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Phosphorus retention in phosphorus ponds and internal eutrophication

A case study of Lake Vombsjön and its catchment area

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List of abbreviations

ATP : Adenosine Triphosphate

DO : Dissolved Oxygen

DP : Dissolved Phosphorus

ORP : Oxidation-Reduction Potential

Ortho: Orthophosphate

PP : Particulate Phosphorus

P-ponds : Phosphorus ponds

T : Temperature

[ ] : References

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Introduction

Sweden is a country with a large proportion of lakes (more than 95 000) which constitute fresh water reservoirs for the production of drinking water. In Scania (South of Sweden), water production is mainly managed by Sydvatten which distributes drinking water to more than 900 000 inhabitants. The company takes this water from three lakes : Vombsjön and Ringsjön in Scania and Bolmen in Småland. This report focuses on Vombsjön.

The main feature of this lake is its huge catchment area mainly dominated by agricultural lands where animals are living and farmers are using fertilizers rich in phosphorus. By runoffs, this phosphorus reaches rivers and then the lake. This additional amount of phosphorus feeds algae and, with warmer temperatures, stimulates its development. Its abundance leads to substantial algal blooms each year. Algal blooms increase the risk of cyanobacteria toxin production that is harmful for humans and animals. However, the water treatment plants of today are not fully capable of extracting harmful cyanobacteria toxins from the lake water. That is why the toxins pose a risk for the drinking water quality. Also, due to the on-going climate change, the presence of cyanobacteria toxins is expected to increase in the future.
In order to decrease the occurrence of algal blooms, phosphorus ponds were constructed in the catchment area of Vombsjön to trap phosphorus coming from runoffs. However, their retention efficiency is today unknown because of many influencing factors. The first aim of this study is to investigate, during one summer, their retention efficiency in measuring at each inlet and outlet of the phosphorus ponds, phosphorus concentrations, flows, turbidity and physical parameters of water, such as temperature, dissolved oxygen, pH, conductivity and redox potential. Then, for each phosphorus pond, a comparison of the results between inlet and outlet will allow to determine if it is efficient in catching phosphorus or if it releases to more phosphorus. An estimation of the load of phosphorus entering and leaving each pond will also be done in considering the additional animal contribution in phosphorus runoffs.

However, it is not only phosphorus rich runoffs from the surrounding lands that lead to eutrophication of a lake. In a lake, when algae and organisms die, they sink to the bottom and are mineralized. Thus, the bottom of the lake contains phosphorus bound to sediments. Summer water stratification, due to warmer air temperatures, changes water conditions and may lead to a phosphorus release by sediments. When released, it is also available for algae, increasing the already on-going eutrophication. This phenomenon is called “internal eutrophication”. The second aim of the study is to do the profile of the water column of Vombsjön in regard to physical parameters (temperature, dissolved oxygen, pH, conductivity and redox potential) and meteorological conditions for a period of nine weeks, to gain knowledge and prevent the risk of internal eutrophication.

I. Literature Review

I.1. General presentation of Sydvatten

I.1.1. Sydvatten Company

Sydvatten AB is a municipally owned company, founded in 1966, producing drinking water for 900000 inhabitants in the region of Skåne (South West of Sweden). The Company is today one of Sweden's largest producers of drinking water.

Every year, Sydvatten produces more than 75 million cubic meters, corresponding approximately to 2400 liters per second.

The firm draws off water from different lakes : Vombsjön (treated at Vombverket), Ringsjön and Bolmen (by Bolmen tunnel and both treated at Ringsjöverket) and distributes drinking water in several cities in Skåne such as Burlöv, Lund, Eslöv, Malmö, Staffanstorp, Svedala and Vellinge, as shown in ***Figure1***.

Figure 1 : Sydvatten drinking water distribution, [Sydvatten]

I.1.2. Lake Vombsjön

Figure 2 : Vombsjön and Vombverket, [Sydvatten]

Vombsjön Lake is a fresh water reservoir of Sydvatten allowing producing 1200 L/s of drinking water at Vombverket. It appears in ***Figure 2***.

The surface of the lake is approximately 12 km². It is relatively round and deep with a maximum depth of 15 meters (average depth of 6,6m).The lake has three inlets (Björkaån, Borstbäcken, Torpsbäcken) and one outlet (Kävlingeån river), and the lake's catchment area is about 435 km² (in light blue in ***Figure 3*** : *Localisation of Vombsjön*). Vombsjön bottom topography with inflows and outflow is given in ***Appendix1***.

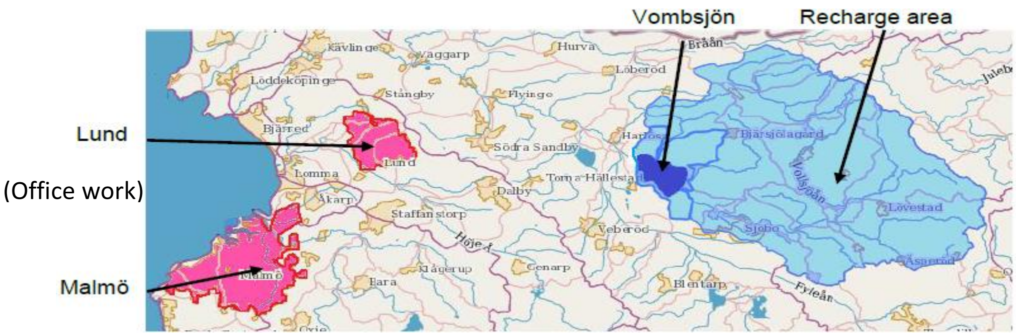


Figure 3 : Localisation of Vombsjön

Vombsjön Lake is surrounded by fields and is far from big towns.

It has four sub-catchment areas (given in ***Appendix 1***) which are composed of 72% agricultural land (in yellow), 13% forest (in dark green), 10% open grounds (in light green), 3% water surface (in blue), and 2% village (in red), as it is shown in ***Figure 4*** : *Land use in the catchment area of lake Vombsjön.*

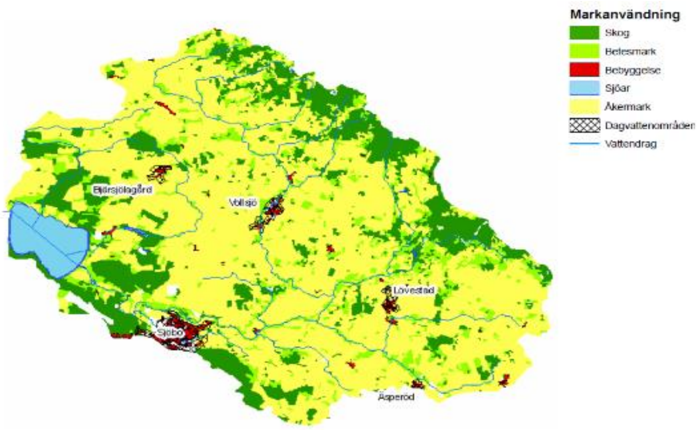


Figure 4 : Land use in the catchment area of lake Vombsjön, [Sydvatten]

Agricultural areas, because of fertilizers added on the fields, are big sources of phosphorus. Indeed, phosphorus reaches the lake by runoffs. That can lead to an eutrophication phenomenon which is not wished for a lake providing drinking water because of the increase of algal growth and the reduction of the water quality.

In its catchment area, it is estimated that the amount of phosphorus which is released is mainly due to : [vattenwebb]

- Waste water plant : 0 kg/year
- Industries : 0 kg/year
- Individual septic installations : 117 kg/year

Obviously, animals and fertilizers also contribute to phosphorus release but the amount concerning this catchment area is not referred.

However, the amount of the release by animal faeces is presented in the following ***Table 1***. Only cows, sheeps and horses are taken into account since they are the main animals present in these farmlands. [Rôle de l'azote et du phosphore dans la pollution animale]

	Release of P by animal faeces	
	g/day	kg/year
1 cow	55	20,1
1 sheep	15	5,5
1 horse	60	21,9

Table 1: Phosphorus release by animal faeces

It is estimated that between 0,5 and 2,5 % of this load of phosphorus, contained in animal faeces or fertilizers, is brought by runoffs. [cnrs.fr]

I.1.3. Water production

Vombverket, the water plant of Vombsjön, started to produce drinking water in 1948. Today, it produces 1200 L/s of drinking water which is distributed to several cities in Skåne.
The different steps of the drinking water production process are shown in ***Figure 5***. It is based on a replication of the natural infiltration process. [Sydvatten]

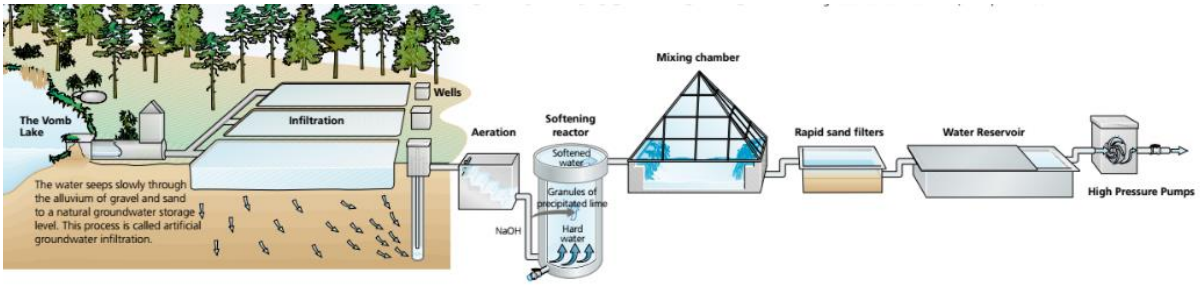


Figure 5 : Drinking water production process at Vombverket, [Sydvatten]

First, raw water is pumped from Vombsjön Lake to micro-strainers where particles, mud and reeds are removed. The water is then channeled into 58 constructed infiltration basins covering a total surface area of 400 000 square meters for the artificial groundwater infiltration process.

<u>Infiltration</u> : The water seeps slowly through the alluvium of gravel and sand to a natural groundwater storage level. After two to three months, the water is pumped up from one of the wells and goes into the Vomb Water Works for final processing.

<u>Aeration and softening process</u> : The water is aerated to remove iron and manganese and then treated in the softening reactors to remove calcium ions, by adding sodium hydroxide. The calcium ions in the hard water are precipitated as lime on grains of sand and soft water is released at the top of the reactor. The grains of sand containing precipitated lime, sink to the bottom of the reactor, and are then removed.

<u>Coagulation – Flocculation and sand filtration</u> : After the softening reactors, the water is combined in the mixing chamber with a minor dosage of ferrous chloride, to bind the remaining lime crystals together in flocks. These are then removed in the next stage using rapid sand filters.
Before the drinking water is pumped out to the pipe network, a secondary disinfectant is added to the water to prevent micro bacterial activities in the pipe network.

I.2. Eutrophication problem

Eutrophication is one of the most widespread environmental problems. It affects as lakes as rivers as seas and because of climate change is concerning more and more countries.

I.2.1. Definition

Eutrophication is a natural form of pollution of some aquatic ecosystems that occurs when the environment receives too many nutrients that algae assimilate and then proliferate.
Eutrophication phenomenon consists in proliferation of algae and cyanobacteria. Algae are stimulated by this amount of nutrients, so they grow and multiply excessively. The growth takes place in the surface water layers because plants need light to grow. When there is a big explosion of the number of cells by milliliter, this phenomenon is called “a bloom”. In this case, the lake water is covered by green algae, as the following ***Figure 6*** illustrates with a photo of Vombsjön harbor.

Figure 6 : Algal bloom in Vombsjön harbor (26/07/2016)

Eutrophication especially takes place in ecosystems whose waters renew slowly and in deep lakes. Indeed, a lake naturally and continually receives amounts of nutrients provided by steams and runoffs.
Major nutrients causing eutrophication phenomenon are phosphorus (included in phosphate) and nitrogen (included in ammonium, nitrate and nitrite). But this report will only focus on phosphorus.
Eutrophication can be significantly accelerated by human activity and lead the aquatic ecosystem to death in a few decades or even a few years.
Eutrophication can be classified as "External eutrophication" due to phosphorus runoffs and "Internal eutrophication" due to phosphorus release directly by sediments of the bottom of a lake.

I.2.2. Causes

The major part of nutrients responsible for eutrophication comes from domestic, industrial or agricultural effluents. Phosphates, which are rejected in the environment, result from runoff of fertilizers, detergents (phosphates are added to detergents to soften water), and human and animal wastes.
An algal bloom requires a hyper fertilization of the environment and a pre-existent population. A high production of organisms results in an increase of dead organisms which are accumulated as sediments in the bottom of the lake. Then, aerobic bacteria of the bottom multiply, mineralize this organic material, consume a lot of oxygen and change the conditions of the natural environment. These modifications lead to the death of many different species of animals and plants. The algal growth starts when the lake is in a period of stability with raising water temperatures at the surface because of high sunlight. The anoxia of the environment leads to the liberation of phosphorus from the sediments. The phenomenon accelerates when temperatures increase because oxygen solubility in water decreases. So, the lake receives an additional contribution of dissolved phosphorus from sediments which only feeds the phenomenon of eutrophication. Finally, a bloom occurs when there is a mixture of the water column due to precipitations, storms or winds.

I.2.3. Consequences

First, eutrophication leads to a reduction of the water transparency. The bloom of algae may also block sunlight from photosynthetic aquatic plants under the water surface and cause a decrease of the production of oxygen.
Eutrophication disrupts normal ecosystem and changes the water parameters (decrease of O_2, increase of pH). Indeed, algae and cyanobacteria consume all the oxygen present in the water, leaving none for other aquatic life. The environment becomes anoxic. This results in the death of many aquatic organisms such as animals or plants, which need the oxygen in the water to live and so the exhaustion of the local biodiversity.
Furthermore, eutrophication can generate "the death" of the lake. Indeed, the proportion of sediments increases, due to the accumulation of organic matter not degraded at the bottom.

Moreover, some kinds of cyanobacteria (as shown in ***Figure 7***) even produce toxins that are harmful to higher forms of life. This can cause problems along the food chain and affect any animal that feeds on them and can even have negative impacts on the human health and on water quality. These toxins are very difficult to remove during the water treatment at water treatment plants. So, filters can be used to catch algae but, due to a high amount of cells in the water, they can be clogged up faster.

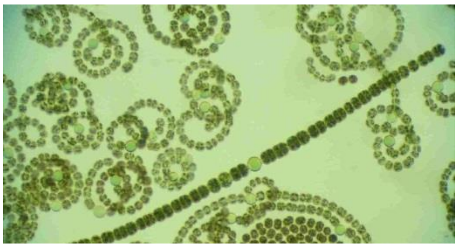


Figure 7 : Cyanobacteria observed by microscope

I.3. Phosphorus, the main nutrient

I.3.1. General description

Phosphorus is a chemical element essential for life which is non-existent in the gas state. Grounds contain only approximately 0,1% of phosphorous. Phosphorus tends to be adsorbed by the major constituents of grounds (iron, calcium, aluminium…). It is not much bioavailable.
Phosphorus is important for all organism since it is used in fundamental processes such as storage and transfer of genetic information (DNA and RNA), cell metabolism (various enzymes), and in the energy system of the cells (ATP).
In water, phosphorus is an essential nutrient for all aquatic plants and algae. Only a very small amount is needed, however, an excess of phosphorus can easily occur. Excess phosphorus is usually considered to be a pollutant because it can lead to eutrophication. Phosphorus is often the limiting factor that determines the level of eutrophication that occurs.

I.3.2. Different forms of Phosphorus

Most phosphorus in surface water is present in the form of phosphates (PO_4^{3-}) which is the inorganic form of importance for organisms.
Phosphorus can be in dissolved or particulate forms and in organic or inorganic forms, as describes the ***Figure 8*** : *Classification of Phosphorus forms*. The sum of these forms is called Total phosphorus. It is the most commonly reported form of phosphate concentration. In water, above 80% of the phosphorus is organic form (incorporated in organisms). [Phosphorus retention variations…,2011]

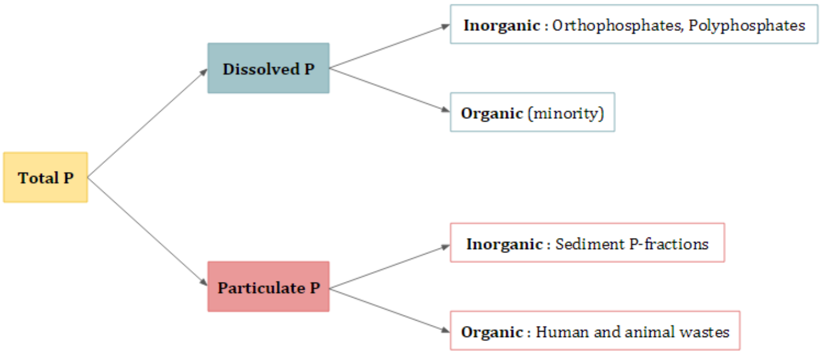


Figure 8 : Classification of Phosphorus forms

Orthophosphates, which are the inorganic forms of phosphate, such as PO_4^{3-}, HPO_4^{2-} and $H_2PO_4^{-}$ are used heavily in fertilizers and are often introduced to surface waters through runoff. The presence of these forms depends on pH.
Polyphosphates (or condensed phosphates), such as $P_3O_{10}^{5-}$, are sometimes added to water supplies and industrial processes to prevent the formation of scaling and to inhibit corrosion. This is the form of phosphate that was commonly found in detergents in the past.
Dissolved inorganic phosphorus is considered bioavailable, whereas organic and particulate P-forms generally must undergo transformations to inorganic forms to be considered bioavailable.
Furthermore, sediments are generally richer in phosphorus than lake water. Phosphorus binds to other elements to form fractions of sediments. Some of these fractions are described above. [Phosphorus fractions…,2012]

Fe-bound : Fe-P
This fraction represents the amount of phosphorus which is fixed to iron. The Fe-bound is one of the biggest reserves of available phosphorus in sediments. This fraction is characterized by seasonal fluctuations and plays an important role in the exchanges of phosphorus from sediments to water. This retention is partially controlled by the redox potential. The phosphorus seems to be essentially adsorbed in aerobic conditions and for high values of redox. However in summer, the increase of the temperature leads to the degradation of the organic matter by bacteria which engenders a reduction of the dissolved oxygen content and so of the redox potential. Consequently, there is a reduction of the Fe-P complex and so a release of phosphorus. Last, it is important to know that the Fe-bound is the fraction which is most influenced by the oxygen content in the water.

Ca-bound : Ca-P
This fraction represents the amount of phosphorus which is fixed to the calcium. It is an important way of storage of phosphorus in sediments. This fraction was considered for a long time as a relatively stable fraction of Phosphorus in the sediments, but it can lead to a release of phosphorus if there is a pH decrease. During spring and summer, the strong photosynthetic activity increases the values of the pH in the water column, which promotes the calcite and phosphorus precipitation. But in autumn, the decrease of the pH releases the phosphorus from the sediments. The high Ca-P content is attributed to the calcareous soil of the recharge area and to the lakes characterized by hard waters, as Vombsjön. However, the mobility of this fraction remains weak compared to Fe-P.

Al-bound : Al-P
This fraction represents the amount of phosphorus which is fixed to aluminium. Phosphorus makes some complexes with the aluminium ions in the water. However this fraction is not the most represented. Moreover, it is like a permanent fraction and can't be the origin of an important release of phosphorus from sediments to water.

I.3.3. Phosphorus cycle and influence of agricultural activity

Phosphates reach surface waters by a variety of means : from the catchment area, via sediment release and atmospheric deposition. Humans add phosphates to water through industrial and agricultural wastes. Fertilizers contain high levels of phosphates and will enter the water by runoffs and soil erosion. Phosphates can also come from the excrement of animals living in or near the water.
The phosphorus cycle is defined as the biogeochemical cycle which describes the movement of phosphorus through the spheres of the ecosystem. It is represented in ***Figure 9*** : *Phosphorus cycle.*

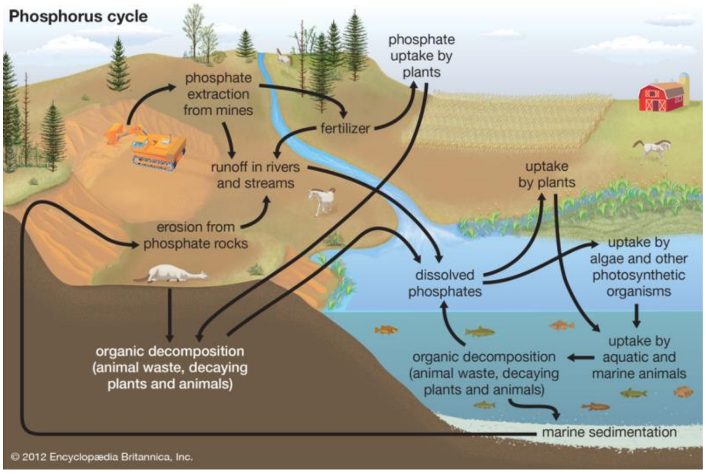


Figure 9 : Phosphorus cycle, [Britannica]

Phosphorus enters the soil and water through the erosion of rocks or may come from fertilizers runoffs. Plants get these phosphorus ions from the soil. Then, phosphates are transferred from plants to animals. Because of excretion and decomposition of dead animals and plants by bacteria, phosphates returned to the soil and into water. In water, organic matter is mineralized by bacteria at the bottom.
Excessive input of phosphorus in lakes leads to eutrophication.

I.3.4. Trophic levels of lakes

Most natural lakes (not affected by man) have phosphorus concentrations between 1 and 100 µg/L. Due to human impact, a major proportion of lakes close to urban or agricultural regions, have considerably higher concentration of phosphorus than undisturbed lakes.

Ponds and lakes are categorized by their total phosphorus level or trophic level, as the ***Figure 10*** : *Lake trophic classification diagram* illustrates, and high phosphorus waters are considered polluted. "Trophic" means nutrition or growth. An oligotrophic lake has quite low nutrient concentrations and low plant growth. On the contrary, a eutrophic ("well-nourished") lake has high nutrients and high plant growth. Eutrophication may occur at a concentration starting from only 20 µg/L of total phosphorus.

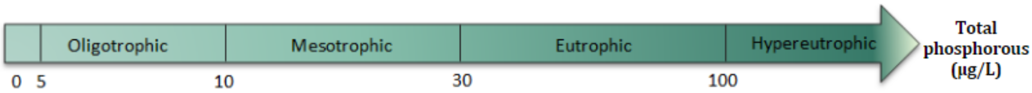


Figure 10 : Lake trophic classification diagram

I.3.5. Regulations

There is no European norm about the phosphorus concentration in drinking water and raw water. However, it is favored to use a resource which is not eutrophic to avoid consequences of eutrophication with algal growth, and production of toxins by cyanobacteria.
Moreover, the eutrophication phenomenon is on the increase because of climate change and is going to affect more countries. That is why it is important to find solutions to limit phosphorus concentrations in water resources. One method used in Sweden is the phosphorus pond which is constructed upstream a lake, for example, in order to catch phosphorus and so to decrease the concentration reaching the lake.

I.4. Phosphorus ponds

I.4.1. Description and utility

Constructed P-ponds can capture some of the phosphorus that is lost from the fields. The ***Figure 11*** represents one of the P-ponds of Vombsjön Lake. P-ponds have an inlet and an outlet which goes to another P-pond, a river or a lake. In Sweden, their construction has been advocated as one of several measures to reduce the transport of phosphorus from agricultural land, which is part of the Swedish Environmental Objective "No eutrophication" and of the Baltic Sea Action Plan [HELCOM 2009].

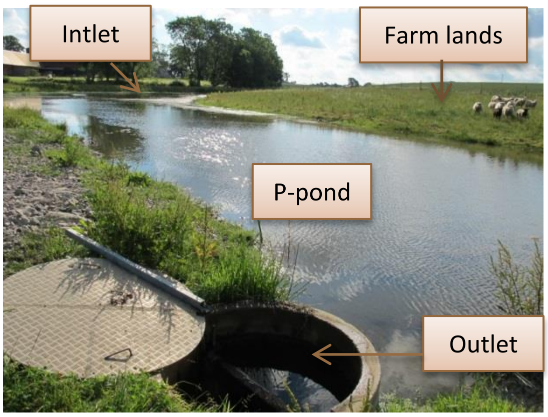


Figure 11 : a P-pond of Vombsjön (27/06/2016)

Many studies have shown that constructed wetlands can function as sinks for phosphorus, but the retention efficiency is highly variable, and occasional releases of phosphorus have been observed. A challenge when constructing ponds for P-retention is that the understanding of how factors such as variable water flows, wetland design and location in the landscape affect phosphorus retention is still incomplete. [Phosphorus retention variations…,2011]

I.4.2. Phosphorus retention process

Phosphorus enters a wetland in inorganic and organic form, and in particulate (PP) and dissolved form (DP). Dissolved inorganic Phosphorus is considered bioavailable, whereas organic and particulate P-forms generally must undergo transformations to inorganic forms to be considered bioavailable. P-retention can be defined as the result of a number of physical and biogeochemical processes leading to removal of Phosphorus from the water column, and storage in a non-bioavailable form in the sediments. The following ***Figure 12*** describes the retention (a) or the release (b) of the DP and the PP.

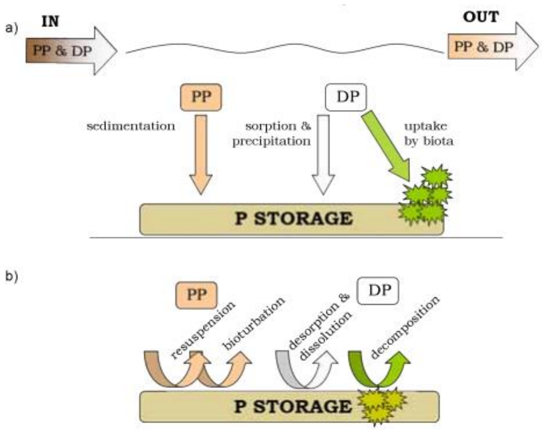


Figure 12 : Different mechanisms for a) retention and b) release of particulate phosphorus (PP) and dissolved phosphorus (DP) in P-ponds, [Phosphorus retention variations…,2011]

As it is shown in ***Figure 12 (a)***, Particulate Phosphorus is retained by sedimentation as the water velocity drops when running water enters a wetland and particles can settle on the bottom. Dissolved Phosphorus is retained by both chemical and biological processes. It can be absorbed by particles or can form chemical precipitates with metal cations. The uptake of Dissolved Phosphorus by biota is also an important retention process.

However, all these processes are reversible. Indeed, particles that have settled on the bottom could be re-suspended, due to high flows or bioturbation by fish, birds and invertebrates. As it is shown in ***Figure 12 (b)***, Dissolved Phosphorus can be released from the chemical bonds depending on a change of the chemical status of the wetland, as pH or redox potential. Furthermore, even if the biological uptake can be fast and effective, there is a temporal heterogeneity because of the different life cycles of the organisms. Most of the assimilated phosphorus is released back into the water column after the death of the organisms.

The balance between the internal processes sedimentation and re-suspension, adsorption, desorption, biological uptake and decomposition will determine if the pond is a trap or a source of phosphorus.

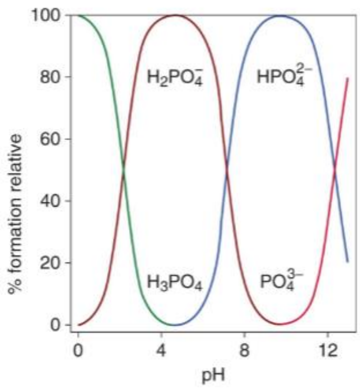
I.4.3. Influences of parameters on the Phosphorus catchment and release

Many factors can affect the transport of phosphorus between water and sediment. Main factors are presented below.

pH

pH really affects the exchange of phosphorus between sediment and water. At pH values below 8, phosphate bindings to metals are strong, whereas at higher pH values, hydroxide ions are exchanged with the phosphate, which then becomes soluble in the water. This may be an important part of the input of phosphorus to the water of eutrophic lakes.

Depending on pH, with the distribution diagram, represented in ***Figure 13*** : *Phosphate forms distribution diagram,* and the predominant form H_3PO_4, $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}, there is a change of the phosphate adsorption/desorption balance. Phosphate adsorption tends to decrease with increasing pH.



$PO_4^{3-} + H^+ \leftrightarrows HPO_4^{2-}$

$HPO_4^{2-} + H^+ \leftrightarrows H_2PO_4^-$

$H_2PO_4^- + H^+ \leftrightarrows H_3PO_4$

Figure 13 : Phosphate forms distribution diagram

Temperature

Usually, phosphate adsorption's speed increases with temperature. Moreover, temperature has an indirect impact on phosphorus exchanges at the interface water-sediment in increasing biological activity and so the mineralization of the organic matter. It leads to liberation of phosphate in interstice water of sediments.

Redox potential

In oxidation conditions, when ORP is high, the part of Fe^{3+}/Fe^{2+} increases, dissolved phosphates combine to Fe^{3+} and become adsorbed or precipitated forms. In conditions of low ORP, when Fe^{3+} can be reduced in Fe^{2+}, phosphates are released in interstice water of sediments. Then, dissolved phosphorus can migrate to the water column.

The increase of microbial activity generates a decrease of ORP at the sediment surface. This can reduce Fe(III) in Fe(II) and generate liberation of phosphates in interstice water.

Oxygen

In a phosphorus pond, it is better that water contains high value of dissolved oxygen. Generally, at the bottom bacteria consume oxygen to decompose organic matter and oxygen level is considerably reduced. More details are given in paragraph ***I.5.2*** when a lake is considered. A depletion of oxygen leads to phosphorus release by sediments, which is problematic when the aim of a P-pond is to trap phosphorus.

Turbidity

Turbidity designs the cloudiness of a fluid caused by suspended solids. Concerning the phosphorus, particulate phosphorus mainly contributes to water turbidity. In case of storms, a mix of water and sediments occurs and turbidity increases.

Pond size impact

P-pond size can affect P-retention efficiency. Some studies have shown that smaller P-ponds had higher specific Total Phosphorus retention. However, larger ponds had a higher relative Total Phosphorus retention. Larger ponds should theoretically have a higher Dissolved Phosphorus retention efficiency, due to the higher residence time, which gives more time for the biogeochemical processes involved in removing DP.

Weather impact

P-ponds are exposed to varying weather events which result in highly variable water flow and nutrient concentrations. In Sweden, the effect of different seasons probably influences P-retention. The highest runoff takes place during snow melt in spring and during heavy rainfall periods in the autumn. In contrast, summer runoff is usually very low and sometimes drops to zero, which can also occur during the winter period if temperatures are below 0°C during a prolonged period. During low-flow periods, the water in the ponds becomes stagnant, which alters the biogeochemical properties of the sediment and can affect P-retention. These seasonal changes in water flow result in very variable inputs of phosphorus.

I.5. Lake stratification and internal eutrophication

I.5.1. Influence of seasons and weather on stratification

Solar radiation is the major source of heat in lakes and consequently, there is variation in water temperatures both on a seasonal and a daily basis. Most of the incoming light energy is converted directly into heat. Most heat is absorbed in the first few meters. Wind-generated currents will distribute heat within the lake but only down to a limited depth. Thus, two layers of water will be formed, a warm less dense layer at the surface and an underlying layer of dense, cool water.
This is called thermal stratification and is crucial for the physical, chemical, and biological processes in lakes. Because of changes in solar radiation and wind turbulence over the year, the stratification is not permanent, but varies between seasons. The ***Figure 14*** : *Stratification of a lake according to seasons* represents this phenomenon. [The Biology of Lakes and Ponds]

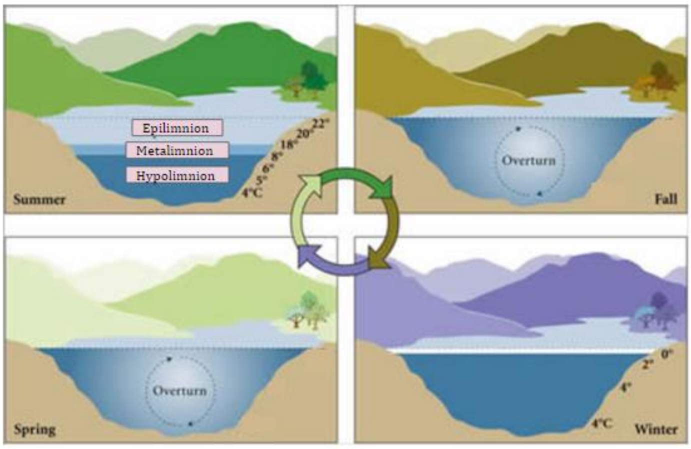


Figure 14 : Stratification of a lake according to seasons, [lakegeorgeassociation]

In spring, the ice cover gradually decreases in thickness and eventually breaks up. The water density is similar throughout the water mass. So, the resistance to mixing is little and only a small amount of wind energy is needed to mix the whole water column. Without the ice cover, the entire water mass circulates.

When summer comes with warm temperatures and calm weather, an upper layer of warmer water develops whereas at the bottom water is still cold. There is a significant difference of density between the two layers and it is sufficient to resist mixing as windier weather. Thus, the lake is stratified into two layers, the upper, warmer is called epilimnion, and the colder at the bottom, dense water, is called the hypolimnion. The stratum between the two layers, characterized by a steep thermal gradient, is called the metalimnion or thermocline, as it is shown on ***Figure 14***.

In autumn, the energy from solar radiation decreases which leads a decreasing temperature and density difference between epilimnion and hypolimnion. Thanks to wind energy, the whole water column recirculates.

In winter, temperature of the lake cools down and water density is at its maximum, an inverse stratification is established where the upper stratum has the lowest temperature and ice may cover the surface.

The formation of the thermocline is the most important physical event for the structure and the function of the lake and dramatically affects the conditions for the lake biota. After stratification, the lake is divided into two separate compartments. In the upper one, where warm water circulates with a high light intensity, the major part of primary production takes place. In the colder one, the decomposition of organisms sedimenting from the epilimnion takes place. Due to the drift of dead organisms into the hypolimnion and the limited exchange between the two layers, nutrient availability becomes a limiting factor for primary production in the epilimnion. [The Biology of Lakes and Ponds]

I.5.2. Lake water quality parameters

Because of this stratification, physical and chemical parameters of lake water are affected and vary depending on the water layer. The following ***Figure 15*** shows their evolutions with the depths.

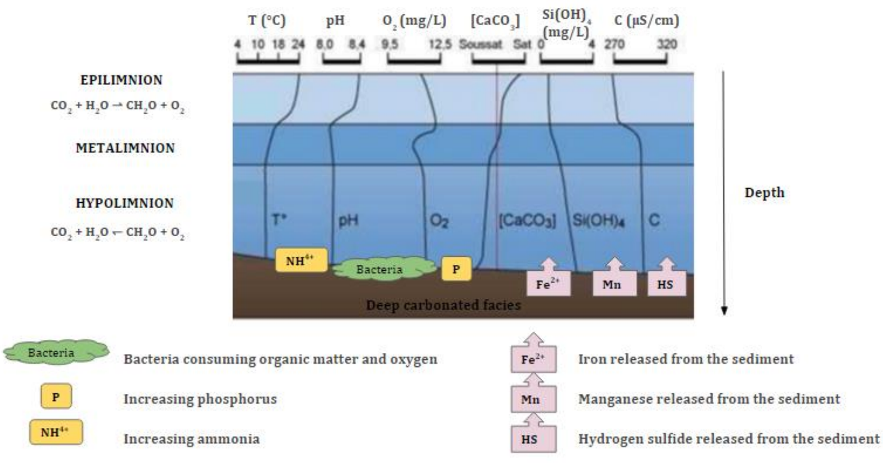


Figure 15 : Parameters according to vertical stratification of a lake

Temperature

Temperature is a key environmental factor in freshwater ecosystems. Warmer temperatures stimulate algal growth and then eutrophication phenomenon.

Water has a high capacity of storing heat, hence the variations of water temperatures on seasonal and daily basis. As described above, stratification can occur. In that case, water is warmer in the epilimnion, a thermocline is formed and below it water temperature decreases.

[The Biology of Lakes and Ponds]

pH

pH, which is a measure of the acidity or alkalinity of a solution, is an important abiotic factor. In the majority of lakes on Earth, pH is between 6 and 9.

pH is strongly related to equilibrium processes of the carbon dioxide bicarbonate system, including free carbon dioxide CO_2, carbonic acid (H_2CO_3), bicarbonate ions (HCO_3^-), and carbonate ions (CO_3^{2-}), as the ***Figure 16*** : *Carbon equilibrium diagram* illustrates.

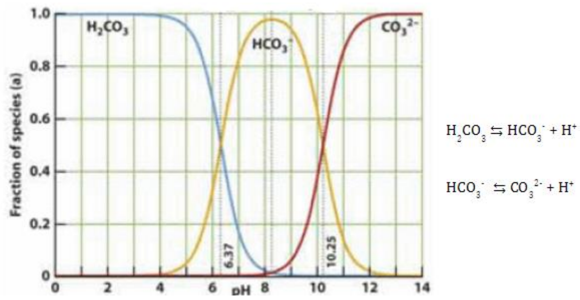


Figure 16 : Carbon equilibrium diagram

CO_2 is very soluble in water. When it is dissolved, it is in equilibrium with H_2CO_3. At an increasing pH, it dissociates into H+ and HCO_3^-, which in turn dissociates into H+ and CO_3^{2-}.

Photosynthesis and respiration are the major biological processes affecting pH by changing the amount of CO_2 in the water. The photosynthesis of green plants uses solar radiation and carbon dioxide to produce sugar and oxygen. The consumption of CO_2 alters the equilibrium, causing an uptake of hydrogen ions and so an increase in pH. As organisms respire, CO_2 is produced, pushing the equilibrium reaction in the opposite direction releasing H+ ions and so reducing gradually the pH. Reduction in pH may negatively affect the reproduction of many organisms.

[The Biology of Lakes and Ponds]

Oxygen

Dissolved oxygen (DO) is the most critical indicator of a lake's health and water quality. Oxygen is necessary required for all organisms with aerobic respiration and for fast oxidation of organic wastes. For a healthy game-fish population, oxygen levels in the 6-10 mg/L range are necessary. Respiration stress in most fish occurs when oxygen levels are reduced to 3-4 mg/L. The major input of oxygen is due to diffusion from the atmosphere and from the release by plants during photosynthesis. In lakes, oxygen is consumed by aerobic organisms during the complex biochemical processes of catabolism where nutrient molecules are broken down, hydrogen is released and then combined with oxygen.

The energy contained in the chemical bonds of the nutrient molecules is transferred to energy-rich adenosine triphosphate (ATP) molecules which are used by the organism for functioning and biosynthesis.

Process of aerobic respiration : $C_6H_{12}O_6 + 6\ O_2 \xrightarrow{\text{enzymes}} 6\ CO_2 + 6\ H_2O$ + energy

The amount of oxygen in water decreases with increasing temperatures. The amount of oxygen varies depending on physical processes, such as mixing and wave action, and on biological processes, such as respiration and photosynthesis. For example, during a period of high photosynthetic activity, water becomes supersaturated with oxygen, whereas when a decomposition process predominates, oxygen level is considerably reduced.

Moreover, oxygen has a low solubility (9,09mg/L in water at 20°C) and a slow diffusion rate in water compared to the thermal diffusion coefficient (Diffusion coefficient of O_2 in water : $D_{O2} = 2{,}60.10^{-9}$ m^2/s ; Thermal diffusion in water : $D_T= 1{,}51.10^{-7}$ m^2/s).

In a lake, dissolved oxygen tends to decrease with the depth because of the decomposition of organic matter by bacteria and is non-existent at the bottom.

[The Biology of Lakes and Ponds], [vertexwaterfeatures]

ORP

Oxidation-reduction potential measures the ability of a lake to cleanse itself or break down waste products, such as contaminants and dead plants and animals. When the ORP value is high, there is a lot of oxygen present in the water. This means that bacteria that decompose dead tissue and contaminants can work more efficiently. In general, the higher the ORP value, the healthier the lake is. As seen above, because of the decomposition of organic matter by bacteria, there is less oxygen closer to the bottom sediments, and therefore lower ORP values. In fact, oxygen disappears very quickly in the bottom mud and ORP falls quickly.

[enr.gov.nt.ca]

Conductivity

The measure of freshwater conductivity estimates the total concentration of the ionized substances dissolved in the water, by the water sample’s ability to carry an electrical current. A significant increase in conductivity may indicate a recent increase in domestic or industrial pollution (as phosphorus release).

In lake water, organisms’ respiration produces CO_2 and H^+ (as seen above). As the same time of a pH decrease, new ions lead to an increase of the conductivity of the hypolimnion. At the bottom, the dissolution of the limestone, a liberation by sediments of ions such as Fe^{2+}, Mn^{2+} and of hydrogen sulfide also contribute to this increase of conductivity in the hypolimnion.

[vertexwaterfeatures]

II. Material and methods

II.1. Work organisation and schedule

The period of internship is divided into three sub-periods, as represented in ***Figure 17***.

- 01/06 to 17/06 : 3 weeks of literature and visits in the different stations (Vombverket and Ringsjöverket), labs, equipment.
- 20/06 to 12/08 : 8 weeks of field work and office (P-ponds sampling and analysis on Mondays and Thursdays, Profile measurements in Vombsjön on Tuesdays, Data analysis and office work on Wednesdays and Fridays).
- 15/08 to 26/08 : 2 weeks of interpretation of data, report writing, and presentation to the company.

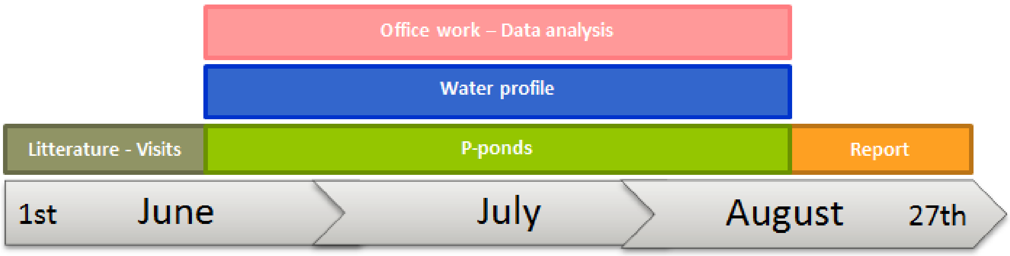


Figure 17 : Schedule

II.2. Water profile of Lake Vombsjön

In order to better understand the conditions of eutrophication and the internal circulations of water in Vombsjön, and to anticipate them, a water profile campaign is done once a week to measure some physical parameters in the water column. It allows highlighting any modifications according to the depth, the weather.

The water profile consists in measures of temperature, pH, dissolved oxygen, conductivity and redox potential of the lake water at six points with different depths, allocated in the entire lake surface. These measured points are represented in ***Figure 18***.

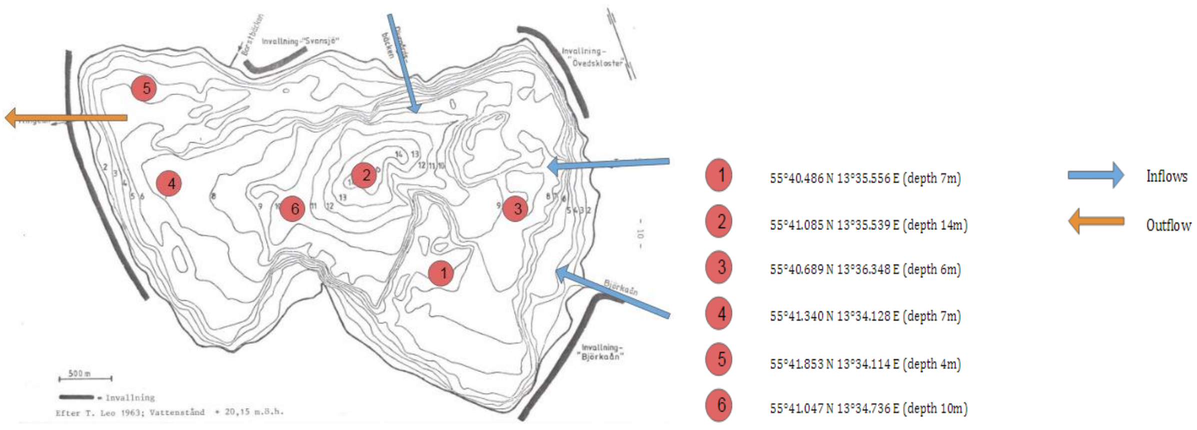


Figure 18 : Location of the measured points

GPS coordinates of pond 3 in ***Figure 18*** were chosen at the beginning of the investigation of the water profile because its previous coordinates (in previous reports) did not match with its wanted location on the map.

The water profile is measured by boat, using a surface water measuring device composed of four probes (T, pH/ORP, Conductivity, Dissolved Oxygen) as shown in ***Figure 19***. Measurements are taken for every one meter, from the surface of the water (1m below the surface) to the bottom (1m above the bottom). Some weights are fixed on the line above the probes so that it is not deviated with the flow.

Figure 19 : Surface water measuring device

II.3. Investigation of the retention of phosphorus in P-ponds

In order to evaluate the efficiency of the P-ponds, and if phosphorus is released or trapped, an investigation is done twice a week to measure some physical parameters at the inlet and the outlet of each pond. It consists in measures of temperature, pH, dissolved oxygen, conductivity and redox potential with the surface water measuring device, in estimations of the flows and in determinations of turbidity, orthophosphates and total phosphorus at the lab. Photos are also taken each time to see the evolution of the water volume, vegetation, water flow.

II.3.1. Description of the different P-ponds

The five studied P-ponds are represented in ***Figure 20*** . They are all located in farm lands but vary in surface and appearance. Ponds 1 to 4 are connected : the first pond is upstream and goes into the second which goes into the third, and then the fourth which reaches the lake. But others agricultural lands and inflows are situated between this four ponds. The pond 5 is isolated by the others and its outlet goes into the lake. They constitute one of the main inflows of Vombsjön.

Figure 20 : Locations of the 5 studied P-ponds in Vombsjön catchment area

The following ***Table 2*** lists the characteristics of each P-pond. Photos and maps of each pond are given in appendix 2. Pond 4 inlet cannot be studied because there is no access to it. However, ponds 3 and 4 are directly connected.

Pond and GPS coordinates	Catchment area	Water surface	Pond volume	Pond depth (average)	Inlet	Outlet	Presence of animals
1 55°41.243'N 13°42.312'E	500 hectares 90 % farm land	0,6 hectare	4500 m3	0,70 m	Drainage pipe from farm land	Well	Sheeps
2 55°41.122'N 13°41.508'E	130 hectares 95% farm land	0,1 hectare	800 m3	0,50 m	Well, 100m east of pond on farm land	1) Well 2) Pipe downstream	Horses
3 "Vassen" 55°41.435'N 13°40.029'E	3200 hectares 70 % farm land	17,5 hectares	No information	No information, *To measure*	Open ditch	Dam	-
4 "Mölledammen" 55°41.409'N 13°38.710'E	No information	1,1 hectares	No information	No information, *To measure*	-	Pipe	Horses
5 "Blommeröd" 55°41.841'N 13°37.974'E	350 hectares 90% farm land	2 hectares	20000 m3	0,90 m	2 open ditches	Well	Cows

Table 2: P-ponds characteristics

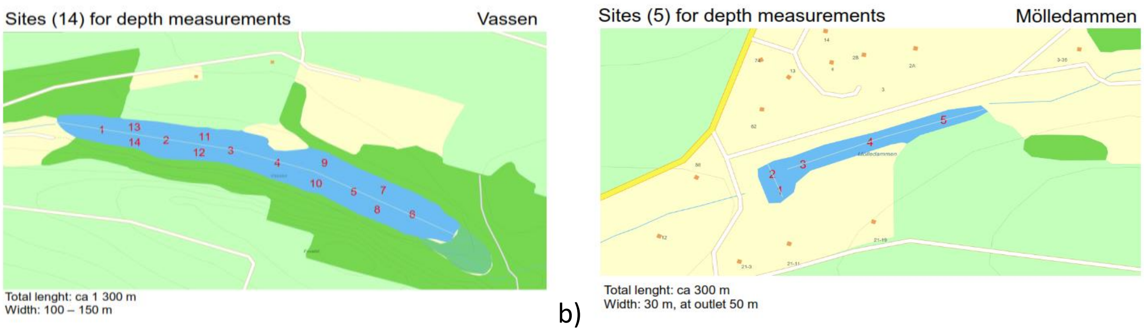
Some information about the depths of ponds 3 and 4 was not available. So, these depths were measured and the ponds volumes calculated.

II.3.2. Depth measurement and turnover time

Depth measurement of ponds 3 and 4

The depths of ponds 3 and 4 are measured in several points in order to cover the entire surface of each pond and determinate the average depth. These points are represented in ***Figure 21***. A canoe was used to access the ponds and a graduated rope to do the measures.
Then, pond volume is calculated as :

$$Pond\ volume\ (m^3) = Average\ depth\ (m) * Water\ surface\ (m^2)$$



a) b)

Figure 21 : Depth measurements locations of a) pond 3 and b) pond 4

Turnover time

The summer (time of investigation) average turnover time of each pond is determined thanks to pond volume and average flow :

$$Average\ turnover\ time\ (s) = \frac{Pond\ volume\ (m3)}{Average\ flow\ (m3/s)}$$

Then, the result is stated in days.
Turnover times allow seeing if water is often renewed or not and comparing the different P-ponds.

II.3.3. Measures of the physical parameters

At inlet and outlet of each P-pond, the following parameters are measured with the surface water measuring device : temperature, pH, dissolved oxygen, conductivity and redox potential.
They allow to control water in each pond and if there is an evolution.

II.3.4. Estimation of the flows

In order to have an idea of the flow, and to compare between each day, flows are estimated at the inlet and the outlet.
According to the design of the inlet/outlet, two different methods are made. Because of an unsuitable design, or an unsafe access, the flows in pond 4 outlet and pond 5 inlet can't be measured.

Method 1 : Measure of the water volume per time unit (ponds 1 inlet/outlet , 2 inlet/outlet and 5 outlet)
The flow can be measured thanks to a 5L bucket and a stopwatch. The time (t) to fill a 5L (volume V) bucket is determined thanks to a stopwatch. Then, the flow (Q) is calculated with this formula :

$$Q(L/s) = \frac{V(L)}{t\ (s)}$$

However, in some ponds only a fraction of the flow is taken because of the bucket size and losses. Therefore, Q is multiplied by a coefficient in order to represent all the water flow.

Method 2 : Estimation of the flow and measure of the section area (pond 3 inlet/outlet)
The flow is estimated downstream the inlet/outlet in the river. A float, a meter and a stopwatch are used. First, a part of the river is selected to do the measure (always at the same place) with a 5m length (L). The width (w) is measured and the average depth (d) is estimated. The time (t) that the float takes to get the 5meters point is measured with a stopwatch.
Then, the flow (Q) is calculated with this formula :

$$Q\ (m^3/s) = \frac{L(m) * w(m) * d(m)}{t(s)}$$

This method is not very precise but it is the only one available.

II.3.5. Water samples

In each pond, water samples are taken at the inlet and the outlet thanks to a bucket or a water sample, depending on the design and the access way. It is important not to take algae or sand in order to analyse the water sample at the lab without big interference. Each water samples is put in a 1L plastic bottle for the turbidity measures and in a 250mL plastic bottle for the phosphorus analyses, as illustrated in ***Figure 22***. Directly after sampling, the samples are put in a cool box and kept cool during transport to lab. Analyses are made on the same day or at the latest on the following day.

a) 
b) 

Figure 22 : a) 250mL and b) 1L water samples

II.3.6. Turbidity measure

The turbidity is measured in each sample with the HACH turbidimeter, as shown in ***Figure 23***, at the lab of Vombverket.

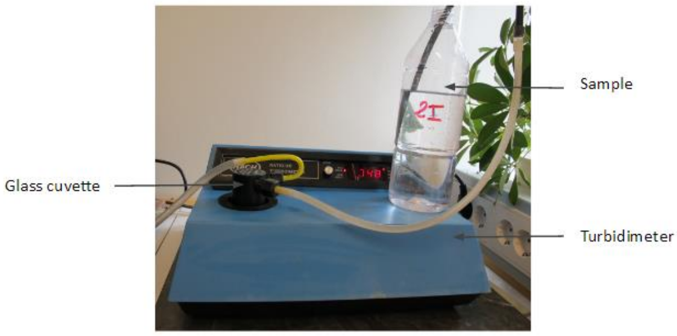


Figure 23 : HACH Turbidimeter of Vombverket

First, a container filled with distilled water is used to do the zero. The inlet tube is put in this container. The tap is turned in order to have a small flow and the distilled water starts to circulate in the system. When the flow is stable, the tap is turned off. The distilled water runs through the glass cuvette. When the digits are stable, the zero is adjusted by turning the screw.

Then, the instrument is ready to measure the samples. As the same, the inlet tube is put in the first sample, and the turbidity value is read when the digits are stable. This is repeated for each sample. If it is necessary, the range can be changed (2, 20, 200, 200 NTU). If the glass cuvette is dirty, it might be cleaned before analysing the next sample. It is cleaned in using a container filled with distilled water. After the last sample, the inlet tube is put in a distilled water container.

II.3.7. Total Phosphorus and Orthophosphate

The Total Phosphorus and the Orthophosphate are measured in each sample thanks to the Test Kit LCK 349 at the lab of Vombverket, shown in ***Figure 24***. The kit protocol is given in ***Appendix3***.

Figure 24 : Phosphorus kit LCK 349

The principle is this : Phosphate ions react with molybdate and antimony ions in an acidic solution to form an antimonylphosphomolybdate complex, which is reduced by ascorbic acid to phosphomolybdenum blue. With hydrolysis (1hour heating 100°C), Total Phosphorus is measured and without it, only Orthophosphates are measured.
The range is: 0,050 - 1,500 mg/L PO_4^{3-} - P. If the results are under the range, it is possible to double the volume of sample and then divide the value per two. Values are read with a spectrophotometric barcode instrument as shown in ***Figure 25*** and expressed in units of mg/L PO_4^{3-} - P, meaning phosphorus in the form of phosphates.

a) b)

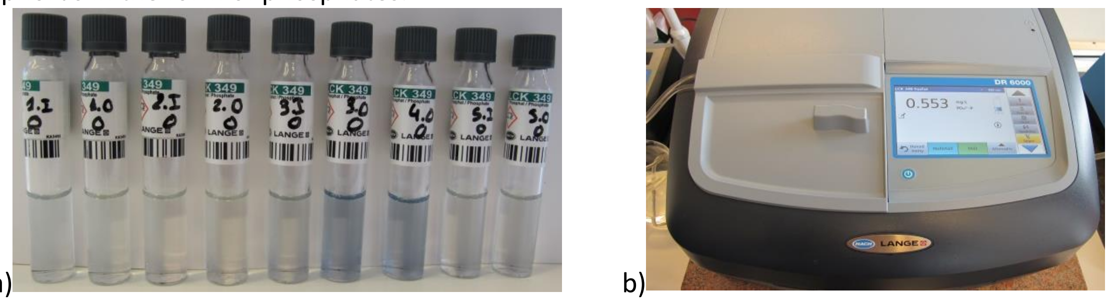


Figure 25 : a) Orthophosphates (blue color = higher concentration) and b) HACH spectrophotometer

It is important to notice that this P-kit is adapted for waste waters and cannot detect very low concentrations of phosphorus, but it was the only one available, and other normed methods couldn't be made because of unsuitable material and missing reagents. Therefore, volumes of samples were doubled (as indicated above) in order to be in the detection range. However, the company asked to keep the values when they were under the range. Even if they are less precise, they allow seeing evolutions of concentrations.
The percentage reduce of phosphorus is calculated between inlet and outlet with the formula :

$$Percentage\ reduce\ (\%) = \frac{C\ inlet\ -\ C\ outlet}{C\ inlet} * 100$$

with :

C inlet : Phosphorus concentration at the inlet

C outlet : Phosphorus concentration at the outlet

The concentration can represent, Total-P, Ortho-P or Particulate-P.

II.3.8. Estimation of the total phosphorus loads

The estimation is done for the time of the investigation : one summer (equal to 60 days).

Total phosphorus loads which enter (inlet) and leave (outlet) a pond

The total phosphorus load which enters and leaves a pond is determined for each pond. All the contributions to phosphorus release taking part in the phosphorus balance are represented in the following ***Figure 26***.

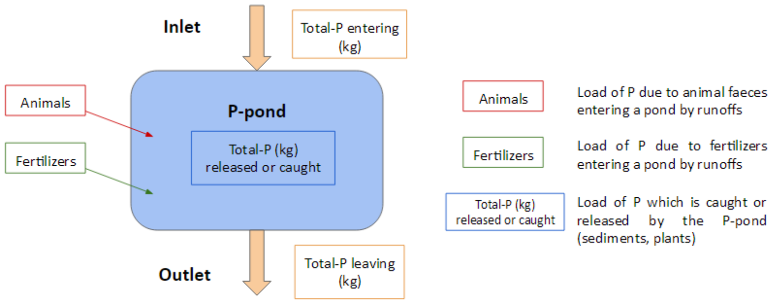


Figure 26 : Phosphorus balance in a pond

<u>If the pond catches Total-P</u> :

Total-P leaving = Total-P entering + Animal + Fertilizers - Total-P caught by pond

<u>If the pond releases Total-P</u> :

Total-P leaving = Total-P entering + Animal + Fertilizers + Total-P released by pond

For each inlet and outlet of a pond, the load of total-P is determined for one summer. First, the average flow (L/s) and the average concentration of total-P (mg/L) is calculated. Then, the load of total-P is calculated in mg/s by the formula :

*Total-P load (mg/s) = Average flow (L/s) * Total-P concentration (mg/L)*

Therefore, in one summer (60 days), the load of total-P (kg) is equal to :

$$\text{Load of total-P (kg/summer)} = \text{Total-P load (mg/s)} * 60 * 24 * 3600 * 10^{-6}$$

To estimate the loads of total phosphorus, some hypothesis need to be made for ponds 4 and 5. Indeed, the inlet of the pond 4 is not studied in the investigation of the P-ponds. But ponds 3 and 4 are directly connected and there is no farmland between them which may contribute to change the water quality. So, it is supposed for this part that water coming at the inlet of pond 4 is exactly the same than water coming from the outlet of pond 3 : same average flow and same average concentration of total phosphorus.

The inlet of pond 5 is unsuitable to measure the flow. During all the summer, it seemed to be lower than at the outlet. It is supposed for this part that the average flow of inlet is equal to the half of the average flow of pond 5 outlet.

Animal contribution

The animal contribution to phosphorus release in one summer is determined for each pond, depending on number of animal species, thanks to values given in the Literature review, paragraph ***I.1.2***. Then, to calculate the load which reaches the pond, the percentage 1% is used, since the load brought by runoffs is between 0,5 and 2,5 % (as said in Literature review, paragraph ***I.1.2***.).

II.3.9. Weather

The daily weather of Vomb [accuweather] is written in order to interpret the results and see some correlations between raises of Phosphorus amount and precipitations which generate runoffs from farmlands to P-ponds.

III. Results and discussion

III.1. Weather in Vomb

Air temperatures and precipitations in Vomb between 10/06/2016 and 11/08/2016 (weeks of sampling and analyzing) are represented in the following graph, ***Figure 27***.

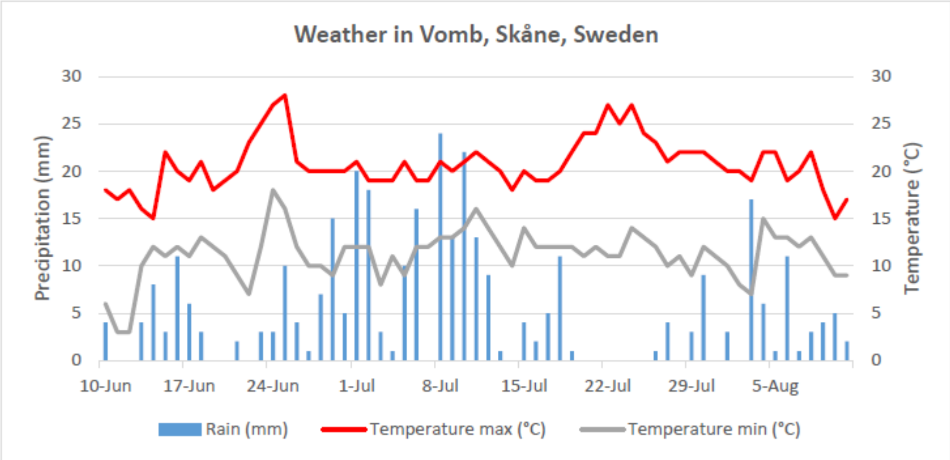


Figure 27 : Weather in Vomb : precipitations and air temperatures

In general, the summer was rainy with temperatures around 18°C. Some days of warm temperatures happened at the end of June and at the end of July.
These data will be used for correlating results of investigations of Vombsjön water profile and of P-ponds retention with the weather.

III.2. Water profile of Lake Vombsjön and internal eutrophication

As seen previously, temperature, dissolved oxygen, pH, redox potential and conductivity are parameters which influence phosphorus release and eutrophication. Stratification on the water column favors this phenomenon. It occurs during summer, when atmosphere temperature is the warmest : sun and air warm the shallower layers of the lake but not the deeper water.
So that, results achieved once a week through the use of the surface water measuring device are analyzed. All these data are indexed in ***Appendix 4***.

III.2.1. Evolution of water temperatures with dates and depth

The point L2 is situated in the middle of the lake and is the deepest point of Vombsjön. The evolution of temperature is traced at different depths (1m, 7m and 14m) according to the dates (each week during 9 weeks) in ***Figure 28***. It allows seeing variations of T according to dates and depths.

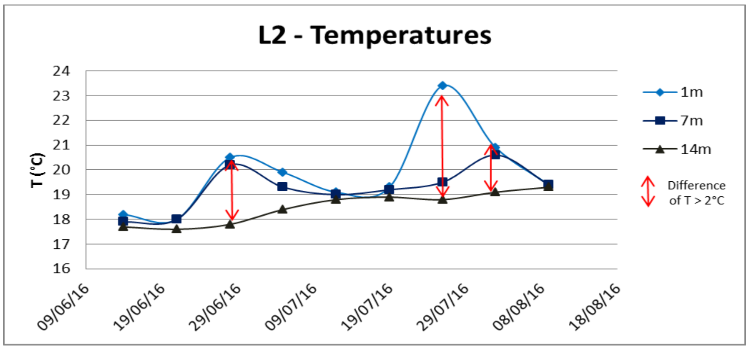


Figure 28 : Evolution of temperatures with the dates at L2 at 1m, 7m and 14m depth

First, at the surface (1m depth), temperature varies a lot with a minimum of 18°C and a maximum of 23,4°C, whereas at the bottom (14m depth) temperature softly increases from 17,6°C to 19,3°C. This is due to solar radiation and summer warmer temperatures. Indeed, the first few meters fast absorb the heat whereas water at the bottom is still cold and needs weeks to win some degrees. This phenomenon is well typical of summer season.

Moreover, when the three curves are quite superposed, it means that temperature is hardly the same in the vertical water column and there is no stratification and thermocline. It is the case for the most of the dates during this summer.
On the contrary, on some dates, a big variation of T is observed according to the depths. It is the case on 28/06/2016, 26/07/2016 and 02/08/2016 where the difference of temperature between the surface and the bottom is more than 2°C. That means a presence of stratification in the water column and a thermocline. These thermoclines are traced in paragraph ***II.2.3.***

II.2.2. Absence of water stratification

Most of the days during this summer were not enough sunny and warm to generate a thermocline and a stratification. It was often windy and rainy days which lead to a mix of the water column and so no different layers of water with the depth. An example of a day without water stratification is represented in ***Figure 29*** with the evolution of the physical parameters.

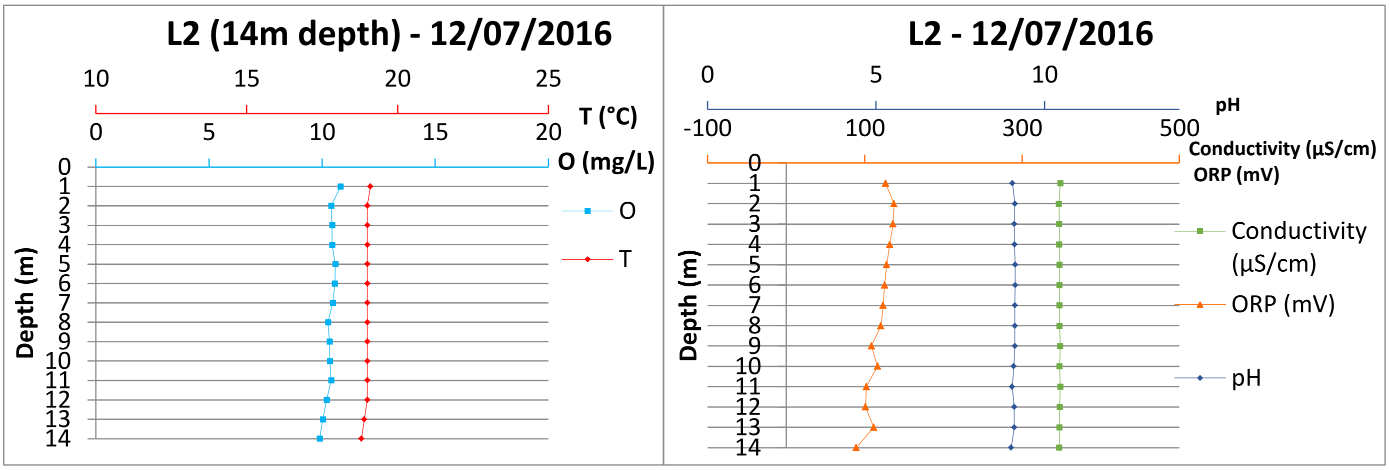


Figure 29 : Evolutions of T, DO, pH, ORP and conductivity according to the depth at L2

These graphs show that temperature is hardly constant in the entire water column. Indeed, it decreases of only 0,3 °C. That is the same for the dissolved oxygen content which decreases of only 0,9 mg/L between the surface and near the bottom. pH and conductivity are also constant with the depth and the redox potential has a very slow decrease.
It represents a case of non-stratification : water in the entire lake is homogenized. Indeed, it is characteristic of windy or rainy days without warm air temperature. This case is better to avoid an internal eutrophication of the lake.

III.2.3. Presence of a water stratification : thermocline and dissolved oxygen

As L2 is the deepest point, it is the most representative to trace thermoclines and show the stratification in the water column. So that, evolution of temperature and dissolved oxygen are traced according to the depth on the dates detected previously : 28/06/2016, 26/07/2016 and 02/08/2016. They are represented in ***Figure 30***.

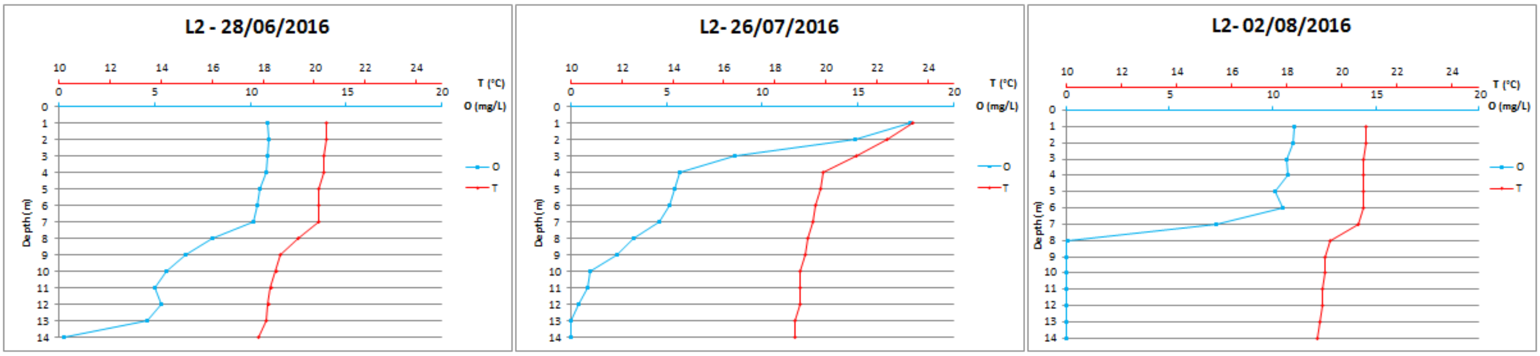


Figure 30 : Evolutions of temperature and dissolved oxygen according to the depth at L2

On the first graph (28/06/2016), a thermocline is observed. Indeed, between 1 and 7m depth, T is warmer (around 20,5°C) whereas from the 8th meter, T fast decreases with a loss of 2°C in only two meters. Dissolved oxygen content has the same trend. Indeed, from 1m to 7m depth, DO is around 10,5 mg/L whereas a strong decrease (a loss of more than 1mg/L at each meter) begins at the 8th meter. At the bottom, there is no oxygen, which is normal, as explained in paragraph ***I.5.2***.

On the second graph, (26/07/2016), the thermocline appears faster. Indeed, surface water is warmer (23,4°C) and temperature decreases of 1°C at each meter until the 4th meter depth. Then, the decrease is softer. In the same way, dissolved oxygen strongly decreases in only four meters (from 17,74mg/L to 5,69mg/L), then the decrease is similar to the first graph.

On the third graph (02/08/2016), T has the same trend than in the first graph with a thermocline at the 7th meter depth. Dissolved oxygen has a notable trend because it is around 10,5mg/L until 6m depth and become non-existent from the 8th meter depth to the bottom, which means a layer of water of six meters with zero dissolved oxygen. This stratification due to dissolved oxygen content could seem strange because the thermocline is not extremely strong. But it occurred only one week after the previous thermocline (26/07/2016, 2nd graph) with strong stratifications of T and DO. Colder and windy previous days can explain a less notable thermocline. Dissolved oxygen could still constitute stratification because it has a slower diffusion in water and therefore the stratification needs more time to disappear.

This type of stratification is problematic for the lake since there is a depletion of oxygen at the bottom which favors phosphorus releases by sediments and so an internal eutrophication.

III.2.4. Influence of lake topography on water stratification

One thermocline is notable on 28/06/2016 as seen before at the point L2 of the lake. Now, evolutions of temperature and dissolved oxygen are traced at this date but at different locations of the lake, where depths are different (5m, 10m and 14m depth). It allows seeing if the stratification appears in all the lake whatever the depth or if there are differences according to the topography. Graphs are represented in ***Figure 31***.

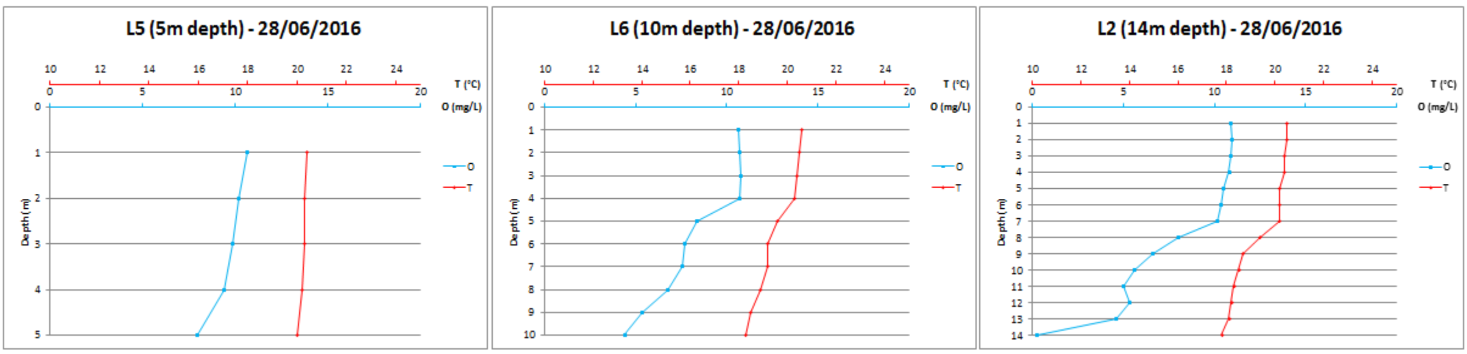


Figure 31 : Evolutions of temperature and dissolved oxygen at locations with different depths

Depending on the locations, thermoclines and DO curves have quite different trends. Indeed, on the first graph (lake site with 5m depth), there is no thermocline and the dissolved oxygen content slowly decreases. However, in the second graph (lake site with 10m depth), thermocline appears at the 4th meter depth, as the dissolved oxygen which begins to fast decrease at the 4th meter depth. On the third graph (lake site with 14m depth), thermocline and strong decrease of DO occur at the 7th meter depth. It means that stratification only occurs at deep locations

That shows that on a same day characterized by a thermocline phenomenon, the stratification of the water column is not the same at each point of the lake. It depends on the topography of the lake (depth, geography of the bottom) and probably also on the water flows and the water circulation.

III.2.5. Conductivity, pH and redox potential evolutions in a water stratification

Conductivity, pH and redox potential are parameters impacted by the water stratification that can influence phosphorus release and so eutrophication. The following graph, represented in ***Figure 32***, shows their evolution according to the depths at L2 (14m depth) on a day characterized by thermocline phenomenon.

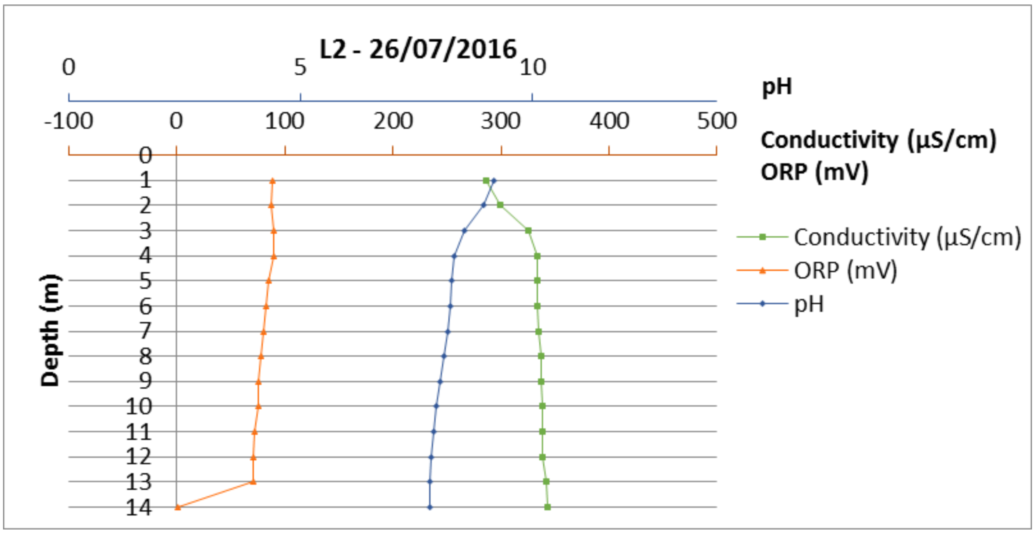


Figure 32 : Evolutions of pH, conductivity and ORP according to the depth at L2

First, this graph shows that the pH of the water decreases with the depth, starting from pH 9,19 at the surface to pH 7,81 at the bottom. Indeed, the decrease is more important between the surface and the 4th meter depth, and then it is slower. It means that there is a different water layer from 4m depth. The decrease is due to an acidification of the water because of a production of CO_2 during respiration of organisms.

The redox potential has the same trend of decrease with the depth. It is due to few dissolved oxygen near the bottom.

The water conductivity has exactly the inverse trend of the pH. Indeed, it increases with the depth, but faster between the surface and the 4m depth, which also shows water stratification from the 4th meter depth. It is due to liberation of ions by sediments. By the way, the thermocline and the DO stratification were also observed at the 4th meter depth in ***Figure 30***, paragraph ***III.2.3***.

These evolutions of conductivity, pH and redox potential are similar to typical evolutions reported in Literature review, paragraph ***I.5.2.***

III.2.6. Consequences of a water stratification internal eutrophication

The following schema in ***Figure 33*** summarizes the links between all the measured parameters in favorable conditions to internal eutrophication.

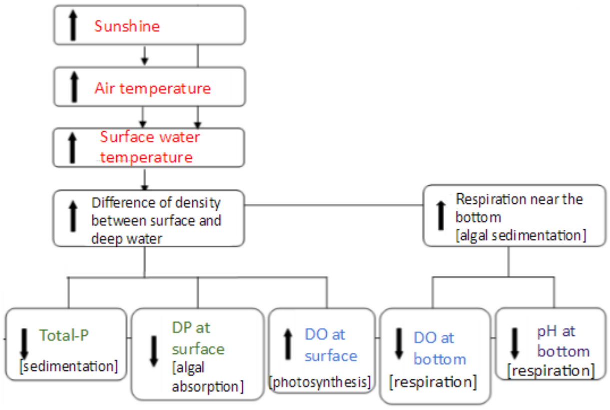


Figure 33 : Links between parameters leading to internal eutrophication

These stratifications mean different water layers in the lake. That avoids exchanges between the different layers and mainly a decrease of the dissolved oxygen content which leads to phosphorus release and then to internal eutrophication.

Moreover, this depletion of oxygen also leads to fish death. Indeed, according to Lars-Anders Hansson, Professor of Limnology at Lund University, every summer fishes die of lack of oxygen and washed up on Vombsjön beach, as illustrated in ***Figure 34***. [sverigesradio.se]
Agricultural lands bright phosphorus which feeds algae and contributes to their development. Then, they sink at the bottom and bacteria use all the oxygen (respiration) to decompose and sediment them.

Figure 34 : Fish death in Vombsjön, [sverigesradio.se]

Water stratification prevents fish to be in the entire water column, because they cannot change of water layer (different physical and chemical conditions). That is why fishes are dying because of a lack of oxygen.

III.2.7. Algal bloom

An algal bloom is a proliferation of algae in the water. On July 26th 2016, an algal bloom was observed in Vombsjön, as the photos illustrate in ***Figure 35***.

a) 

b) 

Figure 35 : Algal bloom in a) Vombsjön harbor and in b) Vombsjön, 26/07/2016

This day was characterized by water stratification and a strong thermocline as seen previously. According to the weather in paragraph ***III.1***, it was the sixth day with warm temperatures, no precipitation nor wind. There was no wave that is why the algal bloom could have been observed. This phenomenon means that there were good conditions to algal growth, a phosphorus release. Indeed, one month before a thermocline was formed and then several weeks of mixing the water column. During water stratification, there was a depletion of oxygen near the bottom which lead to liberation of phosphorus by sediments and death of many species of animals and plants.

Warmer temperatures and these nutrients favored algal growth. Then the mixture of the water column allowed to nutrients reaching the surface, and an algal bloom occurred.
The high amount of oxygen at the surface during this day of algal bloom, as seen in ***Figure 30***, paragraph ***III.2.3***, can be explained by the photosynthesis process which creates oxygen.

III.3. Retention of phosphorus in P- ponds

As seen previously, a P-pond is constructed to catch phosphorus. Its efficiency depends on several parameters as its design, the weather and water parameters which favor a catchment or a release. So that, results achieved twice a week, as phosphorus concentrations, turbidity, flows and water parameters, are analyzed. All these data are indexed in ***Appendix 5.***

III.3.1. Depth measurements and turnover time

Depth measurements of ponds 3 and 4

The results of the measured depths of ponds 3 and 4 are given in ***Appendix 6*** and the average depths and pond volumes are given in the following ***Table 3***.

	Pond 3	Pond 4
Average depth (m)	1,70	1,90
Water surface (ha)	17,5	1,1
Pond volume (m^3)	298 000	20 900

Table 3: Average depth and volume of ponds 3 and 4

These two ponds are the deepest and the biggest. This particularity may be significant for the comparison of the efficiency of each pond.

Average turnover time

The results of the turnover time of each P-pond are given in the following ***Table 4***.

	Average flow (m^3/s)	Volume (m^3)	Turnover time (days)
Pond 1	1,69E-03	4 500	30,84
Pond 2	1,41E-04	800	65,58
Pond 3	8,76E-02	298 000	39,39
Pond 4	8,76E-02	20 900	2,76
Pond 5	8,24E-04	20 000	280,90

Table 4 : Turnover time of each P-pond

The average turnover time corresponding to this summer is very different depending on the P-ponds. Indeed, water of ponds 1 and 3 is renewed in one month approximately, water of pond 2 in two months (which is equal to summer time of investigation) whereas water of pond 4 is renewed in less than 3 days. On the contrary, water of pond 5 needs 9 months to be renewed, which is a long time. So, water of pond 5 was quite stagnant during the summer time of investigation. It is due to the large volume and the low flow of this pond during summer.

III.3.2. Efficiency of each P-pond : comparison between inlet and outlet

Pond 1

Results of the analyses of the samples taken at inlet and outlet are described below. The following graphs in ***Figure 36***, represent the evolutions of the total phosphorus (with parts of Ortho-P and Particulate-P), turbidity and flows at inlet and outlet.

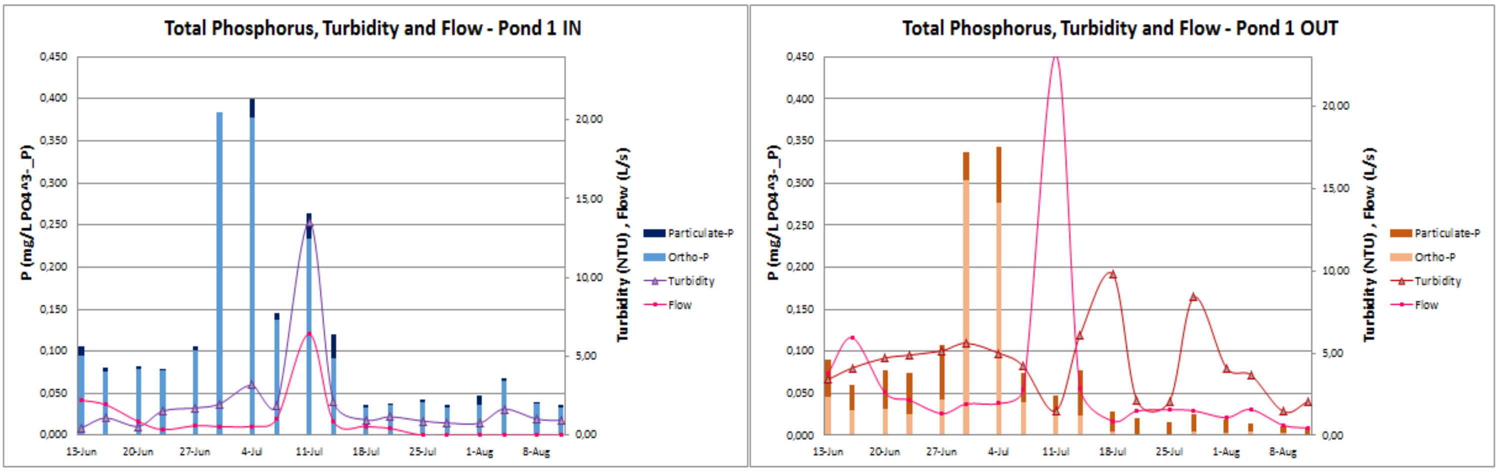


Figure 36 : Evolutions of Total P (Ortho-P + Particulate-P), Turbidity and Flows in Pond 1

In June, total phosphorus at the inlet is around 0,080 mg/L PO_4^{3-}_P, and then a peak of Total-P occurs with excessive values (0,400 mg/L PO_4^{3-}_P) which probably match with an addition of fertilizers in the surrounded farm lands. Indeed, this period was rainy and might have brought runoffs full of phosphorus. After this peak, the amount of total phosphorus decreases and stabilizes around 0,040 mg/L PO_4^{3-}_P. The outlet has the same trend with less total phosphorus.
Moreover, in the water of pond 1 inlet, total phosphorus is mainly composed of orthophosphates whereas at the outlet, there is more Particulate-P than Ortho-P, except on 30/06/2016 and 04/07/2016 (peak of Total-P). At the outlet from mid-July to the end of sampling, Ortho-P is hardly non-existent and there is a little of Particulate-P.

At the inlet, water turbidity is around 1 NTU, except during a peak on 11/07/2016 (13,50 NTU). At the outlet, it varies more but it is always between 2 and 9 NTU.
It is observed that turbidity is higher when phosphorus is most in particulate form. Peaks of turbidity occur at the same time or just after increasing flows, which may be due to the previous rainy days (***Figure 27*** : *Weather in Vomb*). Indeed, rain and higher flow mix water and put sediments in suspension which creates higher water turbidity.

Moreover, some photos in ***Figure 37*** show an evolution of the pond between 23/06/2016 and 27/06/2016.

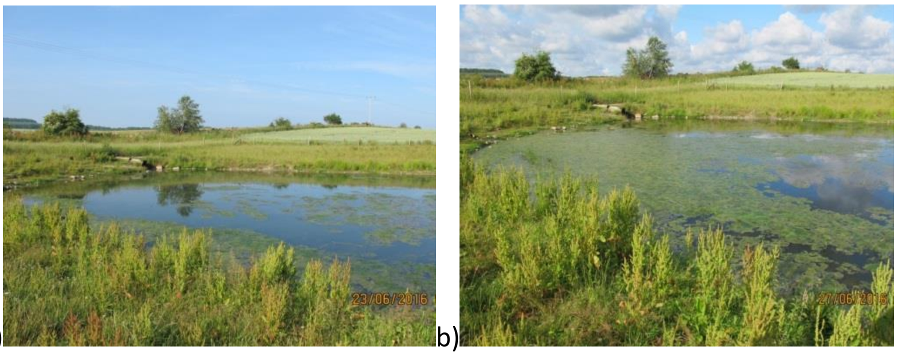
a)  b)

Figure 37 : Pond 1 inlet on a) 23 June 2016 and b) 27 June 2016

In only four days, algae have proliferated and invaded the pond. It occurred just after a peak of air temperature according to the weather reported in ***Figure 27***. Moreover, this proliferation matches with the peak of phosphorus observed in ***Figure 36***. Indeed, the peak of high concentration of phosphorus at the pond 1 inlet appeared at the same days. This proves that phosphorus is a nutrient for algae and allows them to multiply and generate an eutrophication phenomenon.

The following graph, in ***Figure 38***, represents the percentage reduce of total phosphorus, orthophosphates and particulate phosphorus. When the value was negative, which means productions of phosphorus, percentage reduce was put to zero.

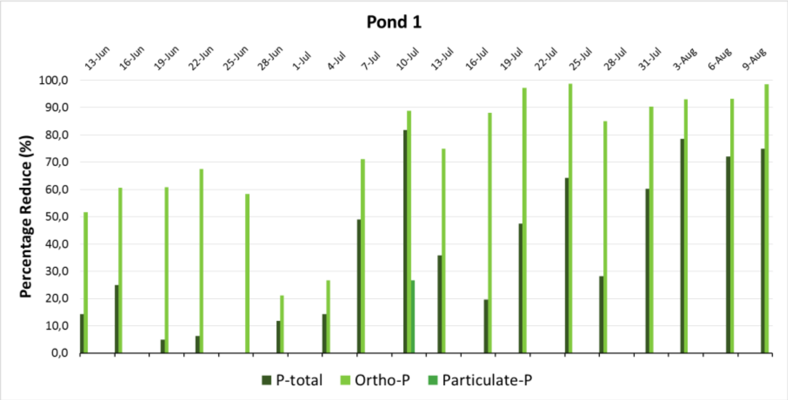


Figure 38 : Efficiency of P-pond 1: percentage reduce between inlet and outlet

These graphs show that the form of phosphorus which is eliminated is the Ortho-P whereas Particulate-P is produced (negative values). However, in this pond the part of Ortho-P which is trapped is superior than the part of Particulate-P which is released, so that considering the concentration of Total-P, this P-pond is a little efficient : less Total-P at the outlet than at the inlet.
It means that P-pond 1 is efficient to catch dissolved phosphorus but releases a little particulate phosphorus. Indeed, as seen in the retention process in the literature review, it is dissolved phosphorus which is absorbed by sediments and plants whereas particulate phosphorus decant and can easily be put in suspension again.

The following graph, in ***Figure 39***, represents the evolutions of the water physical parameters at the inlet and outlet.

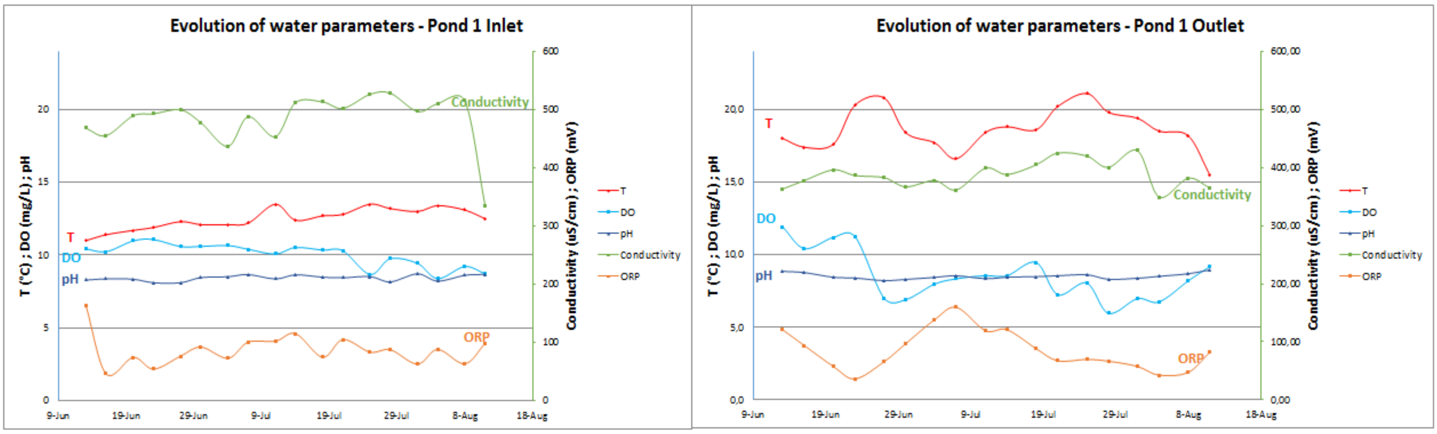


Figure 39 : Evolution of T, DO, pH, conductivity and ORP in pond 1 inlet and outlet

At the inlet, each parameter is generally constant, except water temperature which slowly increases (from 11°C to 13°C).
At the outlet, temperature is warmer and varies more, maybe because of the design of the outlet (well) or because water had time to warm up between inlet and outlet. Dissolved oxygen decreases and is becoming quite low (around 6,5 mg/L). It may be explained by accumulation of organic matter and so bacteria which consume oxygen to decompose it. Conductivity is lower at the outlet than the inlet. pH is constant and exactly the same at inlet and outlet (around pH 8,5).

Pond 2

Results of the analyses of the samples taken at inlet and outlet are described below. The following graphs in ***Figure 40***, represent the evolutions of the total phosphorus (with parts of Ortho-P and Particulate-P), turbidity and flows at inlet and outlet.
However, sampling at the outlet was not similar during the entire summer. Indeed, the first week a flow was present and samples were taken at the outlet, whereas the rest of the summer there was no flow at the outlet, and a part of the pond was dry. So, samples were directly taken into the pond.

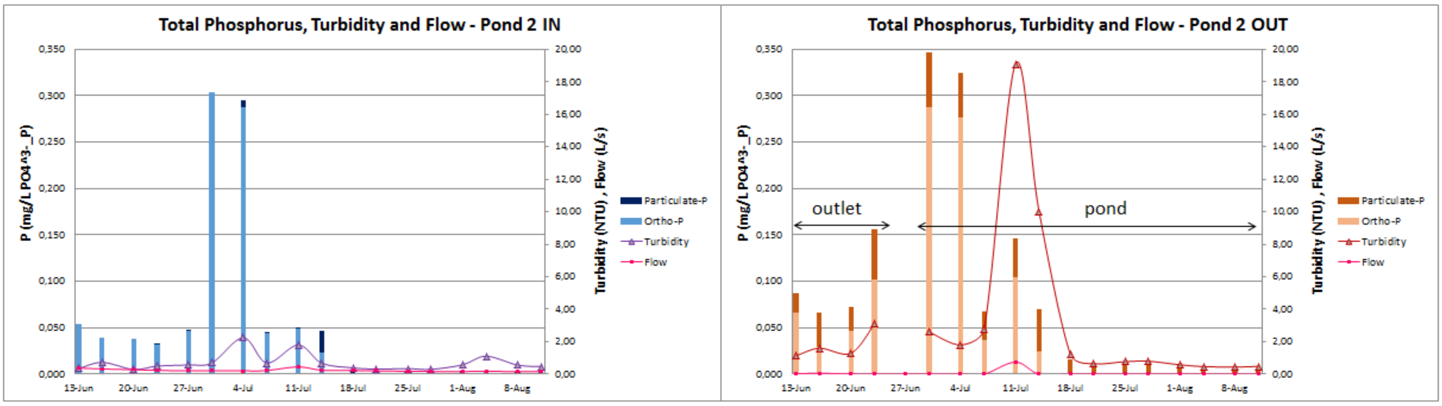


Figure 40 : Evolutions of Total P (Ortho-P + Particulate-P) and Turbidity in Pond 2

These graphs show that the phosphorus concentration has the same trend than in pond 1 with concentrations which tend to decrease, a peak at the beginning of July and total phosphorus mainly composed of Ortho-P at the inlet and a major part of Particulate-P at the outlet. However, concentrations at inlet are generally very low and even at zero for the last weeks.
At the outlet, the peak of turbidity is due to a bad sampling (algae in water), so this point is not to consider. Low turbidity and flow are observed at inlet and outlet during all the summer.
Graphs of percentage reduce and evolutions of T, DO, pH, conductivity and ORP are in ***Appendix 7-8***.
At the end of summer, all the Ortho-P is trapped or transformed and there is a low release of Particulate-P. Concerning the water physical parameters, their evolutions at the inlet are similar to pond 1 inlet : constant parameters but a low decrease of oxygen. At the outlet, concentration of dissolved oxygen varies more, it may be due to changes of sampling.
Because of a dry period at the outlet, and changes in sampling strategy, it is hard to conclude on the efficiency of this pond.

Pond 3

Results of the analyses of the samples taken at inlet and outlet are described below. The following graphs in ***Figure 41***, represent the evolutions of the total phosphorus (with parts of Ortho-P and Particulate-P), and turbidity at inlet and outlet.

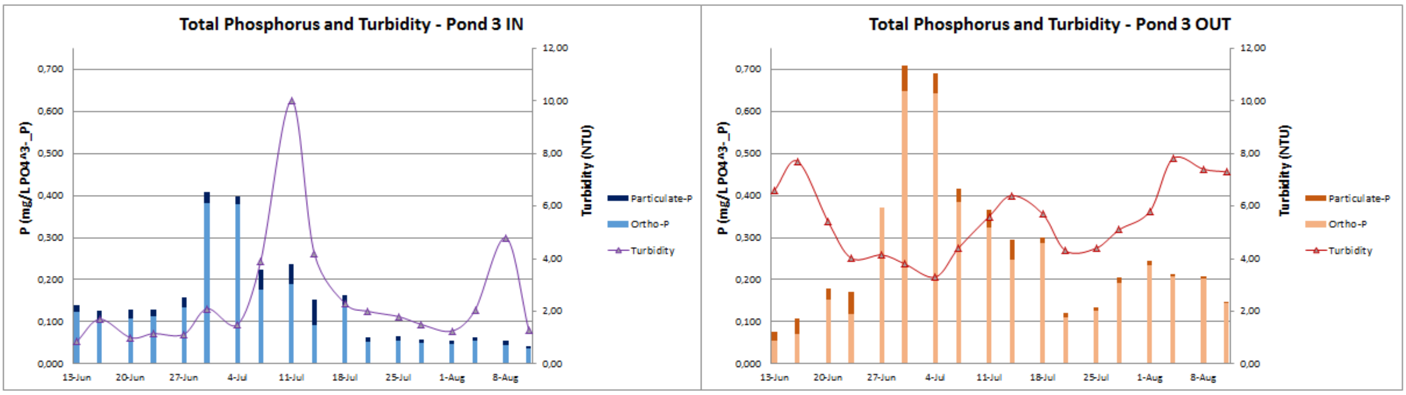


Figure 41 : Evolutions of Total P (Ortho-P + Particulate-P) and Turbidity in Pond 3

These graphs point out high concentrations of total phosphorus during the entire summer (generally >0,100 mg/L at the inlet and >0,150 mg/L at the outlet). Moreover, concentrations are higher at outlet than inlet which expresses a bad efficiency of the pond. Turbidity is also higher at the outlet. So, the released phosphorus may come from the sediments at the bottom.
The percentage reduce graph is in ***Appendix 7*** and confirms that this pond is not efficient.

The following graph, in ***Figure 42***, represents the evolutions of the water physical parameters and flows at the inlet and outlet.

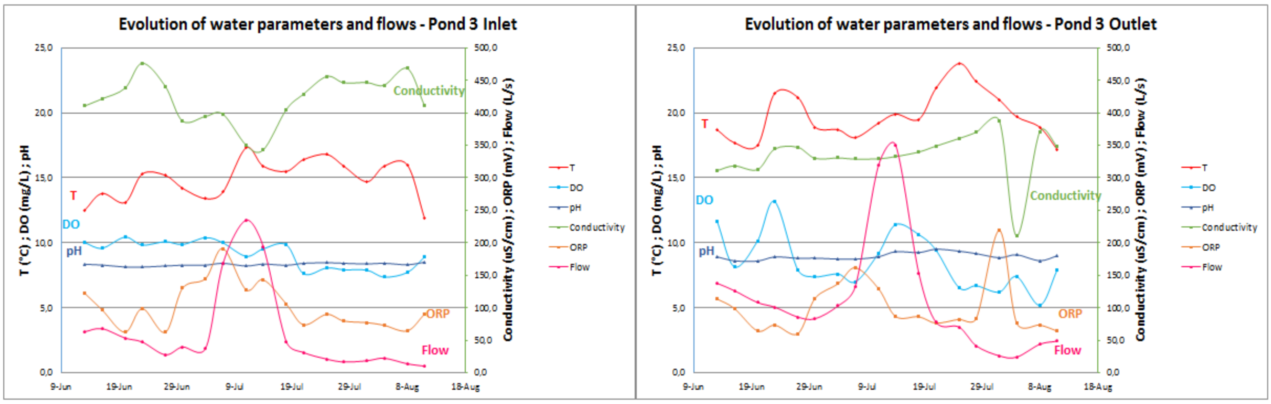


Figure 42 : Evolution of T, DO, pH, conductivity, ORP and flows in pond 3 inlet and outlet

A peak of flow matches with a peak of turbidity and rainy days, as observed at the previous ponds. However, this pond is the biggest and deepest one and is characterized by big flows.
Water temperature is colder at the inlet than at the outlet. This may be due to water which has time to warm up between inlet and outlet (turnover time of one month during summer period). Moreover, oxygen is generally lower at outlet than inlet (with quite low values at the end of the summer, between 5 and 7 mg/L). These observations about temperature and oxygen may explain the release of phosphorus in pond 3 and lead to an internal eutrophication.

Pond 4

Only the outlet is studied because of an unsuitable design of the inlet. Results of the analyses of the samples taken at outlet are described below. The following graphs in ***Figure 43***, represent the evolutions of the total phosphorus (with parts of Ortho-P and Particulate-P), and turbidity at outlet.

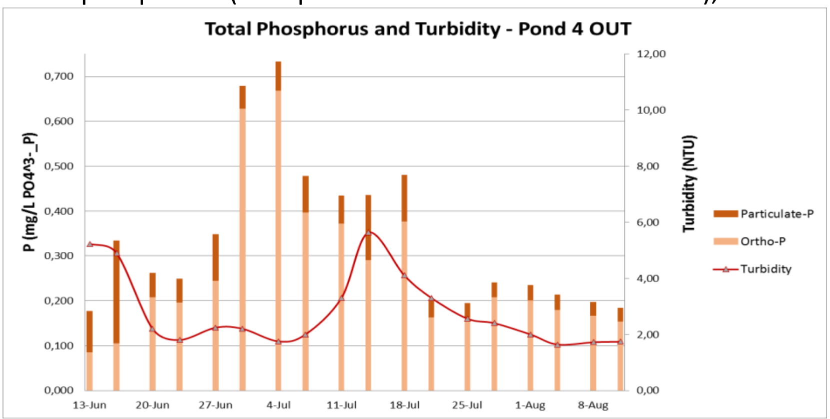


Figure 43 : Evolutions of Total P (Ortho-P + Particulate-P) and Turbidity in Pond 4

This graph shows very high concentrations of total phosphorus, with higher part of Particulate-P than in the other ponds. Turbidity is also higher. It increases when the part of Particulate-P increases, which confirms a link between them. The graph of evolutions of the water physical parameters at the outlet is given in ***Appendix 8***. All the parameters have a similar evolution than the outlet of pond 3.
Pond 4 is characterized by its very fast turnover time (less than three days). This may explain the high concentrations of phosphorus if phosphorus has not the time to decant or be absorbed by plants and sediments.

Pond 5

Results of the analyses of the samples taken at outlet are described below. The following graphs in ***Figure 44***, represent the evolutions of the total phosphorus (with parts of Ortho-P and Particulate-P), turbidity and flows at inlet and outlet.

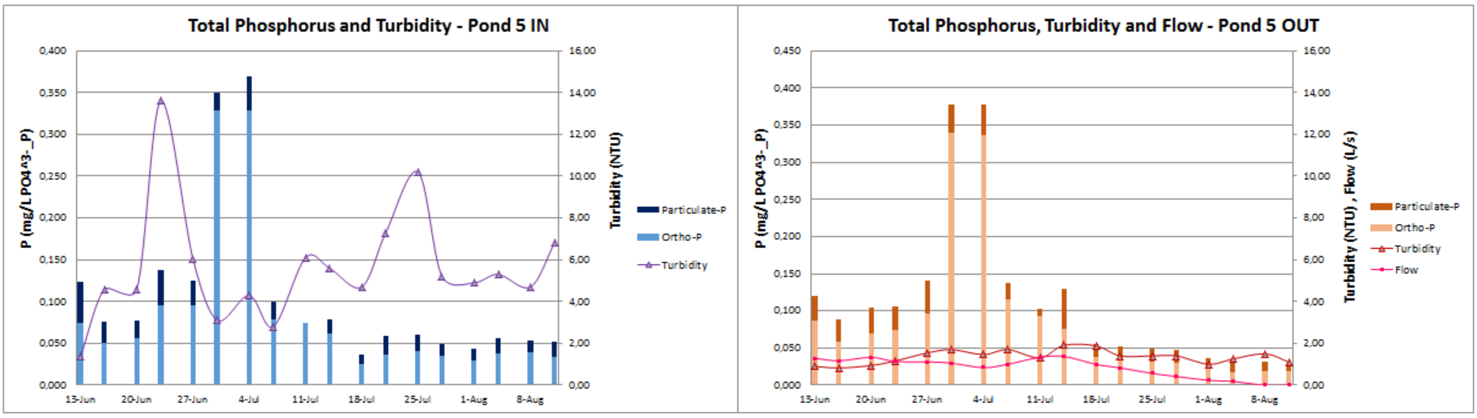


Figure 44 : Evolutions of Total P (Ortho-P + Particulate-P) and Turbidity in Pond 5

Phosphorus concentrations have the same trend at inlet and outlet with high values the first weeks, a peak similar at the other ponds, and then a decrease.

Flow at inlet could not be measured but it was lower and lower with the weeks, as the outlet. Moreover it is a big pond with a very long average turnover time during summer (approximately 9 months), but due to the last weeks with extremely low flows. So, water is not really renewed. It may explain the efficiency of the last weeks if phosphorus has time to decant and be absorbed by sediments and plants. The percentage reduce graph is represented in the following ***Figure 45***.

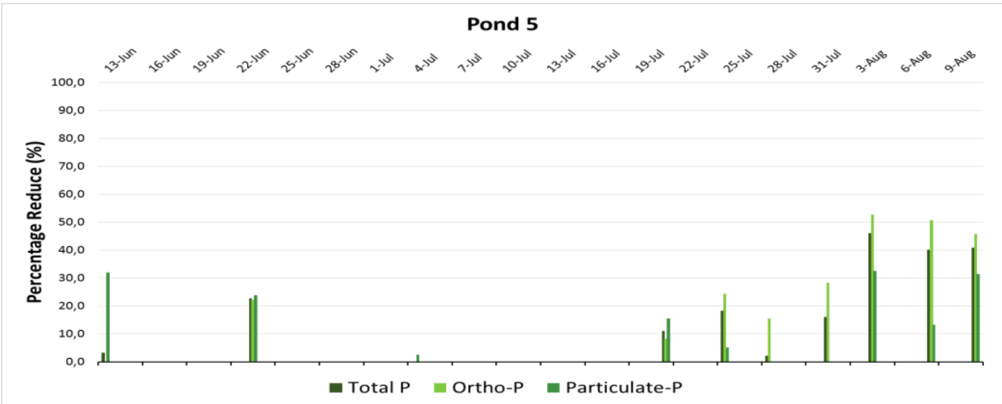


Figure 45 : Efficiency of P-pond 5: percentage reduce between inlet and outlet

Indeed, the first month the efficiency seems bad whereas at the end of the summer efficiency seems better since all forms of phosphorus are eliminated. It means that there is no release by sediments.

The graph of evolutions of the water physical parameters at inlet and outlet is given in ***Appendix 8***. Evolutions are quite similar to other ponds, with a decrease of oxygen in the last weeks.

Conclusion about P-ponds efficiency

Summer investigation on the phosphorus ponds allowed understanding that many parameters impact on efficiency. Indeed, the design of the pond (volume, depth) and the flow are linked to the turnover time. A long turnover time may be better to let phosphorus been absorbed by sediments and plants. Efficiency is also really linked to weather. Warmer summer temperatures can favor algae proliferation and oxygen decrease in the bottom and so a release of phosphorus. High flows due to strong rains may mix water and sediments and also release phosphorus. All of this shows that a P-pond is complex and cannot be always efficient or always not, but depends on extern factors.

III.3.3. Estimation of total phosphorus loads

Total-P loads at inlet and outlet

In this paragraph, only the total phosphorus coming from the inlet is considering entering the ponds (animal and fertilizer contributions are ignored).
All the table with calculating steps is in ***Appendix 9***.
Results of the total phosphorus loads for this summer at the inlet and outlet of each pond and the difference are in the following ***Table 5***. The difference represents the part which is released by the pond if the value is positive (the pond is not efficient) or the part which is caught by the pond if the value is negative (the pond is efficient).

		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
Total-P feeding the pond (kg/summer)	Inlet	0,558	0,066	47,568	199,755	0,226
Total-P leaving the pond (kg/summer)	Outlet	1,006	0,02	199,755	197,998	0,478
Total-P released (+) or caught (-) by the pond (kg/summer)	**(Total-P leaving) - (Total-P feeding)**	**0,448**	**-0,046**	**152,187**	**-1,757**	**0,252**

Table 5: Estimation of the Total-P loads entering and leaving each P-pond

These results show that ponds 2 and 4 are efficient since they trap phosphorus, whereas ponds 1, 3 and 5 release phosphorus. When values were considering as concentrations in paragraph ***III.3.2*** , only pond 1 seemed to be efficient during all the summer. Therefore, it points out that it is important to take account of the flow to consider a load of phosphorus and not just a concentration because it impacts on the efficiency of a P-pond.

Animal contribution

The following ***Table 6*** represents the load of total-P which is released on each pond by animal faeces in one summer. The percentage 1% is used to determine the part which reaches the pond.

		Release of P by animal faeces			Load of P reaching the pond
		/animal	/animal	**Total**	**Total**
P-Pond	Animal	g/day	kg/summer	**kg/summer**	**kg/summer**
1	20 sheeps	15	0,9	**18**	**0,18**
2	2 horses	60	3,6	**7,2**	**0,072**
3	-	0	0	**0**	**0**
4	2 horses	60	3,6	**7,2**	**0,072**
5	8 cows	55	3,3	**26,4**	**0,264**

Table 6 : Animal contribution in phosphorus release for each pond

These results show that the animal contribution in the phosphorus pollution is significant and has to be taken in account in the phosphorus balance.

Results of the total phosphorus loads for this summer entering and leaving each pond, in taking account of the animal contribution, and the difference are in the following ***Table 7***. The difference represents the part which is released by the pond if the value is positive (the pond is not efficient) or the part which is caught by the pond if the value is negative (the pond is efficient).
Fertilizer contribution is ignored since the values are not available.

		Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
Total-P feeding the pond (kg/summer)	Inlet	0,558	0,066	47,568	199,755	0,226
	Animals	0,180	0,072	0	0,072	0,264
	Total	**0,738**	**0,138**	**47,568**	**199,827**	**0,490**
Total-P leaving the pond (kg/summer)	**Outlet**	**1,006**	**0,020**	**199,755**	**197,998**	**0,478**
Total-P released (+) or caught (-) by the pond (kg/summer)	**(Total-P leaving) - (Total-P feeding)**	**0,268**	**-0,118**	**152,187**	**-1,829**	**-0,012**

Table 7 : Estimation of the Total-P loads entering and leaving each P-pond with animal contribution

When the animal contribution is taken in account, the load of total phosphorus which feeds the pond is higher. Since the part which leaves the pond did not change, the part which is trapped or released is better determined, as the pond efficiency. So, ponds 2 and 4 seem efficient this summer. Pond 5 does not seem having a real impact on phosphorus retention. Pond 1 releases phosphorus and pond 3 is not efficient at all since the load of released phosphorus reaches more than 152 kg/summer. However, the estimation of the average load of phosphorus is based on hypothesis of the flow for ponds 4 and 5 and so cannot be significant.

Conclusion

Vombsjön is a lake in the south of Sweden used as a water resource by Sydvatten to produce drinking water. However, its location on agricultural lands leads to additional income of phosphorus by runoffs from the lands to the lake. This favors the eutrophication of the lake, the development of algae and cyanobacteria, and the release of harmful toxins which are a real issue for the drinking water production, especially with the on-going climate change. Indeed, warmer temperatures generate a thermal stratification of the lake which favors phosphorus release by sediments at the bottom and thus internal eutrophication. So, to limit the additional income of phosphorus, constructed phosphorus ponds in the lake catchment area have to catch this phosphorus to avoid it to reach the lake.

So, this study was done to investigate, during one summer, their retention efficiency in measuring at each inlet and outlet : phosphorus concentrations, flows, turbidity and physical parameters of water, such as temperature, dissolved oxygen, pH, conductivity and redox potential. Results show that retention efficiency of the phosphorus ponds depends on many factors, such as weather conditions, pond design, level of dissolved oxygen. So, even in a short period (one summer), results indicate that a P-pond cannot be always efficient or not because of these many influencing factors. Indeed, results point out that phosphorus concentrations are variable and that storms, probably preceded by a recent add of fertilizers in the lands, have generated a peak of phosphorus (observed for each pond at the end of June). However, orthophosphates seem generally well caught (case of ponds 1 and 5), whereas particulate phosphorus is hardly always released by these P-ponds (case of all the ponds except pond 5 at the end of the summer). Considering total phosphorus concentration, only pond 1 seems efficient the entire summer with around 0,025 mg/L PO_4^{3-} - P of total phosphorus at the outlet. Ponds 3 et 4, the biggest ones, are the worse with concentrations at the outlet generally between 0,100 and 0,400 mg/L PO_4^{3-} - P. Conclusion about pond 2 cannot be significant because of dry periods avoiding the same regular monitoring at the outlet, but concentrations values were very low. Considering an average load of phosphorus (in kg/summer) entering and leaving a pond, different results appear : ponds 2 and 4 seem efficient, pond 5 has no impact, pond 1 quite releases phosphorus and pond 3 releases a lot of phosphorus (152 kg/summer). However, the estimation of the average load of phosphorus is based on hypothesis of the flow for ponds 4 and 5 and so cannot be significant. It would be interesting to do it again with real values.

This study was also about the internal eutrophication of the lake due to water stratification. Results have shown that most of the time of this summer, no water stratification was present, except twice including one of only a few days and one longer (about one week). Indeed, this summer was not very warm and often rainy and windy which generates a homogenization of the water column and avoids water to warm up. That is why stratification was not observed for most of the time. However, some sunny weeks with warmer temperatures and no wind have sometimes generated thermal stratification. This succession of thermocline episode and mixture of the water column have even lead to an algal bloom at the end of July and to fish death. This is explained by bacteria consuming a lot of oxygen to decompose organic matter, leading to the depletion of oxygen at the bottom. No oxygen is a favorable condition to phosphorus release by sediments, phosphorus which feeds algae and contributes to internal eutrophication.

Moreover, with the on-going climate change, eutrophication is becoming a bigger issue each year, especially internal eutrophication. That is why it is important to find solutions on what humans may have positive impact : external eutrophication. P-ponds used in Sweden may limit it as soon as their retention efficiency will be well known.

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[vertexwaterfeatures] : “Water parameters”, http://www.vertexwaterfeatures.com/pond-water-chemistry ; visited on 06/2016

[enr.gov.nt.ca] : “redox potential”, http://www.enr.gov.nt.ca/sites/default/files/oxidation-reduction_potential.pdf ; visited on 07/2016

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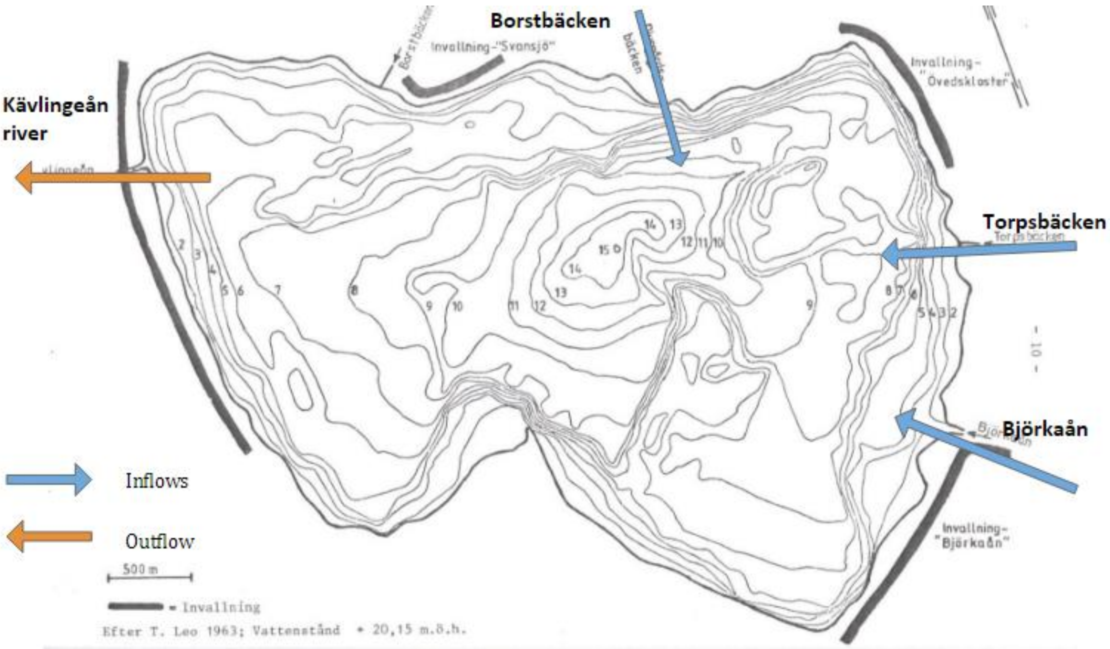
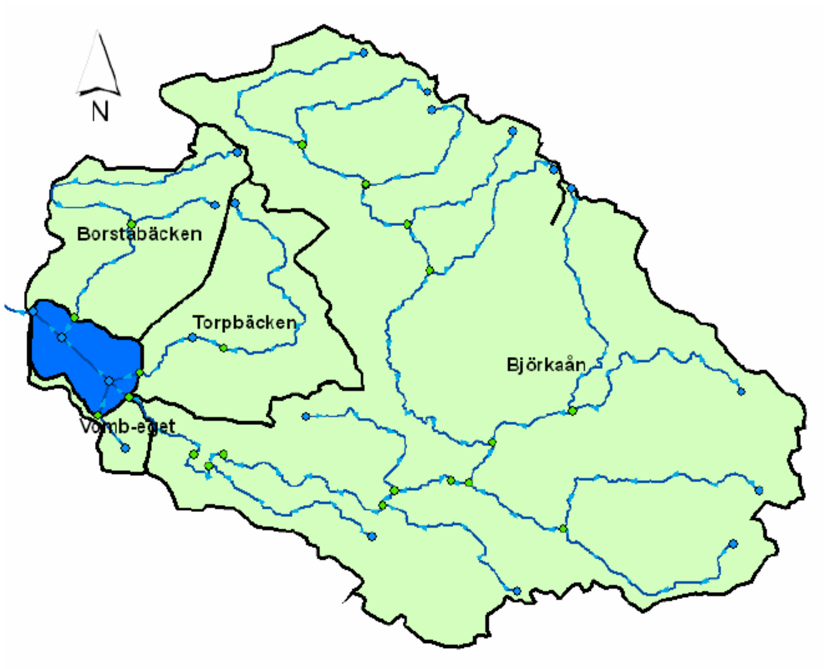
Appendices

Appendix 1 : Vombsjön bottom topography and sub-catchment areas



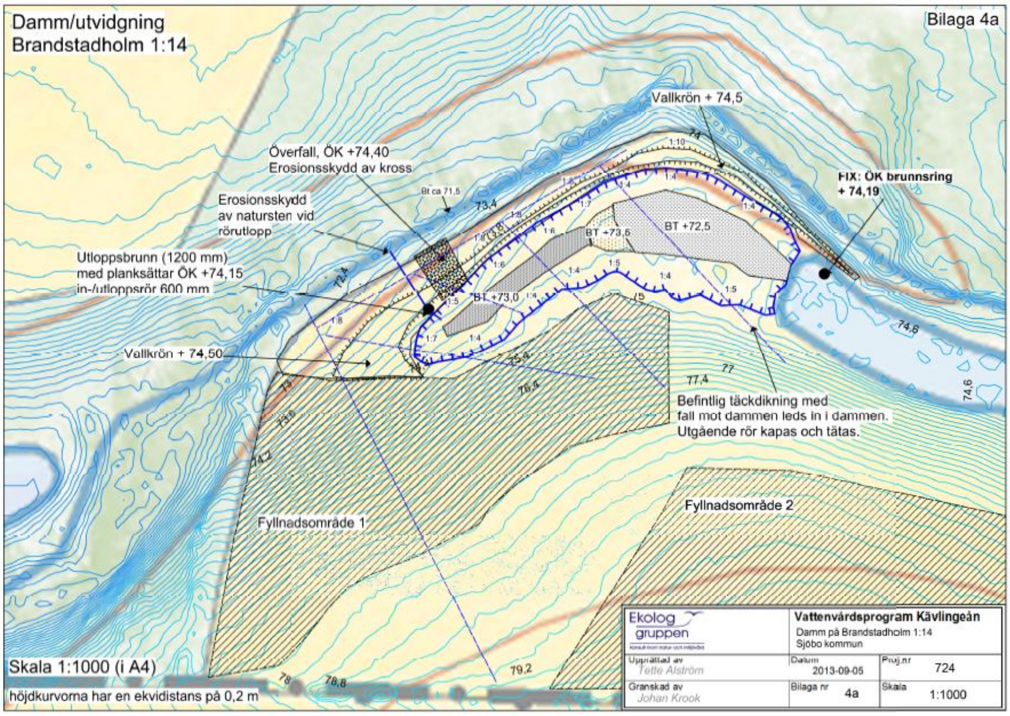


The four sub-catchment areas (*black lines*) of Lake Vombsjön (*blue*).

Appendix 2 : Presentation of the P-ponds

P-pond 1

P-pond 1 : inlet (left) and outlet (right)

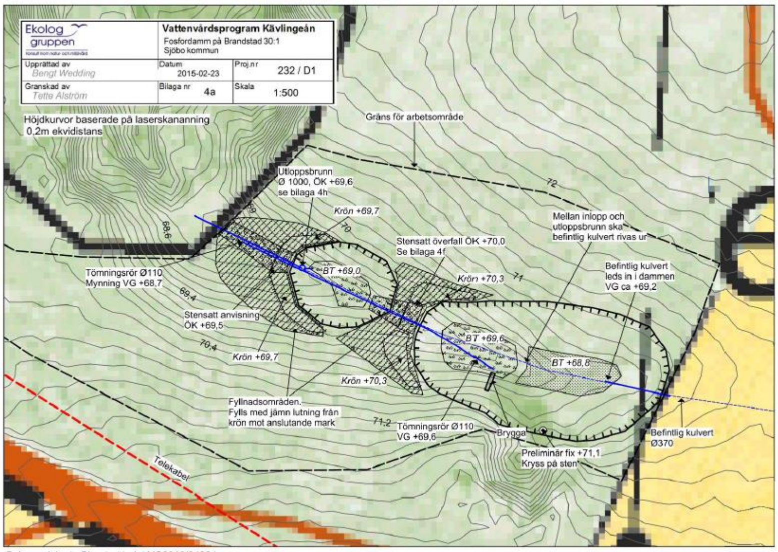


Map of pond 1

P-pond 2

Pond 2

P-pond 2 : inlet (left) and outlet (right)



Bakgrundskarta ©Lantmäteriet MS2013/04204

Map of pond 2

P-pond 3

Pond 3

P-pond 3 : inlet (left) and outlet (right)

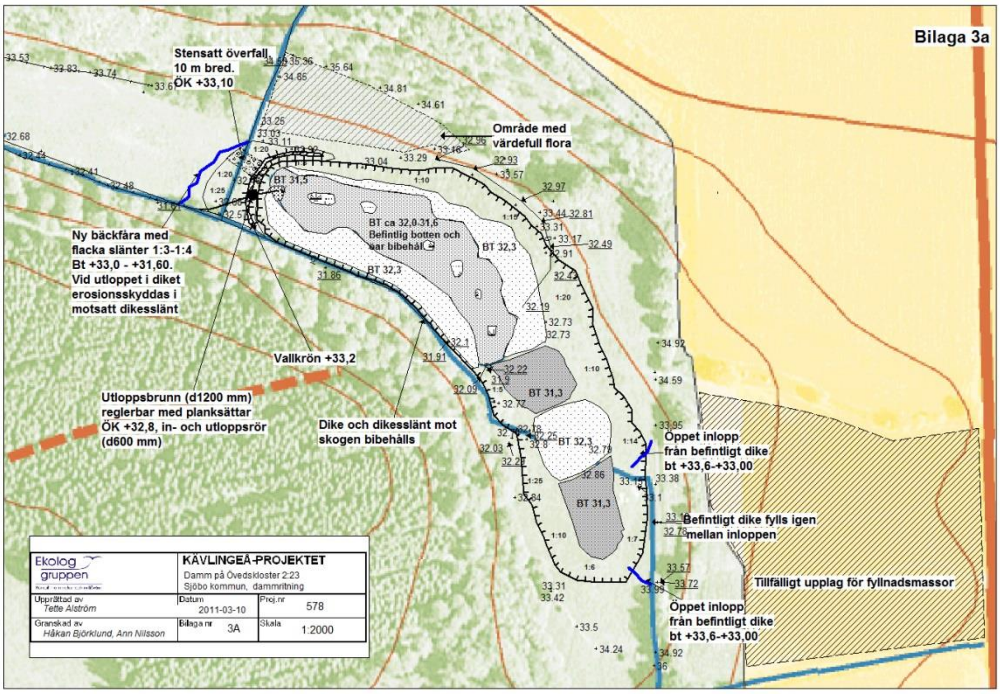
P-pond 4

P-pond 4 (left) and its outlet (right)

P-pond 5

Pond 5

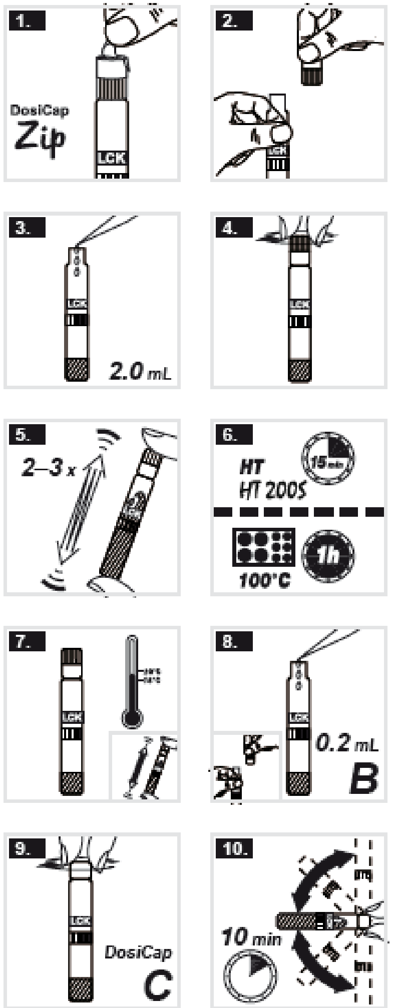
P-pond 5 : inlet (left) and outlet (right)



Map of Pond 5

Appendix 3 : Protocol of Phosphorus kit LCK 349

LCK 349 – PO_4-P / PO_4 / P_2O_5 06/2013



1. – 10.
Gesamt-Phosphor
Phosphore total
Fosforo totali
Fosfor totaal
Total Phosphorus

3., 8. – 10.
Ortho-Phosphat
Orthophosphate
Ortofosfati
Orthofosfaat
Orthophosphate

DE

1. Siegelfolie von dem aufgeschraubten **DosiCap® Zip** ***vorsichtig*** abziehen.
2. **DosiCap® Zip** abschrauben.
3. ***2.0 mL*** Probe pipettieren.
4. **DosiCap® Zip** ***fest*** aufschrauben; Riffelung oben.
5. Kräftig schütteln.
6. Im Thermostaten erhitzen.
   HT 200 S: 15 min im Standardprogramm ***HT***
   Thermostat: 60 min bei ***100°C***
7. Auf Raumtemperatur abkühlen.
   Kräftig schütteln.
8. In erkaltete Küvette pipettieren:
   0.2 mL Reagenz ***B*** (LCK 349 B).
   Reagenz B nach Gebrauch ***sofort*** verschließen.
9. ***Graues*** **DosiCap® C** (LCK 349 C) auf die Küvette schrauben.
10. Küvette schwenken, dabei mehrfach auf den Kopf drehen. Nach ***10 min*** Küvette noch einmal schwenken, außen gut säubern und auswerten.

FR

1. Enlevez ***délicatement*** la feuille de protection du **DosiCap Zip** détachable.
2. Dévissez le **DosiCap Zip**.
3. Pipetter ***2.0 mL*** d'échantillon.
4. Vissez le **DosiCap Zip** ***fermement***, dirigeant le cannelage vers le haut.
5. Secouer énergiquement.
6. Chauffer dans le thermostat.
   HT 200 S: 15 min avec le programme standard ***HT***
   Thermostat: 60 min à 100°C
7. Laisser refroidir à température ambiante.
   Secouer énergiquement.
8. Pipetter dans la cuve une fois refroidie:
   0.2 mL de réactif ***B*** (LCK 349 B).
   Fermer ***immédiatement*** le réactif B après emploi.
9. Visser un **DosiCap C** (LCK 349 C) ***gris*** sur la cuve.
10. Mélanger le contenu de la cuve en la retournant plusieurs fois de suite. Attendre ***10 min***, mélanger de nouveau, bien nettoyer l'extérieur de la cuve et mesurer.

IT

1. Rimuovere ***con attenzione*** il foglio di alluminio.
2. Svitare il **DosiCap Zip**.
3. Pipettare ***2.0 mL*** di campione.
4. Avvitare ***saldamente*** il **DosiCap Zip**; scanalatura esterna verso l'alto.
5. Agitare energicamente.
6. Riscaldare nel termostato.
   HT 200 S: 15 min nel programma standard ***HT***
   Termostato: 60 min a 100°C
7. Fare raffreddare a temperatura ambiente.
   Agitare energicamente.
8. Pipettare nella cuvetta raffreddata:
   0.2 mL di reattivo ***B*** (LCK 349 B).
   Dopo aver prelevato il reattivo B, richiudere ***immediamente***.
9. Avvitare un **DosiCap C** ***(capsula grigia)*** (LCK 349 C).
10. Mescolare capovolgendo la cuvetta più volte. Dopo ***10 min*** mescolare nuovamente, pulire bene la cuvetta esternamente e leggere.

NL

1. Afdekfolie ***voorzichtig*** verwijderen.
2. **DosiCap Zip** afschroeven.
3. ***2.0 mL*** monster pipetteren.
4. **DosiCap Zip** ***stevig vast*** opschroeven; geribbelde zijde naar boven.
5. Krachtig schudden.
6. In het thermostaat verhitten.
   HT 200 S: 15 min in standaard-programma ***HT***
   Thermostaat: 60 min bij ***100°C***
7. Laten afkoelen tot kamertemperatuur.
   Krachtig schudden.
8. In afgekoelde kuvet pipetteren:
   0.2 mL reagens ***B*** (LCK 349 B). De reagens B-fles na gebruik ***onmiddelijk*** dicht draaien.
9. Een ***grijze*** **DosiCap C** (LCK 349 C) op het kuvet schroeven.
10. Kuvet zwenken en daarbij meerdere malen op zijn kop houden. Na ***10 min*** het kuvet opnieuw zwenken, van buiten goed reinigen en meten.

EN

1. ***Carefully*** remove the foil from the screwed-on **DosiCap Zip**.
2. Unscrew the **DosiCap Zip**.
3. Pipette ***2.0 mL*** sample.
4. Screw the **DosiCap Zip** back ***tightly***; fluting at the top.
5. Shake firmLy.
6. Heat in the thermostat.
   HT 200 S: in standard program ***HT*** for ***15 min***
   Thermostat: 60 min at ***100°C***
7. Allow to cool to room temperature.
   Shake firmly.
8. Pipette into the cooled cuvette:
   0.2 mL Reagent ***B*** (LCK 349 B).
   Close Reagent B ***immediately*** after use.
9. Screw a ***grey*** **DosiCap C** (LCK 349 C) onto the cuvette.
10. Invert a few times. After ***10 min*** invert a few times more, thoroughly clean the outside of the cuvette and evaluate.

Appendix 4 : Water profile - data

Water Profile Point L1 (7m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/16	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	18,1	17,9	20,5	19,5	19,2	19,3	23,1	21,0	19,3
	Pressure (Atm)	0,9849	0,9979	0,9998	0,9972	0,9909	1,0038	1,0018	0,998	0,9979
	Oxygen (mg/L)	9,20	9,64	10,45	10,56	10,55	10,70	17,10	12,35	8,19
	Conductivity (µS/cm)	355,8	345,6	337,5	368,4	347,0	320,8	283,4	290,2	295,6
	pH	8,65	8,68	8,87	8,89	9,07	9,15	9,28	9,22	8,84
	ORP (mV)	84,4	89,8	105,2	95,6	108,8	115,4	64,6	122,7	86,4
2m	Temperature (°C)	18,0	17,9	20,5	19,3	19,1	19,3	23,0	20,9	19,3
	Pressure (Atm)	0,9849	0,9979	0,9998	0,9972	0,9909	1,0038	1,0018	0,9981	0,9979
	Oxygen (mg/L)	7,72	9,44	10,39	9,16	10,33	10,86	17,15	11,56	8,25
	Conductivity (µS/cm)	354,5	346,8	370,8	367,2	347	320,8	284,8	292,7	295,7
	pH	8,6	8,59	8,84	8,91	9,07	9,18	9,27	9,17	8,72
	ORP (mV)	85,6	93,2	105,9	105,2	107,8	121,1	70,6	116,2	83,3
3m	Temperature (°C)	18,0	17,9	20,5	19,3	19,1	19,3	22,5	20,8	19,3
	Pressure (Atm)	0,9849	0,9979	0,9998	0,9972	0,9909	1,0038	1,0019	0,9981	0,9979
	Oxygen (mg/L)	8,04	9,36	10,56	9,61	10,27	10,79	16,55	10,58	8,21
	Conductivity (µS/cm)	355,2	360,0	369,2	358,6	347,5	320	291,9	295,5	295,1
	pH	8,59	8,60	8,85	8,93	9,07	9,19	9,14	9,15	8,71
	ORP (mV)	86,9	97,0	108,5	110,1	104,6	120,7	76,2	111,6	74,3
4m	Temperature (°C)	18,0	17,9	20,4	19,3	19,1	19,2	20,9	20,8	19,3
	Pressure (Atm)	0,985	0,9979	0,9998	0,9972	0,9909	1,0037	1,0017	0,9981	0,9979
	Oxygen (mg/L)	8,3	9,53	10,34	9,23	10,15	10,36	10,05	10,29	8,16
	Conductivity (µS/cm)	355,2	360,2	315,2	357,1	347,4	322,3	322	296,5	296
	pH	8,58	8,60	8,85	8,94	9,07	9,18	8,79	9,05	8,7
	Alkalinity (mV)	88,2	102,0	108,2	106,9	102,4	117,4	82,8	99,9	73,0
5m	Temperature (°C)	17,9	17,9	20,2	19,3	19,1	19,2	19,9	20,8	19,3
	Pressure (Atm)	0,985	0,9979	0,9998	0,9971	0,991	1,0037	1,0018	0,998	0,9979
	Oxygen (mg/L)	8,28	9,19	9,45	9,27	10,28	10,40	6,29	10,11	8,19
	Conductivity (µS/cm)	355,4	360,4	376,1	350,2	347,4	322,7	332,2	297,2	296
	pH	8,58	8,64	8,79	8,92	9,07	9,06	8,45	9,02	8,7
	ORP (mV)	88,6	110,8	117,7	105,9	100,7	99,9	83,8	97,8	71,2
6m	Temperature (°C)	17,9	17,9	19,5	19,3	19,1	19,2	19,5	20,1	19,3
	Pressure (Atm)	0,9851	0,998	0,9998	0,9971	0,991	1,0037	1,0017	0,9981	0,9977
	Oxygen (mg/L)	7,85	9,34	7,97	8,92	10,38	10,3	4,57	0,50	8,14
	Conductivity (µS/cm)	355,8	342,7	384,6	359,9	347,6	323	334,8	330,9	295,9
	pH	8,57	8,63	8,67	8,93	9,07	9,03	8,30	8,40	8,70
	ORP (mV)	89,2	114,4	128,3	103,7	99,6	98,4	82,0	113,0	71,7
7m	Temperature (°C)	17,9	17,8	18,5	19,2	19,0	19,1	19,2	19,7	19,2
	Pressure (Atm)	0,9851	0,9979	0,9998	0,9971	0,991	1,0037	1,0016	0,998	0,9978
	Oxygen (mg/L)	7,56	8,74	0,97	6,90	0,34	8,46	1,41	0,24	0,54
	Conductivity (µS/cm)	356,4	356,7	363	358,6	339,5	324,1	337,6	335,6	307
	pH	8,5	8,61	8,19	8,85	8,43	9,12	8,03	8,04	8,19
	ORP (mV)	-55,5	70,3	-139,2	17,4	-115,6	109,6	-7,6	-2,0	-119,1

Water Profile Point L2 (14m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/16	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	18,2	18,0	20,5	19,9	19,1	19,3	23,4	20,9	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9955	0,9912	1,0037	1,0020	0,9982	0,998
	Oxygen (mg/L)	7,81	9,03	10,90	11,20	10,82	10,85	17,74	11,06	8,03
	Conductivity (µS/cm)	346,2	361,6	370,6	353	348,6	307,1	286,1	295,2	295,8
	pH	8,58	8,47	8,82	8,98	9,05	8,97	9,19	9,04	8,66
	ORP (mV)	183,4	135,0	60,3	29,7	126,5	68,4	88,2	85,5	61,0
2m	Temperature (°C)	18,1	18	20,5	19,5	19,0	19,3	22,4	20,9	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9955	0,9913	1,0038	1,0019	0,9982	0,998
	Oxygen (mg/L)	7,8	9,29	10,95	10,25	10,4	10,52	14,82	10,97	8,08
	Conductivity (µS/cm)	346,9	351	371,3	358,8	346,8	324	299,7	295,5	295,7
	pH	8,56	8,50	8,85	9,01	9,12	8,97	8,96	9,03	8,66
	ORP (mV)	176,4	139,2	62,3	58,3	137,3	68,3	86,9	86,2	61,8
3m	Temperature (°C)	18,0	18,0	20,4	19,3	19,0	19,2	21,2	20,8	19,4
	Pressure (Atm)	0,9849	0,9985	1,0001	0,9955	0,9912	1,0038	1,002	0,9982	0,998
	Oxygen (mg/L)	7,87	9,18	10,89	9,53	10,44	10,47	8,56	10,69	8,16
	Conductivity (µS/cm)	347,4	334,3	374,5	357,3	347,2	327,2	325	296,6	295,8
	pH	8,56	8,53	8,86	8,97	9,10	8,96	8,55	9,01	8,65
	ORP (mV)	171,9	143,9	66,5	67,5	136,1	68,1	89,5	86,7	63,5
4m	Temperature (°C)	18,0	18,0	20,4	19,3	19,0	19,2	19,9	20,8	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9955	0,9912	1,0038	1,002	0,9981	0,998
	Oxygen (mg/L)	7,76	9,06	10,80	9,44	10,44	10,34	5,69	10,74	8,13
	Conductivity (µS/cm)	348,2	375,2	376,3	356,3	347,3	327,5	333,8	296,4	295,9
	pH	8,55	8,56	8,88	8,96	9,11	8,95	8,33	9,01	8,64
	ORP (mV)	167,2	151,8	74	72,3	131,7	68	89,3	86,5	65,1
5m	Temperature (°C)	17,9	18,0	20,2	19,3	19,0	19,2	19,8	20,8	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9955	0,9913	1,0039	1,0021	0,9981	0,9981
	Oxygen (mg/L)	7,62	8,85	10,51	9,36	10,58	10,16	5,42	10,09	8,05
	Conductivity (µS/cm)	349,2	351,7	369,4	355,4	347,5	327,7	333,7	297,9	296
	pH	8,54	8,60	8,91	8,96	9,13	8,95	8,27	8,98	8,65
	ORP (mV)	164,8	153,7	77,1	73,0	127,8	67,3	85,4	87,2	65,5
6m	Temperature (°C)	17,9	18,0	20,2	19,3	19,0	19,2	19,6	20,8	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9954	0,9911	1,0039	1,0021	0,9981	0,9981
	Oxygen (mg/L)	7,43	8,86	10,39	9,14	10,56	10,04	5,14	10,47	8,21
	Conductivity (µS/cm)	350,1	357,3	369,9	357,5	347,6	327,6	334	297,4	295,8
	pH	8,54	8,60	8,93	8,97	9,13	8,95	8,24	8,97	8,66
	ORP (mV)	161,3	154,5	79,7	74	125,3	66,7	82,2	85,1	66,6
7m	Temperature (°C)	17,9	18,0	20,2	19,3	19,0	19,2	19,5	20,6	19,4
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9955	0,9911	1,0039	1,002	0,9981	0,9979
	Oxygen (mg/L)	7,54	8,96	10,14	9,41	10,47	10,00	4,63	7,27	8,13
	Conductivity (µS/cm)	350,8	356,5	364,9	357	347,5	327,7	335	309,5	296,2
	pH	8,54	8,61	8,91	8,96	9,12	8,94	8,19	8,62	8,63
	ORP (mV)	158,7	152,5	86,1	74,7	123,3	66,0	80,3	85,5	67,5

8m	Temperature (°C)	17,9	18,0	19,4	19,2	19,0	19,1	19,3	19,6	19,4
	Pressure (Atm)	0,9849	0,9986	1,0003	0,9953	0,9912	1,0038	1,0020	0,9980	0,9979
	Oxygen (mg/L)	7,23	9,07	8,05	9,58	10,26	10,09	3,31	0,04	8,01
	Conductivity (µS/cm)	351,4	357,1	367,9	356,9	347,7	327,9	336,8	337,2	296,2
	pH	8,52	8,60	8,62	8,94	9,12	8,93	8,09	8,08	8,62
	ORP (mV)	156,7	151,6	91,5	76,5	120,6	66,0	77,8	91,8	66,9
9m	Temperature (°C)	17,8	17,9	18,7	19,2	19,0	19,1	19,2	19,4	19,4
	Pressure (Atm)	0,9848	0,9986	1,0002	0,9953	0,9912	1,0039	1,0021	0,998	0,9979
	Oxygen (mg/L)	7,51	8,60	6,63	9,56	10,33	9,95	2,43	0,01	8,09
	Conductivity (µS/cm)	351,7	356,6	365,8	356,8	348,4	327,8	337,2	338	296,3
	pH	8,55	8,58	8,39	8,94	9,12	8,92	8,01	7,92	8,62
	ORP (mV)	152,9	150,6	95,2	77,1	108,6	66,4	75,8	78	66,8
10m	Temperature (°C)	17,8	17,9	18,5	19,2	19,0	19,1	19,0	19,4	19,3
	Pressure (Atm)	0,9849	0,9986	1,0001	0,9954	0,9911	1,0039	1,002	0,998	0,9979
	Oxygen (mg/L)	7,77	8,56	5,61	9,35	10,34	9,64	1,00	0,02	9,04
	Conductivity (µS/cm)	352	356,4	365,2	356,6	347,7	327,7	338,6	338,6	296,3
	pH	8,56	8,59	8,23	8,96	9,09	8,91	7,93	7,88	8,6
	ORP (mV)	150,8	147,7	96,1	76,2	116,3	67,5	75,2	67,9	65,6
11m	Temperature (°C)	17,8	17,9	18,3	19,2	19,0	19,1	19,0	19,3	19,3
	Pressure (Atm)	0,9849	0,9985	1,0002	0,9953	0,9912	1,0039	1,002	0,998	0,9979
	Oxygen (mg/L)	7,97	8,80	5,00	9,02	10,4	9,94	0,85	0,01	8,06
	Conductivity (µS/cm)	351,9	355,7	366,1	356,5	348,6	327,6	338,4	339	296,3
	pH	8,58	8,54	8,15	8,96	9,04	8,91	7,87	7,86	8,62
	ORP (mV)	148,3	145,7	98,7	76,3	102,1	67,1	72,5	47,1	63,9
12m	Temperature (°C)	17,8	17,8	18,2	19,1	19,0	19,1	19,0	19,3	19,3
	Pressure (Atm)	0,9848	0,9986	1,0002	0,9953	0,9911	1,0038	1,0021	0,9980	0,9978
	Oxygen (mg/L)	7,86	8,44	5,35	7,41	10,2	9,95	0,42	0,01	8,18
	Conductivity (µS/cm)	352,2	356,7	363,7	361	347,8	327,5	338,4	339,3	296,2
	pH	8,58	8,53	8,13	8,79	9,10	8,92	7,82	7,85	8,61
	ORP (mV)	146,3	145,1	97,4	79,5	101	66,5	71,4	32,0	62,9
13m	Temperature (°C)	17,7	17,7	18,1	18,4	18,9	19,1	18,8	19,2	19,3
	Pressure (Atm)	0,9848	0,9986	1,0002	0,9952	0,9912	1,0039	1,0021	0,998	0,9978
	Oxygen (mg/L)	7,83	8,34	4,61	2,37	10,03	9,64	0,01	0,01	8,1
	Conductivity (µS/cm)	352,7	356,1	365,1	369,8	347,7	327,7	342,1	341,4	296,4
	pH	8,56	8,49	8,09	8,26	9,1	8,91	7,81	7,86	8,58
	ORP (mV)	145,1	143,6	99,6	-86,2	111,3	66,3	71,0	-16,8	61,9
14m	Temperature (°C)	17,7	17,6	17,8	18,4	18,8	18,9	18,8	19,1	19,3
	Pressure (Atm)	0,9848	0,9986	1,0002	0,9952	0,9911	1,0039	1,0021	0,9979	0,9978
	Oxygen (mg/L)	7,79	7,44	0,28	0,12	9,89	3,32	0,02	0,01	8,13
	Conductivity (µS/cm)	353,5	356,5	356,1	371,9	347,3	329	343,4	343,8	296,4
	pH	8,54	8,46	7,84	8,08	9,01	8,06	7,81	7,87	8,58
	ORP (mV)	138,5	137,0	-133,8	-163,2	89,2	-147,8	0,9	-78,3	61,0

Water Profile Point L3 (6m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/16	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	18,2	18,1	20,7	19,9	19,2	19,4	23,3	21,1	19,0
	Pressure (Atm)	0,9849	0,9985	1,0002	0,995	0,9913	1,0039	1,0022	0,9979	0,9979
	Oxygen (mg/L)	8,77	9,40	10,80	11,25	11,16	11,35	18,76	10,85	8,12
	Conductivity (µS/cm)	355,2	352,1	376,9	332	347,1	323,1	283,0	292,3	294,7
	pH	8,64	8,49	8,84	9,01	9,07	9,00	9,18	9,05	8,61
	ORP (mV)	175,7	128,3	71,1	90,3	97,2	54,2	54,5	19,6	91,6
2m	Temperature (°C)	18,2	18,1	20,7	19,6	19,2	19,4	23,3	21,0	19,1
	Pressure (Atm)	0,9849	0,9985	1,0001	0,995	0,9913	1,004	1,0021	0,9978	0,9977
	Oxygen (mg/L)	8,76	9,59	10,87	11,27	11,13	11,11	18,32	11,32	8,22
	Conductivity (µS/cm)	357,5	370,2	375,9	358	346,9	323,5	283,1	292,7	294,6
	pH	8,62	8,51	8,85	9,04	9,08	9,02	9,23	9,10	8,63
	ORP (mV)	171,8	130,6	71,7	97,1	95,0	56	59,7	34,2	84,2
3m	Temperature (°C)	18,0	18,1	20,5	19,3	19,2	19,3	22,8	21,0	19,1
	Pressure (Atm)	0,9849	0,9985	1,0001	0,995	0,9913	1,0039	1,0022	0,9979	0,9977
	Oxygen (mg/L)	8,62	9,54	10,84	9,98	11,16	10,73	16,68	10,86	8,32
	Conductivity (µS/cm)	356,4	377,5	373,9	356,5	346,7	324,9	294,3	292,7	294,7
	pH	8,59	8,56	8,88	9,01	9,09	9,02	9,13	9,11	8,62
	ORP (mV)	168,7	135,4	74,2	96,9	92,7	56,9	64,9	42,1	80,8
4m	Temperature (°C)	-	18,1	20,5	19,3	19,2	19,3	21,1	21,0	19,1
	Pressure (Atm)	-	0,9986	1,0001	0,995	0,9912	1,0039	1,0022	0,9978	0,9976
	Oxygen (mg/L)	-	9,86	10,78	9,49	11,28	10,59	12,82	10,78	8,18
	Conductivity (µS/cm)	-	364,1	369,6	356,3	346,7	324,9	313,6	293,1	294,6
	pH	-	8,59	8,91	9,00	9,09	9,02	8,92	9,11	8,63
	ORP (mV)	-	143,8	87,1	95,1	101,5	57,2	71,9	45,5	76,5
5m	Temperature (°C)	-	18,1	20,5	19,3	19,2	19,3	20,0	20,9	19
	Pressure (Atm)	-	0,9987	1,0002	0,995	0,9912	1,004	1,0021	0,9977	0,9978
	Oxygen (mg/L)	-	9,22	10,09	9,53	10,99	10,55	6,95	10,18	8,21
	Conductivity (µS/cm)	-	347,6	381,8	355,8	346,8	325,4	332,5	294,4	294,7
	pH	-	8,62	8,94	9,01	9,08	9,00	8,54	9,05	8,62
	ORP (mV)	-	145,5	89,4	92,3	88,6	57,2	78	55,4	74,7
6m	Temperature (°C)	-	18,1	20,4	19,3	19,2	19,2	19,4	20,5	19,0
	Pressure (Atm)	-	0,9985	1,0001	0,9949	0,9913	1,0039	1,0022	0,9978	0,9978
	Oxygen (mg/L)	-	9,41	10,35	9,36	10,62	10,27	4,21	5,24	8,12
	Conductivity (µS/cm)	-	358,2	367,8	357	346,6	325,8	336,2	315,5	294,7
	pH	-	8,62	8,95	9,01	9,08	8,98	8,32	8,35	8,6
	ORP (mV)	-	146,9	88,4	89,6	87,4	56,3	79,6	55,6	72,3

14/06/2016 : Wrong coordinates and engine failure avoided to continue

Water Profile Point L4 (7m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/2016	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	17,7	18,0	20,5	19,4	19,1	19,3	23,9	20,8	19,4
	Pressure (Atm)	0,9851	0,9982	0,9999	0,9967	0,9911	1,0038	1,0019	0,9976	0,9977
	Oxygen (mg/L)	8,48	9,43	10,13	10,55	10,43	10,63	16,3	10,14	8,08
	Conductivity (µS/cm)	353,5	358,9	369,3	363,7	347	326,6	285,2	292,9	296,1
	pH	8,63	8,50	8,88	8,89	9,00	9,11	9,14	8,90	8,63
	ORP (mV)	130,1	150,9	54,4	86	106	115,7	58,3	70,3	47,9
2m	Temperature (°C)	17,7	18,0	20,5	19,3	19,1	19,2	23,4	20,8	19,4
	Pressure (Atm)	0,9851	0,9982	0,9999	0,9967	0,9912	1,0038	1,0019	0,9977	0,9976
	Oxygen (mg/L)	8,61	9,56	10,61	9,30	10,43	10,57	16,42	9,48	8,07
	Conductivity (µS/cm)	354,2	358,1	370,5	362,3	345,6	331,3	292,0	296,3	296,3
	pH	8,62	8,51	8,92	8,91	9,04	9,02	9,13	8,94	8,64
	ORP (mV)	125,7	148,1	62,6	90,7	101,4	101,6	69,0	72,5	53,8
3m	Temperature (°C)	17,7	18,0	20,4	19,2	19,1	19,2	20,9	20,7	19,4
	Pressure (Atm)	0,985	0,9981	0,9999	0,9967	0,9912	1,0037	1,0018	0,9977	0,9977
	Oxygen (mg/L)	8,45	9,19	10,93	8,63	10,41	10,12	10,54	9,10	8,15
	Conductivity (µS/cm)	354,1	363,1	371,8	356,9	347,5	328,2	321,2	297,2	296,4
	pH	8,62	8,54	8,89	8,98	9,05	9,11	8,75	8,85	8,64
	ORP (mV)	122,6	148,2	68,8	92,6	98,5	103,6	79,1	75,1	56,5
4m	Temperature (°C)	17,6	17,9	20,4	19,2	19,1	19,2	19,7	20,5	19,4
	Pressure (Atm)	0,985	0,9982	0,9999	0,9965	0,9911	1,0038	1,0019	0,9978	0,9978
	Oxygen (mg/L)	8,40	9,53	10,09	8,73	10,54	10,05	6,17	8,18	7,99
	Conductivity (µS/cm)	354	343,5	375,4	356,2	347,4	328,1	333,4	301,7	296,3
	pH	8,60	8,56	8,95	8,91	9,06	9,11	8,47	8,70	8,65
	ORP (mV)	119,7	163,6	79,2	88,8	95,8	105,2	82,2	74,1	58,6
5m	Temperature (°C)	17,6	17,9	19,7	19,2	19,1	19,2	19,5	20,3	19,4
	Pressure (Atm)	0,985	0,9982	1,0000	0,9965	0,9911	1,0038	1,0018	0,9979	0,9977
	Oxygen (mg/L)	8,18	9,29	8,09	8,4	10,48	9,68	4,73	9,63	8,02
	Conductivity (µS/cm)	354,2	340,5	371,5	355,2	347,6	328	334,7	293,7	296,4
	pH	8,57	8,58	8,82	8,91	9,06	9,1	8,32	8,9	8,64
	ORP (mV)	118,5	158,7	94	87,1	94,2	102,5	80,2	71,4	59,4
6m	Temperature (°C)	17,5	17,9	19,3	19,2	19,1	19,2	19,3	19,7	19,3
	Pressure (Atm)	0,985	0,9981	1,0000	0,9965	0,9911	1,0039	1,0019	0,9978	0,9977
	Oxygen (mg/L)	8,12	9,08	7,83	8,31	10,47	9,57	3,15	1,70	7,99
	Conductivity (µS/cm)	354,7	356,5	352,4	358,7	347,8	328,2	335,4	328,1	295,9
	pH	8,53	8,56	8,66	8,90	9,04	9,1	8,13	8,19	8,64
	ORP (mV)	117,6	160,8	99,9	84,9	93,4	100	78,2	83,5	59,8
7m	Temperature (°C)	17,5	17,7	19,3	19,2	19,0	19,1	19,0	19,6	19,2
	Pressure (Atm)	0,985	0,9982	1,0000	0,9965	0,9911	1,0038	1,0019	0,9978	0,9978
	Oxygen (mg/L)	7,76	8,34	7,46	7,87	10,16	8,98	0,92	0,95	7,92
	Conductivity (µS/cm)	354,9	356,3	367	357,3	347,9	328,7	337,6	343	295,6
	pH	8,49	8,52	8,62	8,89	9,04	9,08	7,95	7,97	8,63
	ORP (mV)	116,9	161,6	100,6	83,1	92,3	99,1	76,4	-88,3	60,2

Water Profile Point L5 (4m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/2016	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	17,7	18,1	20,4	19,6	18,9	19,3	24,5	20,5	19,2
	Pressure (Atm)	0,9849	0,9982	1,000	0,9965	0,9911	1,0037	1,0019	0,9977	0,9977
	Oxygen (mg/L)	8,57	9,55	10,66	9,61	9,98	11,18	16,93	9,72	8,27
	Conductivity (µS/cm)	353,9	372,9	373,8	368,6	348,7	325,3	287,6	302,4	294,8
	pH	8,67	8,48	8,79	8,89	8,99	9,11	9,15	8,82	8,64
	ORP (mV)	171,1	174,0	61,0	63,7	90,5	86,6	68,5	87,3	59,4
2m	Temperature (°C)	17,7	18,1	20,3	19,1	18,9	19,2	23,3	20,4	19,2
	Pressure (Atm)	0,985	0,9983	1,0000	0,9966	0,9912	1,0037	1,0019	0,9977	0,9978
	Oxygen (mg/L)	8,71	9,87	10,19	8,86	9,98	10,3	15,22	8,48	8,21
	Conductivity (µS/cm)	353,8	358,8	372,4	357,6	348,1	324,9	295,8	305,3	295,1
	pH	8,66	8,52	8,84	8,9	8,99	8,98	9,07	8,73	8,64
	ORP (mV)	166,9	173,0	61,4	76,2	89,4	84,5	68,7	88,7	60,5
3m	Temperature (°C)	17,7	18,1	20,3	19,1	18,9	19,1	20,2	20,2	19,2
	Pressure (Atm)	0,9849	0,9983	1,0000	0,9965	0,9912	1,0037	1,0019	0,9978	0,9978
	Oxygen (mg/L)	8,62	9,86	9,86	7,89	9,85	9,77	6,17	7,27	8,24
	Conductivity (µS/cm)	353,4	283,6	372,8	356,8	348,2	327,1	331,3	310,4	295,1
	pH	8,66	8,54	8,85	8,89	8,99	8,96	8,54	8,55	8,64
	ORP (mV)	162,4	174,4	65,8	75,8	87,3	86,7	77,1	89,1	60,9
4m	Temperature (°C)	17,6	18,1	20,2	19,1	18,9	19,1	19,5	20,1	19,2
	Pressure (Atm)	0,9849	0,9983	1,0000	0,9966	0,9912	1,0037	1,0019	0,9978	0,9978
	Oxygen (mg/L)	8,60	9,80	9,43	7,74	9,84	9,47	2,43	5,81	8,23
	Conductivity (µS/cm)	352,9	360,6	368,4	356,3	348,3	326,7	335,4	313,8	295,1
	pH	8,65	8,57	8,85	8,89	9,00	8,91	8,22	8,42	8,65
	ORP (mV)	159,3	175,4	69,0	74,9	85,8	83,7	79,9	86,5	59,6

Water Profile Point L6 (10m depth)

		14/06/2016	21/06/2016	28/06/2016	05/07/2016	12/07/2016	19/07/2016	26/07/2016	02/08/2016	09/08/2016
1m	Temperature (°C)	18,0	17,9	20,6	19,3	19,2	19,3	23,9	20,9	19,3
	Pressure (Atm)	0,9851	0,998	0,9997	0,997	0,991	1,0038	1,0018	0,998	0,9978
	Oxygen (mg/L)	8,28	9,22	10,64	9,50	10,69	10,69	17,87	11,33	7,95
	Conductivity (µS/cm)	349,7	358,7	373,5	369,6	347,5	321,4	283,8	289,8	294,6
	pH	8,60	8,53	8,82	8,88	9,06	9,11	9,22	9,07	8,64
	ORP (mV)	141,0	148,9	88,1	77,9	80,7	125,3	80,9	85,7	49,6
2m	Temperature (°C)	17,9	17,9	20,5	19,3	19,1	19,3	22,9	20,9	19,3
	Pressure (Atm)	0,9851	0,998	0,9998	0,9969	0,991	1,0037	1,0018	0,998	0,9978
	Oxygen (mg/L)	8,38	9,03	10,72	8,86	10,79	10,29	16,95	11,22	8,03
	Conductivity (µS/cm)	350,2	357,9	294	307,5	347,3	322,3	297,1	289,8	295,2
	pH	8,59	8,82	8,87	8,89	9,06	9,18	9,08	9,12	8,65
	ORP (mV)	135,9	147,9	88,4	85,6	79,8	126,3	82,2	84,5	49,8
3m	Temperature (°C)	17,9	17,9	20,4	19,3	19,1	19,3	21,3	20,7	19,3
	Pressure (Atm)	0,9851	0,998	0,9998	0,9969	0,991	1,0037	1,0018	0,9981	0,9977
	Oxygen (mg/L)	8,44	9,3	10,75	8,64	10,45	10,34	12,55	10,11	7,97
	Conductivity (µS/cm)	351	354,4	366,5	354,9	347,4	324,3	316,4	292,8	295,6
	pH	8,58	8,54	8,87	8,93	9,06	9,17	8,84	9,06	8,66
	ORP (mV)	132,0	150,6	101,3	87,6	78,3	123,6	85,3	91,0	52,0
4m	Temperature (°C)	17,9	17,9	20,3	19,3	19,1	19,2	19,8	20,6	19,3
	Pressure (Atm)	0,9851	0,998	0,9997	0,9969	0,9909	1,0037	1,0018	0,9981	0,9977
	Oxygen (mg/L)	8,23	9,19	10,71	8,91	10,22	10,52	5,57	9,37	8,03
	Conductivity (µS/cm)	351,5	361,5	361,4	353,5	347,5	325	333,5	296,4	295,5
	pH	8,58	8,56	8,94	8,93	9,05	9,06	8,41	9,03	8,74
	ORP (mV)	129,6	152,4	95,2	85,8	78,2	118,4	88,4	105,6	55,6
5m	Temperature (°C)	17,8	17,9	19,6	19,2	19,0	19,2	19,6	20,6	19,3
	Pressure (Atm)	0,9851	0,998	0,9997	0,9968	0,9909	1,0036	1,0019	0,998	0,9978
	Oxygen (mg/L)	8,52	9,05	8,34	8,68	10,31	9,63	4,71	9,48	8,11
	Conductivity (µS/cm)	351,5	369,7	383,3	353,4	347,6	325,9	334	296,5	295,5
	pH	8,58	8,57	8,68	8,92	9,07	9,13	8,28	8,98	8,66
	ORP (mV)	127,3	154,5	104,2	81,9	78,6	118,7	85,0	92,1	54,8
6m	Temperature (°C)	17,8	17,9	19,2	19,2	19,0	19,2	19,5	20,2	19,3
	Pressure (Atm)	0,9851	0,9981	0,9998	0,9969	0,9911	1,0036	1,0018	0,998	0,9978
	Oxygen (mg/L)	8,43	8,87	7,67	8,61	10,33	9,66	4,37	5,62	8,11
	Conductivity (µS/cm)	351,5	360	367,8	355,4	347,7	326,2	334,4	313,3	295,5
	pH	8,59	8,59	8,59	8,91	9,05	9,13	8,2	8,6	8,66
	ORP (mV)	125,0	158,3	111,3	78,9	77,0	115,5	81,1	104,1	56,3
7m	Temperature (°C)	17,7	17,8	19,2	19,2	19,0	19,2	19,4	19,8	19,3
	Pressure (Atm)	0,9851	0,998	0,9998	0,9968	0,9911	1,0037	1,0019	0,9979	0,9977
	Oxygen (mg/L)	8,43	8,86	7,57	8,71	10,17	9,6	4,29	1,85	7,81
	Conductivity (µS/cm)	351,7	356,3	366,2	355	347,1	326,4	334,5	329	295,5
	pH	8,58	8,6	8,53	8,9	9,05	9,12	8,17	7,95	8,67
	ORP (mV)	123,6	158,4	108,3	75,8	78,1	109,6	77,5	78,0	56,2

8m	**Temperature (°C)**	17,6	17,8	18,9	19,2	18,9	19,2	19,3	19,7	19,3
	Pressure (Atm)	0,9852	0,9981	0,9998	0,9969	0,9912	1,0038	1,0019	0,9979	0,9978
	Oxygen (mg/L)	8,29	9,12	6,77	8,04	9,87	9,76	3,17	1,81	8,03
	Conductivity (µS/cm)	351,3	360,8	365,2	355,4	345,6	326,8	335,4	329,7	295,4
	pH	8,57	8,58	8,52	8,89	9,01	9,11	8,07	7,98	8,66
	ORP (mV)	122,3	158,4	113,6	72,5	77,5	108,1	77,0	80,0	56,0
9m	**Temperature (°C)**	17,6	17,8	18,5	19,1	18,8	19,2	19,1	19,4	19,3
	Pressure (Atm)	0,9851	0,9981	0,9999	0,9968	0,9911	1,0038	1,0019	0,9979	0,9977
	Oxygen (mg/L)	8,11	8,61	5,37	7,80	9,68	9,59	1,11	0,26	7,77
	Conductivity (µS/cm)	351,6	375,2	365,1	356,7	346,7	327	337,2	337,8	295,3
	pH	8,56	8,56	8,26	8,82	8,99	9,12	7,94	7,9	8,64
	ORP (mV)	121,1	157,4	110,0	71,9	77,4	105,8	77,2	70,1	54,8
10m	**Temperature (°C)**	17,4	17,7	18,3	18,8	18,8	19,2	18,9	19,4	19,3
	Pressure (Atm)	0,9852	0,9981	0,9998	0,9968	0,9911	1,0038	1,0019	0,9979	0,9977
	Oxygen (mg/L)	8,16	8,28	4,39	5,14	7,65	9,67	0,19	0,17	7,64
	Conductivity (µS/cm)	351,5	353,6	364,9	357,5	346,7	327,4	339,7	338,5	296,6
	pH	8,53	8,51	8,13	8,49	8,89	8,93	7,88	7,85	8,6
	ORP (mV)	120,4	132,9	112,7	71,5	12,4	84,4	64,5	55,9	-96,2

Appendix 5 : Investigation of the P-ponds – data

	Date Analyses P	14/06/16	17/06/16	20/06/16	23/06/16	27/06/16	30/06/13	7/4/2016	7/7/2016	11/7/2016	14/07/16	18/7/2016	21/7/2016	25/7/16	28/07/16	1/8/2016	4/8/2016	8/8/2016	11/8/2016
	Date Samples	13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
1.In	Turbidity (NTU)	0.48	1.10	0.58	1.55	1.74	2.00	3.20	1.90	13.50	2.15	0.99	1.18	0.91	0.79	0.78	1.67	1.04	0.94
	P Total (mg/L P)	0.105	0.080	0.082	0.079	0.106	0.381	0.400	0.145	0.264	0.120	0.036	0.038	0.042	0.036	0.047	0.068	0.040	0.036
	Ortho Phosphate (mg/L P)	0.095	0.076	0.079	0.077	0.101	0.384	0.378	0.138	0.234	0.092	0.034	0.036	0.040	0.034	0.036	0.064	0.037	0.033
	Particulate Phosphorus (mg/L P)	0.010	0.004	0.003	0.002	0.005	0.000	0.022	0.007	0.030	0.028	0.002	0.002	0.003	0.002	0.011	0.004	0.003	0.003
	Temperature (°C)	11	11.4	11.7	11.9	12.3	12.1	12.1	12.2	13.5	12.4	12.7	12.8	13.5	13.2	13	13.4	13.1	12.5
	Pressure (Atm)	0.9856	0.9794	0.9983	1.0018	0.9928	0.9895	0.995	0.9924	0.9818	0.9913	0.9939	0.9948	0.9965	0.9909	0.99	0.9843	0.9887	0.9936
	Oxygen (mg/L)	10.44	10.24	10.98	11.07	10.59	10.6	10.66	10.4	10.08	10.53	10.35	10.3	8.67	9.76	9.44	8.39	9.22	8.72
	Conductivity (µS/cm)	468.2	455.2	489.2	492.7	499.5	477.4	436.7	487.7	453.3	512	513	502	526	528	496.8	510	515	335
	pH	8.29	8.37	8.35	8.11	8.11	8.46	8.52	8.67	8.37	8.65	8.49	8.45	8.53	8.17	8.72	8.22	8.62	8.68
	ORP (mV)	164	46.3	74.6	54.4	76.6	92.2	73	100.8	102.2	115.3	74.7	105.1	83.6	87.6	63	88.2	63.4	98.5
	Flow (L/s)	2.23	1.94	0.88	0.37	0.62	0.57	0.58	1.04	6.44	0.89	0.58	0.44	-	-	-	-	-	-

		13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
1.Out	Turbidity (NTU)	3.40	4.10	4.70	4.88	5.14	5.60	5.00	4.20	1.49	6.12	9.80	2.10	2.08	8.40	4.10	3.68	1.45	2.05
	P Total (mg/L P)	0.090	0.060	0.078	0.074	0.108	0.336	0.343	0.074	0.048	0.077	0.029	0.020	0.015	0.026	0.019	0.015	0.011	0.009
	Ortho Phosphate (mg/L P-PO4)	0.046	0.030	0.031	0.025	0.042	0.303	0.277	0.040	0.026	0.023	0.004	0.001	0.001	0.005	0.004	0.005	0.003	0.001
	Particulate Phosphorus (mg/L P)	0.044	0.030	0.047	0.049	0.066	0.033	0.066	0.034	0.022	0.054	0.025	0.019	0.015	0.021	0.015	0.010	0.009	0.009
	Temperature (°C)	18.0	17.4	17.6	20.3	20.8	18.4	17.7	16.6	18.4	18.8	18.6	20.2	21.1	19.8	19.4	18.5	18.2	15.5
	Pressure (Atm)	0.9855	0.9797	0.9983	1.0019	0.9930	0.9898	0.9951	0.9924	0.9819	0.9909	0.9940	0.9947	0.9965	0.9909	0.9900	0.9843	0.9884	0.9936
	Oxygen (mg/L)	11.92	10.42	11.19	11.24	7.02	6.90	7.98	8.34	8.56	8.55	9.47	7.25	8.05	5.96	6.97	6.75	8.19	9.18
	Conductivity (µS/cm)	363.10	377.60	396.00	386.20	382.70	366.90	377.60	361.40	398.70	387.90	404.60	424.80	419.90	400.30	429.00	349.20	381.60	364.80
	pH	8.85	8.77	8.45	8.39	8.22	8.30	8.44	8.55	8.35	8.45	8.49	8.55	8.62	8.31	8.38	8.51	8.69	8.95
	ORP (mV)	120.8	93.6	57.7	36.3	65.8	96.8	138.2	159.4	119.3	120.9	88.5	67.4	69.8	66.7	57.7	42.6	47.3	82.1
	Flow (L/s)	3.79	5.92	2.59	2.14	1.33	1.91	1.94	2.80	23.12	2.90	0.87	1.49	1.55	1.50	1.08	1.57	0.62	0.45
	Percentage Reduce P total (%)	14.3	25.0	4.9	6.3	-1.9	11.8	14.3	49.0	81.8	35.8	19.7	47.4	64.3	28.2	60.2	78.5	72.2	75.0
	Percentage Réduce Ortho-Phosphate (%)	51.6	60.5	60.8	67.5	58.4	21.1	26.7	71.0	88.9	75.0	88.1	97.2	98.7	85.1	90.3	93.0	93.2	98.5

	Date Analyses P	14/06/16	17/06/16	20/06/16	23/06/16	27/06/16	30/06/13	7/4/2016	7/7/2016	11/7/2016	14/07/16	18/7/2016	21/7/2016	25/7/16	28/07/16	1/8/2016	4/8/2016	8/8/2016	11/8/2016
	Date Samples	13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
2.In	Turbidity (NTU)	0.35	0.73	0.29	0.50	0.57	0.70	2.25	0.69	1.80	0.68	0.39	0.32	0.34	0.30	0.58	1.11	0.56	0.47
	P Total (mg/L P)	0.050	0.039	0.037	0.033	0.047	0.300	0.295	0.045	0.050	0.047	0.004	0.004	0.004	0.002	0.004	0.002	0.003	0.002
	Ortho Phosphate (mg/L P)	0.054	0.039	0.038	0.032	0.046	0.304	0.288	0.044	0.049	0.023	0.002	0.002	0.002	0.003	0.002	0.004	0.002	0.000
	Particulate Phosphorus (mg/L P)	0.000	0.000	0.000	0.001	0.001	0.000	0.007	0.001	0.001	0.024	0.002	0.002	0.002	0.000	0.002	0.000	0.001	0.002
	Temperature (°C)	10.2	10.3	10.4	10.7	11.3	10.6	11.0	11.0	11.8	11.4	11.6	12.0	12.1	12.2	12.1	12.4	12.5	12.2
	Pressure (Atm)	0.9858	0.9802	0.9988	1.0022	0.9931	0.9900	0.9954	0.9926	0.9822	0.9911	0.9941	0.9949	0.9968	0.9914	0.9904	0.9847	0.9886	0.9940
	Oxygen (mg/L)	10.61	10.78	11.41	11.01	10.91	11.18	10.85	10.96	10.42	10.94	11.18	9.82	8.97	8.15	9.24	8.99	8.83	8.95
	Conductivity (µS/cm)	391.8	399.0	397.5	383.7	411.5	400.0	410.8	397.5	409.9	408.9	429.8	417.2	416.5	421.5	430.1	432.3	433.6	418.8
	pH	8.30	7.83	8.05	7.57	7.85	8.21	8.16	8.51	7.97	8.40	8.15	8.00	7.94	7.62	8.34	8.06	8.05	8.65
	ORP (mV)	124.7	113.0	75.9	208.4	79.4	144.7	143.6	173.1	135.8	134.2	124.1	93.5	101.2	94.6	83.6	78.5	67.8	71.7
	Flow (L/s)	0.38	0.32	0.28	0.24	0.21	0.22	0.20	0.23	0.45	0.25	0.23	0.21	0.18	0.17	0.17	0.18	0.16	0.17

		13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
2.Out	Turbidity (NTU)	1.14	1.60	1.29	3.10	-	2.60	1.80	2.80	19.10	10.04	1.25	0.65	0.77	0.80	0.58	0.47	0.44	0.48
	P Total (mg/L P)	0.087	0.066	0.072	0.156	-	0.347	0.324	0.067	0.146	0.070	0.016	0.011	0.011	0.014	0.011	0.005	0.005	0.005
	Ortho Phosphate (mg/L P)	0.066	0.029	0.046	0.102	-	0.287	0.277	0.037	0.104	0.024	0.002	0.001	0.002	0.001	0.001	0.000	0.000	0.000
	Particulate Phosphorus (mg/L P)	0.021	0.037	0.026	0.054	-	0.060	0.047	0.030	0.042	0.046	0.015	0.011	0.010	0.013	0.010	0.005	0.005	0.005
	Temperature (°C)	14.1	15.3	14.2	14.4	-	16.5	16.5	16.4	18.1	18.2	18.4	20.2	20.4	18.6	17.2	18.0	18.2	13.9
	Pressure (Atm)	0.9864	0.9807	0.9993	1.0028	-	0.9903	0.9956	0.9930	0.9828	0.9909	0.9942	0.9951	0.9967	0.9915	0.9906	0.9847	0.9887	0.9940
	Oxygen (mg/L)	7.91	7.95	8.78	3.91	-	9.42	13.00	12.62	9.17	12.31	9.10	9.22	6.38	6.72	7.85	8.45	8.17	9.30
	Conductivity (µS/cm)	365.4	369.5	365.9	395.8	-	372.9	359.9	346.0	364.8	343.4	422.3	415.7	417.9	425.5	378.8	382.6	381.1	340.5
	pH	8.07	8.04	7.86	7.68	-	8.00	8.38	8.66	7.90	8.17	7.89	7.90	7.87	7.86	8.07	8.26	8.17	8.51
	ORP (mV)	34.6	87.3	-4.1	136.2	-	140.0	128.2	180.7	124.7	157.1	87.0	69.5	74.2	84.1	95.7	68.9	60.6	72.0
	Flow (L/s)	0.03	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Percentage Reduce P total (%)	-74.0	-69.2	-94.6	-372.7		-15.7	-9.8	-48.9	-192.0	-48.9	-357.1	-214.3	-214.3	-575.0	-200.0	-150.0	-100.0	-125.0
	Percentage Réduce Ortho-Phosphate (%)	-22.2	25.6	-21.1	-218.8		5.6	3.8	15.9	-112.2	-4.3	0.0	66.7	25.0	80.0	66.7	100.0	100.0	#DIV/0!
					Standing Water		Pond	Pond	Pond		Pond	Pond	Pond	Pond	Pond	Pond	Pond	Pond	Pond

	Date Analyses P	14/06/16	17/06/16	20/06/16	23/06/16	27/06/16	30/06/13	7/4/2016	7/7/2016	11/7/2016	14/07/16	18/7/2016	21/7/2016	25/7/16	28/07/16	1/8/2016	4/8/2016	8/8/2016	11/8/2016
	Date Samples	13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
3.In	Turbidity (NTU)	0.85	1.70	1.00	1.15	1.13	2.10	1.50	3.90	10.00	4.20	2.30	2.00	1.80	1.50	1.25	2.05	4.80	1.30
	P Total (mg/L P)	0.139	0.126	0.130	0.128	0.158	0.407	0.398	0.224	0.236	0.153	0.164	0.064	0.066	0.058	0.054	0.063	0.055	0.043
	Ortho Phosphate (mg/L P)	0.123	0.105	0.108	0.112	0.135	0.382	0.379	0.175	0.189	0.093	0.135	0.053	0.056	0.051	0.047	0.055	0.046	0.037
	Particulate Phosphorus (mg/L P)	0.016	0.021	0.022	0.016	0.023	0.025	0.019	0.049	0.047	0.060	0.029	0.011	0.010	0.006	0.007	0.009	0.010	0.006
	Temperature (°C)	12.5	13.8	13.1	15.3	15.2	14.2	13.4	13.9	17.3	15.9	15.5	16.4	16.8	15.9	14.7	15.9	16.0	11.9
	Pressure (Atm)	0.9887	0.9832	1.0018	1.0052	0.9958	0.9929	0.9987	0.9961	0.9852	0.9940	0.9974	0.9979	0.9995	0.9944	0.9932	0.9876	0.9916	0.9971
	Oxygen (mg/L)	10.02	9.59	10.44	9.83	10.09	9.88	10.40	10.00	8.97	9.54	9.86	7.62	8.07	7.93	7.90	7.37	7.72	8.91
	Conductivity (µS/cm)	410.5	421.6	437.8	476.5	440.9	387.3	394.6	398.0	350.7	343.0	405.0	428.9	456.0	446.3	446.6	442.7	468.4	411.1
	pH	8.36	8.29	8.15	8.14	8.22	8.28	8.29	8.43	8.22	8.37	8.28	8.43	8.47	8.43	8.38	8.43	8.32	8.51
	ORP (mV)	122.6	97.1	62.5	98.8	62.4	130.2	145.2	191.3	128.0	143.2	105.9	74.0	90.0	79.7	77.3	73.1	64.6	90.4
	Flow(L/s)	63.30	68.06	53.57	47.43	27.85	39.92	37.86	167.78	235.03	194.54	47.97	31.35	21.26	16.82	18.55	22.45	13.98	10.34

		13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
3.Out	Turbidity (NTU)	6.60	7.70	5.40	4.02	4.14	3.80	3.30	4.40	5.60	6.40	5.70	4.30	4.40	5.10	5.80	7.80	7.40	7.30
	P Total (mg/L P)	0.143	0.217	0.253	0.218	0.496	0.758	0.750	0.483	0.407	0.395	0.395	0.152	0.161	0.235	0.285	0.283	0.289	0.228
	Ortho Phosphate (mg/L P)	0.055	0.072	0.152	0.117	0.372	0.648	0.643	0.385	0.323	0.248	0.286	0.112	0.126	0.192	0.236	0.207	0.202	0.144
	Particulate Phosphorus (mg/L P)	0.088	0.145	0.101	0.101	0.124	0.110	0.107	0.098	0.084	0.147	0.109	0.040	0.035	0.044	0.049	0.076	0.087	0.084
	Temperature (°C)	18.7	17.7	17.5	21.5	21.2	18.9	18.7	18.1	19.2	19.9	19.5	21.9	23.8	22.4	21.0	19.7	18.9	17.2
	Pressure (Atm)	0.9885	0.9835	1.0017	1.0055	0.9960	0.9933	0.9989	0.9966	0.9855	0.9940	0.9976	0.9982	0.9997	0.9946	0.9935	0.9881	0.9916	0.9973
	Oxygen (mg/L)	11.67	8.16	10.14	13.17	7.93	7.39	7.60	7.00	9.18	11.41	10.64	9.44	6.55	6.70	6.22	7.41	5.20	7.88
	Conductivity (µS/cm)	311.3	318.4	312.8	344.4	347.1	330.1	330.6	328.9	329.3	332.8	339.8	348.9	360.6	370.2	387.4	210.6	370.9	348.2
	pH	8.93	8.62	8.60	8.92	8.81	8.82	8.76	8.75	8.93	9.32	9.25	9.51	9.36	9.17	8.86	9.08	8.63	9.00
	ORP (mV)	113.7	99.0	64.6	73.4	60.2	114.7	137.1	161.7	129.8	86.6	86.3	76.6	82.4	83.9	219.3	76.6	73.7	64.3
	Flow (L/s)	137.89	126.37	108.24	101.08	85.87	83.29	103.10	133.21	318.72	350.19	153.64	77.79	70.34	41.52	26.16	24.21	43.93	48.81
	Percentage Reduce P total (%)	-2.9	-72.2	-94.6	-70.3	-213.9	-86.2	-88.4	-115.6	-72.5	-158.2	-140.9	-136.7	-143.2	-308.7	-426.9	-349.2	-425.5	-435.3
	Percentage Réduce Ortho-Phosphate (%)	55.28	31.43	-40.74	-4.46	-175.56	-69.63	-69.66	-120.00	-70.90	-166.67	-111.85	-110.38	-124.11	-275.49	-401.06	-279.82	-343.96	-294.52

	Date Analyses P	14/06/16	17/06/16	20/06/16	23/06/16	27/06/16	30/06/13	7/4/2016	7/7/2016	11/7/2016	14/07/16	18/7/2016	21/7/2016	25/7/16	28/07/16	1/8/2016	4/8/2016	8/8/2016	11/8/2016
	Date Samples	13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
4.Out	Turbidity (NTU)	5.23	4.90	2.20	1.80	2.24	2.20	1.75	2.00	3.30	5.63	4.10	3.30	2.56	2.40	2.00	1.64	1.72	1.74
	P Total (mg/L P)	0.177	0.334	0.262	0.249	0.348	0.679	0.733	0.478	0.435	0.436	0.480	0.203	0.195	0.241	0.236	0.214	0.198	0.184
	Ortho Phosphate (mg/L P)	0.085	0.105	0.208	0.196	0.244	0.628	0.668	0.397	0.372	0.290	0.377	0.164	0.162	0.208	0.201	0.179	0.167	0.154
	Particulate Phosphorus (mg/L P)	0.092	0.229	0.054	0.053	0.104	0.051	0.065	0.081	0.063	0.146	0.103	0.039	0.033	0.033	0.035	0.035	0.031	0.031
	Temperature (°C)	16.7	16.6	16.6	18.9	20.0	18.1	17.3	16.7	18.5	18.8	18.8	21.1	22.4	20.5	19.5	18.7	18.3	15.9
	Pressure (Atm)	0.9895	0.9844	1.0023	1.0060	0.9966	0.9939	0.9992	0.9973	0.9861	0.9947	0.9981	0.9990	1.0000	0.9952	0.9941	0.9887	0.9918	0.9977
	Oxygen (mg/L)	9.29	9.10	7.68	8.31	7.80	6.94	6.86	7.20	7.51	7.38	6.25	5.81	6.21	4.62	5.76	6.02	5.95	6.49
	Conductivity (µS/cm)	364.5	351.4	351.6	365.9	286.9	359.2	355.3	333.9	355.9	343.5	359.2	375.1	393.1	385.2	392.0	392.2	325.7	382.6
	pH	8.40	8.30	7.93	8.04	8.13	8.07	7.97	8.10	8.12	8.70	8.49	8.77	8.73	8.33	8.20	8.17	8.08	8.28
	ORP (mV)	121.3	102.3	89.4	103.9	102.0	127.6	150.6	186.3	131.3	106.9	91.6	57.8	73.7	60.0	115.8	56.1	58.2	92.4
	Flow (L/s)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Date Analyses P	14/06/16	17/06/16	20/06/16	23/06/16	27/06/16	30/06/13	7/4/2016	7/7/2016	11/7/2016	14/07/16	18/7/2016	21/7/2016	25/7/16	28/07/16	1/8/2016	4/8/2016	8/8/2016	11/8/2016
	Date Samples	13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
5.In	Turbidity (NTU)	1.37	4.60	4.58	13.60	6.04	3.10	4.30	2.80	6.10	5.60	4.70	7.30	10.20	5.20	4.90	5.30	4.70	6.80
	P Total (mg/L P)	0.124	0.076	0.077	0.137	0.125	0.350	0.370	0.099	0.064	0.079	0.037	0.059	0.061	0.049	0.044	0.057	0.054	0.052
	Ortho Phosphate (mg/L P)	0.074	0.050	0.056	0.095	0.096	0.329	0.329	0.078	0.074	0.061	0.025	0.036	0.041	0.036	0.030	0.038	0.039	0.034
	Particulate Phosphorus (mg/L P)	0.050	0.026	0.021	0.042	0.029	0.021	0.041	0.021	0.000	0.018	0.012	0.023	0.020	0.013	0.014	0.019	0.015	0.018
	Temperature (°C)	12.7	13.7	18.2	19.1	17.3	15.8	14.7	14.8	15.6	14.4	16.2	19.4	21.6	18.6	16.8	17.6	18.5	13.1
	Pressure (Atm)	0.9899	0.9853	1.0028	1.0069	0.9975	0.9946	1.0004	0.9984	0.9869	0.9954	0.9993	0.9999	1.0008	0.9960	0.9948	0.9893	0.9926	0.9987
	Oxygen (mg/L)	10.26	9.79	14.83	8.54	9.06	9.81	9.51	9.79	9.52	9.09	8.89	7.73	6.50	6.91	6.88	6.92	6.52	8.08
	Conductivity (µS/cm)	436.0	432.1	446.5	482.3	458.8	440.4	429.4	431.1	494.4	471.9	467.4	498.9	521.0	503.0	476.2	495.7	499.8	443.1
	pH	8.37	8.24	8.21	7.98	8.10	8.22	8.18	8.26	8.36	8.44	8.24	8.28	8.33	8.25	8.20	8.19	8.18	8.30
	ORP (mV)	130.6	109.6	84.1	92.2	110.2	118.6	155.8	191.8	120.3	120.3	125.1	69.2	71.4	73.7	104.0	70.5	58.5	91.4
	Flow (L/s)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		13-Jun	16-Jun	20-Jun	23-Jun	27-Jun	30-Jun	4-Jul	7-Jul	11-Jul	14-Jul	18-Jul	21-Jul	25-Jul	28-Jul	1-Aug	4-Aug	8-Aug	11-Aug
5.Out	Turbidity (NTU)	0.90	0.82	0.94	1.16	1.54	1.70	1.46	1.70	1.31	1.91	1.88	1.40	1.40	1.40	1.00	1.25	1.50	1.10
	P Total (mg/L P)	0.12	0.088	0.104	0.106	0.141	0.377	0.377	0.138	0.102	0.129	0.055	0.052	0.050	0.048	0.037	0.031	0.032	0.031
	Ortho Phosphate (mg/L P)	0.086	0.058	0.069	0.074	0.097	0.34	0.337	0.116	0.093	0.076	0.037	0.033	0.031	0.03	0.022	0.018	0.019	0.019
	Particulate Phosphorus (mg/L P)	0.034	0.03	0.035	0.032	0.044	0.037	0.04	0.022	0.009	0.053	0.0175	0.019	0.0185	0.0175	0.015	0.013	0.013	0.012
	Temperature (°C)	16.1	17	17.3	20.9	20	17.9	17.7	16.6	19.6	19.7	19.1	22.7	24	21	-	19.1	19	14.9
	Pressure (Atm)	0.9898	0.9855	1.0029	1.0069	0.9975	0.9945	1.0004	0.9983	0.9869	0.9952	0.9992	0.9999	1.0008	0.9959	-	0.9895	0.9925	0.9988
	Oxygen (mg/L)	9.04	9.84	10.06	10.54	6.71	5.95	7.91	7.43	8.85	9.58	8.32	9.8	7.32	5.52	-	6.01	6.25	6.45
	Conductivity (µS/cm)	211.6	217.6	224.9	244.6	236.3	234.1	236.9	236.2	226.2	230.5	236.4	244.5	249.8	256.1	-	244.7	243.1	223.4
	pH	9.64	9.6	9.35	9.47	8.89	8.8	9.08	8.6	9.22	9.39	9.03	9.5	9.49	8.89	-	8.91	8.9	8.85
	ORP (mV)	90.1	84.2	73.7	35.9	91.9	94.5	158.5	202.7	119.2	100.4	127.9	54.5	27.3	51.4	-	43.5	73.5	68.5
	Flow (L/s)	1.29	1.17	1.33	1.13	1.12	1.05	0.84	1.00	1.33	1.37	0.99	0.82	0.56	0.41	0.23	0.18	-	-
	Percentage Reduce P total (%)	3.2	-15.8	-35.1	22.6	-12.8	-7.7	-1.9	-39.4	-59.4	-63.3	-49.3	11.1	18.2	2.1	16.1	46.0	40.2	40.8
	Percentage Réduce Ortho-Phosphate (%)	-16.2	-16.0	-23.2	22.1	-1.0	-3.3	-2.4	-48.7	-25.7	-24.6	-48.0	8.3	24.4	15.5	28.3	52.6	50.6	45.6

Appendix 6 : Depth measurements

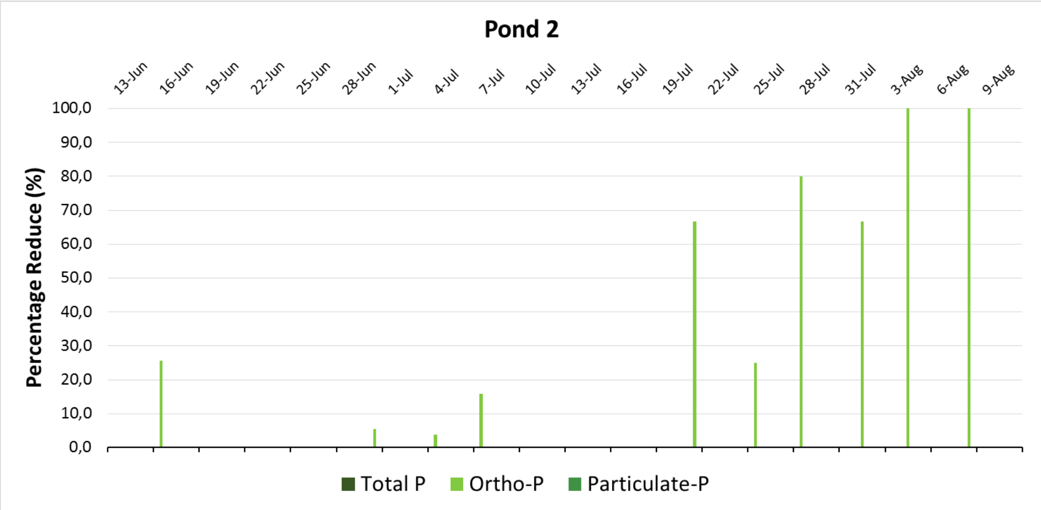
Pond 3

Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Depth (m)	2,60	2,40	2,40	2,60	1,90	0,70	1,00	1,40	1,40	1,80	1,50	2,00	1,50	1,50
Average depth (m)	1,70													
Water surface (ha)	17,5													
Pond volume (m^3)	298 000													

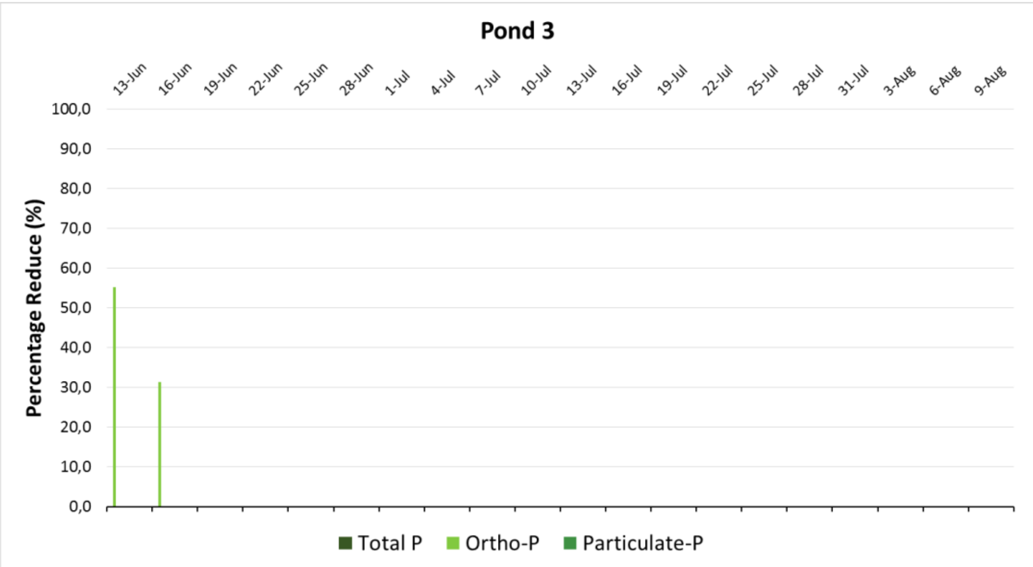
Pond 4

Point	1	2	3	4	5
Depth (m)	3,00	2,10	1,60	1,20	1,35
Average depth (m)	1,90				
Water surface (ha)	1,1				
Pond volume (m^3)	20 900				

Appendix 7 : Investigation of the P-ponds – Efficiency

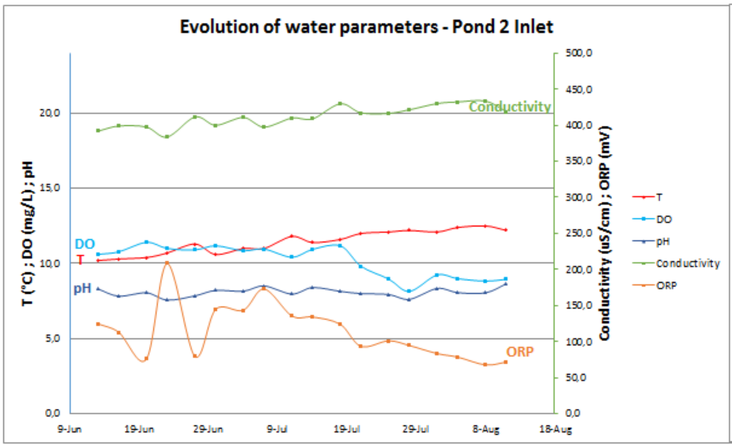


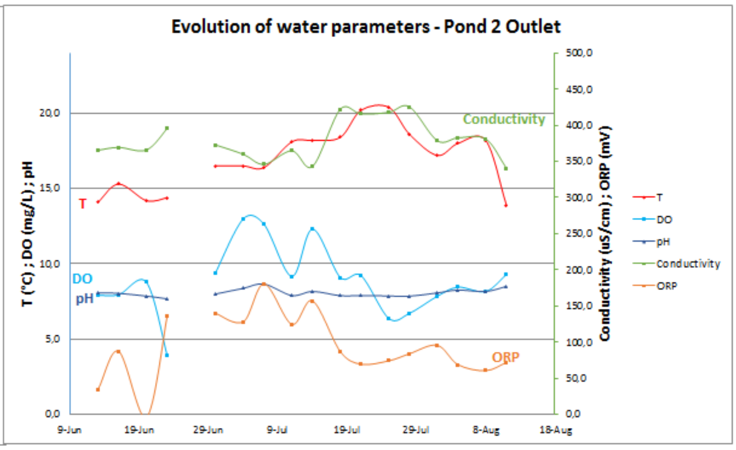
Efficiency of P-pond 2 : percentage reduce between inlet and outlet

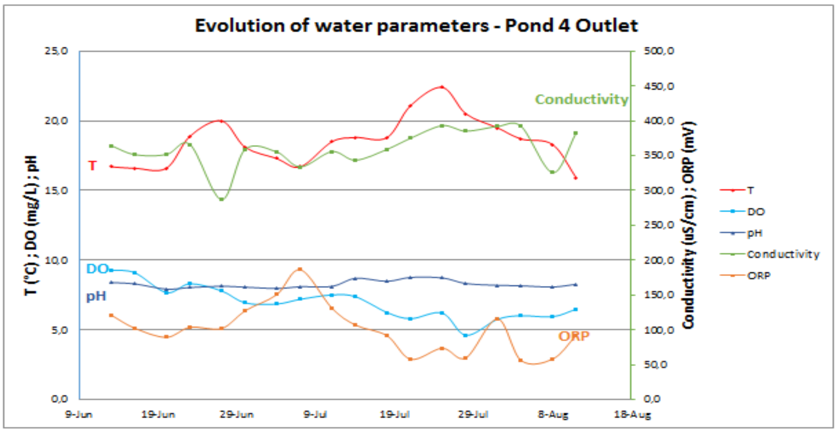


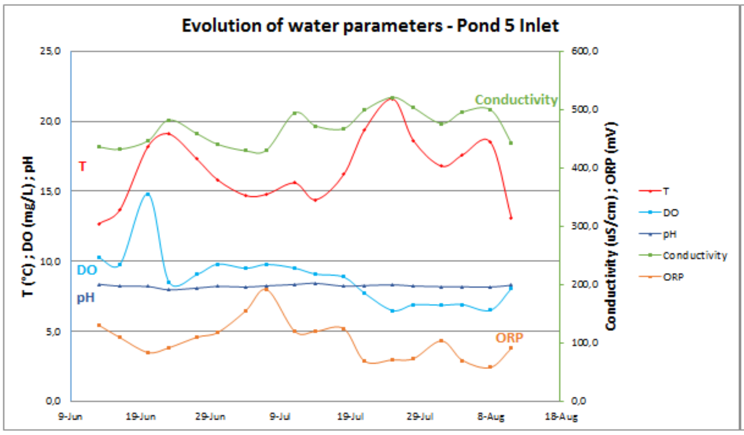
Efficiency of P-pond 3 : percentage reduce between inlet and outlet

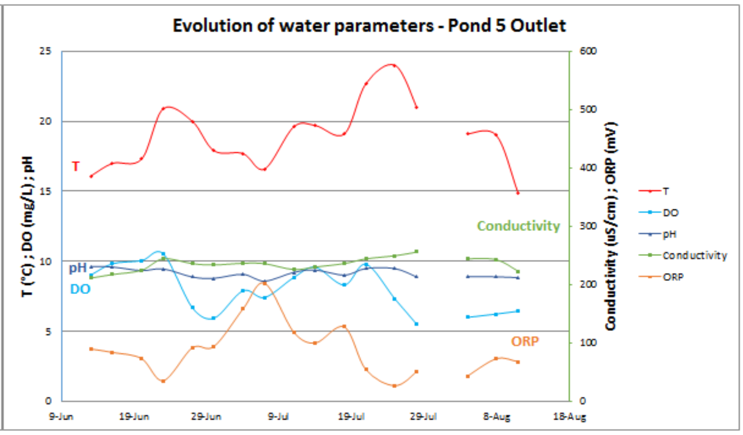
Appendix 8 : Investigation of the P-ponds – Water parameters











Evolution of T, DO, pH, conductivity, ORP and flows in ponds 2, 4 and 5 inlet and outlet

Appendix 9 : Investigation of the P-ponds – Loads of phosphorus

		pond 1 inlet	pond 1 outlet	pond 2 intlet	pond 2 outlet	pond 3 inlet	pond 3 outlet	pond 4 intlet	pond 4 outlet	pond 5 inlet	pond 5 outlet
	Average flow (L/s)	0,921	2,457	0,235	0,047	62,000	113,000	113,000	113,000	0,412	0,824
	Total P (mg/L)	0,117	0,079	0,054	0,083	0,148	0,341	0,341	0,338	0,106	0,112
	Load of P (mg/s)	0,108	0,194	0,013	0,004	9,176	38,533	38,533	38,194	0,044	0,092
	Time (days)	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000
	Time(s)	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000	5184000,000
for 60 days	Load of P (mg)	558430,330	1006229,952	65896,934	20218,481	47568384,000	199755072,000	199755072,000	197997696,000	226395,648	478479,053
	Load of P (kg)	**0,558**	**1,006**	**0,066**	**0,020**	**47,568**	**199,755**	**199,755**	**197,998**	**0,226**	**0,478**

In light blue : hypothesis done for ponds 4 and 5

Abstract

Vombsjön is a big Swedish lake which is used as a water resource by Sydvatten to produce drinking water. However, it is situated on agricultural lands where many fertilizers rich in phosphorus are added and brought by runoffs in the lake. Phosphorus is a nutrient for algae which stimulates algal growth and so production of toxins by cyanobacteria which threaten the water quality. In order to limit this eutrophication phenomenon, several phosphorus ponds were constructed in the catchment area of Vombsjön to trap this phosphorus. The aims of this study are to determine the retention efficiency of these phosphorus ponds and to do the water column profile of the lake to observe and prevent the possible summer stratification which favors internal eutrophication.

This report highlights that retention efficiency of the phosphorus ponds depends on many factors, such as weather conditions, pond design, level of dissolved oxygen. It emphasizes that orthophosphates are mainly caught by the ponds whereas particulate phosphorus is released because of low concentration of oxygen or storms leading to big flows. Due to strong rains and probably recent add of fertilizers, a peak of phosphorus concentration is observed in all the ponds at the end of June. For the lake, most of the time of this summer, no water stratification was observed, except twice including one of only a few days and one longer (around one week). This succession of thermocline episode and mixture of the water column even lead to an algal bloom at the end of July which shows the important eutrophication problem to whom the lake is confronted.

Keywords : Vombsjön Lake – Eutrophication – Phosphorus – Algal bloom – Cyanotoxins - Phosphorus ponds – Lake water stratification – Thermocline

Résumé

Vombsjön est un grand lac suédois utilisé comme ressource en eau par l'entreprise Sydvatten pour produire de l'eau potable. Cependant, il est situé sur des terres agricoles faisant l'objet d'une utilisation intensive de fertilisants riches en phosphore. Ce phosphore est ensuite entraîné dans le lac par ruissellements. Le phosphore est un nutriment pour les algues stimulant leur croissance et donc la production de toxines par les cyanobactéries, ce qui menace la qualité de l'eau. Afin de limiter ce phénomène d'eutrophisation, plusieurs étangs ont été construits dans le bassin versant du lac Vombsjön dans le but de capturer ce phosphore. Cette étude vise à déterminer l'efficacité de rétention du phosphore de ces étangs et à établir le profil de la colonne d'eau du lac pour observer et prévenir d'une éventuelle stratification estivale qui favoriserait une eutrophisation interne.

Ce rapport met en évidence les nombreux facteurs influençant la rétention du phosphore par les étangs artificiels, dont les conditions météorologiques, la conception de l'étang, le niveau d'oxygène dissous. Il souligne le fait que les ortho-phosphates sont principalement retenus par les étangs tandis que du phosphore particulaire est libéré à cause de faibles concentrations en oxygène ou de tempêtes entraînant d'importants courants d'eau. A cause des fortes pluies et probablement de récents ajouts d'engrais fertilisant, un pic de concentration en phosphore est observé dans chacun des étangs à la fin du mois de Juin. Quant au lac, pour la majorité de l'été, aucune stratification de l'eau n'a été observée, excepté à deux reprises dont une courte de seulement quelques jours et une plus longue (environ une semaine). Cette succession d'épisode de thermocline et d'homogénéisation de la colonne d'eau ont même mené à une prolifération algale à la fin du mois de Juillet, ce qui montre l'importance du problème d'eutrophisation auquel le lac est confronté.

Mots clés : Lac Vombsjön – Eutrophisation – Phosphore – Prolifération algale – Cyanotoxines – Etangs artificiels « pièges » à phosphore – Stratification d'un lac - Thermocline