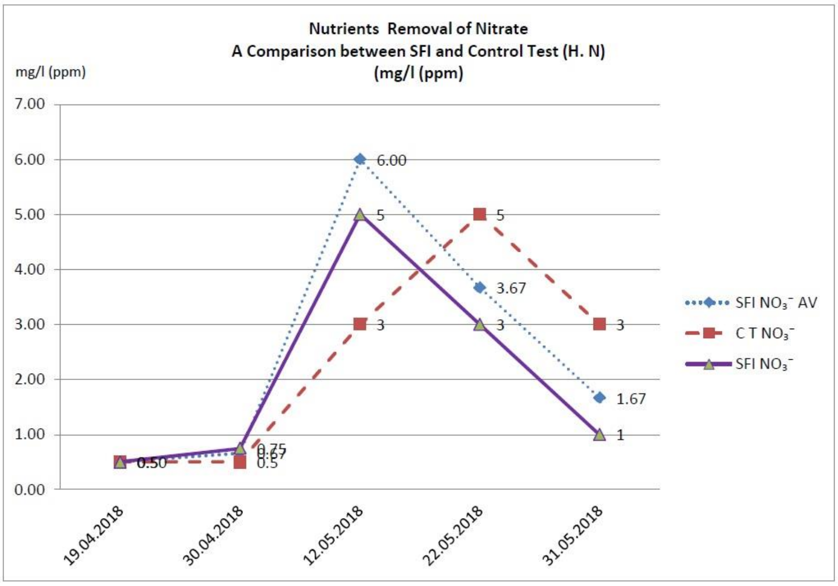
Plants:
1. Phragmites australis
2.Carex acut1.Carex acuta
2. Caltha palustris
3. Ranunculus repens
4. Saponaria officinalis
5. Rumex crispus
6. Scirpus sylvaticusa

Growing pond 2 (Low Nutrients)
SFI NO_3^- AV: The average level of NO_3^- between the growing ponds that has same Low nutrients level
CT NO_3^-: Level of NO_3^- in Low Nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 2 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 14. Nitrate removal chart from growing pond 2

In growing pond 3 where the nutrients concentration is high the nitrate level formed a peak on May 12th and then started to go down while in the control growing pond there was a peak on May 22nd and it then started to go down. However, the final test of nitrate in the growing pond 3 was lower than the control growing pond by 2 mg\l (figure 15).

In growing pond 4, there is a formation of nitrate peak on May 12th reach to 10mg\l, The nitrate level start to drop until the end of experiment where the nitrate level was in the growing pond was similar to control growing pond from May 22nd to end up the experiment (figure 16).



Shading percentage: 46%

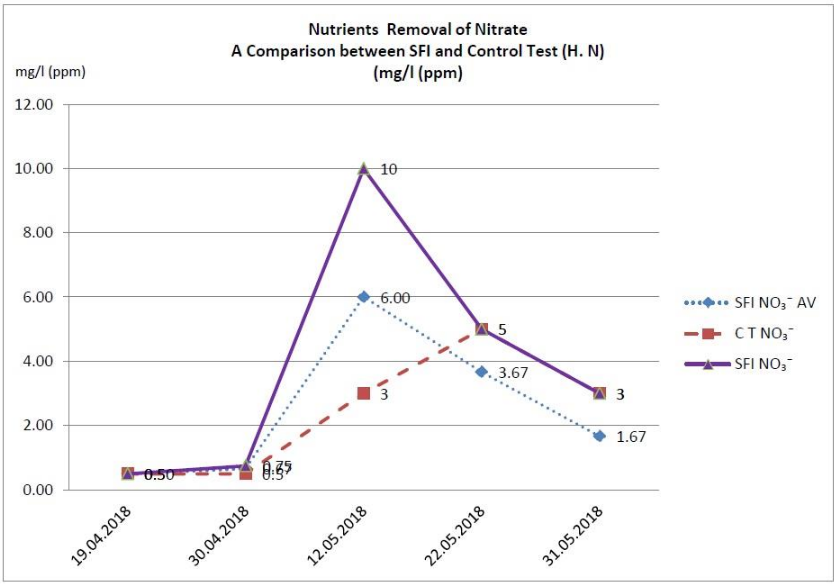
Water volume within the growing pond (m^3): 0.445

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 3 (High Nutrients)
SFI NO_3^- AV: The average level of NO_3^- between the growing ponds that has same high nutrients level
CT NO_3^-: Level of NO_3^- in high nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 3 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 15. Nitrate removal chart from growing pond 3



Shading percentage: 46%

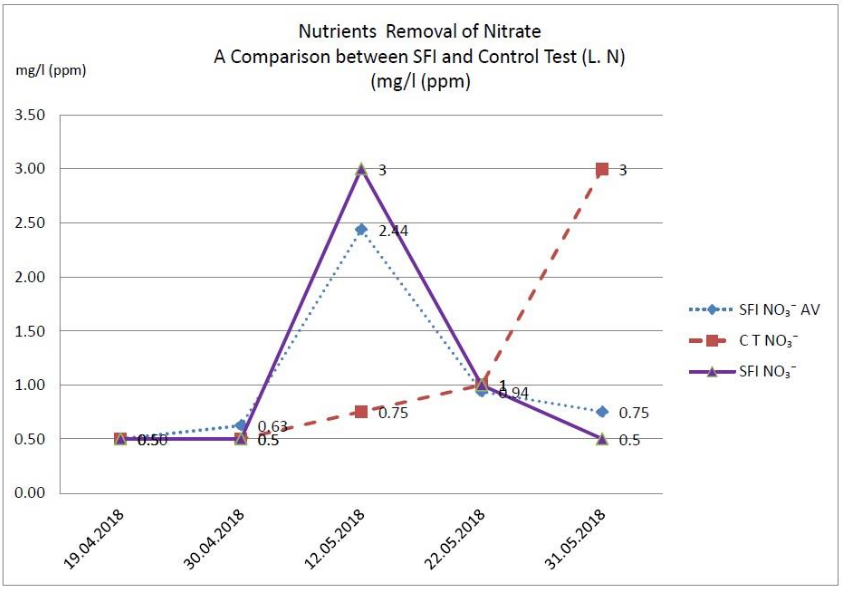
Water volume within the growing pond (m^3): 0.328

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 4 (High Nutrients)
SFI NO_3^-AV: The average level of NO_3^- between the growing ponds that has same high nutrients level
CT NO_3^-: Level of NO_3^- in high nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 4 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 16. Nitrate removal chart from growing pond 4



Shading percentage: 46%

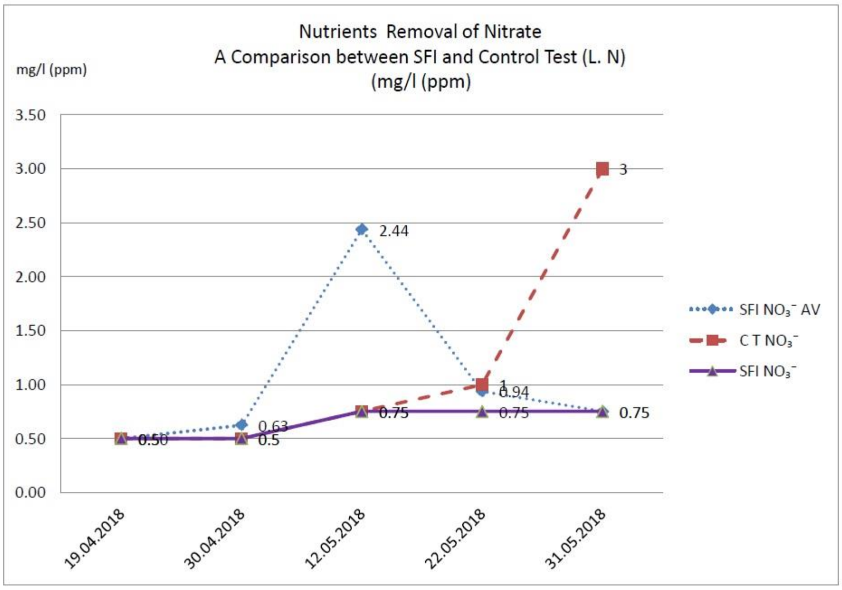
Water volume within the growing pond (m^3): 0.289

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 5 (Low Nutrients)
SFI NO_3^-AV: The average level of NO_3^- between the growing ponds that has same Low nutrients level
CT NO_3^-: Level of NO_3^- in Low Nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 5 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 17. Nitrate removal chart from growing pond 5



Shading percentage: 46%

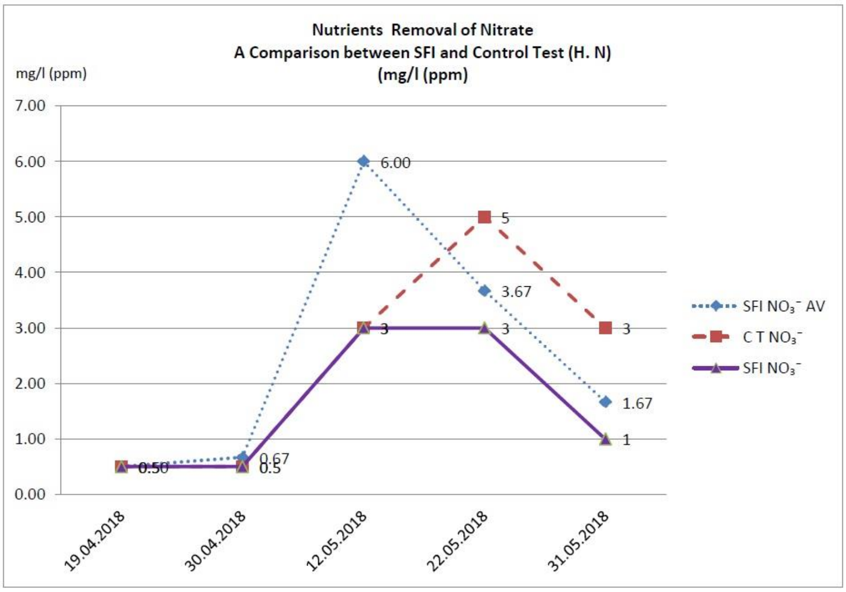
Water volume within the growing pond (m^3): 0.461

Plants:
1. Juncus effusus

Growing pond 11 (Low Nutrients)
SFI NO_3^-AV: The average level of NO_3^- between the growing ponds that has same Low nutrients level
CT NO_3^-: Level of NO_3^- in Low Nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 11 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 18. Nitrate removal chart from growing pond 11

In growing pond 12 nitrate level raised as same as it did in control growing pond till May 12th where nitrate level stayed on 3mg\l till May 22nd and then started to go down to reach 1 mg\l as a final result which is less than the control growing pond final test by 2 mg\l (figure 19)



Shading percentage: 14%

Water volume within the growing pond (m^3): 0.435

Plants:
1. Scirpus sylvaticus

Growing pond 12 (High Nutrients)
SFI NO_3^-AV: The average level of NO_3^- between the growing ponds that has same high nutrients level
CT NO_3^-: Level of NO_3^- in high nutrients Control Test
SFI NO_3^-: Level of NO_3^- in growing pond number 12 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 19. Nitrate removal chart from growing pond 12

4.2.3 Nitrite NO_2^-

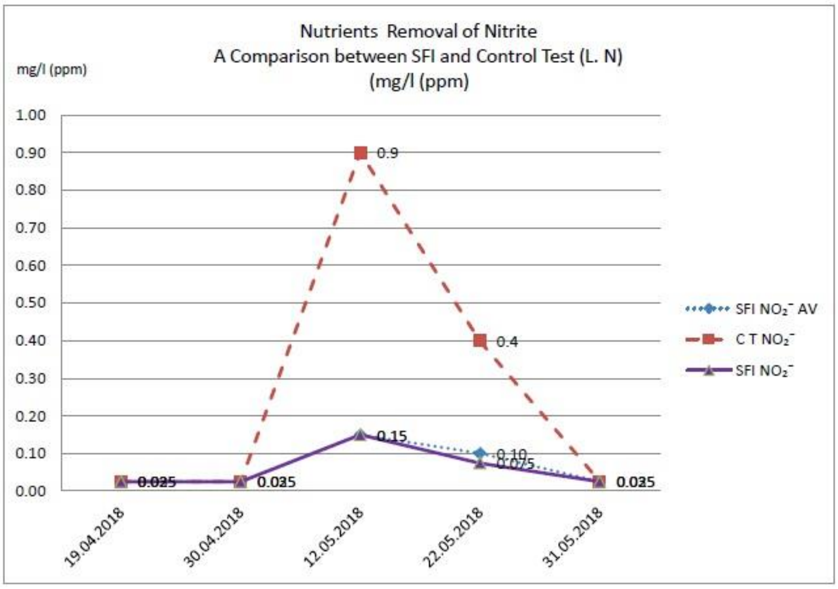
Table 7 Shows the results of the Nitrite NO_2^- removal from the growing ponds. Besides the charts (figures 20-26), additional details are given about the conditions and factors (SFI area, water volume in the growing pond, the name of the plants) that might have affected the relevant result of growing ponds.

TABLE 7 Results of the Nitrite removal test from all growing ponds

	Nitrite mg/l (ppm)										
	With Floating Island							Average		Control Test	
	L.N	L.N	H.N	H.N	L.N	L.N	H.N	H.N	L.N	H.N	L.N
Date	G-P 1	G-P 2	G-P 3	G-P 4	G-P 5	G-P 11	G-P 12			G-P 6	G-P 7
19.04.2018	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.03	0.03	0.025	0.025
30.04.2018	0.025	0.025	0.05	0.075	0.025	0.025	0.05	0.06	0.03	0.025	0.025
12.05.2018	0.15	0.025	0.025	0.025	0.025	0.4	0.15	0.07	0.15	0.5	0.9
22.05.2018	0.075	0.1	0.3	0.5	0.025	0.2	0.6	0.47	0.10	1	0.4
31.05.2018	0.025	0.025	0.025	0.05	0.025	0.025	0.3	0.13	0.03	1	0.025
Removal amount	0	0	0	0.025	0	0	0.275	0.10	0.00	0.975	0
Removal Percentage %	0%	0%	0%	-	0%	0%	-	-	0.00	-	0%

It has been observed that the growing pond 1, where the nutrient concentration is low, the final test of nitrite on May 31st was similar to the final test at the control growing pond of same nutrients concentration. However, during the experiment time the nitrite level at the growing pond was the same as the control growing pond until April 30th when the nitrite level raised by 0.75mg\l in control growing than the one equipped with a SFI as on May 12th. The Nitrite level dropped in both the growing pond and the control one, but in May 22nd the control growing pond nitrite level was still higher than the SFI growing pond by 0.325 mg\l. At the end of the experiment on May 31st, there was a similarity in the test results (figure 20).

It has been noticed that in low nutrient concentration, there are similarities in the final test between the growing pond 2 that was equipped with a SFI and the control growing pond. Also, there was an almost similar performance of nitrite removal. The differences were on May 12th were the nitrite level in the control growing pond was higher by 0.875 mg\l compared to growing pond 2, and on May 22nd by 0.3 mg\l higher than growing pond 2 (figure 21).



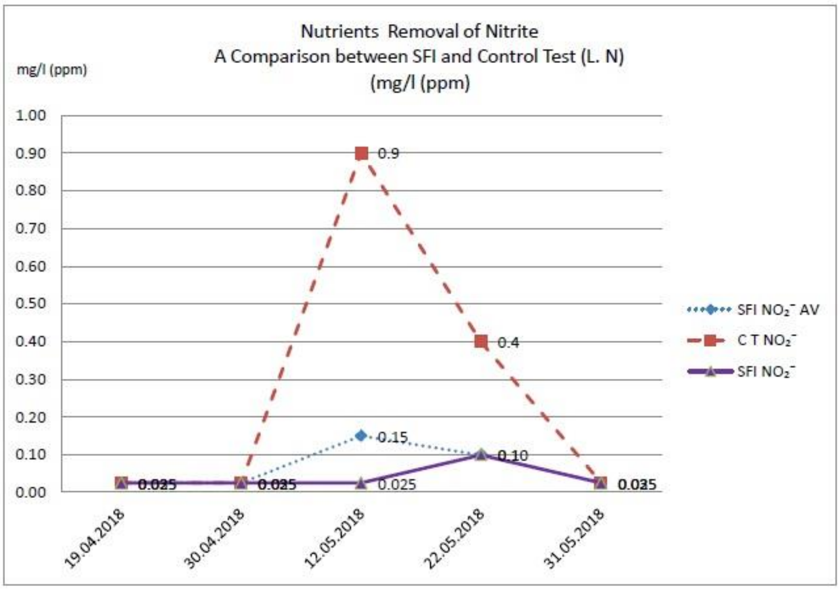
Shading percentage: 28%

Water volume within the growing pond (m^3): 0.422

Plants:
1. Phragmites australis
2.Carex acuta

Growing pond 1 (Low Nutrients)
SFI NO_2^- AV: The average level of NO_2^- between the growing ponds that has same Low nutrients level
CT NO_2^-: Level of NO_2^- in Low Nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 1 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 20. Nitrite removal chart from growing pond 1



Shading percentage: 28%

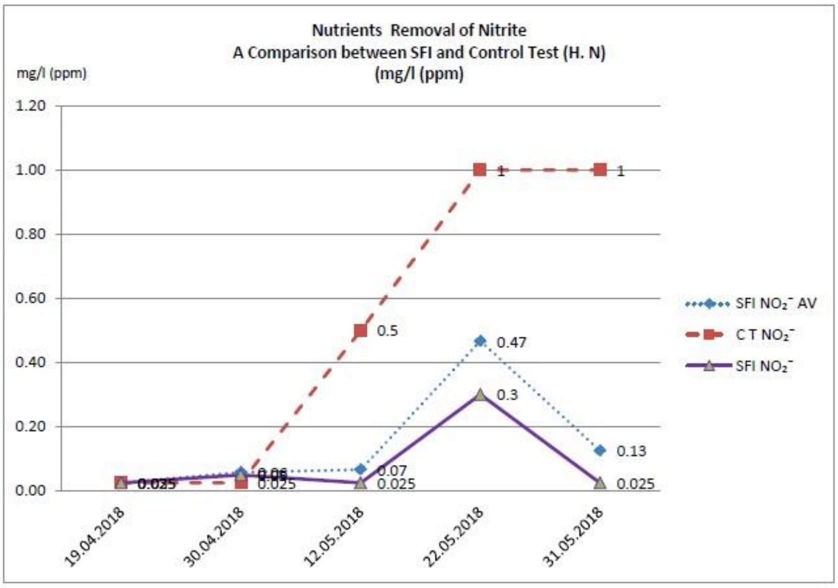
Water volume within the growing pond (m^3): 0.413

Plants:
1. Phragmites australis
2.Carex acut1.Carex acuta
2. Caltha palustris
3. Ranunculus repens
4. Saponaria officinalis
5. Rumex crispus
6. Scirpus sylvaticusa

Growing pond 2 (Low Nutrients)
SFI NO_2^- AV: The average level of NO_2^- between the growing ponds that has same Low nutrients level
CT NO_2^-: Level of NO_2^- in Low Nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 2 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 21. Nitrite removal chart from growing pond 2

In high nutrients concentration like in growing pond 3 which equipped with SFI the final test of nitrite was lower than the control growing pond by 0.975 mg\l (the highest scale of the used lab test is 1.0 mg\l). However, test result chart (figure 22) shows that the highest nitrite peak (for the growing pond with SFI) was on May 22nd and the nitrite level was 0.3 mg\l while the other test results were below that. On another side, the nitrite level for the control growing pond escalated from April 30th till and did not go down.



Shading percentage: 46%

Water volume within the growing pond (m^3): 0.445

Plants:
1. Juncus effusus

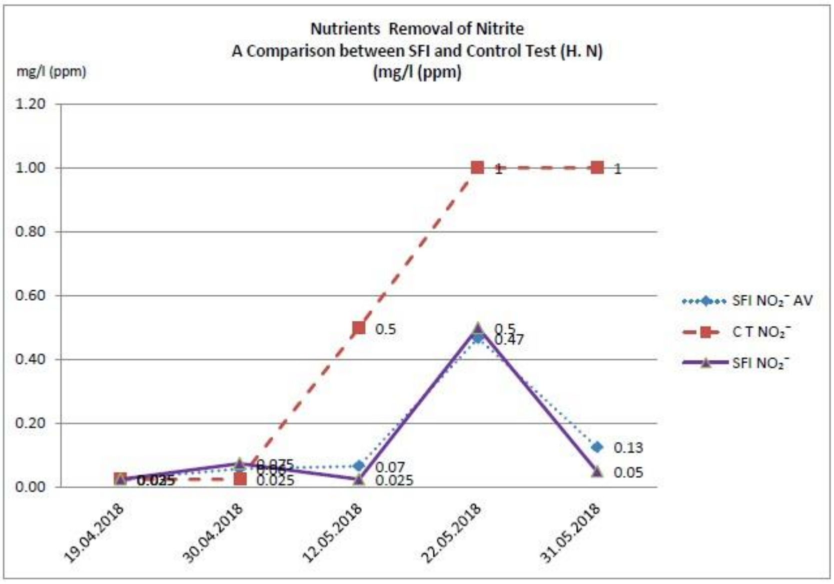
2. Ranunculus repens

Growing pond 3 (High Nutrients)
SFI NO_2^- AV: The average level of NO_2^- between the growing ponds that has same high nutrients level
CT NO_2^-: Level of NO_2^- in high nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 3 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 22. Nitrite removal chart from growing pond3

Similar high nutrients concentration in growing pond 4 as growing pond 3 but as seen from the nitrite test chart (figure 23) the highest nitrite level with SFI was 0.5 mg\l. However, the final test result was nearly similar to the final test result of growing pond 3 (0.05 mg\l).

At growing pond 12, nitrite removal chart (figure 26) relatively similar to the one in growing pond 4. However, the highest nitrite peak was 0.6 mg\l, and the final test was relatively high 0.3 mg\l compared to the growing pond 4. At anyhow the final test for growing pond 12 was lower than the control growing pond by 0.7 mg\l (the highest scale of the used lab test is 1.0 mg\l).



Shading percentage: 46%

Water volume within the growing pond (m^3): 0.328

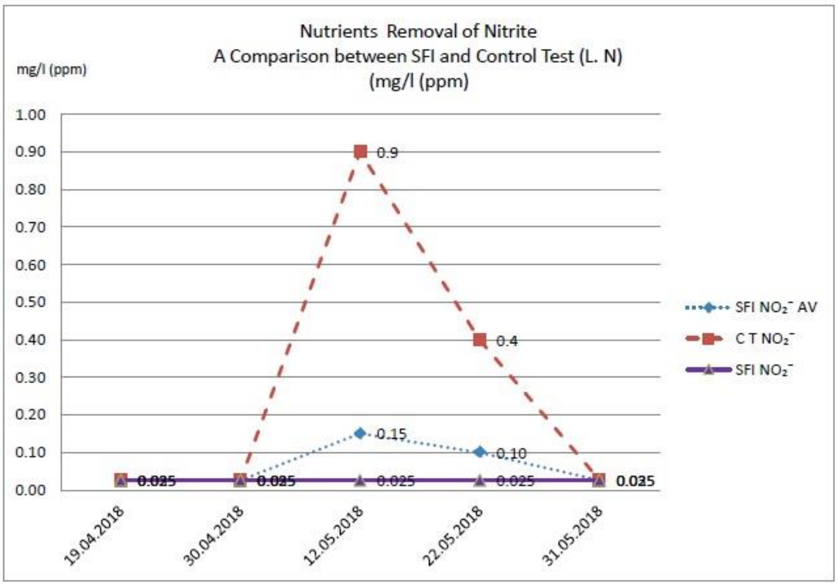
Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 4 (High Nutrients)
SFI NO_2^- AV: The average level of NO_2^- between the growing ponds that has same high nutrients level
CT NO_2^-: Level of NO_2^- in high nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 4 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 23. Nitrite removal chart from growing pond 4

Nitrite level in growing pond 5 during the whole experiment was level at 0.025 without any peaks (figure 24).



Shading percentage: 46%

Water volume within the growing pond (m^3): 0.289

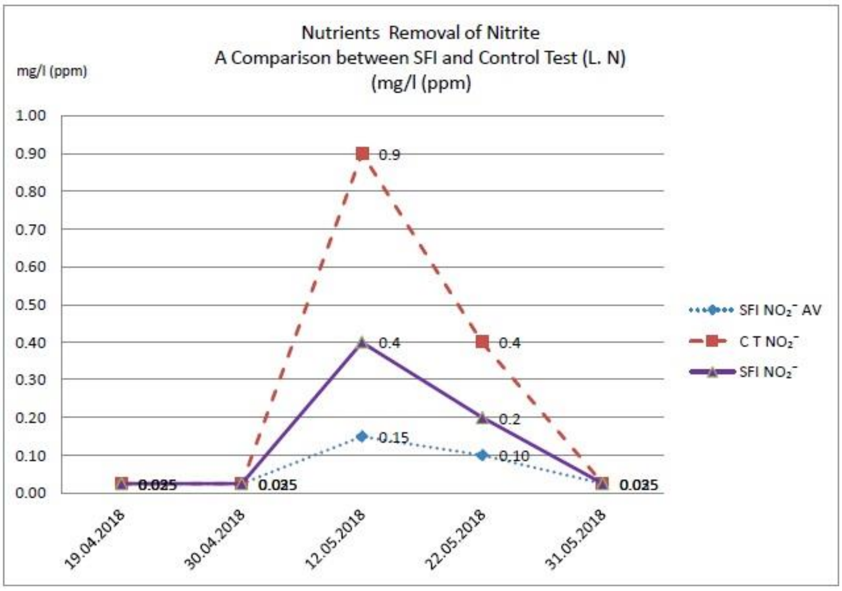
Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 5 (Low Nutrients)
SFI NO_2^-AV: The average level of NO_2^- between the growing ponds that has same Low nutrients level
CT NO_2^-: Level of NO_2^- in Low Nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 5 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 24. Nitrite removal chart from growing pond 5

At the growing pond 11 the high nitrite peak was on May 12th but was lower than the control growing pond by 0.5 mg\l, but there was an identical final test with control growing pond at the end of the experiment (figure 25).



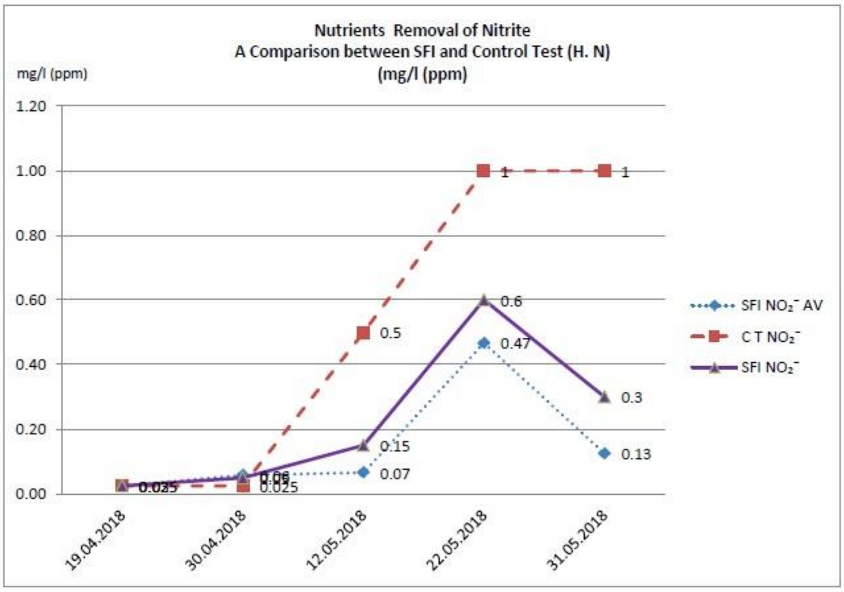
Shading percentage: 46%

Water volume within the growing pond (m^3): 0.461

Plants:
1. Juncus effusus

Growing pond 11 (Low Nutrients)
SFI NO_2^-AV: The average level of NO_2^- between the growing ponds that has same Low nutrients level
CT NO_2^-: Level of NO_2^- in Low Nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 11 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 25. Nitrite removal chart from growing pond 11



Shading percentage: 14%

Water volume within the growing pond (m^3): 0.435

Plants:
1. Scirpus sylvaticus

Growing pond 12 (High Nutrients)
SFI NO_2^-AV: The average level of NO_2^- between the growing ponds that has same high nutrients level
CT NO_2^-: Level of NO_2^- in high nutrients Control Test
SFI NO_2^-: Level of NO_2^- in growing pond number 12 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 26. Nitrite removal chart from growing pond 12

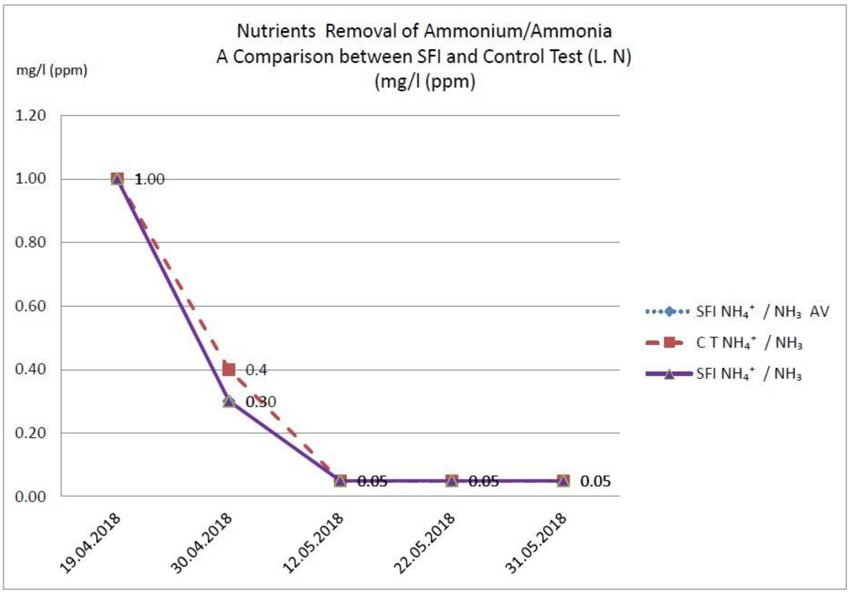
4.2.4 Ammonium/Ammonia NH_4^+ / NH_3

Table 8 Shows the results of the ammonium/ammonia NH_4^+ / NH_3 removal from the growing ponds. Besides the charts (figures 27-33), additional details are given about the conditions and factors (SFI area, water volume in the growing pond, the name of the plants) that might have affected the relevant growing ponds.

TABLE 8 Results of the Ammonium/Ammonia removal test from all growing ponds

	Ammonium/Ammonia mg/l (ppm)										
	With Floating Island							Average		Control Test	
	L.N	L.N	H.N	H.N	L.N	L.N	H.N	H.N	L.N	H.N	L.N
Date	G-P 1	G-P 2	G-P 3	G-P 4	G-P 5	G-P 11	G-P 12			G-P 6	G-P 7
19.04.2018	1	1	2.25	2.25	1	1	2.25	2.25	1.00	2.25	1
30.04.2018	0.3	0.3	1.5	1.5	0.3	0.3	1.5	1.50	0.30	2.25	0.4
12.05.2018	0.05	0.05	0.05	0.05	0.05	0.05	0.3	0.13	0.05	1.5	0.05
22.05.2018	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
31.05.2018	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Removal amount	-0.95	-0.95	-2.2	-2.2	-0.95	-0.95	-2.2	-2.20	-0.95	-2.2	-0.95
Removal Percentage %	-95%	-95%	-98%	-98%	-95%	-95%	-98%	-0.98	-0.95	-98%	-95%

In growing pond 1 where the nutrient concentration is low, the final result of Ammonium/Ammonia on May 31st was equal to that of the control growing pond at the same date. It is also observed that on April 30th the test results of Ammonium/Ammonia are lower than the control growing pond by 0.1 mg/l as seen in (figure 27) and then there were matching test results between the growing pond and the control growing pond. A similar result is also observed at low nutrient concentration growing ponds number 2, 5 and 11 seen in (figures 27, 31,32) respectively.



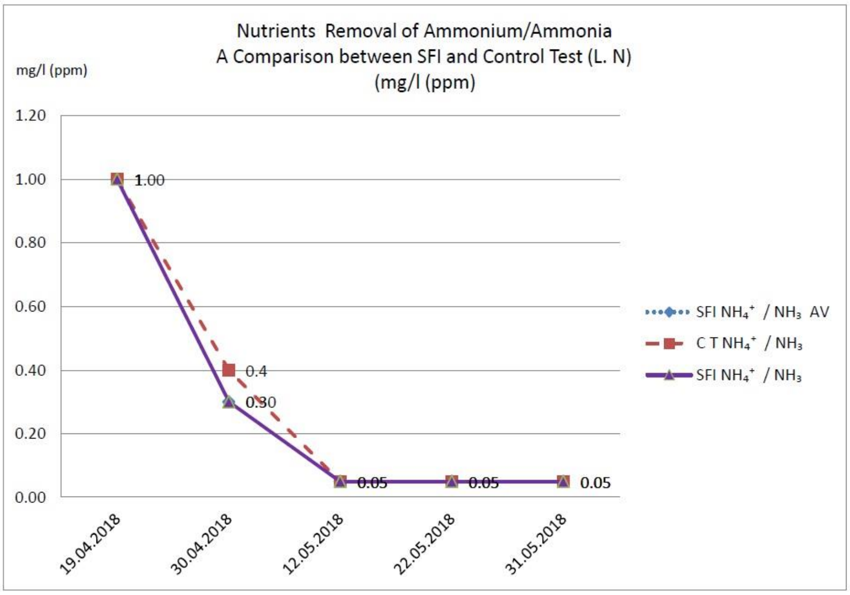
Shading percentage: 28%

Water volume within the growing pond (m^3): 0.422

Plants:
1. Phragmites australis
2.Carex acuta

Growing pond 1 (Low Nutrients)
SFI NH_4^+ / NH_3 AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same Low nutrients level
CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in Low Nutrients Control Test
SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 1 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 27. Ammonium/Ammonia removal chart from growing pond 1



Shading percentage: 28%

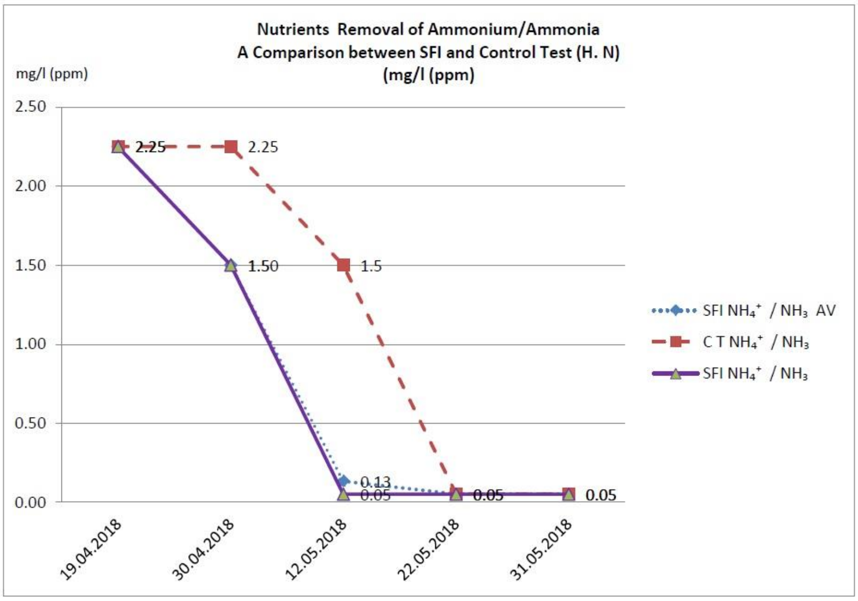
Water volume within the growing pond (m^3): 0.413

Plants:
1. Phragmites australis
2.Carex acut1.Carex acuta
2. Caltha palustris
3. Ranunculus repens
4. Saponaria officinalis
5. Rumex crispus
6. Scirpus sylvaticusa

Growing pond 2 (Low Nutrients)
SFI NH_4^+ / NH_3 AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same Low nutrients level
CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in Low Nutrients Control Test
SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 2 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 28. Ammonium/Ammonia removal chart from growing pond 2

In growing pond 3 where the nutrient concentration is high the final result of ammonium/ammonia on May 31st was same as the control growing pond. However, it has been noted that the Ammonium/Ammonia test for the growing pond equipped with SFI was less by 0.75 mg/l on April 30th compared to the control growing pond and by 1.45mg/l on May 12th. Moreover, the test results were matching only May 22nd until the end time of the experiment (figure 29). On the other hand, growing pond number 4 has similar results as in growing pond 3 (figures 30) while growing pond 12 has only slightly different from growing pond 3, and 4 in a test on May 12th where the difference is only 1.2mg\l (figure 33).



Shading percentage: 46%

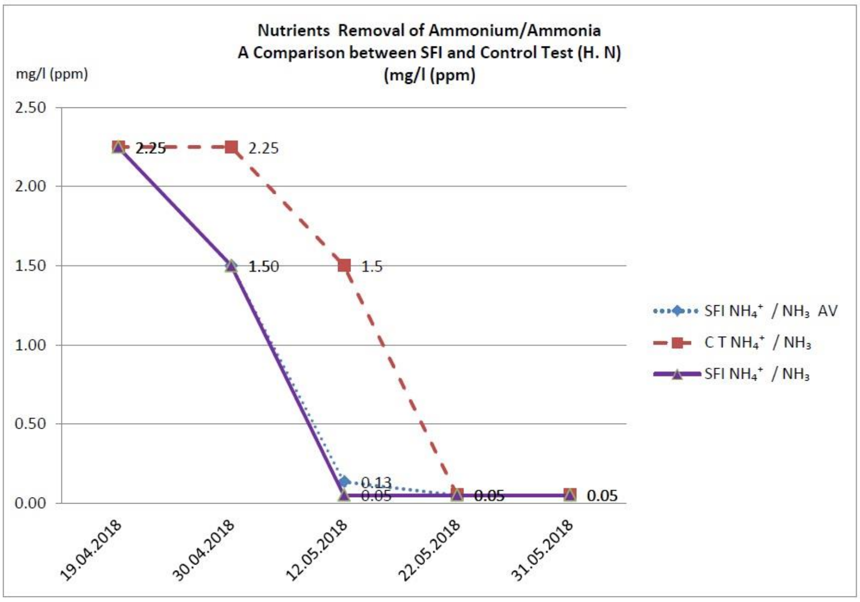
Water volume within the growing pond (m^3): 0.445

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 3 (High Nutrients)
SFI NH_4^+ / NH_3 AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same high nutrients level
CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in high nutrients Control Test
SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 3 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 29. Ammonium/Ammonia removal chart from growing pond 3



Shading percentage: 46%

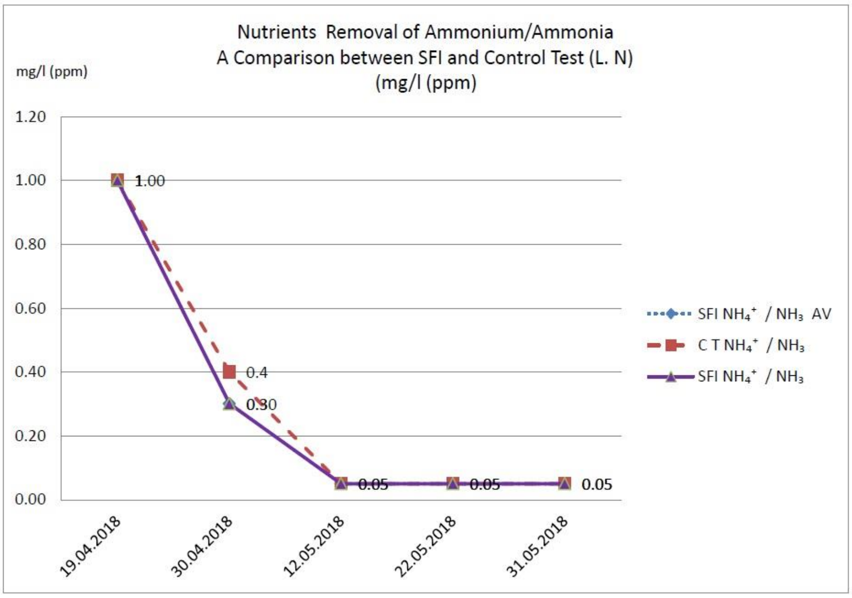
Water volume within the growing pond (m^3): 0.328

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 4 (High Nutrients)
SFI NH_4^+ / NH_3 AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same high nutrients level
CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in high nutrients Control Test
SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 4 (where high nutrients)
(H.N): High Nutrient Condition

FIGURE 30. Ammonium/Ammonia removal chart from growing pond 4



Shading percentage: 46%

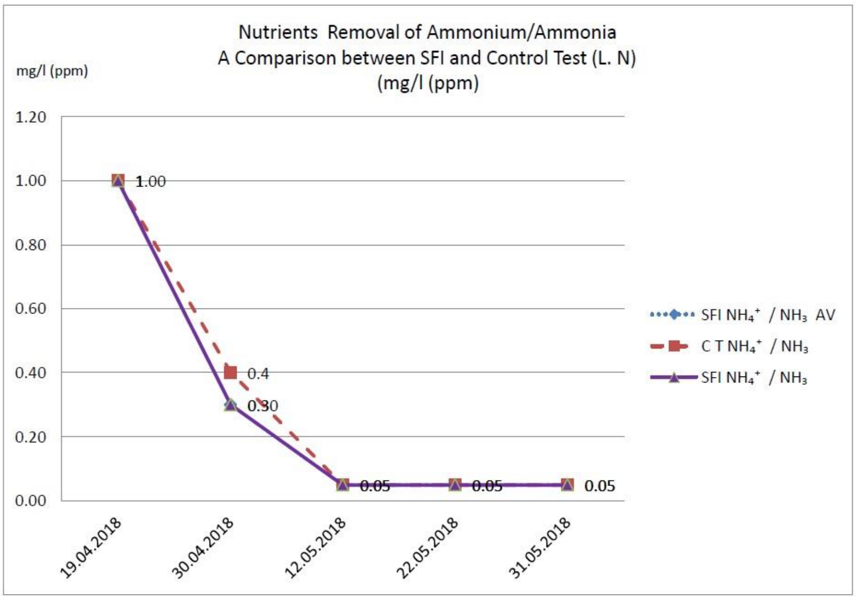
Water volume within the growing pond (m^3): 0.289

Plants:
1. Juncus effusus

2. Ranunculus repens

Growing pond 5 (Low Nutrients)
SFI NH_4^+ / NH_3AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same Low nutrients level
CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in Low Nutrients Control Test
SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 5 (where low nutrients)
(L.N): Low Nutrient Condition

FIGURE 31. Ammonium/Ammonia removal chart from growing pond 5



Shading percentage: 46%

Water volume within the growing pond (m^3): 0.461

Plants:

1. Juncus effusus

Growing pond 11 (Low Nutrients)

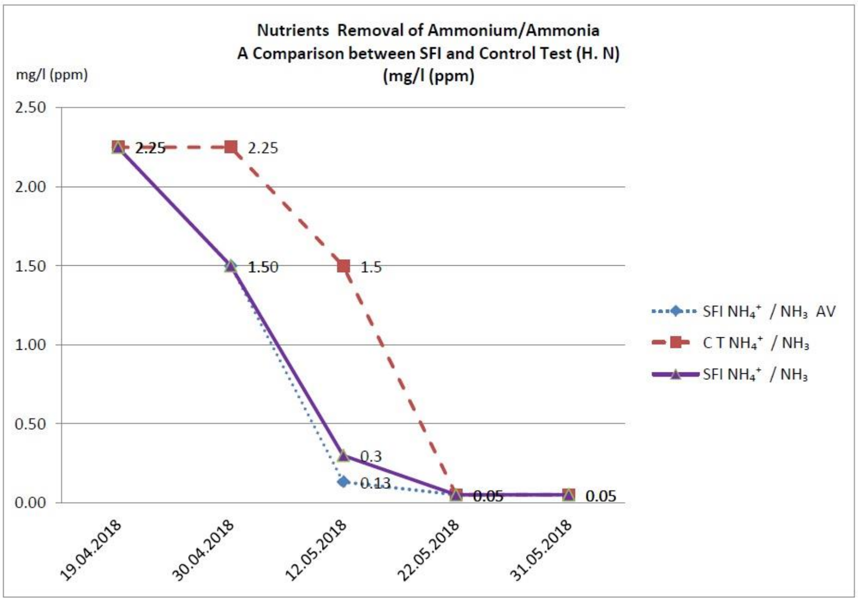
SFI NH_4^+ / NH_3AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same Low nutrients level

CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in Low Nutrients Control Test

SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 11 (where low nutrients)

(L.N): Low Nutrient Condition

FIGURE 32. Ammonium/Ammonia removal chart from growing pond 11



Shading percentage: 14%

Water volume within the growing pond (m^3): 0.435

Plants:

1. Scirpus sylvaticus

Growing pond 12 (High Nutrients)

SFI NH_4^+ / NH_3AV: The average level of NH_4^+ / NH_3: between the growing ponds that has same high nutrients level

CT NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in high nutrients Control Test

SFI NH_4^+ / NH_3: Level of NH_4^+ / NH_3: in growing pond number 12 (where high nutrients)

(H.N): High Nutrient Condition

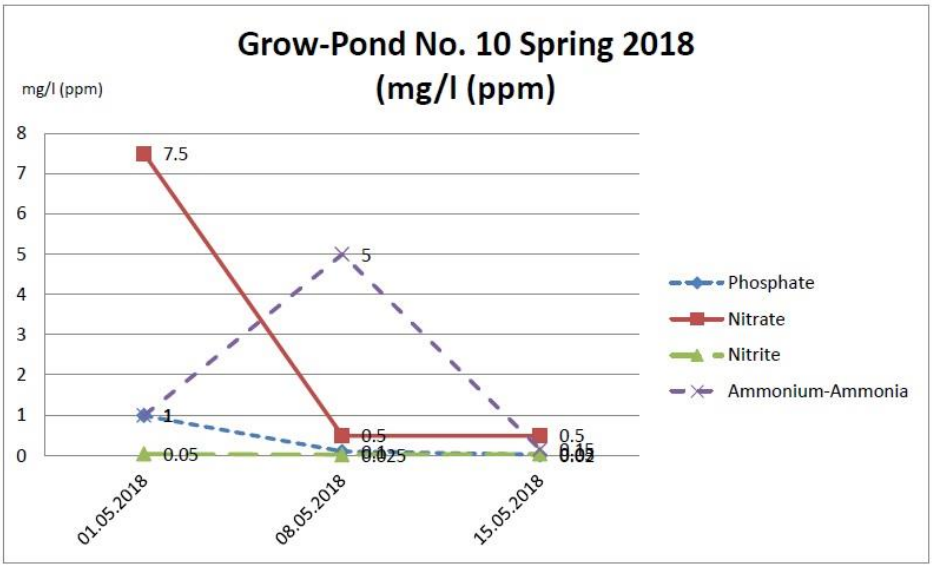
FIGURE 33. Ammonium/Ammonia removal chart from growing pond 12

4.2.5 Growing pond10 results

In this section, the result from growing pond 10 (Table 9) is covered

TABLE 9 Test results for the nominated nutrients in growing pond 10

Date	mg/l (ppm)			
	Phosphate	Nitrate	Nitrite	Ammonium-Ammonia
01.05.2018	1	7.5	0.05	1
08.05.2018	0.1	0.5	0.025	5
15.05.2018	0.02	0.5	0.05	0.15
Removed Ammount of Nutrients	-0.98	-7	0	-0.85
Removal Percentage %	-98%	-93%	0%	-85%



Shading percentage: 24%

Water volume within the growing pond (m^3): 0.455

Plants:
1. Avena sativa

FIGURE 34. Nutrient removal chart from growing pond 10

4.3 Visual results

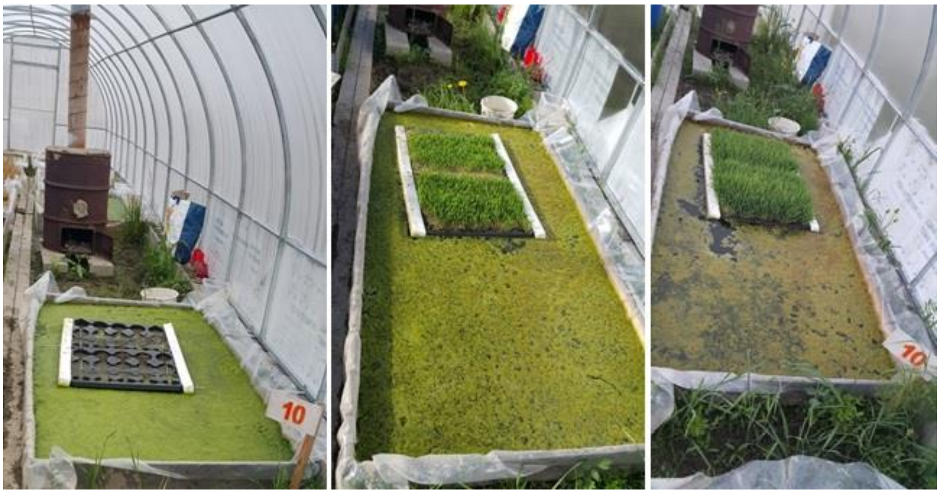
There are visual observations from the experiment that can be summarized as follows;

4.3.1 Algae growth

The algae growth was inhibited at the growing ponds equipped with SFI compared to the control growing ponds with no SFI (picture 17).

PICTURE 17. Algae growth; on the left is the control growing pond and on right growing ponds equipped with SFI

Moreover, in growing pond10 (picture 18) shows the three stages of *Avena sativa* growth along with the algae that cover the rest of the surface area.



PICTURE 18. Stages of the growth of *Avena sativa* and algae in 15 days (from left to right)

4.3.2 Roots growth

The plants that succeeded in the new aquatic condition showed good root growth although the growth varied between the types of plants. The largest root growth was observed in *Scirpus sylvaticus* (picture 19).

PICTURE 19. Roots growth of *Scirpus sylvaticus* under SFI

5 DISCUSSION

5.1 Adaptation of the plants

Many plants were tested during summer and autumn 2017 to find out their ability to adapt to the new aquatic condition. The plants that adapted to the aquatic condition faced the freezing winter of Finland. All the plants that adapt to the aquatic condition survived the freezing winter (the minimum temperature recorded was -29 degree Celsius during the experiments) in a different level. However, the death of some plants in spring 2018 could be due to dehydration as the air in the greenhouse was warm and the roots were still in the frozen water and unable to absorb water.

However, the best plant among the surviving list can be *Scirpus sylvaticus* because it survived 100% throughout the aquatic conditions and the extremely low temperature winter. Moreover, the species was not affected by dehydration during the springtime, and it showed (limited to the experiment conditions) no invasion capability in this new condition. Also, *Scirpus sylvaticus* had the largest root growth among the list of the plants (in length and fibrous dense).

There has been an idea commonly proposed that plants survive the winter as the soil protects roots from the harsh winter, and these plants would not be able to survive if the roots were in direct contact with water. After this experiment, this idea was found to be not entirely correct, and some plants (i.e., tested plants) can survive the harsh freezing winter even if the roots are in direct contact with frozen water.

5.2 Nutrient removal

5.2.1 Phosphate PO_4^{3-}

From the phosphate removal results, it was noticed that the growing ponds equipped with SFI show less phosphate removal compared to the control growing ponds in both high and low nutrients. Moreover, the phosphate removal rate was faster in the control growing pond.

Algae in the control growing ponds might have played the major role in phosphate removal as the open surface area is larger than that equipped with SFI.

5.2.2 Nitrate NO_3^-

Regarding nitrate removal, the observations from the results and charts in the previous section show different behaviors regarding nitrate removal in the high nutrients condition compared to the low nutrients condition.

Despite these differences, the overall results show that nitrate removal was more effective in the growing ponds equipped with SFI with faster removal rate compared to the control growing ponds as in growing ponds 3 and 12 where nutrients concentration is high and growing ponds 1, 2, 5, and 11 where the concentration of nutrients is low.

Regarding growing pond 4, although it shows similarity of nitrate removal value at the final test after 42 days, compared to the final test at control growing pond. There is a high peak of nitrate on May 12^{th,} 2018 test, unlike the other growing ponds with high nutrients concentration. At the same time, it does not look like the shading or plant type affects the high peak of nitrate compared to the other high nutrients growing ponds. The only difference noticed was that the water volume in growing pond 4 was nearly a quarter less compared to other growing ponds with similar conditions. This raises the question: did the urea convert into nitrate faster in low depth water, and then the nitrate uptake rate of the plant was the same as other growing ponds make it faster to reduce the nitrate from such less water volume as found in the growing pond 4.

5.2.3 Nitrite NO_2^-

Regarding nitrite removal, it was noticed that in the case of high nutrient levels, the growing pond equipped with SFI nitrite removal is higher in quantity and faster in rate compared to the control growing pond.

In low nutrient concentrations, growing ponds equipped with an SFI and the control test achieved almost the same removal quantities of nitrite after five weeks. However, the removal rate with SFI was faster compared to the control test. In addition to that, the high peak of Nitrite in all growing ponds equipped with an SFI was lower than the control growing ponds, which can affect the life of some species.

5.2.4 Ammonium/Ammonia NH_4^+ / NH_3

Both high nutrient and low nutrient concentrations showed almost the same removal quantities in growing ponds equipped with SFI and the control test growing ponds. However, at high nutrient levels, the growing ponds with an SFI showed faster removal rate compared to the control test. Moreover, the low nutrients concentration showed almost identical ammonium/ammonia removal in both the growing ponds with SFI and the control test.

5.2.5 Growing pond10

The results within growing pond10 were interesting regarding the nutrient removal in a short time and regarding algae control. Also, growing the *Avena sativa* on an SFI has succeeded. The visual result shows the 3 stages in growing pond10 and how algae weakened in the three stages.

There are many factors besides the growth of *Avena sativa* that might have affected results.

- The *Avena sativa* grows over a layer of expanded clay balls as a medium and as mentioned in the VTT stormwater conference in November 14th, 2017 Helsinki; there are some water quality improvements (nutrient removal) by using the expanded clay balls on green roofs.
- The expanded clay balls were within the SFI since winter time.
- Algae were growing along with *Avena sativa* and might play a large role in nutrient removal.

6 CONCLUSIONS AND RECOMMENDATIONS

This thesis evaluated the nutrient removal from the water body using stormwater floating islands in cases of high and low nutrients concentrations.

In this study, a preliminary assessment was carried out to determine whether the addition of floating islands supports the removal of nutrients (PO_43^-, NO_3^-, NO_2^-, and NH_4^+ / NH_3) from water bodies such as wetlands or ponds, natural or constructed. The experiment tested nutrient removal from waters with high and low concentrations of nutrients. Various designs of floating islands were also tested with the use of different percentages of recycled materials, up to 100% in some designs. The SFI designs were tested in this experiment, and all of these designs were successful in performing the job.

The surface area of the tested SFI varied. Moreover, the plants used on the SFI also varied to cover factors that might affect the SFI performance.

One of the most important results of this study is that the concept of SFI in Nordic countries is feasible although winter temperatures fall below zero (reaching -29 degree Celsius in the winter of 2017-2018 in Nastola in the Päijät-Häme region in Southern Finland where the experiment was conducted). Native plants were collected from nature and installed on the SFI, where the roots of these plants were exposed to a new submerged condition. In this experiment, some plants were found to be capable of adapting to this newly submerged condition and were also found to be able to withstand freezing temperatures during the winter. These plants grew again in the next spring despite the submerging and freezing conditions.

The plants used on the SFI show the ability to form a large network of roots in this water medium. And thus help to absorb the largest amount of nutrients in the water with the help of the biofilm that formed on the surfaces of those roots and the SFI material.

For the growing ponds with SFIs, the average percentage of phosphate removal in low nutrient concentration was 42%, and in high nutrient concentration was 88%. Moreover, the phosphate removal rate in control growing ponds was 83% in the low nutrient concentration and 90% in the high nutrients concentration. Therefore, it was noticed that in the case of low nutrient concentration, the performance of nutrient removal from the control growing ponds was higher than the ponds equipped with SFI. On the other hand, in the growing ponds equipped with SFI and the control growing ponds with high nutrient concentration, the performance, and the final test after 42 days are almost similar with slightly advantage to control growing ponds.

As for nitrate, although the nitrate level was rising in all ponds in both high and low nutrient concentrations, the performance of nitrate reduction was higher in the growing ponds equipped with SFI, except for growing pond 4, where the result was similar after 42 days. After the review and investigation, no factor were found that might affect such a different result, except that the volume of water in growing pond number 4 was about one-quarter less than other growing ponds with exception to growing pond number 5 which had almost the same volume of water as growing pond 4, but had a low nutrients concentration. Another observation regarding growing pond 4 is that most of the plants in growing pond 4 were replaced with new plants from nature at the beginning of spring due to the death of the plants from dehydration. Some clay might have remained on the roots of the new plants (even though these plants were washed), which might be the reason for the high nitrate level of 10 mg/l.

In general, given the average results, the observation regarding the nitrate removal is that the performance of growing ponds equipped with SFI is better than the control growing ponds.

Regarding nitrite, a similar behavior of nitrite removal was observed in the growing ponds equipped with SFI compared to the control growing pond of the same nutrients concentration.

In high nutrient concentration, and regarding the nitrite, growing ponds equipped with SFIs had the advantage in nitrite removal performance and the final results compared to the control growing pond with the same nutrients concentration. The growing ponds with low nutrients concentration showed similarity in the final results after 42 days with the control growing pond of the same nutrient concentration, while the performance of nutrient removal during the experiment period for the growing pond equipped with SFI was better than the control growing pond. However, It has been noticed a formation of a peak of the nitrite in the control growing pond, unlike the one equipped with SFI. Eliminating the nitrite peak could be critical for the life of some aquatic species.

Regarding the ammonium/ammonia, there is a similarity in the final results and the performance of ammonium/ammonia removal from the growing ponds with SFI and low nutrients concentration and the control growing pond of the same low nutrients concentration. For high nutrients concentration, the result of removing ammonium/ammonia from growing ponds with SFI was similar to that of the control growing pond after 42 days. However, the performance of removal of ammonium/ammonia from growing pond with SFI was better because the ammonium/ammonia concentration dropped earlier by about 10 days before the same happened in control growing pond.

In general, the final result and performance of growing ponds for removal of ammonium/ammonia, nitrate, and nitrite from growing ponds with SFI were advantage over the control growing ponds. However, the result of phosphate removal in control growing ponds was better than those were equipped with SFI. The control growing ponds had a significant role in reducing the phosphate in the water and without much apparent effort. Algae might have played the biggest role in this reduction of phosphate. However, algae would die and stay in the water (rather after the algae bloom or in autumn) and due to the decomposition process, most of the nutrients that algae absorbed during the growing season and the organic mass that it gained through the photosynthesis process would be released back to the water when the algae die. Therefore, leaving wetlands to be treated from phosphate with the help of algae is questionable from the perspective of long-term effectiveness.

Moreover, despite the cost of SFIs, one of the most important observations in this study is the ability to harvest those plants and completely remove them from the water, thus preventing the nutrients that were absorbed together with the organic mass that was gained during the growing season from being released back in to the water in the next cycle.

This research is a preliminary study on the concept and performance of SFIs in the Nordic climatic conditions, where the temperature in winter could reach below -30 degrees Celsius in Nastola in Finland, where the study was conducted. Such a study sheds light for future studies that could investigate further aspects of the use of SFIs, such as the effect of the SFI shading on the absorption of nutrients from the water and the performance of various plant species in nutrient removal.

Furthermore, there is importance to study removal of other nutrients and contaminants including, for example, heavy metals like mercury, copper and to investigate further to cover the removal of total nitrogen and total phosphorus.

On the other hand, there are needs to see such application of similar studies on a larger scale in nature such as wetland to examine both positive and negative effects on the surrounding ecosystem.

Moreover, further investigation is required to find out whether the algae, plants, expanded clay balls, or some or all of these, resulted in high nutrient removal, as is the case in growing pond10. It is very important to perform water testing in laboratories with advanced equipment.

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APPENDICES

Appendix 1:

Table 1 presents examples from around the world with their performance in removing nitrogen and phosphorus

Appendix 2:

Päijät-Häme Regional Council supported this research by a total amount of Eur 14,275.00 including VAT under the project title INNOHULE “Innovatiiviset kokeilut hulevesien puhdistuksessa”.

The project execution time: 01.07.2017 to 31.12.2018

Appendix 3:

Screenshot from October 2017 cost analysis covers the “cast on-situ concrete class C” item only (1 figure).

Appendix 4:

The proposed and actual Project Plan (2 figures).

Appendix 5:

Pictures of the remaining native plants used on the stormwater floating islands and the field of observation in Finland. (8 pictures and 8 figures)

Appendix 6:

Pictures of the gardening plants used on the stormwater floating island. (8 pictures)

APPENDIX 1

TABLE 1 TFI examples from around the world with their performance in removing nitrogen and phosphorus

Treatment Targets	Used Plants	Floating Material Structure	Project Location	Total Nitrogen Removal %	Total Phosphorus Removal %	Total Ammonium Removal%	Testing Period	Reference
Domestic wastewater	Typha domingensis	Floating freely supports by plastic pipes	Carrion, Spain	not measured	20	not measured	Nov 2008 - Feb 2009	Ahmad and van Bruggen (2010)
Dairy farm wastewater	Schoenoplectus validus, Phragmites australis, Glyceria maxima, Baumea articulata, Bolboschoenus fluviatilis, Cyperus involucratus, Juncus effusus, Zizania latifolia	Unknown	Ruakura Research Centre HamiltonNew Zealand	65-92	79-93	not measured	4 months (summer - autumn)	Tanner (1996)

Continued-								
Treatment Targets	**Used Plants Name**	**Floating Material Structure**	**Project Location**	**Total Nitrogen Removal %**	**Total Phosphorus Removal %**	**Total Ammonium Removal%**	**Testing Period**	**Reference**
Municipal sewage	caduciflora, Zizania, Canna generalis	nylon nets supported by PVC pipes	parallel oxidation ditches along a lake in Guang-zhou, China	Not measured	72	52	Five months (Autumn-Winter)	Wu et al. (2006)
Polluted lake water	Canna gen-eralis, Zizania caduciflora	nylon nets supported by PVC pipes	parallel oxidation ditches along a lake in Guang-zhou, China	Not measured	65	50	23 weeks (summer-autumn)	Wu et al. (2006)
Wastewater	Phragmites karka, Reed Grass	Unknown	Jiwaji Observato-ry in river Kshipra - India	Not measured	Not measured	53	Five months	Billore, Prashant and Sharma (2008)
Polluted lake water	Canna	Unknown	Pearl River in Guangzhou, Chi-na	50	Not measured	100	Five days	Sun et al. (2009)

Continued-								
Treatment Targets	**Used Plants Name**	**Floating Material Structure**	**Project Location**	**Total Nitrogen Removal %**	**Total Phosphorus Removal %**	**Total Ammonium Removal%**	**Testing Period**	**Reference**
Wastewater	Carex spp., Juncus effusus Lythrum salicaria, Phragmites australis,	Unknown	Drongen, Belgium	42	22	35	Ten months	Van de Moortel et al. (2010)
Aquaculture	Phragmites australis, Carex elata, Juncus effusus, Typha latifolia, Chrysopogon zizanioides, Sparganium erectum, Dactylis glomerata	Unknown	Sile River, Italy	Not measured	65	Not measured	May 2005-Mar-2006	De Stefani, Tocchetto and Salvato (2011)

Continued-

Treatment Targets	Used Plants Name	Floating Material Structure	Project Location	Total Nitrogen Removal %	Total Phosphorus Removal %	Total Ammonium Removal %	Testing Period	Reference
Stormwater	Bolboshoenus, Baumea, Carex, Juncus	Unknown	Stormwater Wetlands, New South Whales, Australia	33-50	30-50	Not measured	Jul 2007-Oct 2008	Duncan (2009)
Wetland	Carex virgate Cyperus ustulatus	polymer fibers	Town of Greymouth, South Island, New Zealand	40	Not measured	Not measured	Nov 2009	Floating Wetlands Research Vol.I
Dry weather inflows	Polygonum pulchrum Vetiveria zizanioides	Unknown	Singapore	84 45 7	35 9 23	Not measured	One year	Chua et al. (2010)

APPENDIX 2

Maakuntahallitus	§ 112	14.08.2017

ALUEELLISET INNOVAATIOT JA KOKEILUT RAHOITUKSEN MYÖNTÄMINEN HANKKEELLE INNOVATIIVISET KOKEILUT HULEVESIEN PUHDISTUKSESSA - INNOHULE

87/00.01.05.05/2017

Maakuntahallitus 14.08.2017 § 112

Lahden ammattikorkeakoulu Oy hakee 3.8.2017 korjatulla (alkuperäinen 9.6.2017) hakemuksella alueelliset innovaatiot ja kokeilut (AIKO) -rahoitusta hankkeelle Innovatiiviset kokeilut hulevesien puhdistuksessa – INNOHULE.

Hanke: Innovatiiviset kokeilut hulevesien puhdistuksessa – INNOHULE

Hakija: Lahden ammattikorkeakoulu Oy

Tavoitteet:
Tavoitteena on kokeilla Lahdessa kelluvien vesikasvillisuuslauttojen toimivuutta Suomen olosuhteissa ja tutkia erityisesti kasvillisuuslautan vaikutusta veden typpi- ja fosforipitoisuuksiin. Tavoitteena on arvioida tämän uuden testatun menetelmän sopivuutta Suomen hulevesien puhdistusmenetelmäksi. Kokeilukohteeksi on alustavasti sovittu Ranta-Kartanon uusi hulevesiallas. Hanke luo/mahdollistaa yritysratkaisumallin palveluiden ja ratkaisujen tuottajaksi.

Toimenpiteet:
Tiedonhankinta ja kansainväliset kokemukset.
Rakenneratkaisut ja kasvillisuuden valinnat (talvisäilyvyys tai säilytys)
Kierrätysmateriaalit ratkaisuissa.
Pilotointi ja yrittäjyystoiminta.

Tulokset ja vaikutukset:
Taajaan asuttujen hulevesien uusi ratkaisumalli, jolla voi syntyä uusia palvelumarkkinoita.
Pitoisuuksien määrää vähenee hulevesissä vesistöihin.
Uudet liiketoimintamallit ja –avaukset ja myötävaikutuksella syntyy mahdollisesti startup –yritys.

Käynnistyvät kehitysprosessit	1
Kansainvälisen tason referenssikohteet	0 (1, mikäli kokeilu toteutuu)
Käynnistyvät kokeilut	1
Myötävaikutuksella syntyvät uudet yritykset	1
Myötävaikutuksella syntyvät uudet työpaikat	1
Hanke edistää resurssitehokkuutta	

Hanke edistää hiilineutraalisuutta ja resurssitehokkuutta.
Hanke edistää maahanmuuttajien työllistymistä ja yrittäjyyttä.

Hankkeelle esitetyt alkamis- ja päättymispäivät: 1.7.2017 - 31.10.2018.

Hankkeen rahoitussuunnitelma

Rahoitus	Hakijan esitys	Valmistelijan esitys
AIKO-rahoitus	25 000	10 000
Kuntarahoitus	-	-
Muu julkinen rahoitus	19 715	4 275
Yksityinen rahoitus	-	-
Tulot	-	-
Rahoitus yhteensä	35 715	14 275

Hakijan omarahoitus on varmistettu. Rahoitus on leikattu hankkeen tutkimuksellisuuden takia painottuen toimiin, jotka edistävät uuden ympäristöalan yritystoiminnan käynnistymistä.

Asian on valmistellut aluekehityspäällikkö Juha Hertsi, puh. 044 3719 442.

Maakuntajohtaja:

Maakuntahallitus päättää myöntää Päijät-Hämeen alueelliset innovaatiot ja kokeilut rahoitusta seuraavasti:

Hanke: Innovatiiviset kokeilut hulevesien puhdistuksessa – INNOHULE

Hakija: Lahden ammattikorkeakoulu Oy

Toteutusaika: 1.7.2017 - 31.12.2018

Tarkoitus ja toimenpiteet:
Hankkeessa kehitetään konkreettinen uudenlainen hulevesien puhdistuksen menetelmä ja kelluntarakenne, jossa hyödynnetään Suomen olosuhteisiin sopivia kelluvia vesikasvillisuuslauttoja.
Altaan materiaali- ja rakenneratkaisuissa huomioidaan kierrätysmateriaalien käyttö. Uutta hulevesien puhdistusmenetelmää testataan Lahden kaupungissa 2018. Kokeilussa huomioidaan Suomen sääolot, ja esimerkiksi selvitetään myös kasvillisuuden talvehtimismahdollisuudet kasvihuoneessa.

Päätöksen perustelut:
Hanke toteuttaa uutta maakuntastrategiaa ja voimassa olevaa maakuntaohjelmaa. Hanke kehittää alueen ympäristöosaamista, kansainvälistä verkostotyötä ja uuden yrittämisen käynnistämistä (ohjelman painopiste).

Myönnetään alueelliset innovaatiot ja kokeilut -rahoitusta 10 000 euroa. Avustusprosentti on enintään 70%.

Hyväksytty kustannusarvio sisältää hakijan omaa rahoitusta vähintään 4 275 euroa.

Avustuksen piiriin hyväksyttävät kustannukset:

	euroa
Henkilöstökustannukset	9 093
Ostopalvelut	-
Matkakustannukset	-
Muut kustannukset	3 000
Flat rate 24%	2 182
Yhteensä	14 275

Ostojen ja palveluiden hyväksymisen edellytyksenä on hankintojen kilpailuttaminen.

Hankkeen toteuttajan on tiedotettava hankkeesta ja käytettävässä viestinnässä Päijät-Hämeen tunnuksia.

Tässä päätöksessä noudatetaan, mitä 20.1.2014 voimaan tulleessa Laki alueiden kehittämisen ja rakennerahastohankkeiden rahoittamisesta (8/2014) esitetään Tuen käyttöä koskevista ehdoista (18 §) sekä Tuen maksamisen edellytyksistä (19-20 §) ja Takaisinperinnän edellytyksistä (37 §).

Valtionavustuslain 14 §:n mukaan valtionavustuksen saajan tulee antaa valtionapuviranomaiselle valtionavustuspäätöksen ehtojen noudattamisen valvomiseksi oikeat ja riittävät tiedot.

Valtionavustuksen saajan tulee ilmoittaa viipymättä valtionapuviranomaiselle valtionavustuksen käyttötarkoituksen toteutumiseen vaikuttavasta muutoksesta tai muusta valtionavustuksen käyttöön vaikuttavasta muutoksesta.

Avustuksen saajan on toimitettava hanketta koskeva maksatushakemus 4 kk:n kuluessa hankkeen päättymisestä.

Päijät-Hämeen liitolle on varattava mahdollisuus olla mukana seuraamassa hankkeen etenemistä. Hankkeelle on asetettava ohjausryhmä.

Päijät-Hämeen liiton yhteyshenkilö on erityisasiantuntija Petri Veijalainen.

Päätös:

Ehdotus hyväksyttiin.

APPENDIX 3

Cast on-situ concrete class C (bricks filling)	1.5.1	25 kg cement pack 42.5 N	No.	10	6.5	65				Kodinterra-Lahti	Bill No. 005-10-2017	25kg plussementti per pack	Paid
	1.5.2	Gravel and sand	Sum			No fees			Waseem	Owned			
	1.5.3	Water	M3			No fees			Waseem	Owned			
	1.5.4	Car	K.M	64	0.09		5.76						
	1.5.5	Trailer	Day			No fees			Waseem	Owned			
	1.5.6	Man power	Hour	10	12			120					
	1.5.7	Concrete mixer	Day			No fees			Waseem	Owned			
	1.5.8	Hand shavel	Day			No fees			Waseem	Owned			
	1.5.9	Four wheel tractor with bucket	Hour			No fees			Waseem	Owned			
	1.5.10	Electricity uses	Sum			No fees			Waseem	Owned			

FIGURE 1. Screenshot from October 2017 Cost analysis (cover the “cast on-situ concrete class C” item only)

APPENDIX 4

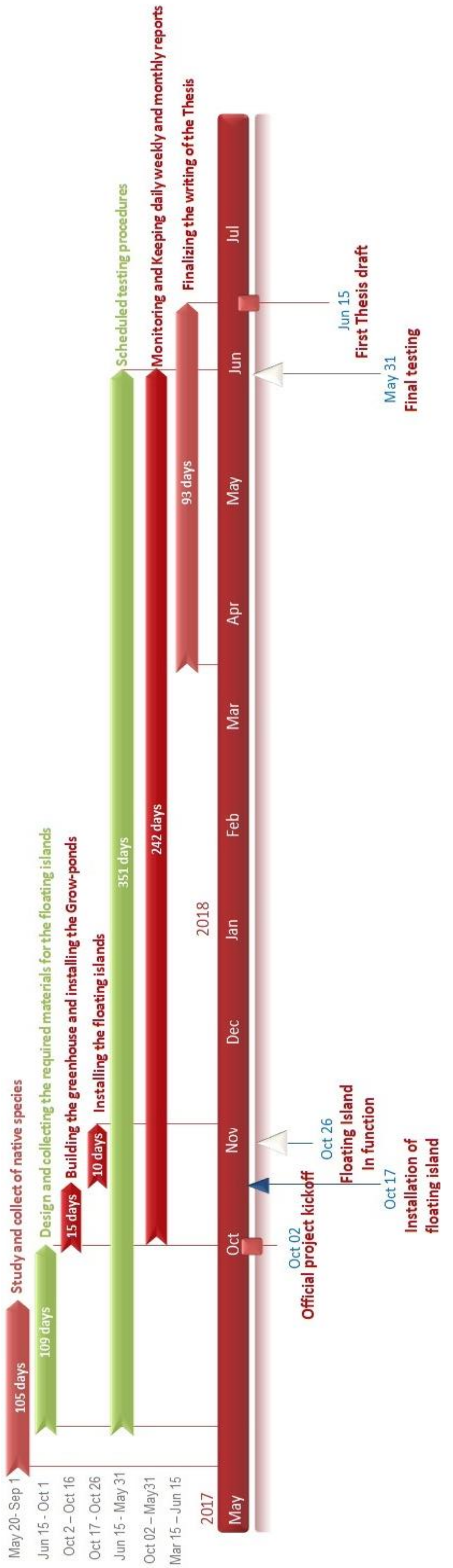

FIGURE 1. Proposed Project Plan

FIGURE 2. Actual Project Plan

APPENDIX 5

The pictures in this appendix are from Suomen Lajitietokeskus**.**

FIGURE 1. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 1. *Phragmites australis* in nature

FIGURE 2. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 2. *Carex acuta* in nature

FIGURE 3. Areas within the green rectangles shows Field observations of the species in Finland
© Maanmittauslaitos

PICTURE 3. *Caltha palustris in* nature

FIGURE 4. Areas within the green rectangles shows Field observa-tions of the species in Finland
© Maanmittauslaitos

PICTURE 4. *Ranunculus repens* in nature

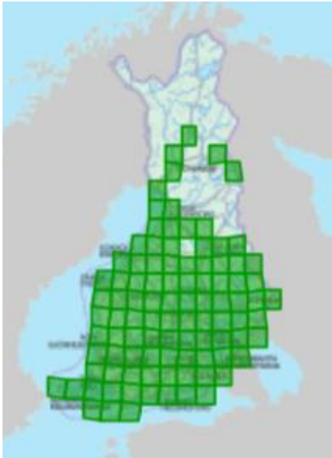

FIGURE 5. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 5. *Saponaria officinalis* in nature

FIGURE 6. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 6. *Rumex crispus* in nature

FIGURE 7. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 7. *Avena sativa* in nature

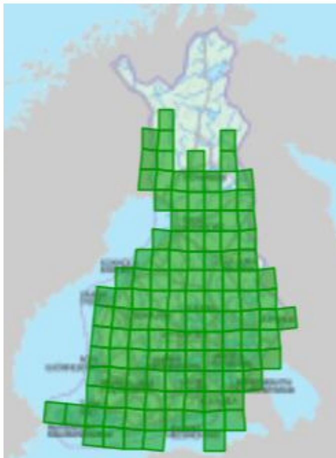

FIGURE 8. Areas within the green rectangles shows Field observations of the species in Finland © Maanmittauslaitos

PICTURE 8. *Scirpus sylvaticus in nature*

APPENDIX 6

Gardening plants used on SFIs include;

PICTURE 1. *Primula Vialii*

(Jparkers 2018)

PICTURE 2. *Hemerocallis*

(Ballyrobertgardens 2018)

PICTURE 2. *Iris Pumila*

(Theamericanirissociety 2018)

PICTURE *3. Hemerocallis 'Lacy Doily'*

(Hankkija 2018)

PICTURE 4. *Phalaris arundinacea 'pict*

(Azgardens 2018)

PICTURE 5. *Hosta Sieb Blue Angel*

(Baumschule-horstmann 2018)

PICTURE 6. *Hosta Wide Brim*
(Jparkers 2018)

PICTURE 7. *Sedum*
(Almanac 2018)

PICTURE 8. *Jacobaea Maritima*
(Armaghangiah 2018)

References of appendix 6

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