Spatial comparison of the physicochemical properties of Lake Vansjø during winter 2010

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Undergraduate Research Project

30 ECTS

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2 ABSTRACT

Eutrophication is the word used to describe the nutrient enrichment of a water body often accelerates as a result of human activity. This phenomenon reduces water quality and alters ecological structure and functions of the affected freshwater environment.

The present study is focused in knowing and understanding the winter physicochemical state of Lake Vansjø waters. Lake Vansjø is the largest lake in the Vansjø-Hobøl catchment situated on the southeastern part of Norway and receives excess of P loads from surrounding agricultural fields and other sources, making the lake eutrophic.

A spatial winter monitoring were conducted taking samples from 25 different locations around the lake between February and March of 2010.

The results of the winter chemical, physical and biological variables of the 25 sampling points were compared between them. The winter results of the three most representative sampling points (Storefjorden, Grepperødfjorden and Vanemfjorden) were compared with the results of other season to see some seasonal differences and to understand the winter dynamics and from here make sure some hypotheses of winter dynamics obtained from simulation models such as My Lake.

The gradients of temperature with depth recorded by CTD device showed clear inverse lake stratification. Conductivity, pH and alkalinity values were fairly constant throughout the different sampling points. Total suspended solids concentrations were higher in Grepperødfjorden than Vanemfjorden and Storefjorden but in general much lower than the other seasons. Total and particulate phosphorus fractions were lower at every sampling point in Lake Vansjø during ice cover. Dissolved inorganic forms of phosphorus were slightly higher during winter. The highest concentrations of inorganic phosphate were found in the lower layers of the lake, specifically in Storefjorden area.

3 PURPOSES

Because of the difficulties involved in taking water samples through ice during the cold months, i.e. because taking samples and working on the ice is dangerous and in some cases is not possible due to poor and unsafe ice thickness, field trips to cold lakes usually involve wearing skis or snow-shoes and hauling equipment on sledges, comparatively little is known about winter limnology in temperate and high latitudes.

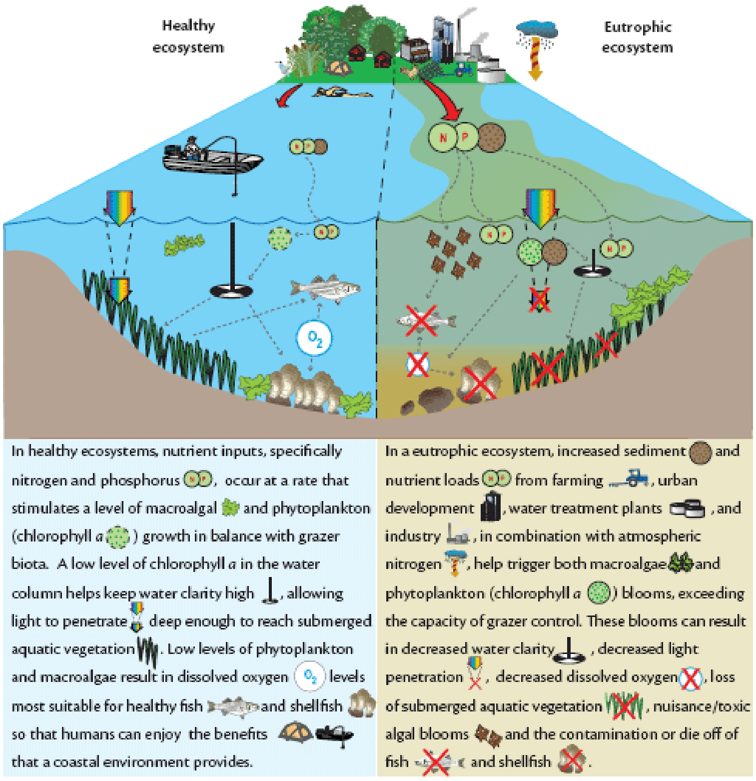
In this way, my research project is focused mainly on knowing and studying the winter physicochemical state of Lake Vansjø water; situated in the south eastern part of Norway, and in some areas affected by eutrophication phenomena. Furthermore and also linked to this main focus, I will attempt to understand the nutrient phosphorus behaviour during the winter season and verify some predicted results which have been obtained using a simulation model (Soloranta and Andersen, 2007).

4 INTRODUCTION

4.1. Eutrophication concept

The word “eutrophication” comes from the Greek “eutrophos” (which means well fed) and can be defined as a nutrient enrichment of a water body as a result of human activity.

All plants and algae require nutrients to growth, and in aquatic environments the availability of nutrients often limits plant growth. However, when nutrients are introduced into a waterway at greatly increased rates, usually due to human activities, the productivity of aquatic plants and algae can increase dramatically, often leading to blooms of undesirable species. (see Thomson and Dieter, 2005). This process can continue and the population of photosynthetic organisms can increase day by day causing a green water color and also favoring the emergence of anaerobic conditions which can lead to fatal effects on the aquatic environment (see eutrophication process in Figure 1).



In healthy ecosystems, nutrient inputs, specifically nitrogen and phosphorus, occur at a rate that stimulates a level of macroalgal and phytoplankton (chlorophyll *a*) growth in balance with grazer biota. A low level of chlorophyll *a* in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of phytoplankton and macroalgae result in dissolved oxygen levels most suitable for healthy fish and shellfish so that humans can enjoy the benefits that a coastal environment provides.

In a eutrophic ecosystem, increased sediment and nutrient loads from farming, urban development, water treatment plants, and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and phytoplankton (chlorophyll *a*) blooms, exceeding the capacity of grazer control. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen, loss of submerged aquatic vegetation, nuisance/toxic algal blooms and the contamination or die off of fish and shellfish.

Figure 1. Conceptual diagram comparing a healthy system with no or low eutrophic condition to an unhealthy system exhibiting eutrophic symptoms. (Source: Center for coastal monitoring and assessment (CCMA)).

The fact that eutrophication reduces water quality and alters ecological structure and function of freshwater is well known and understood (see Carpenter et al., 1998 and Dodds et al., 2000). On the other hand, also important are other repercussions also linked to this phenomenon such as the potential economic losses that can be related to social, ecological and policy-related responses (Pretty et al., 2003).

4.2. Eutrophication phenomenon in Norway

Recent studies of the water quality in 297 Norwegian lakes carried out during 2004-2006 by the Norwegian Institute for water research (NIVA, 2008) showed that more than 90% of the lakes have good or very good water quality. Nevertheless, the remaining 10% can be an important problem in affected areas.

4.2.1. Where are the affected areas?

In Norway, eutrophication of freshwater tends to occur in low-lying areas, particularly near settlements and agricultural land.

Exposed areas include the Oslo fjord, the low-lying areas of Eastern Norway, the Stavanger area, Jæren and areas along the Trondheim fjord (NIVA, 2008). As can be seen in Figure 2 the lowest concentrations of phosphorous occur in lakes in Western Norway and Northern Norway, as well as the mountainous areas of Southern Norway. The highest concentrations occur in the south and south-west.

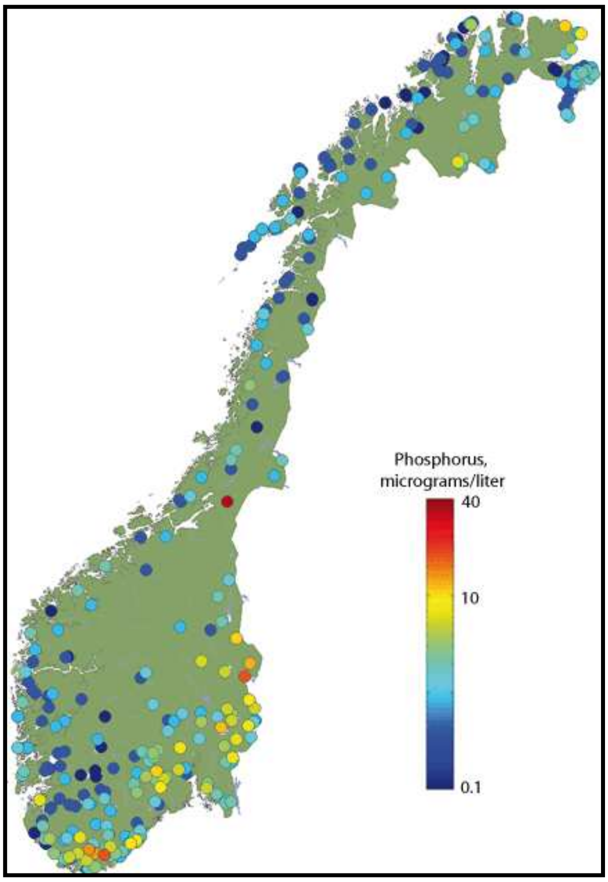


Figure 2. Concentrations of phosphorus in 297 Norwegian lakes 2004-2006. (Source: Institute for water research (NIVA), 2008)

4.3. Eutrophication phenomenon in the studied area: Lake Vansjø

The major eutrophication occur in the south and south-west of Norway (see chapter 4.2). In this way, the study lake of the present research is inside this "risk area".

4.3.1. Vansjø-Hobøl catchment

The Vansjø-Hobøl catchment is according to Norwegian standards (relatively) highly affected by anthropogenic activities. Most of the nutrients and pollutants which affect the water quality in Vansjø-Hobøl catchment are introduced from the runoff of agricultural and domestic sewage.

Water authorities in the late 70's paid an increasing attention to the watercourse due to increasing eutrophication and large water use conflicts. Intensity of eutrophication increased rapidly in Lake Vansjø during the 70's and 80's, and today the water quality (especially in parts of the Hobøl River, Lake Sæby and Lake Vansjø) is largely affected by micro pollutants and plant nutrients.

4.3.2. Lake Vansjø

The study site, Vansjø (see chapter 4.5) is the largest lake in the Vansjø-Hobøl catchment, southeastern Norway. Vansjø receives excess P loads from surrounding agricultural fields and other sources, making the lake eutrophic. The eutrophication became a particular societal concern when it induced toxic cyanobacterial blooms, which have been reducing the recreational value of the lake and causing concern for the drinking water quality (see, for example, Saloranta 2006).

4.4. The importance of nutrients in a lake

The reason why nutrients play such a decisive role for the environmental state of lakes is the fact that the primary production of lakes is strongly limited by nutrient availability. Increased nutrient input therefore leads to enhanced lake productivity, with cascading effects on the remaining trophic levels and the interactions between them (Jeppesen, 1998).

4.4.1. Phosphorus in the environment

Phosphorus is an indispensable element to life. It is intimately involved in energy transfer as ATP and the passage of genetic information as DNA (see Westheimer, 1987). We can also find phosphorus as a component of cell membranes, and in the bones and teeth of vertebrates (as calcium phosphate).

Phosphorus is found in soils, rock minerals, living organisms and water, but unlike nitrogen it is not present in the atmosphere. Nor is it found in its elementary form in the nature. Pure phosphorus is highly reactive (it is what makes matches burn), and rapidly combines with oxygen when exposed to air. In natural water systems it usually exists as phosphate, in which each phosphorus atom is surrounded by 4 atoms of oxygen. The simplest phosphate is orthophosphate ($PO4^{3-}$).

Particularly phosphorus is important among the many nutrients in water environments that apart from carbon and other elements contribute to plant primary production and, thus form the basis for the other components of the food chain (Dillon and Rigler, 1974). Therefore, the availability of phosphorus is frequently considered as being the single most important factor for the overall environmental state of lakes.

4.4.2. Phosphorus forms in freshwater environment

Phosphorus is a major limiting nutrient in many freshwater aquatic ecosystems, and it is important to study the different fractions of phosphorus and how the different types behave in the interested areas (see Table 1).

Table 1. Different fractions of phosphorus in a lake (Source: Thomson and Dieter, 2005)

- **Dissolved Inorganic phosphorus (DIP)**: This phosphorus fraction is composed mostly for the inorganic orthophosphate (PO_4) form of phosphorus. Orthophosphate is the phosphorus form that is directly taken up by algae. It is usually present as a combination of HPO_4^{2-} and $H_2PO_4^-$, depending on pH, but for simplicity will be simply referred to here as PO_4.

- **Dissolved Organic phosphorus (DOP)**: Phosphorus is also found as a soluble organic compound. A number of organic phosphorus molecules have been identified, but two main classes seem to predominate in natural waters. The first are low molecular weight compounds, apparently derived from algal and bacterial metabolism. The second are colored, large molecular weight compounds, perhaps phosphorus bound in humic complexes, which release orthophosphate in the presence of ultraviolet light.

- **Particulate Inorganic Phosphorus (PIP)**: Includes inorganic forms such as phosphate sorbed onto suspended clay particles, and suspended crystalline and amorphous precipitates of PO_4^{3-} with Ca, Mg, Al and Fe.

- **Particulate Organic phosphorus (POP)**: Organic POP is associated with deterial matter from dead and decomposing bacteria, phytoplankton, zooplankton cells, and periphyton, as well as organic phosphorus content in living cells of algae and plants.

4.4.3. Phosphorus inputs to a lake

Most of the phosphorus entering to a lake from the catchment is attached to soil particles. Increases in soil erosion can result mainly from hydrology changes such as straightening of streams and rivers, pavement of large surfaces limiting infiltration of waters and climate changes. Other influences which increase soil erosion are clearing and ploughing of agricultural land, or soil disturbance due to forestry, urban development, stock tracks and watering areas, and gravel roads. The use of phosphate fertilizers can greatly increase the phosphorus content of soil eroded from cropland.

Following are shown the main sources of phosphorus in a lake with some related examples (see Table 2).

Table 2. Distribution of the main phosphorus sources in a lake (Source: Thomson and Dieter, 2005)

- **Diffuse catchment inputs**: particulate phosphorus and soluble phosphate (PO4), e.g. from fertilizers, animal wastes, detergents, and soil erosion, are washed into surface waters from throughout the catchment.
- **Point source discharges:** PO4 is discharged directly to waterways from sewage treatment plants and some industry .

- **Groundwater inputs**: PO4 is leached through macropores (cavities which are larger than 50 nm which may occur in various solids. In the soil, they created by such agents as plant roots, soil cracks, or soil fauna. Macropores increase the hydraulic conductivity of the soil, allowing water to infiltrate faster or for shallow groundwater to flow faster.

4.4.4. Other nutrients

Another significant nutrient, nitrogen, typically occurs in concentrations much higher than those of phosphorus and despite that the demand by primary producers for nitrogen is higher than for phosphorus there will often be a nitrogen surplus. Even though phosphorus is usually the growth limiting nutrient in many lakes, in a few cases is possible to find places where nitrogen has the role of limiting nutrient. Generally in nutrient-rich freshwater systems during growing seasons (Schindler, 1977). Nevertheless abundant data indicate that N is the nutrient limiting in marine ecosystems (Howarth and Marino 2006).

Nitrogen limitation is considered by some to be a transitory condition of minor importance to the productivity of aquatic ecosystems because nitrogen deficiency may be offset by the growth of nitrogen fixing blue-green algae (Schindler, 1977). However, some investigators have found the variance in phytoplankton productivity and biomass explained by both nitrogen and phosphorus is much greater than that explained by phosphorus alone (Smith, 1979 and 1982).

4.5. Study area

4.5.1. Vansjø-Hobølv catchment

The Vansjø-Hobølv catchment (Figure 3) is part of the larger Moss river catchment located in the south-eastern part of Norway. The watershed has an area of 690 km^2 and can be divided into 9 subcatchments as shown in Figure 4. Is comprised for 959 km of streams and 34 lakes. As can be seen from Table 3, Lake Vansjø makes up 75% of the entire surface water in the catchment, and 85% of the total volume.

The watershed area is predominantly forest (80%), as 550 km^2 is woodland and forest area. The open water area is 48 $km^{2.}$ The elevation range is 25 to 275 m. Mineral distribution of Vansjø-Hobølv catchment is shown in Figure 7. The soil composition is 81% clay, 18% sand and 1% organic soil (see Figure 5). Land use in the watershed is 16% row–crop agriculture (see Figure 6). The principle crops are rye, barley, oats and wheat.

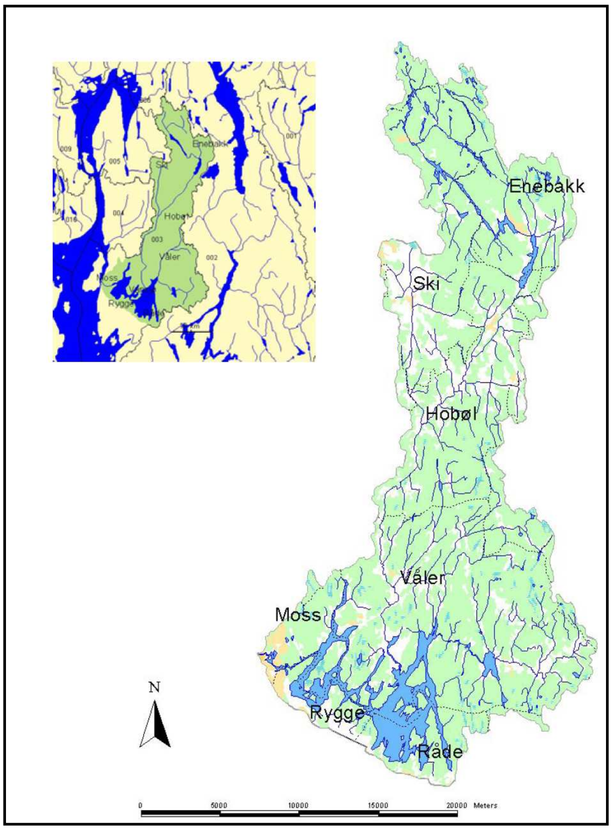


Figure 3. Vansjø-Hobølv catchment (Source: NIVA, 2006b)

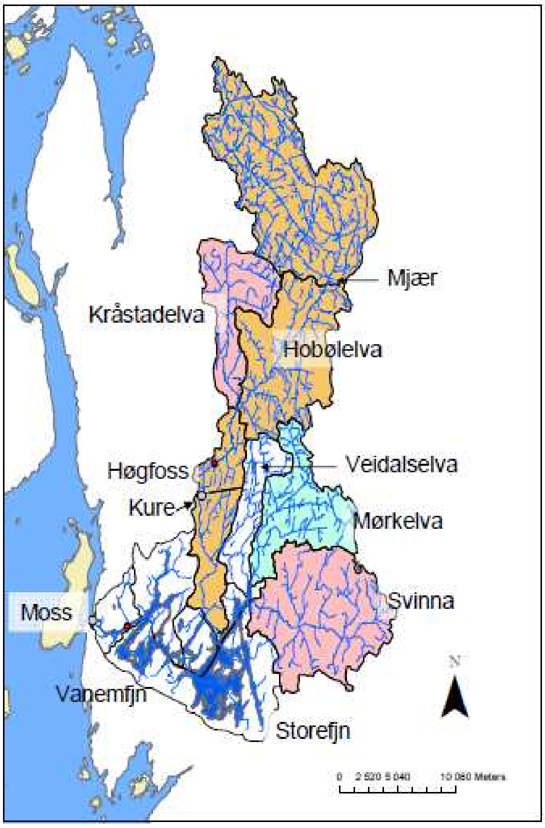


Figure 4. Vansjø-Hobølv catchment divided in 9 most representative basains or subcatchments (Source: Biofrosk, 2009)

Table 3. Area and volume of Vansjø-Hobølv catchment surface water system.

	Area		Volume	
	ha	%	10^6 m^3	%
Lake Vansjo	3600	75	266	85
Deep lakes	569	12	40	13
Shallow lakes	381	8	3	1
Rivers and streams	216	5	2	1
Total	4766		311	

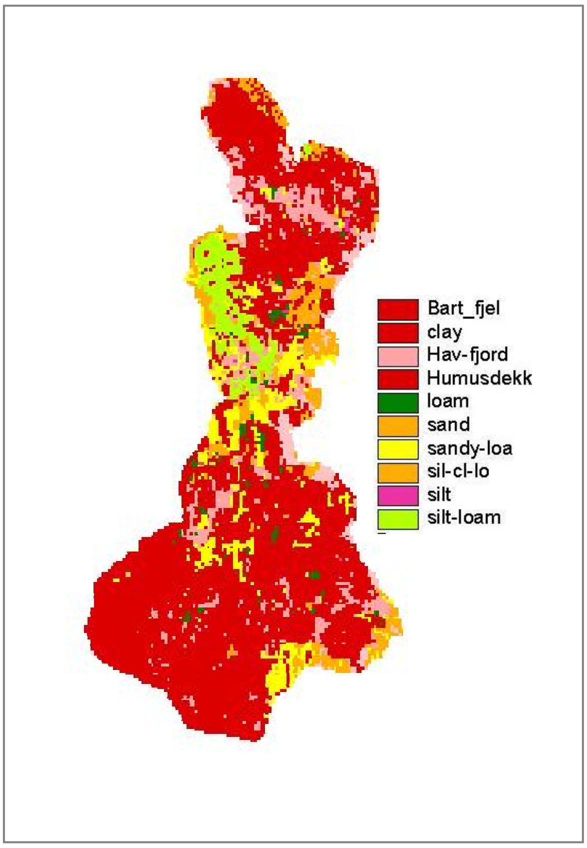


Figure 5. Soil map of Vansjø-Hobølv catchment (Source: NIVA, 2006b)

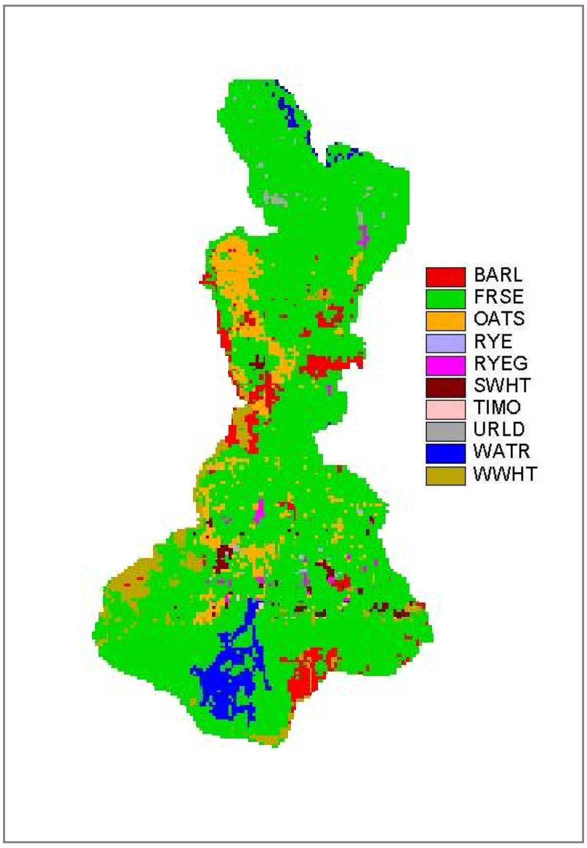


Figure 6. Land use map of Vansjø-Hobølv catchment (Source: NIVA, 2006b)

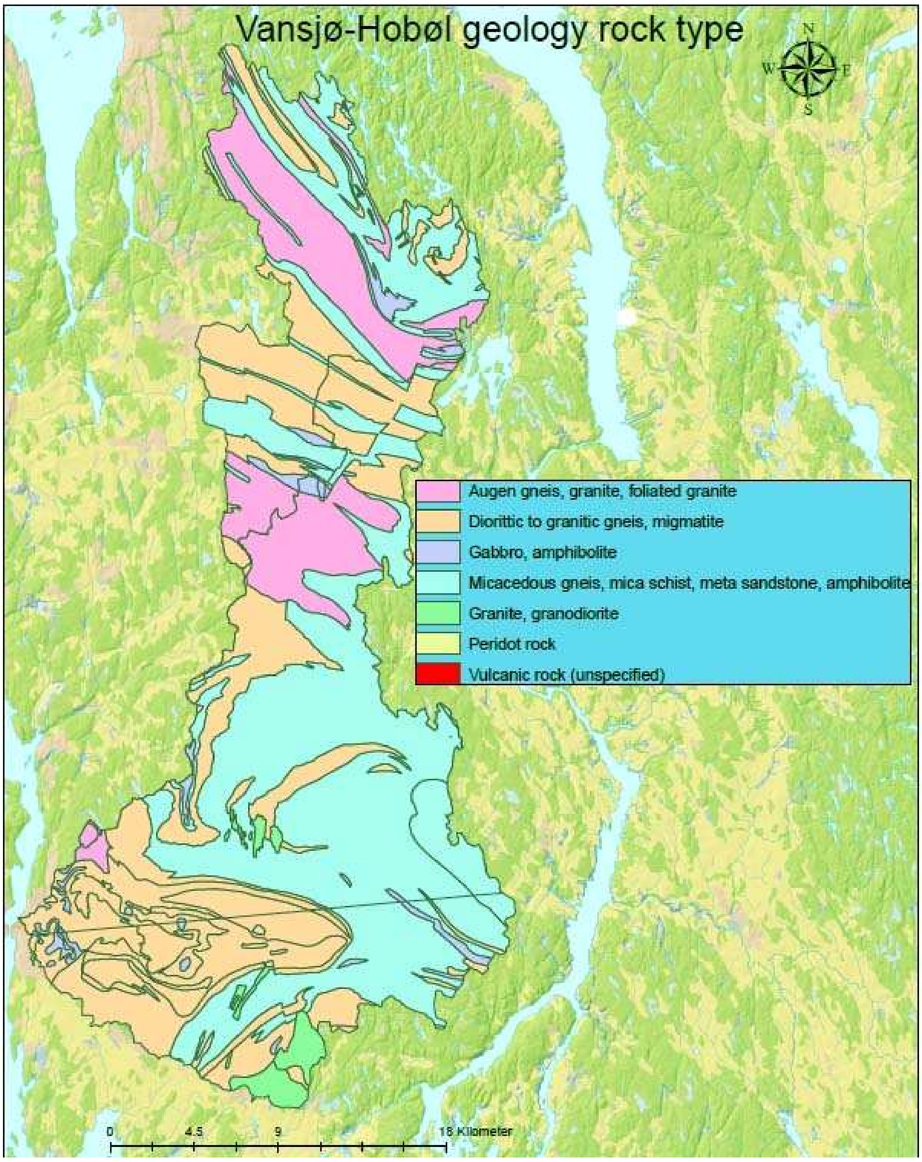


Figure 7. Mineralogy map of Vansjø-Hobølv catchment.

The mean annual precipitation in Vansjø-Hobølv catchment is 810 mm (see Figure 8). Meteorological conditions during the reporting period are given in Figure 9. Temperature was lower during winter 2010 comparatively with last winters and precipitations were higher comparatively with last winters. Consequently, on winter 2010 there was a greater ice thickness and higher amount of snow onto the ice surface. The precipitations were in snow form during all the period and therefore no increases of water flow were noted.

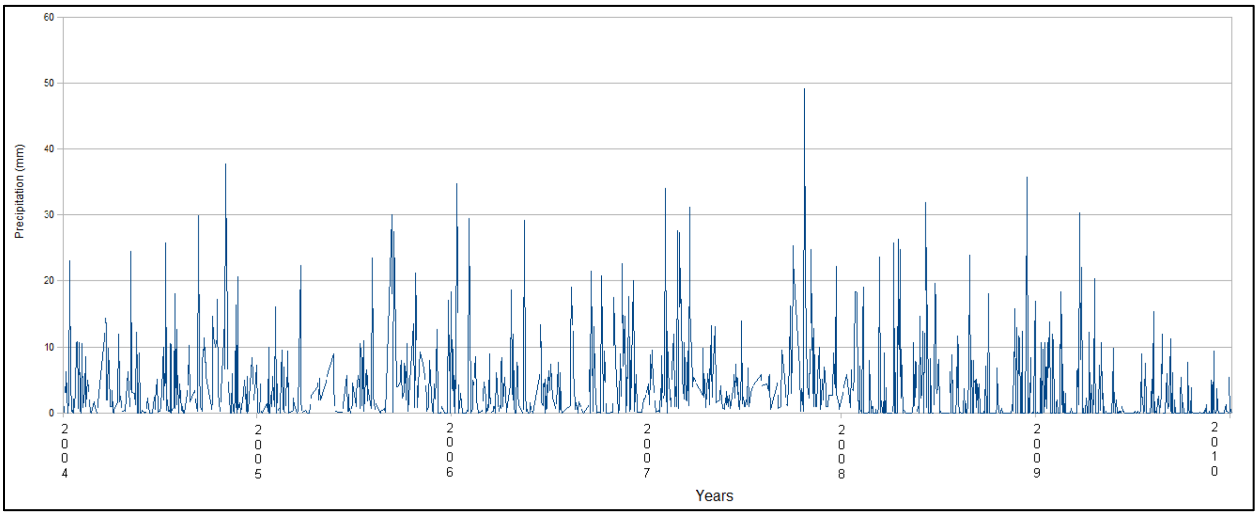


Figure 8. Last six years recorded precipitations in the meteorological station of Rygge (Source: Norwegian Meteorological Institute)

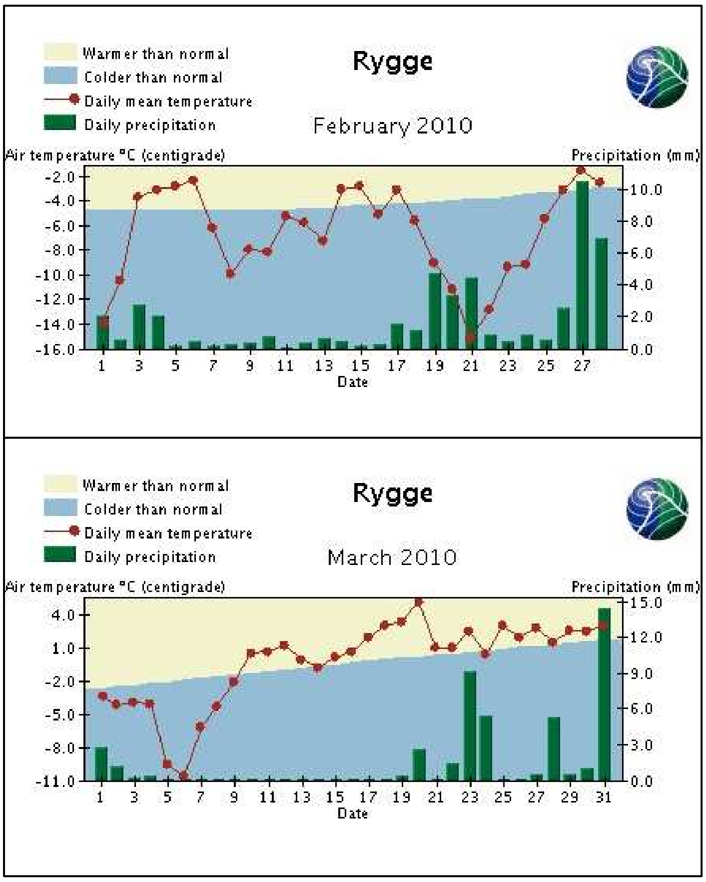


Figure 9. Meteorological conditions during February and March of 2010 (Source: Norwegian Meteorological Institute)

4.5.2. The lake Vansjø

Lake Vansjø is 36 km^2 and consists of several basins that are separated by narrow straits and shallow thresholds (see Figure 10). We often divide the lake in two major basins, an eastern part (Storefjorden) that is 24 km^2 and the western part (Vanemfjorden) that is 12 km^2. The major inputs of water are flowing into the Storefjorden (Hobøleva, Nesaelva, Nordbyelva and some other streams) while the outflow is from Vanemfjorden via Mosseelva and into Moss Strait (Oslofjorden). Morphological data for the lake are shown in Table 4.

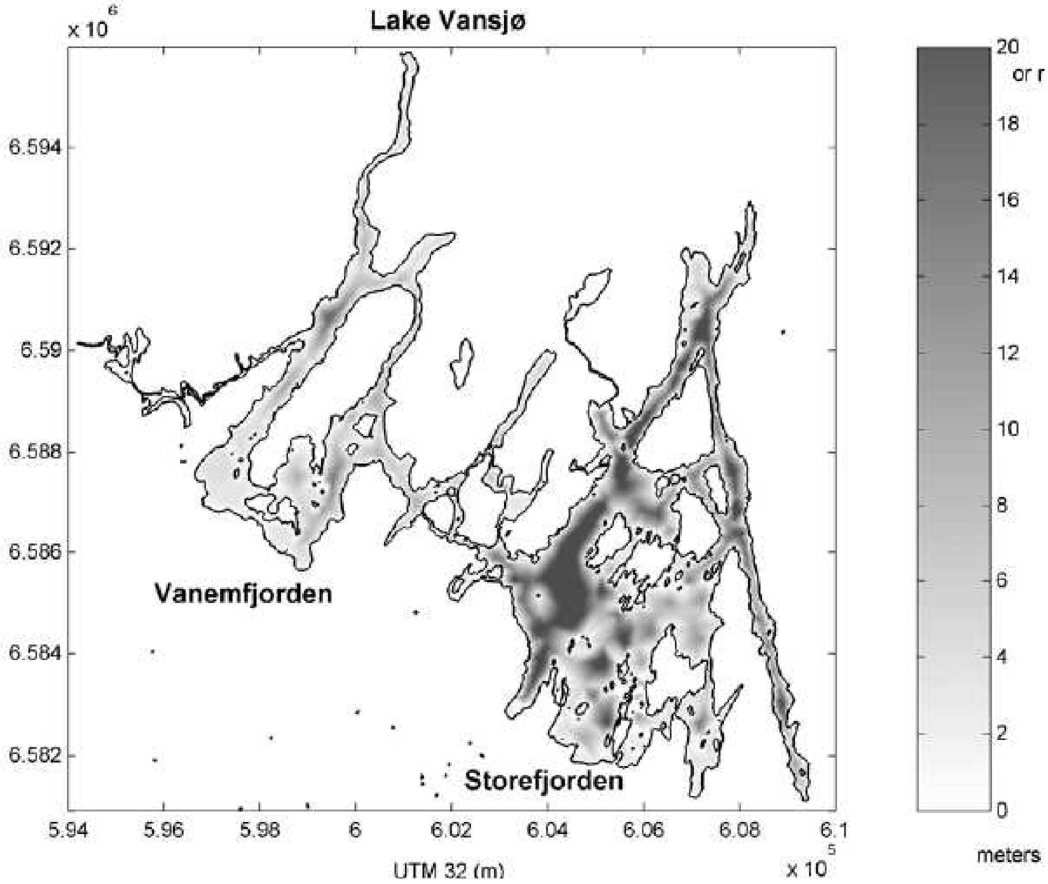


Figure 10. Depth Map of Vansjø Lake (Source: Biofrosk, 2009)

Table 4. Morphological data for lake Vansjø (Source: Biofrosk, 2009)

	Storefjorden	Vanemfjorden
Surface area (km^2)	23,8	12
Average Depth (m)	9,2	3,7
Maximum depth (m)	41	17
Theorical water retention time (years)	0,85	0,21

4.6. Winter lake dynamics: Brief approach to ice-covered lakes behavior

The chemical and physical conditions in the water column in winter differ from other seasons conditions (see Agbeti, 1995).

In cold temperate regions, the presence of ice and snow cover in winter play a major role in determining phytoplankton growth and therefore influence the dynamics of some nutrients such as phosphorus. For example, (Odum, 1959 and Talling, 1962) suggested that low winter temperatures and reduced light should result in low phytoplankton populations and photosynthetic rates. High phytoplankton biomass may sometimes be found in some lakes during ice cover (Wright, 1964 and Nebaeus, 1984), probably because of continued photosynthesis under low light intensities over relatively long time periods during ice cover (Wright, 1964).

In some eutrophic lakes during winter, the great reduction in photosynthesis under ice, in combination with respiratory demand from bacterial decomposition, can lead to anoxia conditions.

Winter conditions in an ice-covered lake present a challenging environment for phytoplankton (primary producers). First, not only is the solar radiation at its lowest level in the yearly cycle, but light transmission is reduced due to ice cover, and diminished further by snow, when present (Bolsenga and Vanderploeg, 1992). Second, temperature is at its lowest. Because inverse stratification occurs in many temperate lakes during this period, the uppermost layers of water that are receiving the most light are, at the same time, the coldest. Third, ice cover effectively seals off the water column from the mixing action of the wind, preventing wind-induced turbulence and the accompanying sediment-nutrient exchanges.

5 METHODOLOGY PART

5.1. Study locations

Samples were collected at Lake Vansjø between February 5 and March 11. The site positions are indicated in Figure 11 and some other information of sampling points such as site names, position coordinates and sampling dates are presented in Table 5.

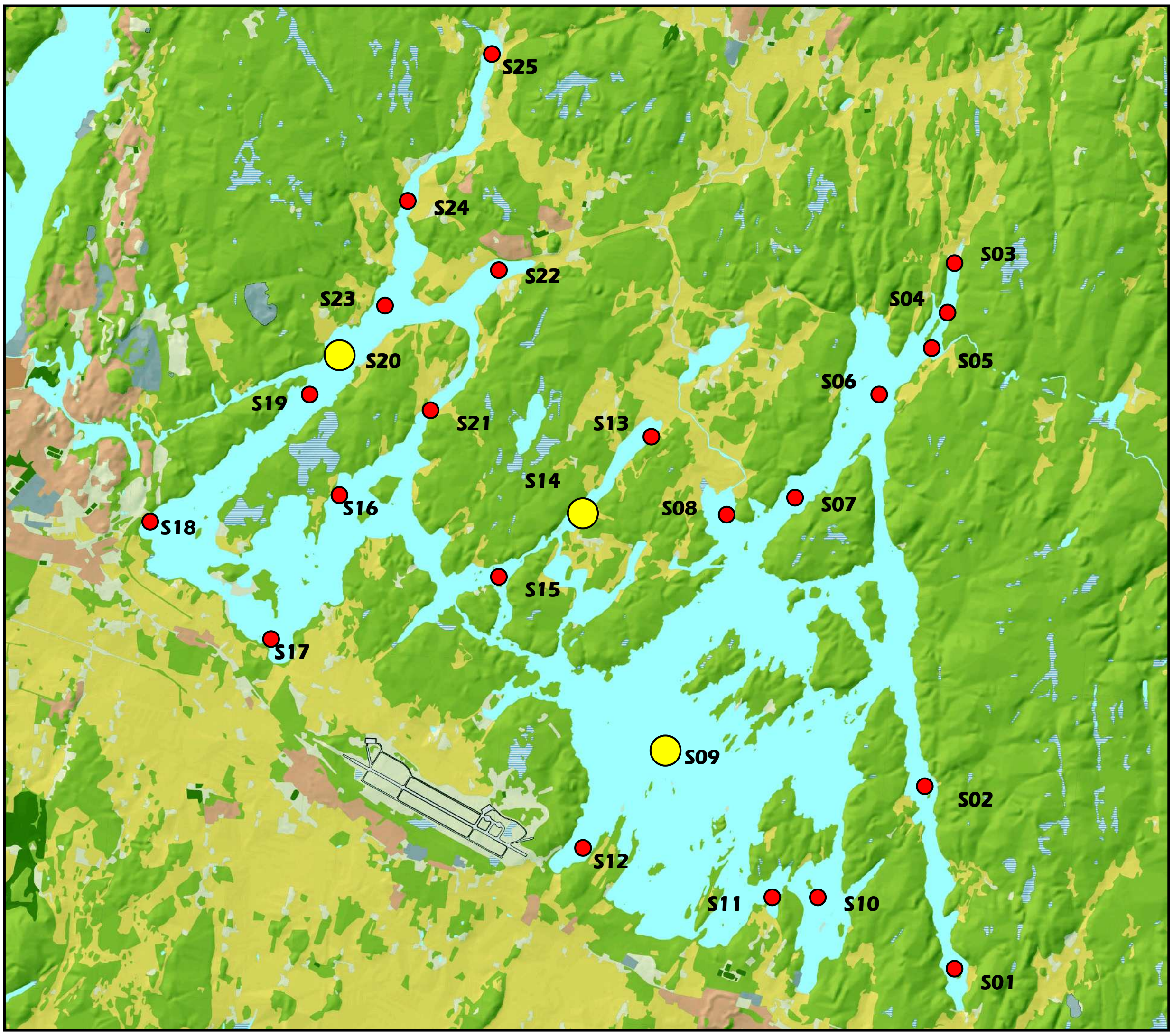


Figure 11. Situation of the 25 studied sampling points. Yellow points to indicate sampled sites in Utredninger Vansjo Report 2005 and also sampled in the present project. (S09=Storefjorden; S14=Grepperojorden; S20=Vanemfjorden)

Table 5. Study sites information

Site name	Sampling date			Coordinates	
	Day	Mo	Year	Northing	Easting
S01	5	2	2010	6581440	609262
S02	5	2	2010	6584880	608367
S03	9	2	2010	6592537	608224
S04	9	2	2010	6591821	607944
S05	9	2	2010	6591406	608064
S06	9	2	2010	6590454	607264
S07	16	2	2010	6588389	605815
S08	16	2	2010	6588566	605195
S09	25	2	2010	6585300	604299
S10	11	3	2010	6582735	606874
S11	11	3	2010	6582821	606517
S12	25	2	2010	6583233	603531
S13	16	2	2010	6589656	603832
S14	16	2	2010	6588557	603130
S15	5	3	2010	6587383	601983
S16	5	3	2010	6588399	599655
S17	2	3	2010	6586096	598890
S18	2	3	2010	6587837	596817
S19	5	3	2010	6589864	599045
S20	23	2	2010	6590750	599499
S21	2	3	2010	6590091	600990
S22	2	3	2010	6592044	601248
S23	23	2	2010	6591363	600022
S24	23	2	2010	6592764	600057
S25	23	2	2010	6595231	601068

5.2. Field work procedures

This section is focused on the field work procedures and contains a detailed explanation of rationale and experimental tasks conducted during sampling period.

5.2.1. Verification of the tools and the other equipment required for collecting samples

The equipment which was used to collect the samples were checked before starting the field trip, also the sampling points were logged into GPS and the weather forecast were checked the day before. (Important thing to avoid days of heavy snowfalls and useful to prepare extra material such as skis, snow shoes or hauling equipment on sledges if it is necessary).

5.2.2. Sampling point approximation

The thickness and the quality of the ice were checked every day before start to walk on the ice. Is of great importance ensure that the ice that we have to step on to reach the sampling point is absolutely safe (see Figure 12 and the Department of natural resources of Minnesota web page).

Once the quality of the ice was checked, the next step was locating the sampling point. A GPS with the coordinates entered previously was used to locate the sampling point.

Figure 12. Rough guidelines with recommended minimum ice thickness (Source: Department of natural resources of Minnesota)

5.2.3. Sampling

The sampling procedure was basically the same for every site, only some changes were made in some sampling points as will be explained below.

Figure 13. Ice auger used to do the holes.

At every site, holes were drilled into the ice with a 200 mm diameter ice auger (Figure 13). Once the remains of snow and the broken ice were removed and with the hole completely clean, the next step was to measure the thickness of the ice and the snow as well as the depth of the lake using an echo sounder (a device for measuring depth of water by sending pressure waves down from the surface and recording the time until the echo returns from the bottom). Depth profiles for temperature and conductivity were recorded using a CTD device (Conductivity, temperature, density).

Table 6. Relation between site depths and CTD measurement applicability.

Site name	Site depth	CTD measument
S01	6,6	applicable
S02	17,4	applicable
S03	4,9	applicable
S04	8,5	applicable
S05	1,1	not applicable
S06	33,9	applicable
S07	40,3	applicable
S08	3,9	applicable
S09	37	applicable
S10	3,8	applicable
S11	4,8	applicable
S12	24	applicable
S13	4,1	applicable
S14	5,8	applicable
S15	2,4	applicable
S16	2,7	applicable
S17	4,4	applicable
S18	0,8	not applicable
S19	4,9	applicable
S20	14	applicable
S21	2,4	applicable
S22	1,9	not applicable
S23	2,9	applicable
S24	4,1	applicable
S25	3,9	applicable

The immersion was carried out manually and steadily. Temperature, conductivity and pressure were measured 6 times per second. Total pressure measures, recorded with a CTD device, were also used to estimate the depth of the lake using an Equation 1. Atmospheric pressure values were obtained from the Norwegian Meteorological Institute (eKlima on-line services).

The CTD measurements were only carried out just on sites which were deeper than two meters to avoid sediment resuspension problems when the device touches the bottom (see red mark on Table 6). Three sites were measured but not recorded due to a lack of battery of the CTD device (see yellow mark on Table 6).

Equation 1

$$Depth = \frac{\left[\left[P_{CTD} - P_{25}\right] \bullet 10000\right]}{\left[1000 \bullet 9.81\right]}$$

Depth= Estimated depth in meters
P_{CTD}= Total pressure in N/m^2
P_{25}= Atmospheric pressure at Lake Vansjø altitude in N/m^2

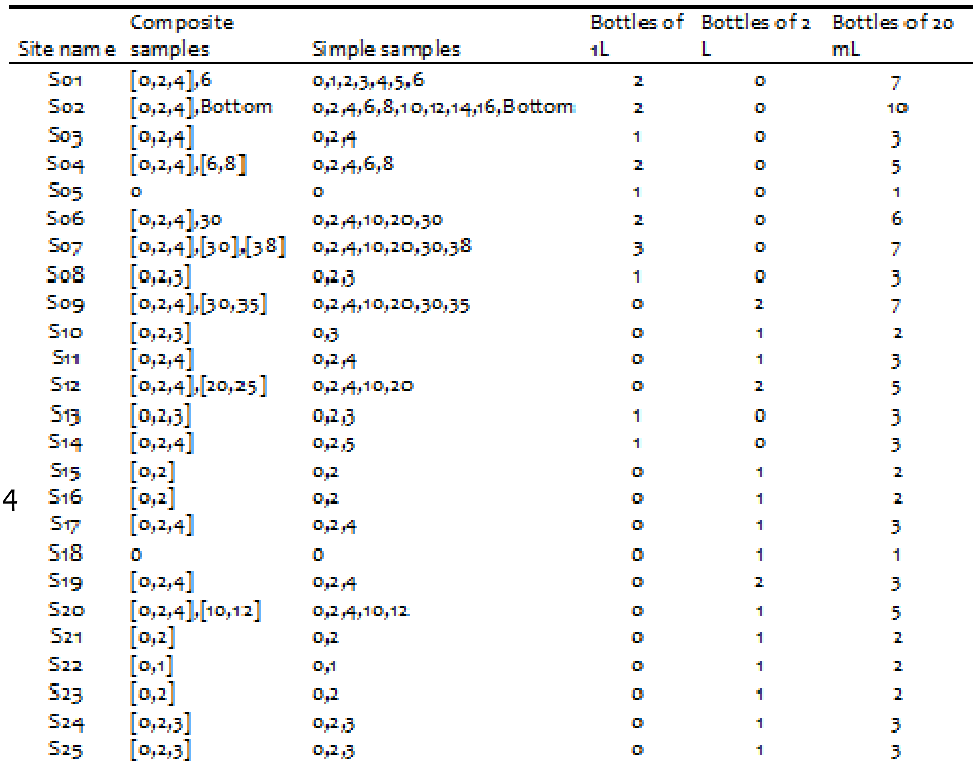
Water sampling was carried out following CTD measurements using a water sampling device as shown in Figure 14. Water samples were taken throughout the entire water column in order to obtain a wide characterization of the lake's water body. The samples that were taken in each site, sample depth and sample volumes are specified in Table 7. As can be seen in Table 7 bottles of 1 and 2 Liters were used to take composite samples and bottles of 20 mL to take simple samples.

Composite water samples were used to determine basic water variables such as absorbencies, pH, conductivity, alkalinity, concentrations of suspended solids and major anions and cations in the solution at the Department of Chemistry, University of Oslo (UiO). Total phosphorus concentrations and concentrations of orthophosphate were conducted at the Norwegian Institute of Water research (NIVA) On the other hand, samples of 20 mL were

Figure 14. Water sampler device used for Lake Vansjø sampling.

used to analyze total phosphorus and chlorophyll-a at the Department of Biology, UiO.

Table 7. Waters samples that were taken from Lake Vansjø, also shown water volume per sample and sampling depths. In brackets different depths of composites samples.



Site name	Composite samples	Simple samples	Bottles of 1L	Bottles of 2 L	Bottles of 20 mL
S01	[0,2,4],6	0,1,2,3,4,5,6	2	0	7
S02	[0,2,4],Bottom	0,2,4,6,8,10,12,14,16,Bottom	2	0	10
S03	[0,2,4]	0,2,4	1	0	3
S04	[0,2,4],[6,8]	0,2,4,6,8	2	0	5
S05	0	0	1	0	1
S06	[0,2,4],30	0,2,4,10,20,30	2	0	6
S07	[0,2,4],[30],[38]	0,2,4,10,20,30,38	3	0	7
S08	[0,2,3]	0,2,3	1	0	3
S09	[0,2,4],[30,35]	0,2,4,10,20,30,35	0	2	7
S10	[0,2,3]	0,3	0	1	2
S11	[0,2,4]	0,2,4	0	1	3
S12	[0,2,4],[20,25]	0,2,4,10,20	0	2	5
S13	[0,2,3]	0,2,3	1	0	3
S14	[0,2,4]	0,2,5	1	0	3
S15	[0,2]	0,2	0	1	2
S16	[0,2]	0,2	0	1	2
S17	[0,2,4]	0,2,4	0	1	3
S18	0	0	0	1	1
S19	[0,2,4]	0,2,4	0	2	3
S20	[0,2,4],[10,12]	0,2,4,10,12	0	1	5
S21	[0,2]	0,2	0	1	2
S22	[0,1]	0,1	0	1	2
S23	[0,2]	0,2	0	1	2
S24	[0,2,3]	0,2,3	0	1	3
S25	[0,2,3]	0,2,3	0	1	3

4

5.2.4. Storage of samples

The water samples of 1 and 2 Liters bottles were stored in the cooling room at a temperature of 8 °C and water samples of 20 mL were stored in the freezer at a temperature of -5°C.

5.3. Laboratory analysis

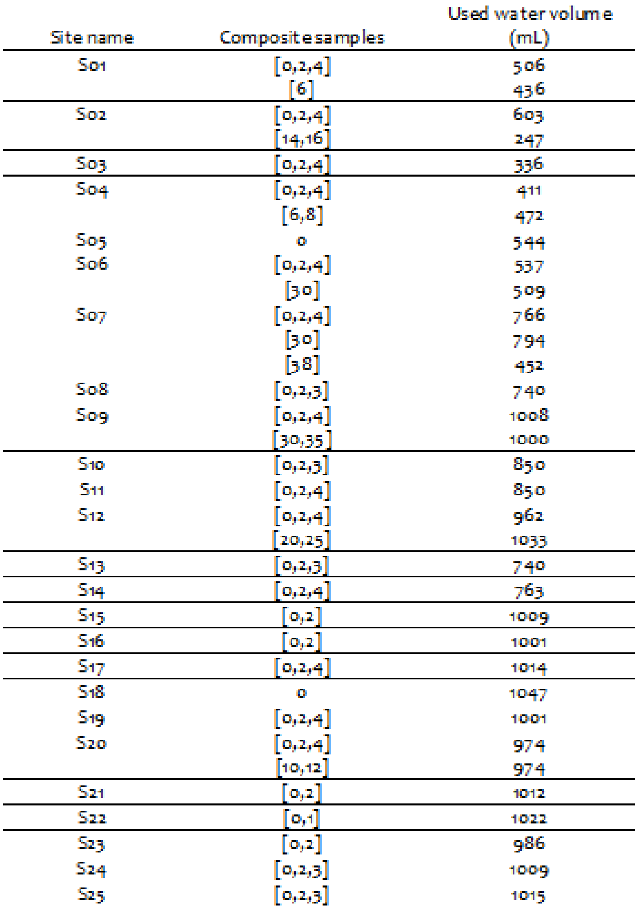
As has been explained previously (see chapter of sampling), composite water samples of 1 and 2 L were used to determine the following variables:

- **UV-VIS absorbance** was determined at 254 and 400 nm using a Shimadzu UV-1201 UV-VIS Spectrophotometer following the NS 9462: 2006 standard (Water quality - Determination of UV-absorbance).

- The **Conductivity** was determined using a Mettler Toledo Five-Go Portable Conductivity Meter and following ISO 7888:1985 standard (Water quality -- Determination of electrical conductivity).

- Measurements of **pH** were carried out using an Orion ROSS electrode and following NS 4720:1979 standard (Water analysis- Determination of pH).

Table 8. Volume of water sample filtered to determine Suspended Solids concentration in water.



Site name	Composite samples	Used water volume (mL)
S01	[0,2,4]	506
	[6]	436
S02	[0,2,4]	603
	[14,16]	247
S03	[0,2,4]	336
S04	[0,2,4]	411
	[6,8]	472
S05	0	544
S06	[0,2,4]	537
	[30]	509
S07	[0,2,4]	766
	[30]	794
	[38]	452
S08	[0,2,3]	740
S09	[0,2,4]	1008
	[30,35]	1000
S10	[0,2,3]	850
S11	[0,2,4]	850
S12	[0,2,4]	962
	[20,25]	1033
S13	[0,2,3]	740
S14	[0,2,4]	763
S15	[0,2]	1009
S16	[0,2]	1001
S17	[0,2,4]	1014
S18	0	1047
S19	[0,2,4]	1001
S20	[0,2,4]	974
	[10,12]	974
S21	[0,2]	1012
S22	[0,1]	1022
S23	[0,2]	986
S24	[0,2,3]	1009
S25	[0,2,3]	1015

- The **Total alkalinity** of the water was determined by an automatic titration with standard HCl solution to a fixed pH endpoint of 4,5 determined potenciometrically. Following NS-EN ISO 9963-1:1995 Standard (Water quality - Determination of alkalinity - Part 1: Determination of total and composite alkalinity)

- The concentration of **Total suspended solids** was determined by filtration of a known volume of sample water (see Table 8) through a Whatman glass microfiber filter of 47 mm of diameter. The concentration of **organic suspended solids** was determined by analyzing the difference between weight before and after combustion of the filters at 500°C.

The concentration of **inorganic suspended solids** was determined by calculating the difference between the total suspended solids and the organic suspended solids.

All steps mentioned above were carried out following ISO 11923:1997 (Water quality - Determination of suspended solids by filtration through glass-fiber filters).

- Analysis of **Phosphorus fractions** for the 32 composite samples was carried out with an specific NIVA PCN analysis robot using the Molybdenum Blue Colorimetric Method (see applied principle). Following is explained NS 4724 standard procedure:

  The **Total phosphorus fraction (Tot-P)** was determined with the Molybdenum Blue Colorimetric Method after a prior digestion (oxidation by peroxidisulphate $S_2O_8^{2-}$) to oxidize the organic matter and release P as orthophosphate contained in the raw water samples.

  The **Free phosphate fraction or inorganic dissolved phosphorus (free PO4)** was determined directly with Molybdenum Blue Colorimetric Method (NS 4724) after a prior filtration using a Whatman glass microfiber filter of 47 mm of diameter.

  The **Dissolved organic phosphorus (Org-P)** was obtained from the difference between Total filtered phosphorus and inorganic dissolved phosphorus (Filt-tot-P – free PO4 = Org-P).

  The **Total Particulate Phosphorus (Particulate-P)** was obtained from the difference between Total phosphorus fraction (Tot-P) and Total filtered phosphorus fraction.

  The **Organic particulate phosphorus (Organic particulate-P)** and **inorganic particulate phosphorus (Inorganic particulate-P)** from total particulate phosphorus (Particulate- P) were not determined.

Principle: The automated procedure for the determination of Phosphate is based on the following reaction; ammonium heptamolybdate and potassium antimony(III) oxide tartrate react in an acidic medium phosphate to form an antimony-phospho-molybdate complex. This complex is reduced to an intensely blue-coloured complex by L(+)ascorbic acid. The amount of this complex is determined by measuring the absorbency at 880 nm

- Analysis of the **Nitrogen fractions** for the 32 composite samples was carried following these principles:

  The Total Nitrogen, Nitrate and Nitrite (Tot-N, $NO3^-$ and $NO2^-$) fractions were analyzed using an automated method based on the cadmium reduction method; the sample is buffered at pH 8.2 and is passed through a column containing granulated coppercadmium to reduce the nitrate to nitrite. The nitrite (originally present plus reduced nitrate) is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)ethylenediamine dihydrochloride to form a highly coloured azo dye. The amount of this dye is measured by determining the adbsorbency at 540 nm.

  Amonia fraction ($NH4^+$) was determined using an automated procedure which is based on the following reaction; the sample reacts with orthophtaldialdehyde (OPA) and sulfite. This reaction produces an intense fluorescent product which is measured fluorimetrically. The excitation wavelength is 370 nm and the emission wavelength is 450-1200 nm.

- The **Total Organic Carbon (TOC)** concentrations were obtained from 254 nm UV absorbance. The lineal relationship between TOC and UV-254 (TOC (mg/l) = 21.193UV-254) was obtained from other samples previously collected from Vansjø that have been analyzed for both their absorbency as well as their TOC at the Department of Chemistry, UiO.

- **Chlorophyll-a** concentrations were obtained from Tot-P concentrations. The logarithmical relationship between Tot-P and Chlorophyll (log[Chl a] = 1.449 log[TP]-1.136) was obtained from Dillon and Rigler, F.H. ,1974.

- **Major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+})** in solution were determined using an inductively coupled plasma - optical emission spectrometer (ICP-OES). **Major anion** determination was not carried out due to difficulties with the ionic chromatography equipment.

6 RESULTS AND DISSCUSIONS

Analysis and discussion of results has been divided into two main parts. The first part includes analysis, comparison and discussion of the results from the different sampling points throughout the lake (spatial variation). The second part is mainly focused on a comparison between the results obtained in winter 2010 and the results obtained from other periods studied in the past (temporal variation).

As can be seen below and for reasons of simplicity and the comparison between the results obtained in winter 2010 and the results obtained from other periods studied in the past has been mainly based on the main NIVA sampling stations: Storefjorden, Grepperødfjorden and Vanemfjorden (yellow points on sampling map (Figure 11) situated at methodology chapter). The data was extracted from Bioforsk, 2008 and NIVA, 2005.

The results of CTD measurements, conductivity and alkalinity have not been compared with results of other analysis and studies due to the lack of comparable data.

6.1. Ice and snow thickness

In cold temperate regions the presence of ice and snow cover in winter play a major role in determining phytoplankton growth and therefore influence the dynamics of some nutrients such as phosphorus.

Presence of ice cover is common during winter in Lake Vansjø but it is not so usual to find the same amount of snow above ice every winter.

Ice and snow thickness are largely related to meteorological conditions in Lake Vansjø.

Results:

As illustrated in Figure 16 the results for depth and snow thickness throughout Lake Vansjø during the studied period (February and March of 2010) were fairly varied and differed between 27 and 53 cm of ice and between 9 and 47 cm of snow. Hence, we can find sites where the total ice and snow cover was really thick (for instance see site S19) or on the contrary places where the total cover was relatively thin, such as S05 or S08 for example.

In conclusion we can assume that the amount of ice and snow cover found throughout Lake Vansjo was enough to prevent the entrance of light (is believed that less than 10% can cross ice and snow cover) and of course avoid wind action influence.

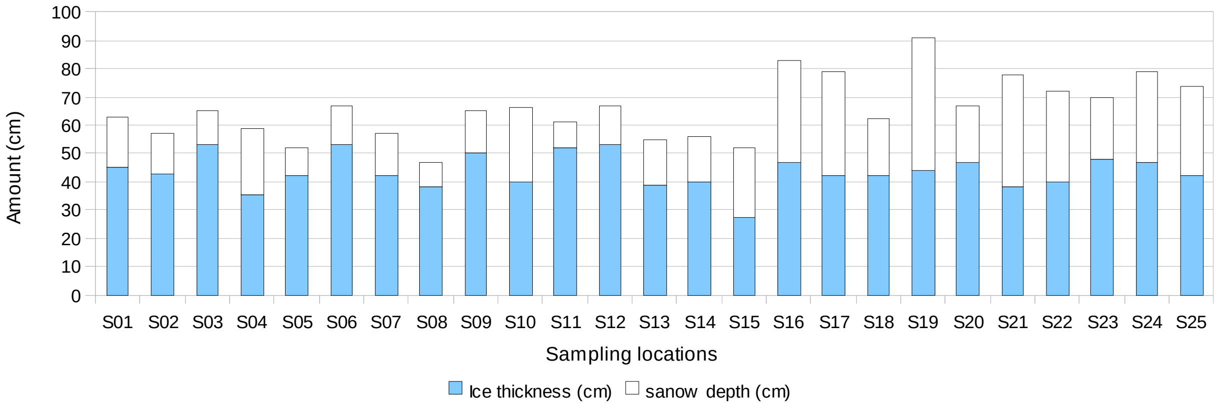


Figure 15. Ice thickness and snow depth distributions around Lake Vansjo.

6.2. Depth profiles for temperature and conductivity

Shown bellow in Figures 16, 17, 18 and 20 are the results of depth profiles for temperature and conductivity measured with a CTD device for two of the three NIVA sites (Vanemfjorden and Storefjorden). Results from other sampling sites can be found in Appendix.

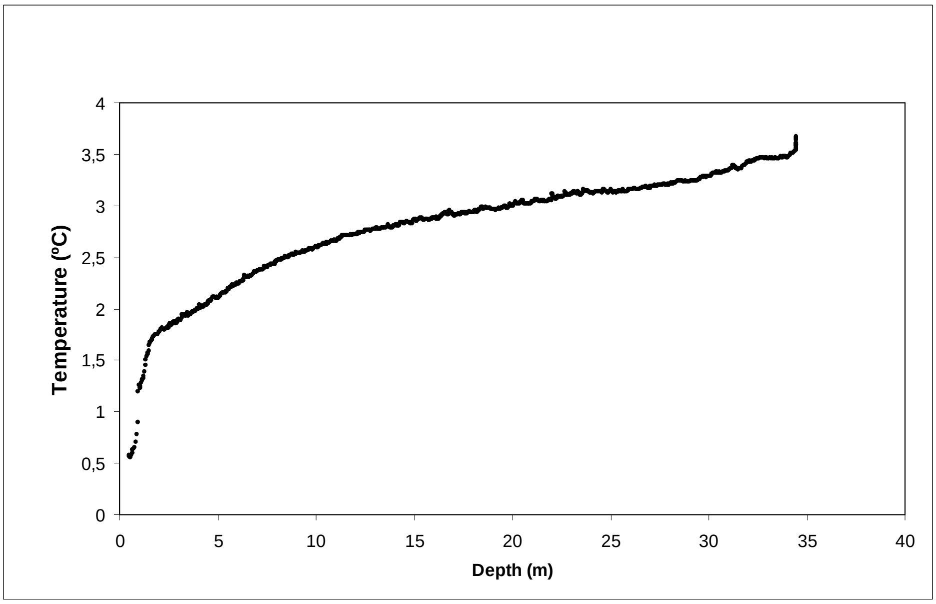


Figure 16. Estimated depth profiles vs. temperature for Storefjorden Site (S09).

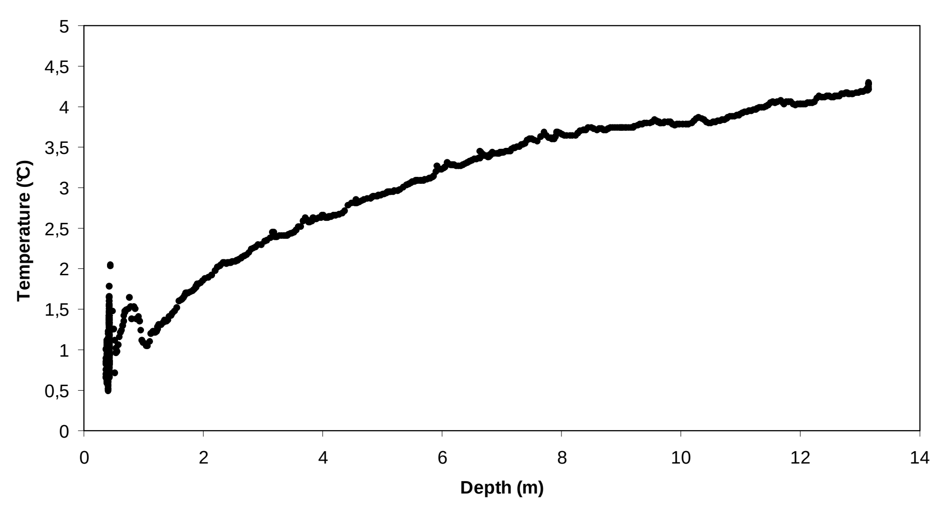


Figure 17. Estimated depth profiles vs. temperature for Vanemfjorden Site (S20).

6.2.1. Depth vs. temperature

Temperature exerts a major influence on the biological activity and growth of aquatic organisms. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have their optimal temperature ranges. As temperatures becomes far above or below this optimal range, the number of individuals of the species decreases until finally there are few, or none.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. Therefore biologically mediated parameters such as dissolved oxygen concentration, pH, nutrient concentrations are strongly influenced by temperature

As we know, the main consequence of lake temperature variations is lake thermal stratification, which is a temperature layering effect that occurs in water due to the change in water's density with temperature.

During the winter, ice cover prevents wind from mixing the lake water and a layer of low density water colder than 4°C, but warmer than 0°C forms just under the ice.

Results:

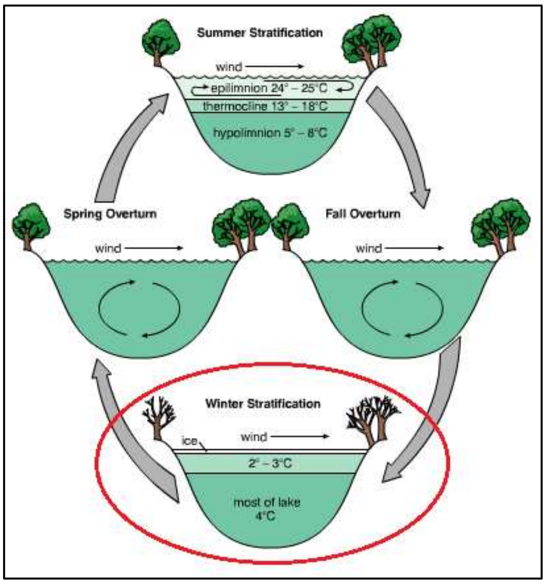


Figure 20. Seasonal patterns of water column temperature in Lake Vansjø. Winter period when the present study was made is surrounded in red.

As can be seen in all graphs of depth vs. temperature during winter period the temperature in the top of the water column (just under the ice) is around 0 °C and is between 3 and 5°C at the bottom, this could suggest that lake presents a clear phenomenon of winter thermal stratification (see Figure 20 of winter inverse stratification in lakes surrounded by red). In addition, ice cover prevents wind from mixing the lake water and therefore this stratification can be maintained over a long period.

It is also interesting to see that the increase of temperature occurs until reaching approximately 4 or 4.5 °C in all analysed sites. This means that shallow places have a greater increase of temperature with depth, therefore higher slopes in depth vs. temperature graphs. On the contrary deep places will have lower slopes in graphs due to a weak increase of temperature with depth.

6.2.2. Depth vs. Conductivity

Conductivity is the ability of water to conduct an electrical current. It is a thermophysical property of water. Dissolved ions in the water are conductors so the variation in conductivity reflects differences in ionic composition. The major positively charged ions in freshwater systems are sodium (Na^{+}), calcium (Ca^{+2}), potassium (K^{+}) and magnesium (Mg^{+2}). The major negatively charged ions in freshwater systems are chloride (Cl^{-}), sulphate ($SO4^{-2}$), carbonate ($CO3^{-2}$) and bicarbonate ($HCO3^{-}$). Nitrates ($NO3^{-2}$) and phosphates ($PO4^{-3}$) are minor contributors to conductivity. The commonly used unit of EC is microSiemens per centimetre (µS/cm). Natural rivers and lakes have conductivities between 10 and 1000 µS/cm. Specific conductivity is the conductivity normalised at 25 °C.

Results:

Specific conductivity of Lake Vansjø has a little variation with depth (see graphs 18, 19 and data of the other 23 sites in Appendix). One can also notice a higher increase of the conductivity towards the bottom. Generally the waters near the sediments of the lake are more conductive than the shallower waters.

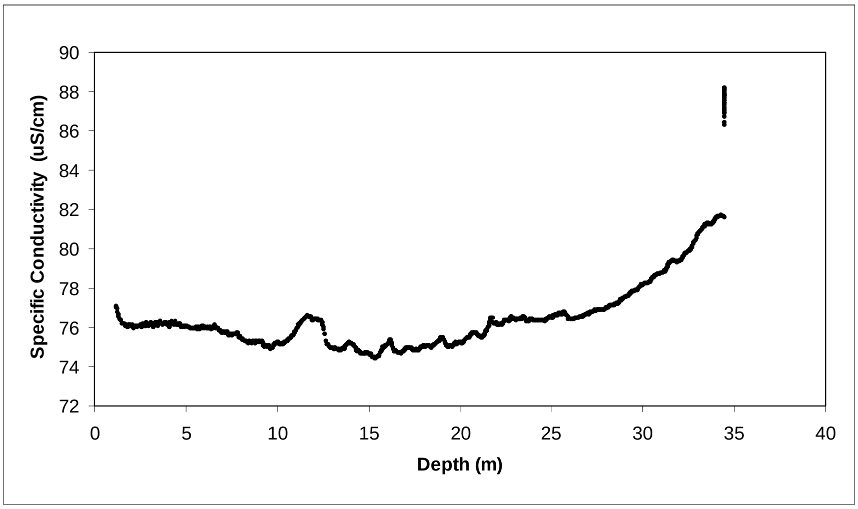


Figure 18. Estimated depth profiles vs. conductivity for Storefjorden (S09).

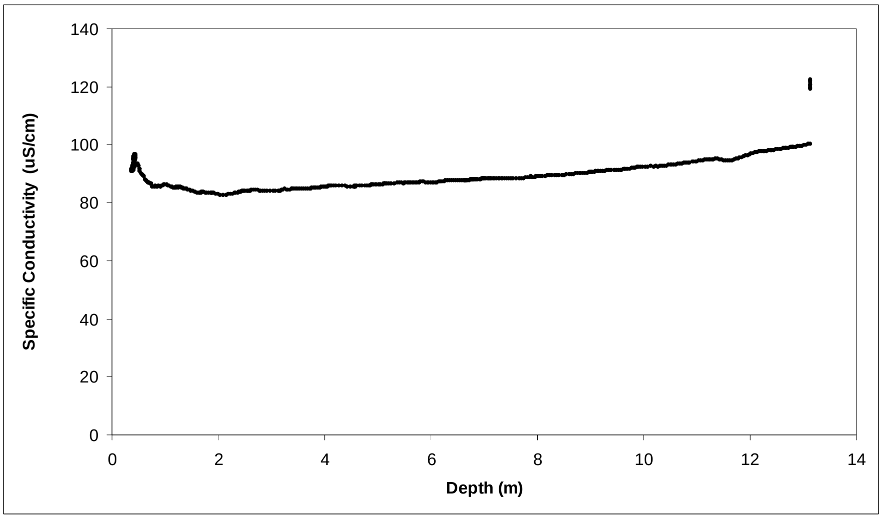


Figure 19. Estimated depth profiles vs. conductivity for Vanemfjorden Site (S20).

6.3. Conductivity

Results:

i) Spatial comparison

The results of conductivity measurements did not show a high concentration of dissolved ions throughout Lake Vansjø compared with results obtained from literature (see Moore, 1989).

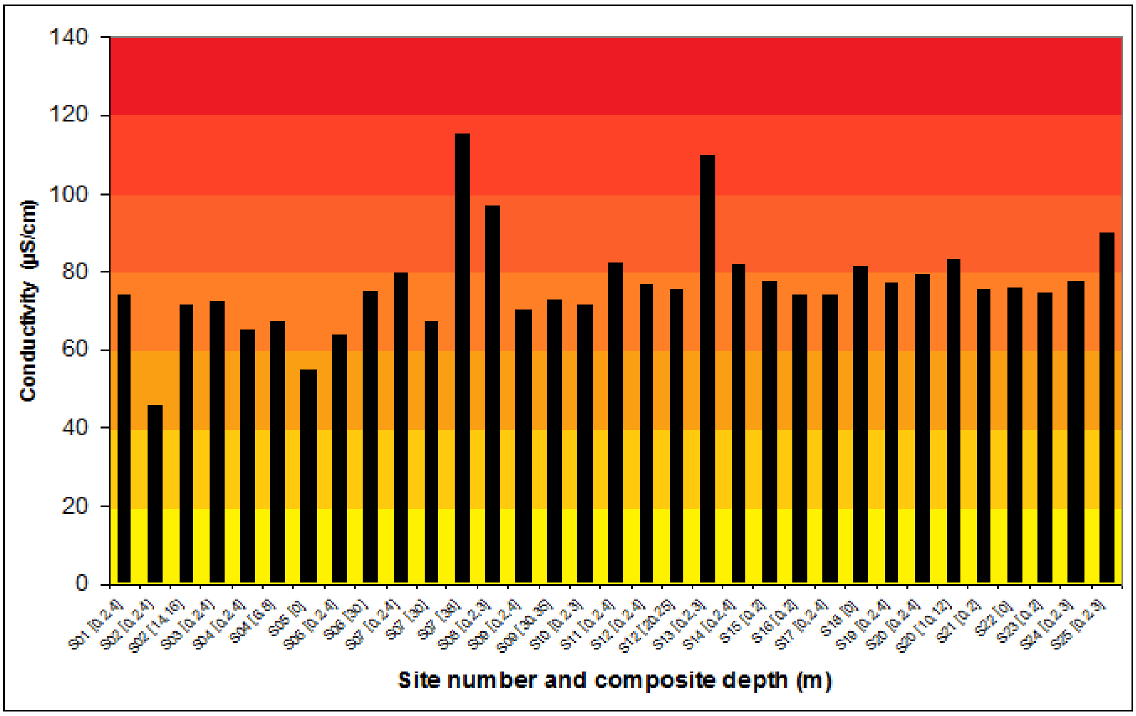


Figure 21. Conductivity values of winter 2010 in Lake Vansjø.

The results were fairly constant over all sampling points, conductivities are in the rang between 45,5 and 115,3 µS/cm (see Figure 22). Only three points have comparatively higher values. An interesting sample with high conductivity is the mouth of Hobøleva River (S08 [0,2,3]). The other two samples with high conductivity may be due to that one during sampling have touched the bottom of the lake (S07 [38] and S13 [0,2,3]) .

In addition, a slight increase of conductivity in the lower layers of the lake was observed again (see above).

6.4. Major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+})

Lake water contains minute amounts of chemicals, often called salts. This general term describes chemicals which, when dissolved in water, separate into positively and negatively charged particles called ions. Common cations (positively charged ions) include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}); anions (negatively charged ions) include bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}), sulphate (SO_4^{2-}) and chloride (Cl^{-}). The ions may join in various combinations to form salts such as calcium carbonate.

In aquatic systems, the natural concentrations of metal ions are principally dependent on the ambient distribution, weathering and leaching of the elements from the soil in the catchment area and in some cases due to man made activities

Results:

i) Spatial comparison

Distributions of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) throughout Lake Vansjø during winter period are shown in Figure 22. The results were fairly constant over all sampling points. The site with label S07 [38] experimented higher values of cation concentrations due to bottom touching. Other high concentrations of cations were found in Grepperødfjorden area.

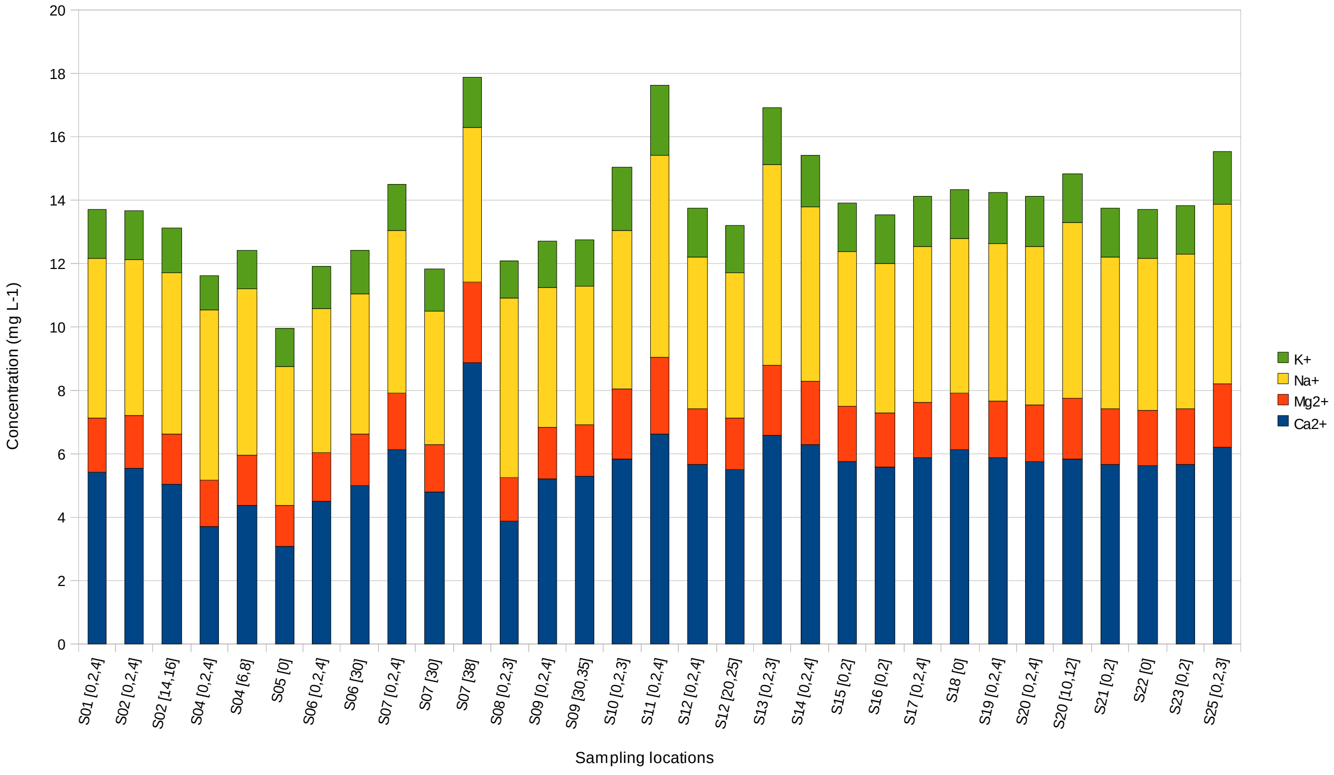


Figure 22. Major cation distributions in Lake Vansjo.

6.5. Alkalinity

Alkalinity is the buffering capacity of a water body to neutralize acids and bases maintaining a fairly stable pH. It is a total measure of the substances in water that have "acid-neutralizing" ability. The alkalinity of water is widely used for the monitoring of natural water. The concentration of hydrogen 0carbonates is often calculated from this alkalinity index. However, this is incorrect because other salts of weak acids can contribute to the alkalinity of water.
Without this buffering capacity, any acid added to a lake would immediately change its pH.

Why is alkalinity important?

Aquatic organisms benefit from a stable pH value in their optimal range. To maintain a fairly constant pH in a water body, a higher alkalinity is preferable. High alkalinity means that the water body has the ability to neutralize strong mineral acidic pollution from rainfall or basic inputs from wastewater.

What affects alkalinity?

Alkalinity of lakes is mainly related to basin bedrock regional geology, specially the content of carbonate minerals. Alkalinity comes from rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges (detergents and soap based products are alkaline). If an area's geology contains large quantities of calcium carbonate ($CaCO_3$, limestone), water bodies tend to be more alkaline. Granite bedrock is deficient in alkaline materials to buffer acidic inputs.

Results:

i) Spatial comparison

Obtained results of alkalinity around Lake Vansjø are illustrated in Figure 23. Alkalinity values were rather constant regarding different sampling places (ranging between 147,1 and 286.4 mg/L $CaCO_3$) with the exception of S08 [0,2,3], S11 [0,2,4], S13 [0,2,3] and S14 [0,2,4].

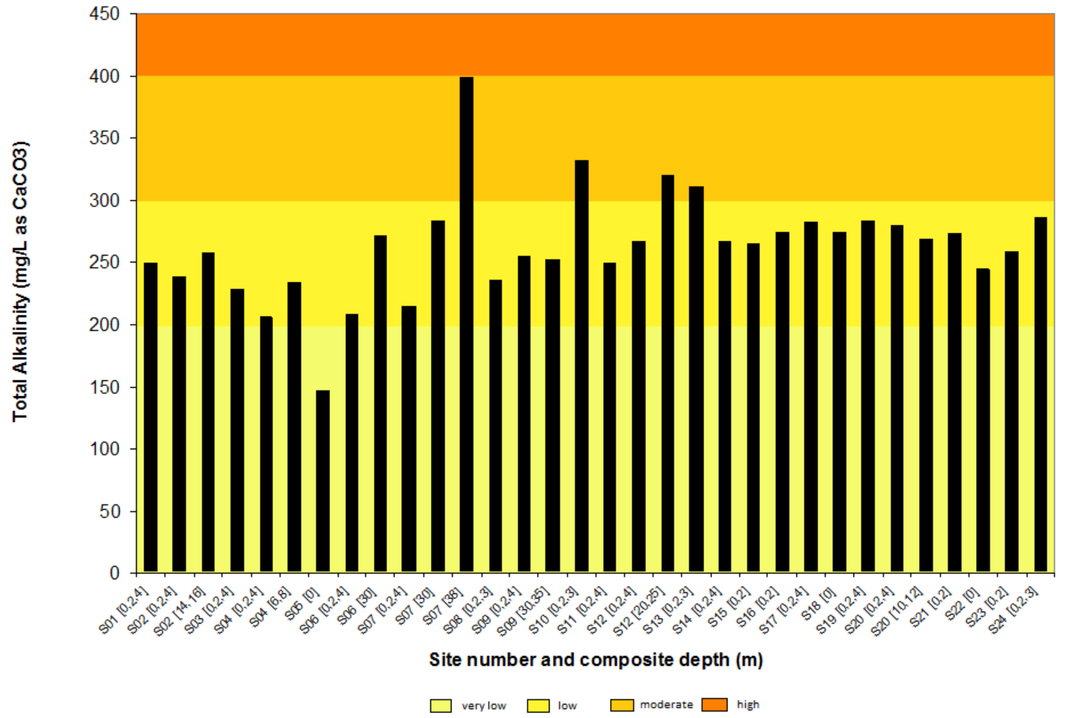


Figure 23. Alkalinity values of Lake Vansjo studied sites, colour gradient refers to bibliographic alkalinity values (Source: Lake Access).

Given that basin geology of Lake Vansjø (see Figure 7 in chapter 4.5) is principally composed of igneous and metamorphic rocks such as granite (igneous), gneiss, amphibolites, mica schist and migmetite (metamorphic) which are poor sources of alkalinity would be expected lower alkalinity values. However, we have to consider other factors which are able to influence alkalinity of streams and lakes such plant activity and wastewater. Increases of alkalinity can also be one of the effects of eutrophication.

Wastewater can have higher alkalinity because it typically has higher concentrations of nutrients and ions, some with acid buffering properties, such as silicates and phosphates.

stormwater runoff leading to streams can carry lime (either calcite or dolomite), which is applied to lawns and agricultural fields to increase soil pH and buffer soil.

6.6. pH

pH is an intensity measure of water acidity. Common nutrient poor to medium nutrient-rich lakes often have pH around the neutral point of 7.0 or slightly acidic. In nutrient-rich lakes with strong photosynthesis in the upper water layers can be very high pH in the summer - especially on windless days.

Similar to the temperature of the lake pH is also affected by seasonal variation. In the summer months, plankton is more active in Vansjø's waters. Plankton consumes CO_2 which makes the water less acidic in the summer. This is because of a chemical reaction that occurs between CO2 and H2O, which yields hydrogen ions (H^+) and bicarbonate ions ($HCO3^{-2}$). In the winter months, however, there is less photosynthesis activity, and more decomposition, meaning more CO_2 and a lower pH.

pH and phosphorus release

The importance of pH for phosphorus release is mainly related to the fact that the binding of phosphorus to oxidized iron compounds decreases at high pH values, phosphorus being replaced by hydroxy ions on iron particle surfaces (Andersen, 1975; Lijklema, 1976). Thus, increased phosphorus release at high pH has been observed in connection with resuspension events in summer when pH is high due to high photosynthesis activity (Koski-Vahala & Hartikainen. 2001). Photosynthetically increased pH in the water phase may also influence the sediment pH, and this may again affect the binding forms of phosphorus in the sediment and thereby also the potential phosphorus release (Søndergaard, 1988; Welch & Cooke, 1995; Istvánovics & Pettersson, 1998).

Results:

i) Spatial comparison

During the studied period pH values in the lake ranged from 6.20 to 7.01 (see Figure 24). Relatively lower pH was found in Storefjorden area.

ii) Seasonal comparison

Broadly speaking, we can see that the pH values recorded during the present study for the sites (winter 2010) are a lower than the recorded data of spring and autumn between 2005 and 2008 and are much lower than the recorded data of summer 2008 (see appendix chapter and Bioforsk, 2008. Therefore, pH was lower probably due to the reduction of photosynthetic activity during winter and this coupled with a possible increase of decomposition rates (The breakdown of organic matter by bacteria and fungi) which produces an increase of oxygen consumption and moreover a increase of carbon dioxide in the affected environment.

We can also add that during the winter pH values remained fairly constant in contrast to other seasons in which occur large fluctuations in pH (see Bioforsk, 2008).

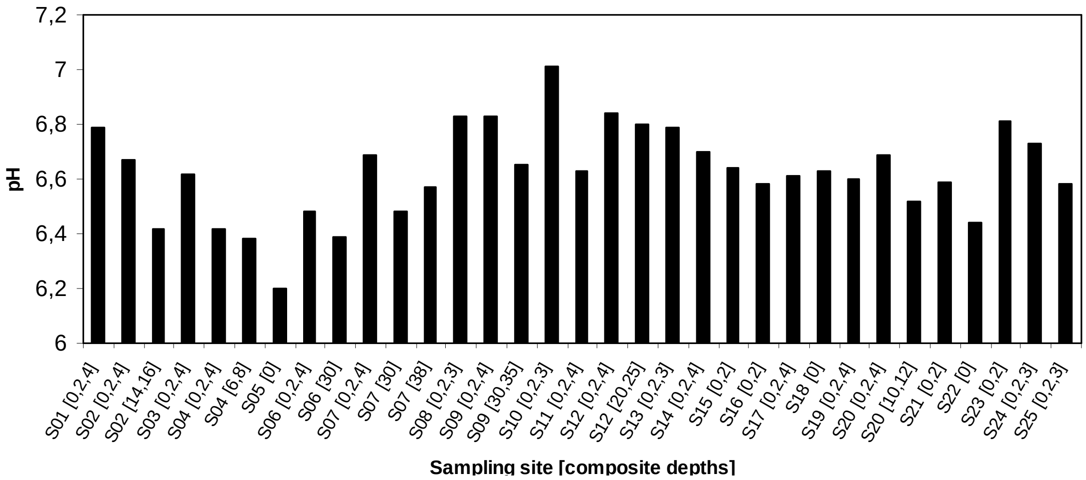
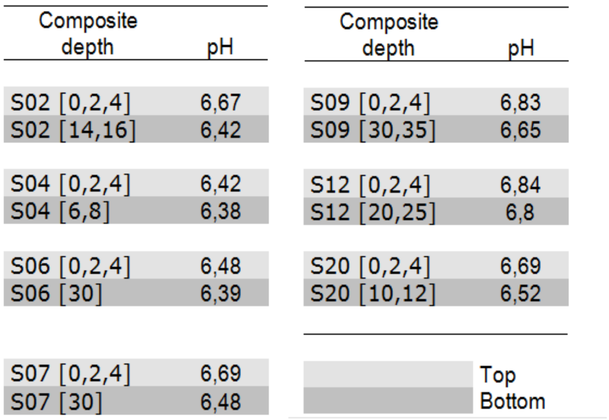


Figure 24. pH values of winter 2010 around Lake Vansjø.

Measured pH was lower in the lower layers of the water column (see Figure 24 and Table 9). This may be due to relatively more decomposition than photosyntehesis in the lower layers during winter period. This produces a relative increase in CO_2 release and therefore a decrease of pH.

Table 9. Veritcal variation of pH values in Lake Vansjø during winter 2010



Composite depth	pH	Composite depth	pH
S02 [0,2,4]	6,67	S09 [0,2,4]	6,83
S02 [14,16]	6,42	S09 [30,35]	6,65
S04 [0,2,4]	6,42	S12 [0,2,4]	6,84
S04 [6,8]	6,38	S12 [20,25]	6,8
S06 [0,2,4]	6,48	S20 [0,2,4]	6,69
S06 [30]	6,39	S20 [10,12]	6,52
S07 [0,2,4]	6,69	░	Top
S07 [30]	6,48	▒	Bottom

6.7. Suspended Solids

Suspended solids is a measure of particulate material (inorganic and organic) in the water. It is expressed as mg L^{-1}.
Previous studies of Lake Vansjø (Bioforsk, 2008 and NIVA, 2005) show that the highest concentrations of suspended solids in the lake occur between April and May, during this period there is a considerable increase in river flow due to snowmelt runoff . This increase of water flux produces heavy erosion and consequently a high increase of suspended material transport and concentration in a lake.

Results:

i) Spatial comparison

As shown Figure 25 the highest concentrations of total suspended solids are in the north part of Storefjorden (sites 03, 04, 05, 06, 07, 08 with an average value of 4.97 ppm). This is probably because these six points are located at the estuary of the three main rivers flowing into the lake: Hobøleva, Nordbyelva and Nesaelva in order of importance). Previous studies (Biofrosk, 2008) have shown that these rivers are loaded with high amounts of suspended particulate matter. However, limited to the NIVA monitoring stations the concentration of TSS was higher in Vanemfjorden than in Storefjorden (Figure 25).

Ratios between inorganic suspended solids and organic suspended solids show that the above mentioned sites where the three main rivers flow into lake Vansjø (north part of Storefjorden) contains high concentrations of inorganic particulate matter.
In the southern part of Storefjorden we can see high amounts of organic suspended solids relative to inorganic material (S01, S02, S09, S10, S11 and S12). This is likely due to that this area is far away from the main inputs of water into Vansjø lake and therefore inorganic solids have time to settle on the bottom before reach this southern part.
Finally we note that in Vanemfjorden is the part of the lake system that had highist concentrations of organic suspended solids.

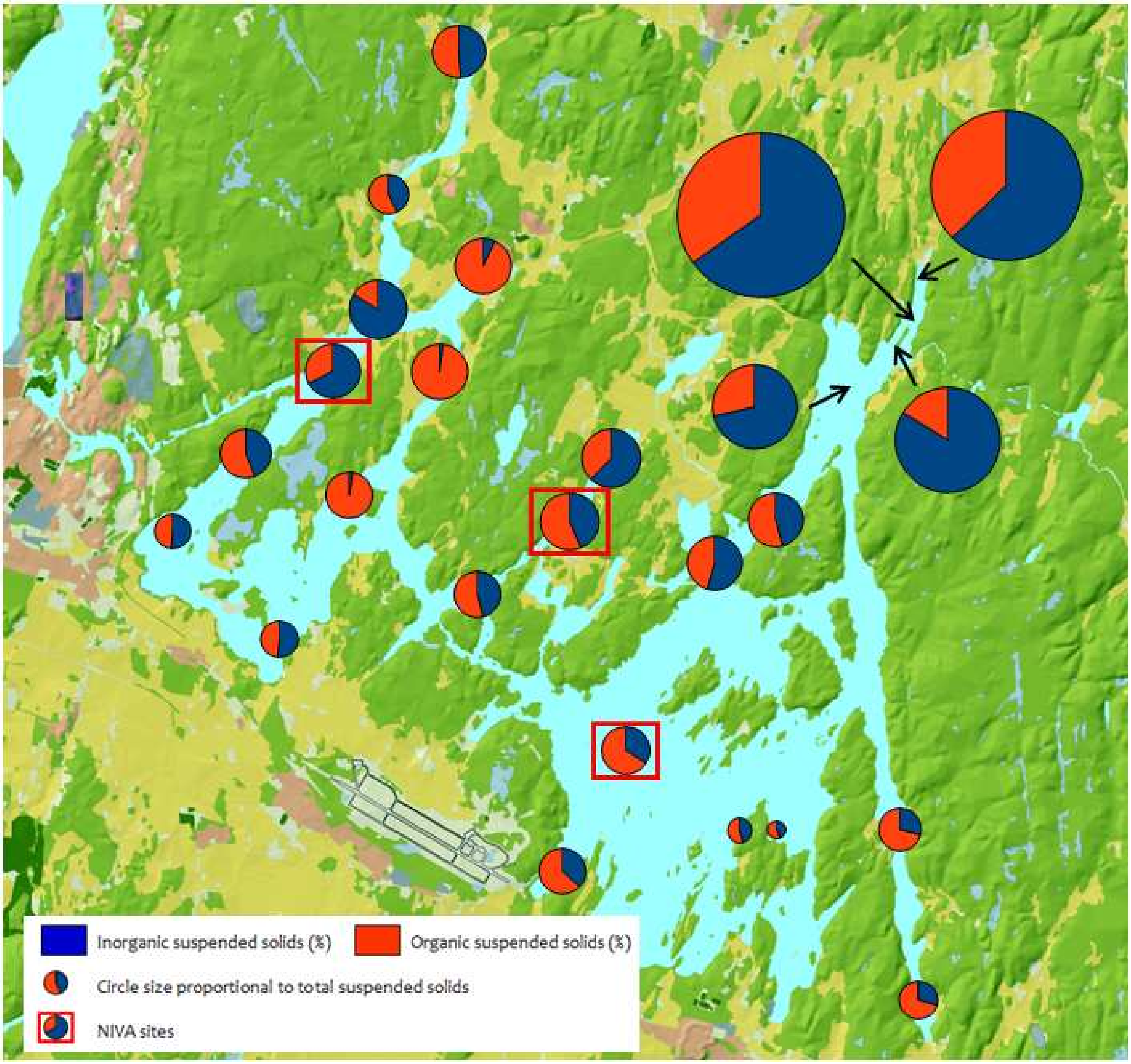


Figure 25. Winter distribution of Total Suspended Solids, Inorganic Suspended Solids and Organic Suspended Solids throughout Lake Vansjø.

ii) Seasonal comparison

We can compare our results (winter 2010) with the results obtained from the NIVA monitoring stations from 2005 (Spring, Summer and Fall) and 2008 (Spring, Summer and Fall). In winter 2010 there is a lower concentration of total suspended solids in both studied points (Storefjorden and Vanemfjorden) (Figures 26, 27 and 28). This difference is mainly due to hydrological and biological conditions. In general during winter there is a minor baseflow in the Inlet Rivers and streams and a decrease of photosynthetic activity.

Hydrological effects:

The samples from 2005 and 2008 were taken between April and September/October. During this period there is a considerable rivers water discharge due to rainfall and snowmelt runoff (see chapter of meteorology and Figure 30).This increase of water flux produces heavy erosion and consequently a high increase of suspended material transport and concentration in a lake. On the contrary the samples of 2010 were collected during winter period which the precipitations are in snow form and the flow of river water is softer. Accordingly erosion phenomena and hence suspended solids transportation into lake are minimal.

Additionally, the presence of ice cover prevents the wind mixing of lake waters and therefore prevents resuspension phenomena of inorganic and organic particulate matter from the sediments (see concentrations of 2.04 and 2.36 ppm in winter). The impact of wind-induced turbulence on mixing and sediment resuspension in lakes is an important factor during non-ice cover period and particularly in Vanemfjorden area where the lake is shallower.

Biological effects:

Aside from these hydrological phenomena, it is assumed that the higher values of total suspended solids during non-ice cover period (specially in Vanemfjorden area) are manly due to organic particles (mostly algae).

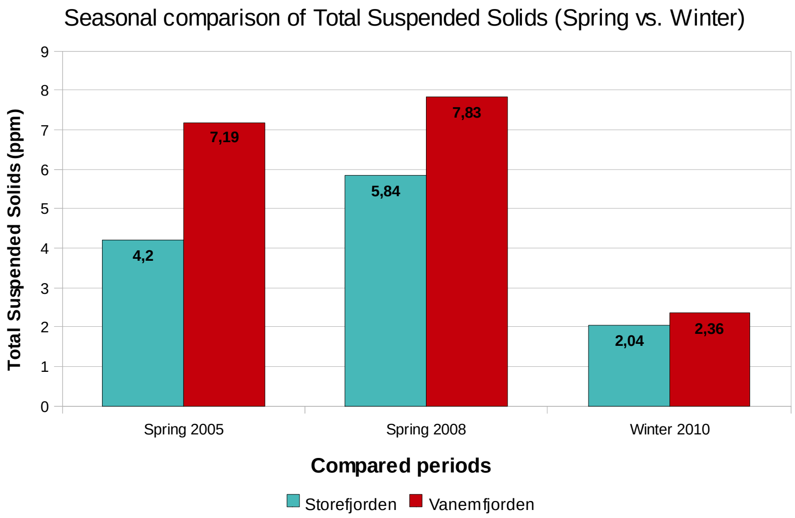


Figure 26. Seasonal comparison of Total Suspended Solids between Spring of 2005, Spring of 2008 and winter of 2010 on Storefjorden and Vanemfjorden.

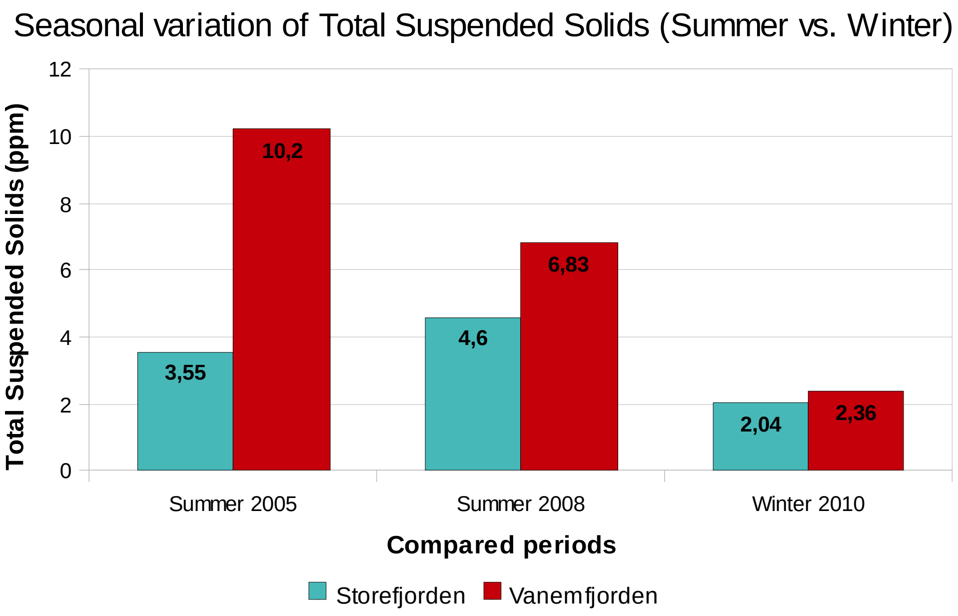


Figure 27. Seasonal comparison of Total Suspended Solids between Summer of 2005, Summer of 2008 and winter of 2010 on Storefjorden and Vanemfjorden.

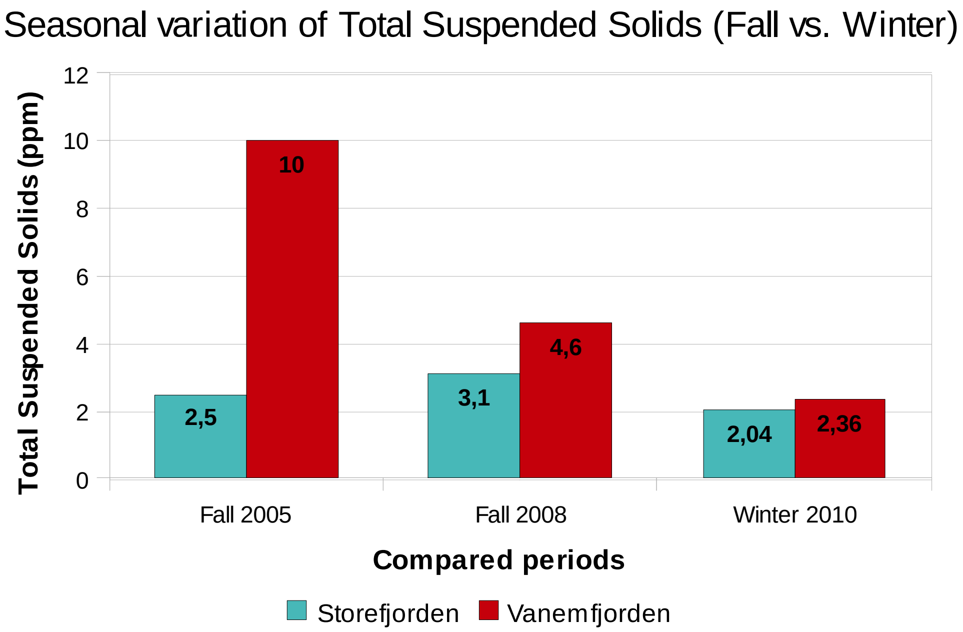


Figure 28. Seasonal comparison of Total Suspended Solids between Fall of 2005, Fall of 2008 and winter of 2010 on Storefjorden and Vanemfjorden.

6.8. Phosphorus

Total phosphorus (Tot-P) includes all phosphorus compounds in the water, both which are bound to particles and those which are dissolved in the water.

Particulate phosphorus (Particulate-P) is the phosphorus that is bound to biological material as well as inorganic particles.

Dissolved inorganic phosphorus or orthophosphate (Free PO_4^{3-}) is the phosphorus part which is assumed immediately available for phytoplankton.

Dissolved organic phosphorus (Org-P) is the fraction composed by soluble organic forms in water.

Results:

i) Spatial comparison

Distributions of phosphorus fractions throughout Lake Vansjø during winter period are shown in Figure 29 and 30.

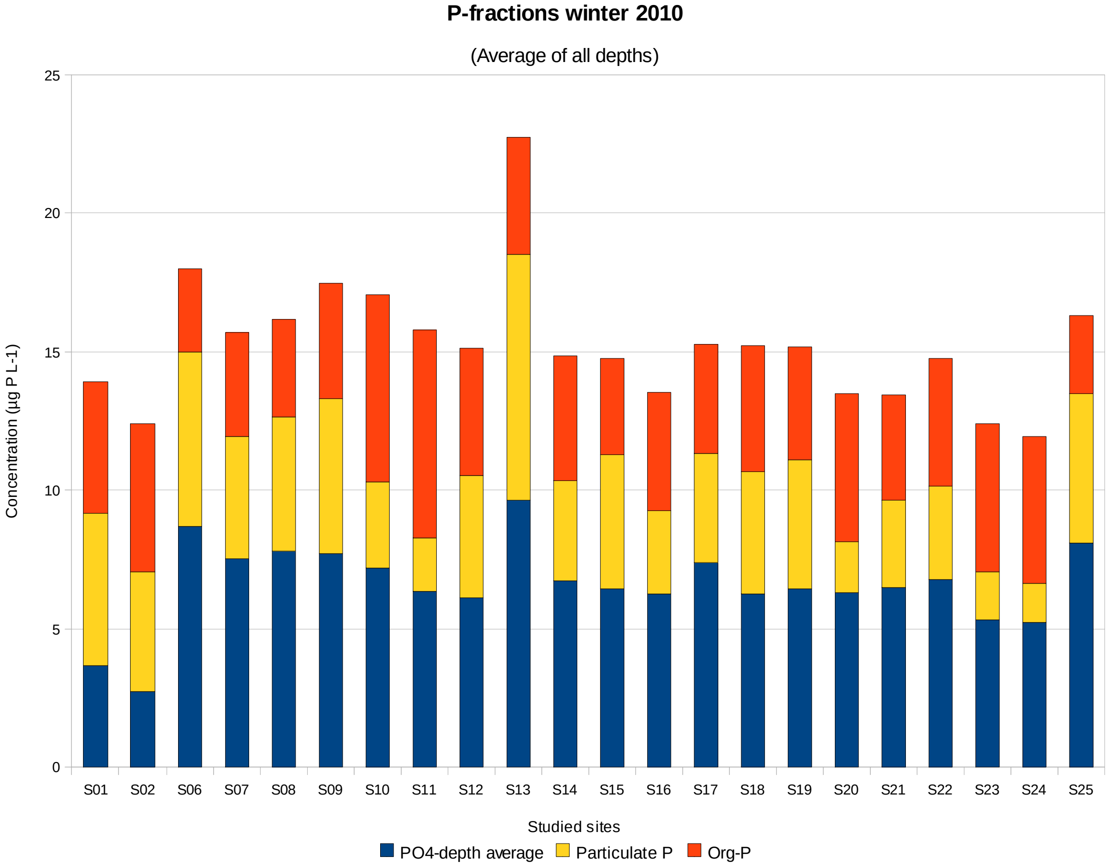


Figure 29. Distributions of phosphorus fractions throughout Lake Vansjø during winter period.

Total Phosphorus (Tot-P)

Little variation in Tot-P concentrations were found throughout the lake. Results are always between 17,1 and 11.9 µg P L$^{-1.}$ An important exception was seen on site 13, located in Grepperødfjorden. A significant finding is that inorganic phosphorus (PO4) constitutes the greatest fraction of the total phosphorus loading.

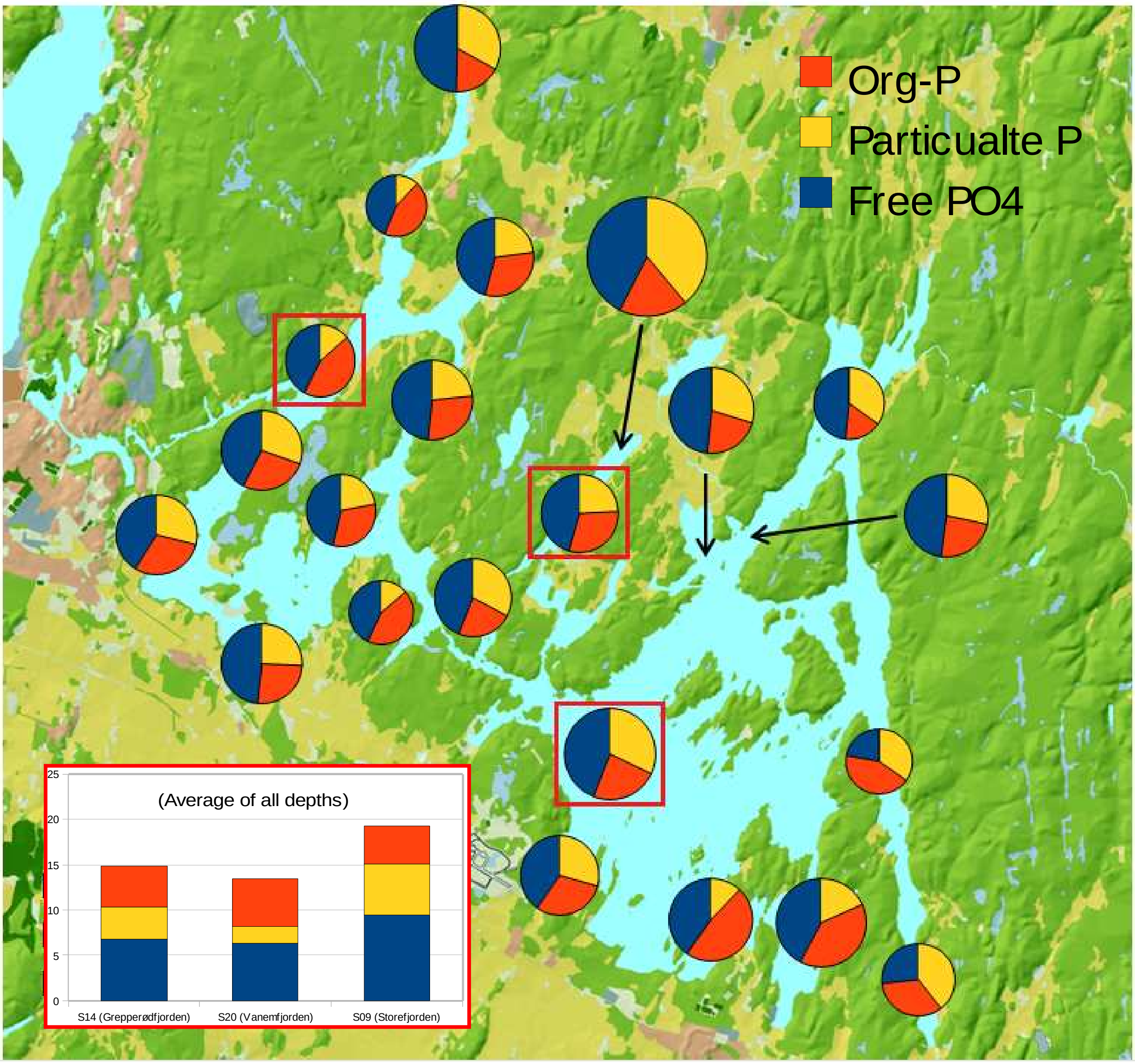


Figure 30. Distribution of Total Total Phosphorus (circle size), free orthophosphate, organic dissolved phosphorus and total particulate phosphorus throughout Lake Vansjø. Framed in red the three NIVA control stations sites (S09 (Storefjorden), S14 (Grepperødfjorden) and S20 (Vanemfjorden)).

Free phosphate (Free PO_4^{3-})

Orthophosphate levels all over Lake Vansjø are high and similar: in all cases a little less than 50% of Tot-P. The values were in the range between 5.22 and 9.66 µg P L^{-1}. Only sites 8 and 9 have an unexplained low free phosphate concentration (see Figure 29 and/or 30).

Regarding to a vertical distribution of PO4 in Storefjorden and Vanemfjorden, we can see a very similar concentrations on the top layers of the water column but an important variation on the bottom layers of the water column (see Figure 31). It is presumed that the reduced conditions are stronger in the bottom layers of Storefjorden due to an important inverse stratification effect. This may therefore be a strong indication of increase of PO4 due to release from sediments.

It could be also of a great importance to consider the decreased assimilation and increased decomposition rates as an other possibilities which influenced the higher phosphate concentrations in the lower layers of the lake.

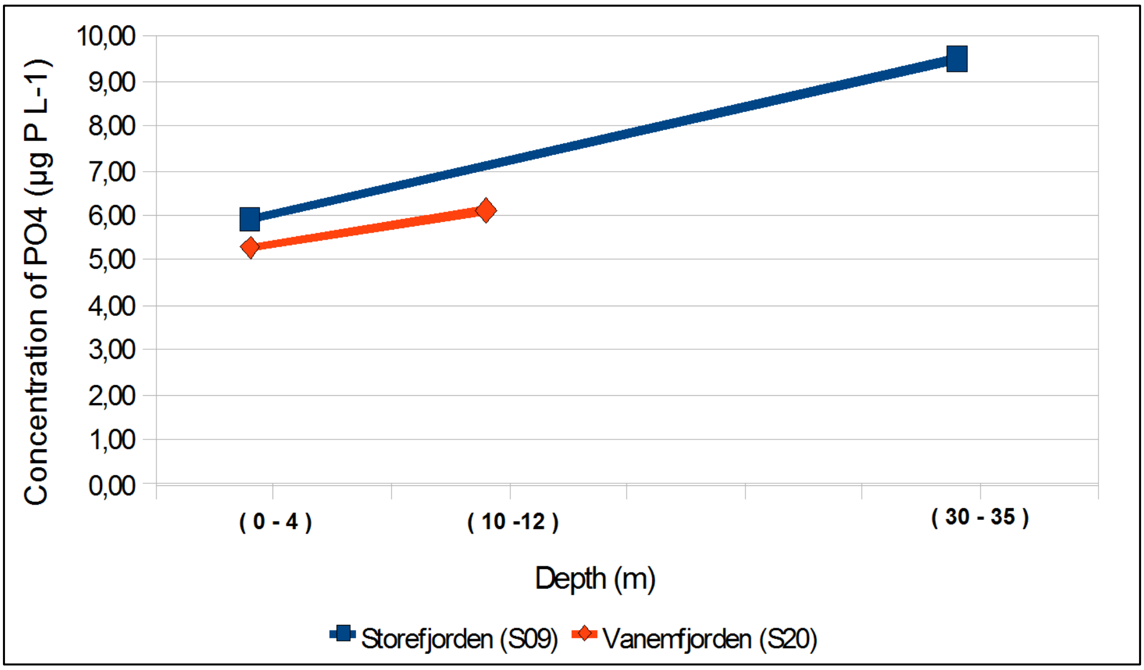


Figure 31. Vertical distribution of PO4 in Storefjorden and Vanemfjorden sites.

Dissolved organic phosphorus (Org-P)

Concentrations of Org-P varied throughout the lake. We can see areas where the concentrations were really high, for instance the southern part of Storefjorden, areas where the concentration was moderate such as Vanemfjorden as well as places where the levels of Org-P were relatively low, for example see north part of Storefjorden and north part of Grepperødfjorden.

Particulate phosphorus (Particulate-P)

As discussed in the chapter about suspended solids, the concentration of total particulate phosphorus was higher at the mouth area of the three main rivers flowing into the lake (see the north part of Storefjorden) and lower in other places such as Vanemfjorden or south of Storefjorden.

Accordingly and even the incoming water flow during winter is lower corporately to other periods (see Figure 32). Despite low flow it is clear that the velocity is high enough to carry particulate matter into the lake.

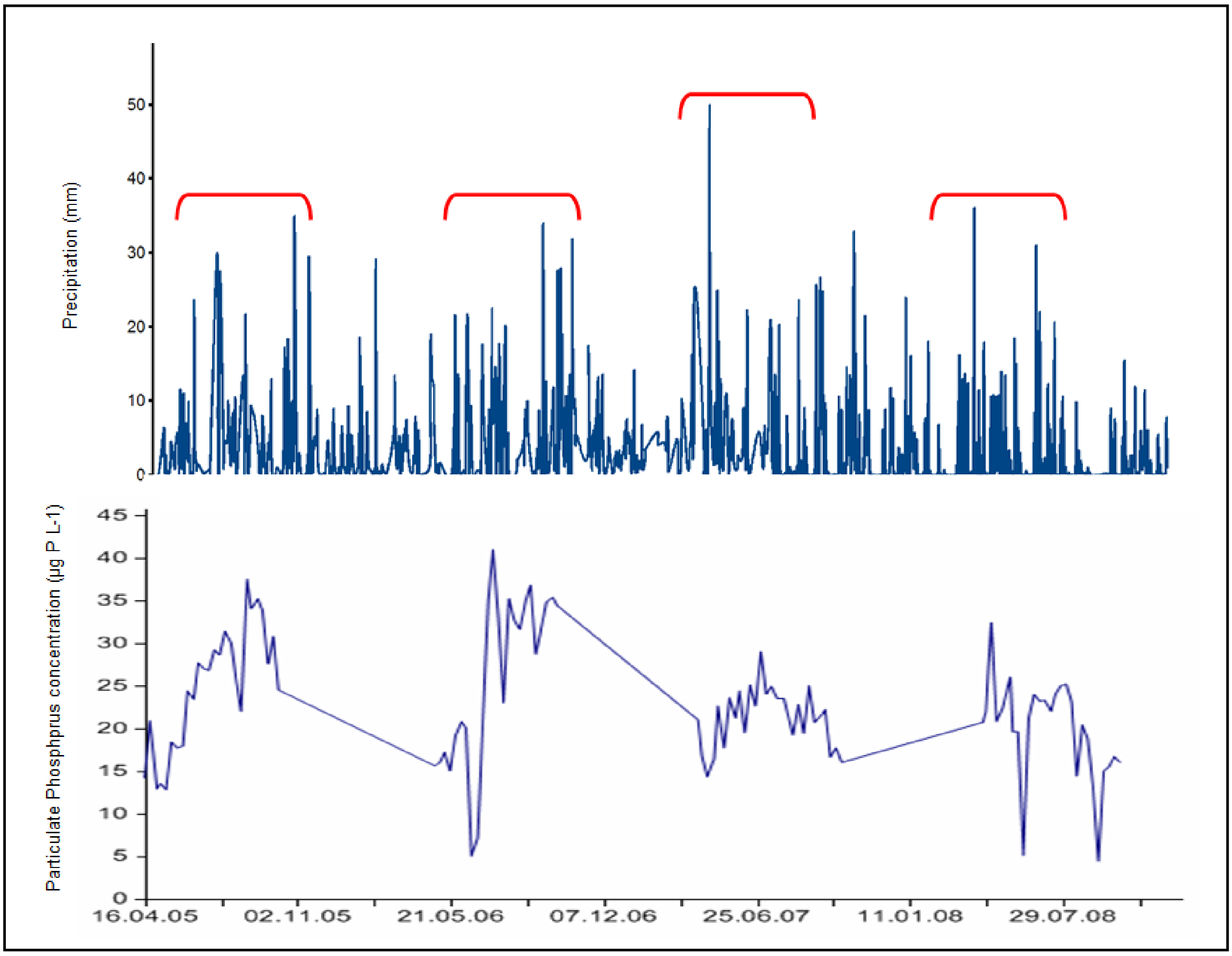


Figure 32. Relationship between precipitations and particulate phosphorus concentration between 2005 and 2008 in Vanemfjorden part of Lake Vansjø. Indicated in red periods of high rainfall.

ii) Seasonal comparison

Distributions of phosphorus fractions of winter 2010 compared with results from other seasons and other years are shown in Figure 33. Annual distributions of phosphorus fractions in the three NIVA control stations sites are shown in Figures 34, 35 and 36. Additionally are shown the results of My Lake simulation model (Soloranta and Andersen, 2007) in Storefjorden site (Figure 37)

Figure 33. Comparison between phosphorus distributions of Winter of 2010 and Spring, Summer and fall of 2005, 2006, 2007 and 2008 on the three NIVA control stations sites (S09 (Storefjorden), S14 (Grepperødfjorden) and S20 (Vanemfjorden))

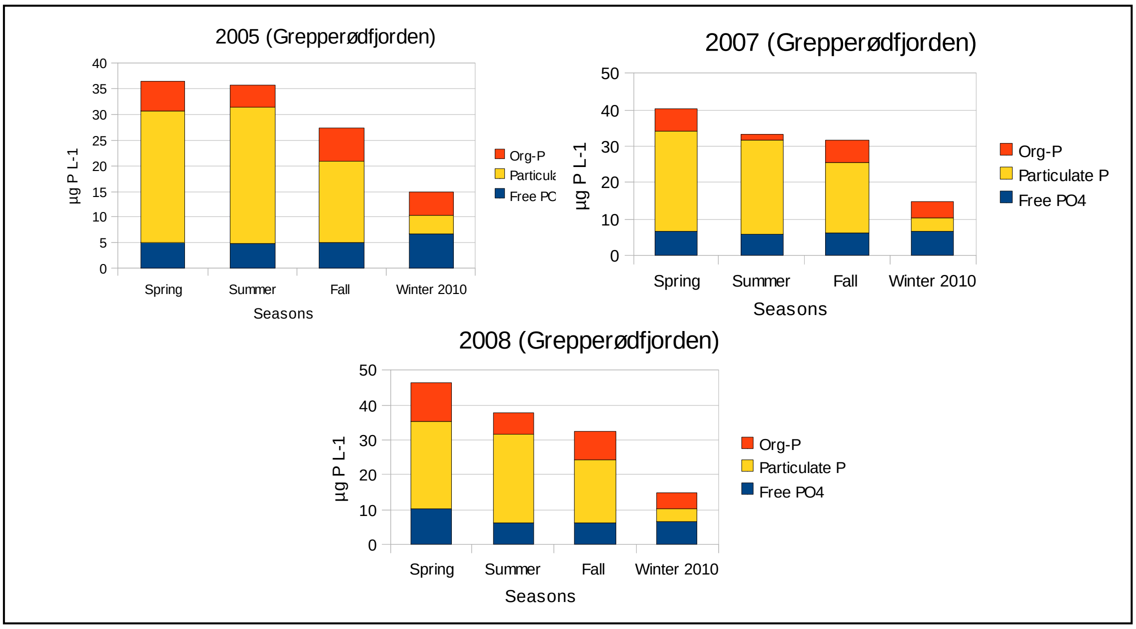


Figure 34. Grepperødfjorden annual phosphorus distributions.

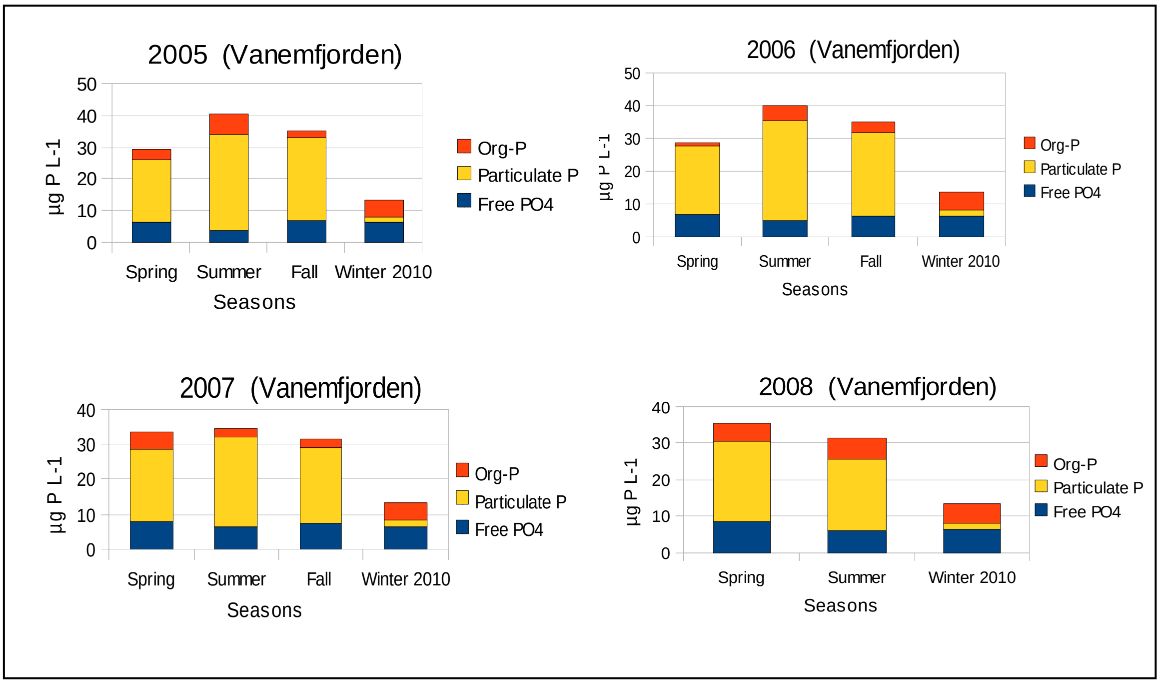


Figure 35. Vanemfjorden annual phosphorus distributions.

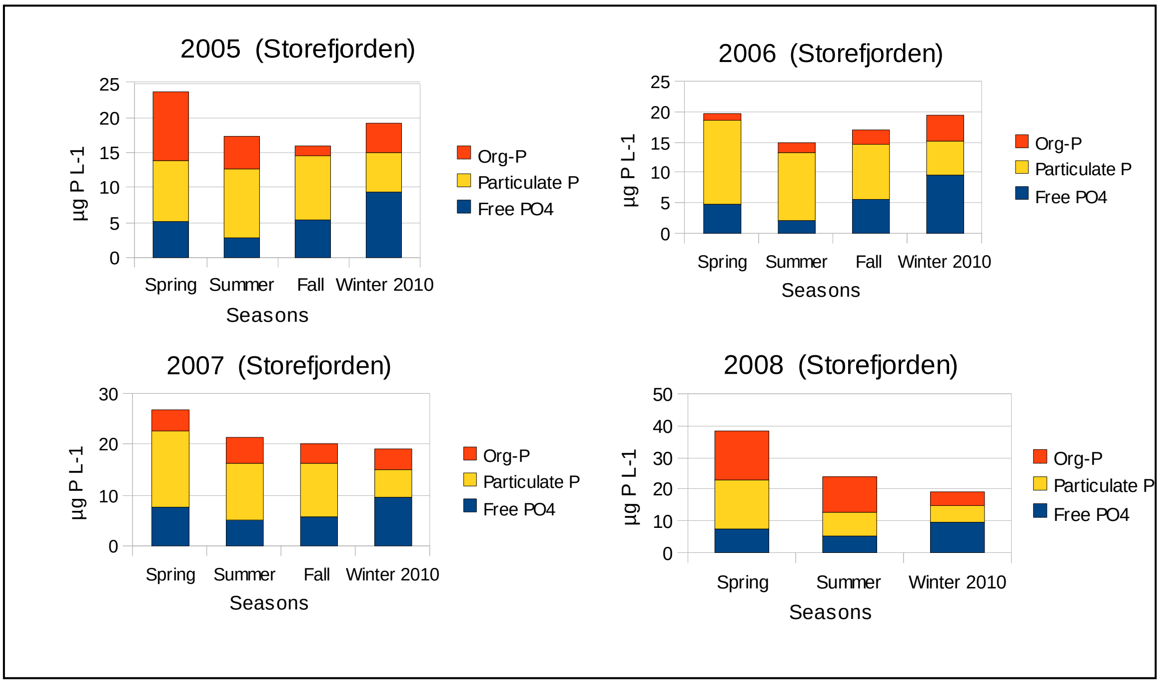


Figure 36. Storefjorden annual phosphorus distributions.

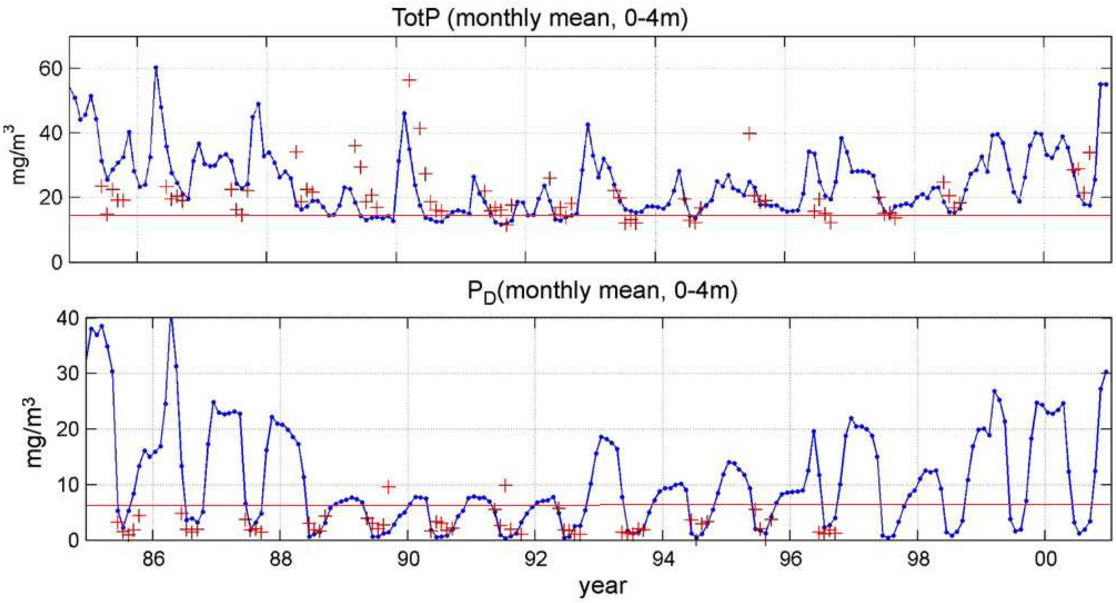


Figure 37. Simulated (solid lines) vs. observed (+) surface layer (0–4 m) monthly mean time series of total P (TotP) and dissolved inorganic P (PD) in Lake Vansjø-Storefjorden (Soloranta and Andersen, 2007). . Winter 2010 values (red solid line).

Total Phosphorus (Tot-P)

Winter concentrations of Tot-P were significantly lower than average values of other seasons and years (see Figures 33, 34, 35, 36 and 37). The most important Tot-P seasonal changes occur in Grepperødfjorden and Vanemfjorden. As total phosphorus case shown, Storefjorden is a big and deep water system and therefore need major influences to change water parameters. In contrast, small influences are enough to change the environmental water conditions of Grepperødfjorden and Vanemfjorden.

Particulate is the fraction of phosphorus which plays the most important role in the decrease of total phosphorus concentration in winter in Grepperødfjorden and Vanemfjorden.

Dissolved organic phosphorus (Org-P)

Generally concentrations of Org-P remained fairly constant between seasons. That means that concentrations of Org-P in winter 2010 are similar to concentrations of other seasons on 2005, 2006, 2007 and 2008. Only some increases were recorded for example in 2008.

Free phosphate (Free PO_4^{3-})

As Figures 38, 39 and 40 showed and following the general dynamics, concentrations of free phosphate increased in winter 2010. Compared to the date of orthophosphate from the monitoring carried out during the last few years we can see that free phosphate concentrations are in some cases higher during winter than during spring, summer and fall.

Free phosphate concentrations we expected to be significantly higher during winter than during other seasons due mainly to the lack of algae assimilation. An empirical indication of this from the monitoring data is the increase of free PO_4^{3-} in late winter and early spring (in some cases such as Grepperødfjorden even in the late spring). The studies conducted during the past five years have not recorded winter data (there are only data recorded in late autumn and early spring) and therefore we have till now not been able to see the possible fluctuations of this parameter during winter.

The reason why the main increase of free phosphate is expected to occur in the late winter and the early spring is because this is the most distant period since the beginning of the ice cover formation and therefore the start of the decline of photosynthetic activity (Vanemfjorden later because the ice was also formed later) directly linked to reduced assimilation of orthophosphate. Coinciding effect is that without photosynthetic activity it is noted a decrease of dissolved O_2 (mainly in the lower layers) which can lead to reducing conditions in the bottom of the lake enhancing the dissolution of phosphorus absorbed in lake sediments.

Particulate phosphorus (Particulate-P)

As was mentioned above on the total phosphorus section the decreases in concentrations of Particulate-P are largely the cause of the decline of total phosphorus during winter. All analyzed samples from the winter have lower amounts of Partiuclate-P compared with the other seasons (see Figures 33, 34, 35, 36, 37 and attached Figures in Appendix). It seems that only in Storefjorden area the concentrations of particulate-P do not differ so much in winter 2010 from the other seasons (see Figure 36).

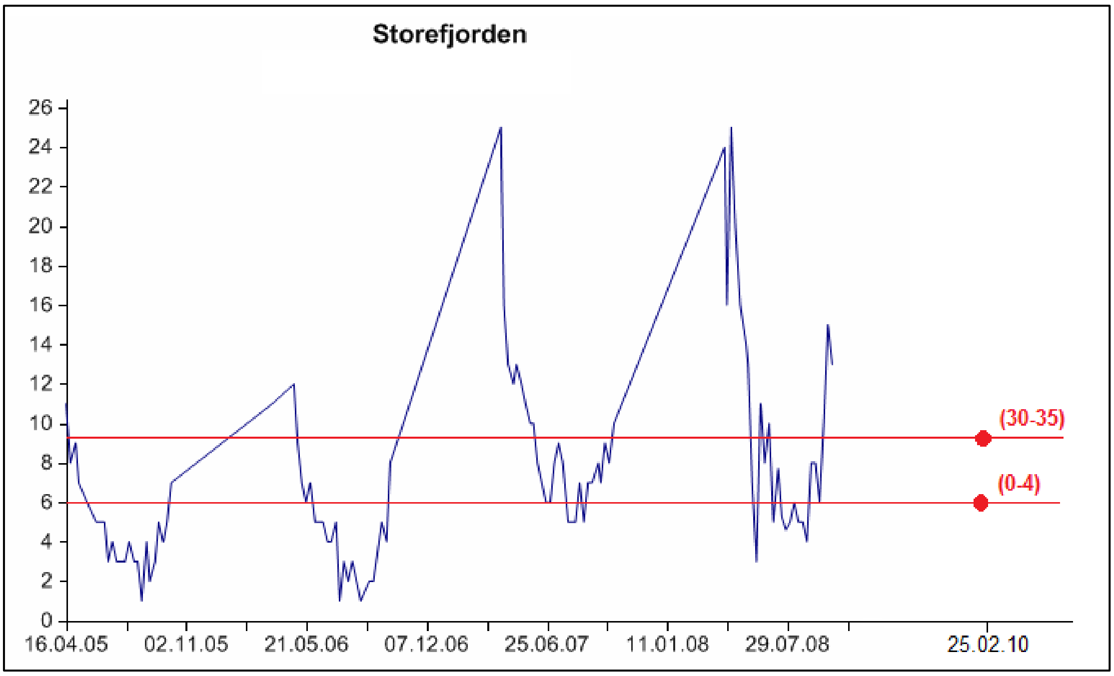


Figure 38. Free phosphate (Free PO_4) yearly evolution in Storefjorden area. Data from 2005 to 2008 (blue line) and winter 2010 (red point).

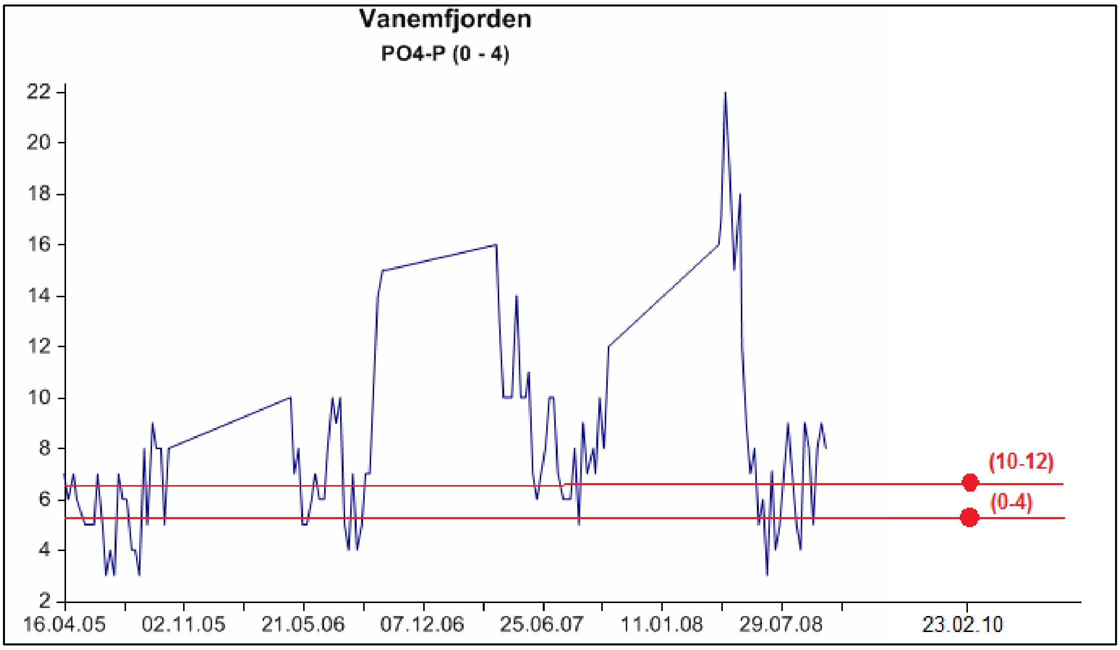


Figure 39. Free phosphate (Free PO_4) yearly evolution in Vanemfjorden area. Data from 2005 to 2008 (blue line) and winter 2010 (red point).

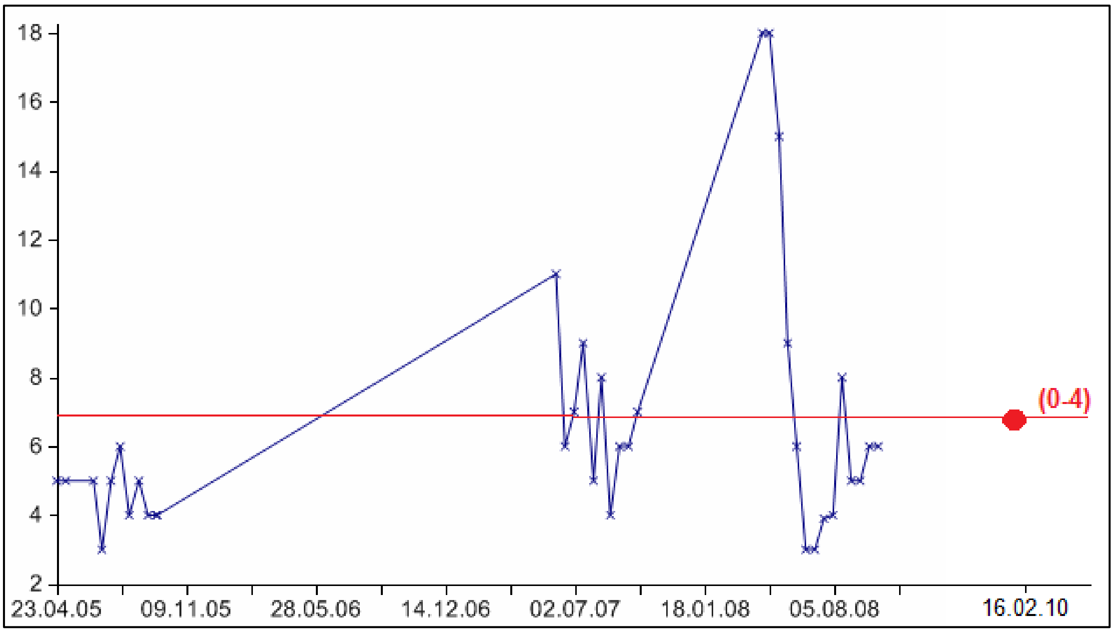


Figure 40. Free phosphate (Free PO_4) yearly evolution in Grepperødfjorden area. Data from 2005 to 2008 (blue line) and winter 2010 (red point).

Finally it is also important to assess the distribution of the different phosphorus fractions throughout the water column (vertical distribution of phosphorus fractions). As Figure 41 and results attached in the Appendix chapter showed, concentrations of almost all phosphorus fractions (Tot-P, PO_4, Particulate-P) were higher at the bottom of the water column during winter season. Just Org-P is lower in this bottom layers.

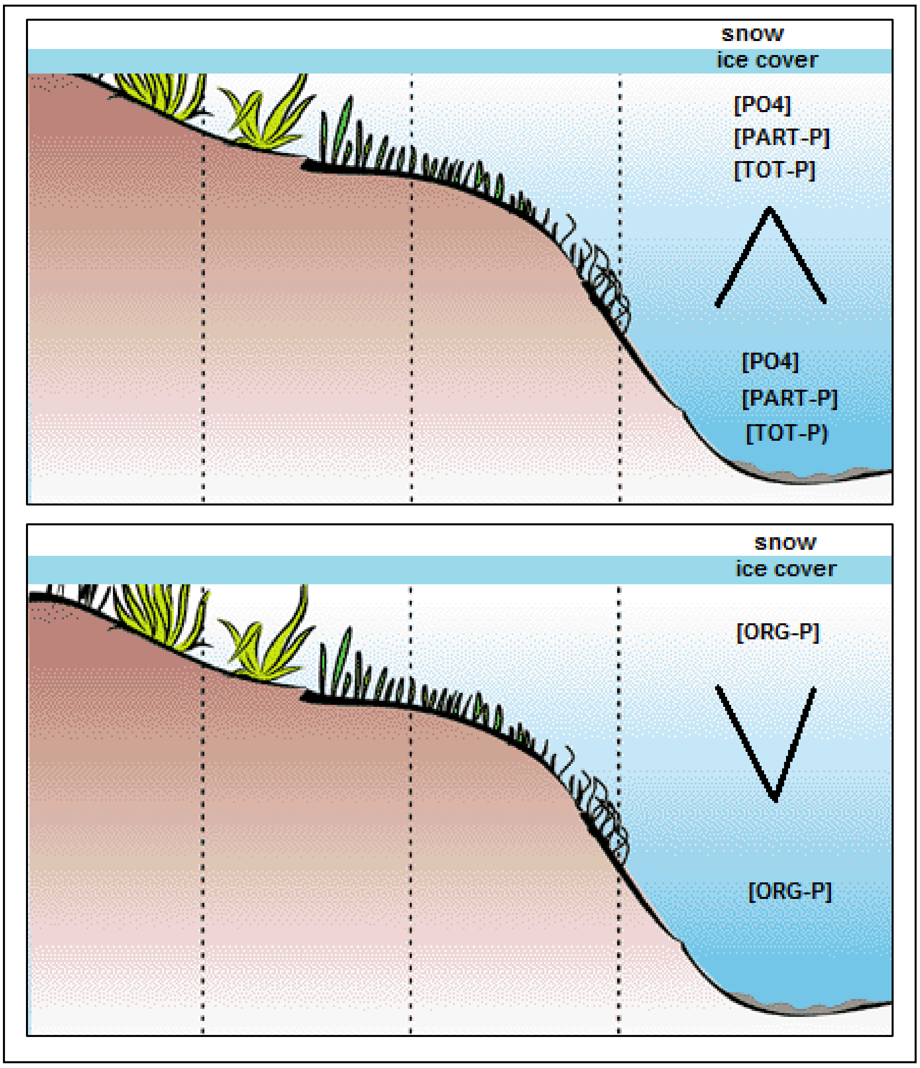


Figure 41. Winter vertical distribution of phosphorus fractions throughout the water column of Lake Vansjo.

6.9. Nitrogen

Even though phosphorus is usually the growth limiting nutrient in many lakes, in some cases it is possible to find places where nitrogen has the role of limiting nutrient. Generally in nutrient-rich systems during growing seasons. Additionally, in the places where nitrogen is the growth limiting nutrient it is possible that this leads to outbreaks of nitrogen fixing blue-green algae growth.

A N: P ratio of 16:1 it is often used to estimate the limiting nutrient for phytoplankton growing in freshwater environments (Redfield, 1958). Since the winter results show ratios higher than (16:1) we can assume that during the winter in Lake Vansjø the limiting nutrient is phosphorus and not nitrogen.

Total nitrogen (Tot-N) includes all nitrogen compounds in the water.

Nitrate, nitrite and ammonia (NO_3^- / NO_2^- / NH_4^+) are the simple inorganic forms which plants can take up nitrogen.

Results:

i) Spatial comparison

Concentrations of Tot-N at the different sampling points are shown in Figure 42. We can see that the concentrations lay almost always between the range of 0.8 and 1.2 mg L^{-1}. Only two cases were greater than 1,4 mg L^{-1} (S08 and S12) and there was one site with lower concentrations than 0,8 mg L^{-1} (S04).

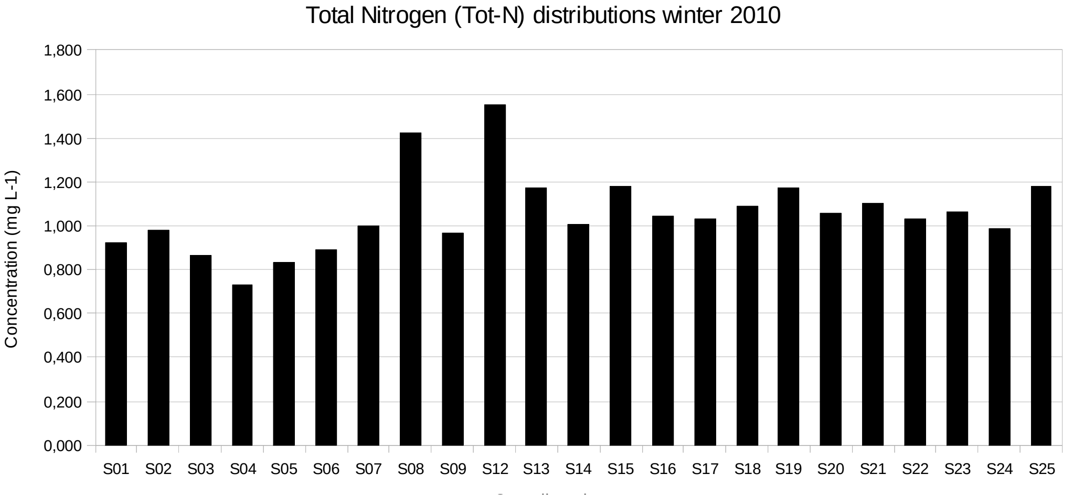


Figure 42. Distributions of Total nitrogen throughout Lake Vansjø during winter period.

In Figure 43 the varying levels of total inorganic nitrogen (NO_3^- / NO_2^- / NH_4^+) at the different sampling points are shown. The concentrations of inorganic N were almost always between the range of 0,4 and 0,85, and completely dominated by nitrate.

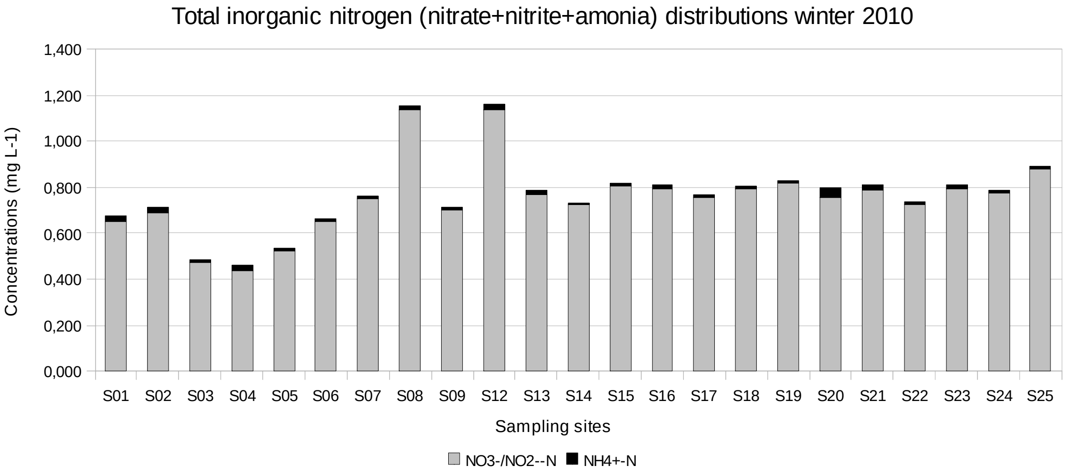


Figure 43. Distributions of Inorganic Nitrogen throughout Lake Vansjø during winter period.

The inorganic N, specifically oxidized form, constituted the main fraction of total nitrogen (see Figure 43).

6.10. Total organic carbon (TOC)

Total organic carbon parameter is an expression of total amount of particulate and dissolved organic compounds in water. Concentration of TOC in surface water is mostly determined by humic material, algae and dead organisms. Water colour and TOC are the most commune indicators of organic matter in water environments.

Results:

i) Spatial comparison

Estimated concentrations of TOC around the Lake Vansjø are shown in Figure 44. The results are quite constant and only show an increase of TOC at sites which are close to the estuaries of the rivers flowing into the lake. The watershed area of Lake Vansjø is predominantly forest, which have high carbon (C) pools in their soils. Humid climate and low temperatures retard complete decomposition and favour the accumulation of organic matter on soil surface. Humic rich soil water seepage to streams eventually draining into lakes is an important input flux of C to the surface water system. For this reason we can see a major concentration of TOC close to the mouth area of the rivers. During highflow more water is draining directly from the forest floor, rich in humic matter, out into the streams causing higher concentration of TOC during rainfall and snowmelt seasons (see Appendix chapter). For instance, the high concentrations that were found on S13 and S14 (Grepperødfjorden area) were mainly due to the influence of waters which come from Lake Brønnerødtjern, a significant source of organic carbon.

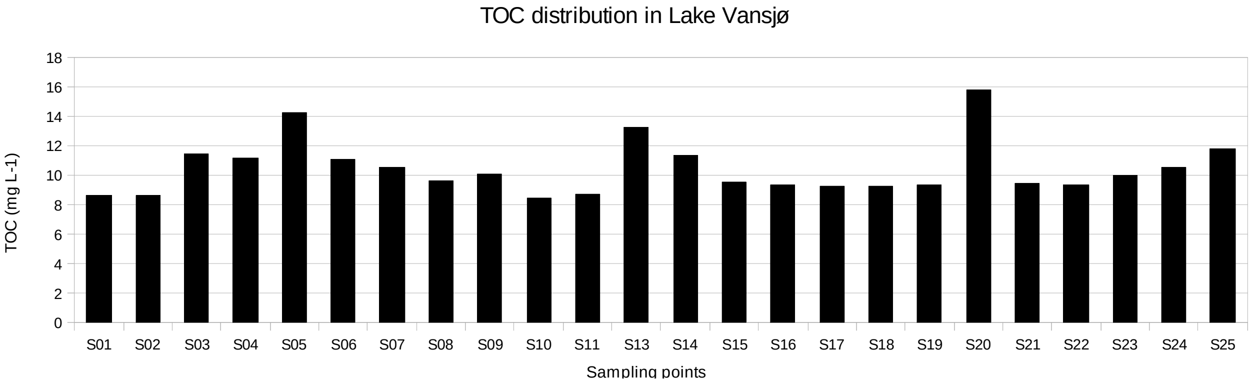


Figure 44. Distributions of TOC throughout Lake Vansjø during winter period.

There are higher concentrations of TOC on the bottom layers of the lake relative to the surface layers (see Figure 45).

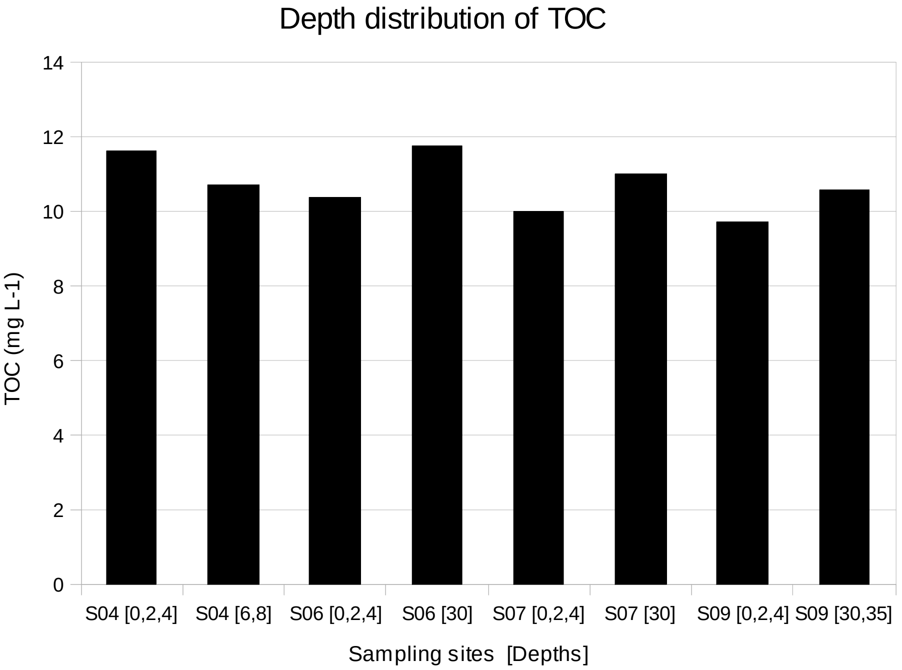


Figure 45. Vertical Distributions of TOC throughout Lake Vansjø water colum during winter period.

6.11. Chlorophyll-a

Chlorophyll-a is the green pigment that is responsible for a plant's photosynthesis converting sunlight into the chemical energy needed to fixate CO_2 into carbohydrates. Besides its importance in photosynthesis, chlorophyll is probably the most-often used estimator of algal biomass in lakes and streams. Chlorophyll is used to measure algal biomass that is relatively unaffected by non-algal substances. Chlorophyll provides an estimate for measuring algal weight and volume, and acts as an empirical link between nutrient concentration and other biological phenomena in aquatic ecosystems.

Results:

i) Spatial comparison

Estimated concentrations of Chlorophyll-a around the Lake Vansjø are shown in Figure 46. The results of the winter concentrations are quite low in all sampling points except S13 where the concentration of Chlorophyll-a reached 7 µg P L^{-1}. The spatial differences between the lakes comply with previous findings; Comparing Figures 46, 47 and 48 show that the highest concentrations of chlorophyll-a are found on Grepperødfjorden firstly, followed by Vanemfjorden, and the lowest concentrations are found on Storefjorden area. The concentrations of chlorophyll-a in Storefjorden were much lower in all seasons compared to Grepperødfjorden and Vanemfjorden areas. The seasonal fluctuations of chlorophyll-a were much lower as well.

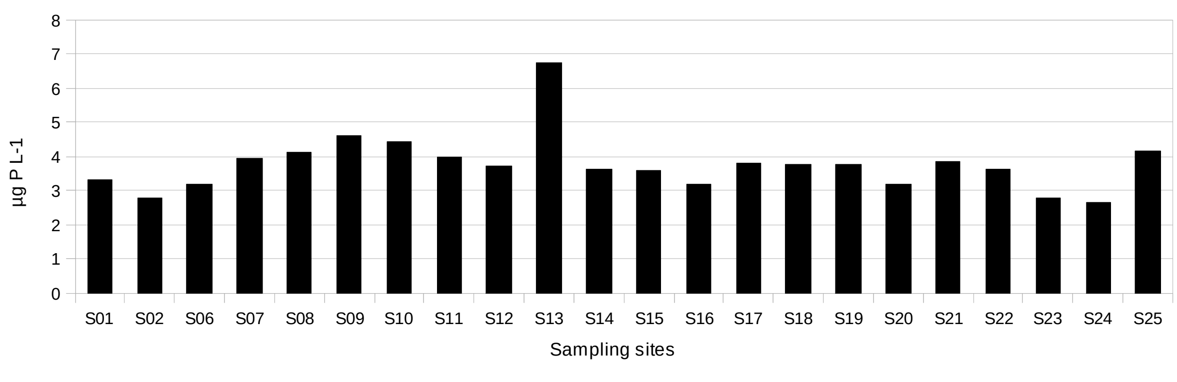


Figure 46. Distribution of Chlorophyll-a concentrations all over Lake Vansjø.

ii) Seasonal comparison

Regarding seasonal variation, there is as expected a great winter decrease of chlorophyll-a in the Lake Vansjø water basins (see Figures 47, 48 and 49). The main decrease was registered in Grepperødfjorden and Vanemfjorden reaching concentrations of 5.2 and 3.5 µg P L-1 respectively.

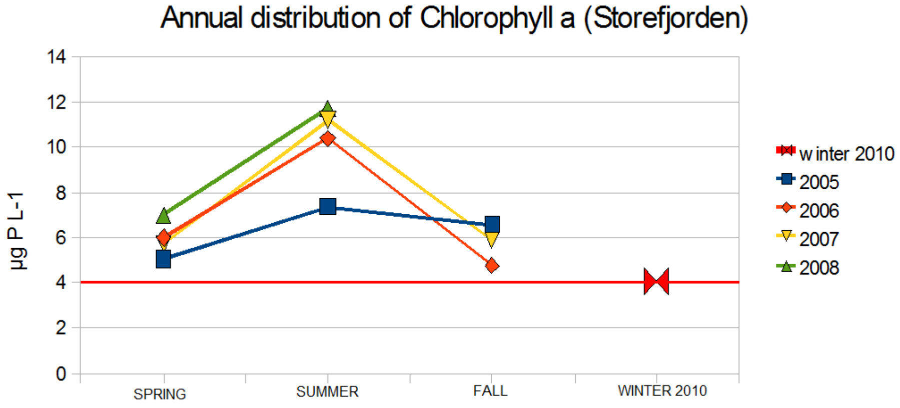


Figure 47. Last five years seasonal variations of Chlorophyll-a at Storefjorden control station.

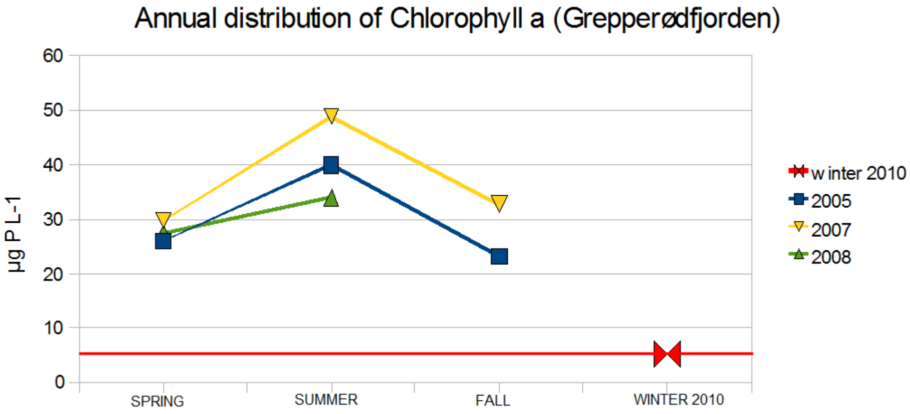


Figure 48. Last five years seasonal variations of Chlorophyll-a at Grepperødfjorden control station.

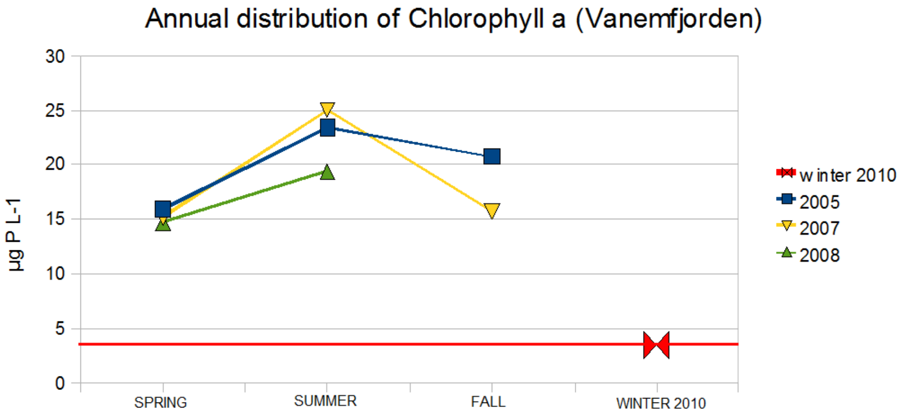


Figure 49. Last five years seasonal variations of Chlorophyll-a at Vanemfjorden control station.

7 CONCLUSIONS AND FUTURE CHALLANGES

As a result of the presence of ice-cover and the decrease of water inputs into the lake, phenomena such as strong water currents and water mixtures are completely minimized during the winter period. That's why the physicochemical conditions studied during winter 2010 remain fairly constant throughout the different sampling points around Lake Vansjø as illustrated in the previous chapters. Earlier reports and studies, which were conducted during other seasons showed significant differences between the different sampling points.

Regarding the distribution of phosphorus during winter, we found that the total phosphorus concentrations and especially the particulate phosphorus fraction were considerably lower than what is found during other seasons in the lake water. The dissolved organic fraction was relatively similar throughout the year and the inorganic phosphate concentrations were slightly higher during winter at every sampling point in Lake Vansjø. Assuming that the input of new nutrients into the lake is very low during winter and physical re-suspension of material from the lake bottom is negligible one could argue that the small increase of dissolved phosphate is mainly due to the sediment phosphate release under more reduced conditions during winter stagnation, and also due to the release of PO4 from organic compounds by a microbial breakdown (mineralisation) which is much higher than the assimilation process (uptake of phosphate and conversion to organic phosphorus by phytoplankton)

From the chemical analysis made on samples from different parts of the lakes at different depths we hypothesize an increase of reduced conditions in the lower layers of the lake during winter. Presence of lower pH, higher temperatures and high concentrations of phosphate at the bottom of the lake relative to the epilimnion, are indicators of this fact. This situation is more aggravated at the bottom of Storefjorden compared with the bottom of other areas such as Vanemfjorden. This is due to that Storefjorden is deeper, darker and there is less oxygen due to the strong inverse stratification.

Considering the importance of redox conditions it is apparent that the use of a dissolved oxygen measurement instrument would be very interesting for future studies enabling a better understanding of redox equilibriums that occur in the lower layers of the lake, behaviour of organic matter decomposition by bacteria and many other phenomena linked to dissolved oxygen concentrations.

Finally, as a general evaluation of the conducted work it may be stated that the main goal of the research project, i.e. a spatial mapping of winter physicochemical conditions on Lake Vansjø, has been fulfilled successfully

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9 APPENDIX

APPENDIX A. Table of results

APPENDIX B. CTD plots

APPENDIX C. pH

APPENDIX D. Suspended solids

APPENDIX E. Nitrogen

APPENDIX F. Total Organic Carbon

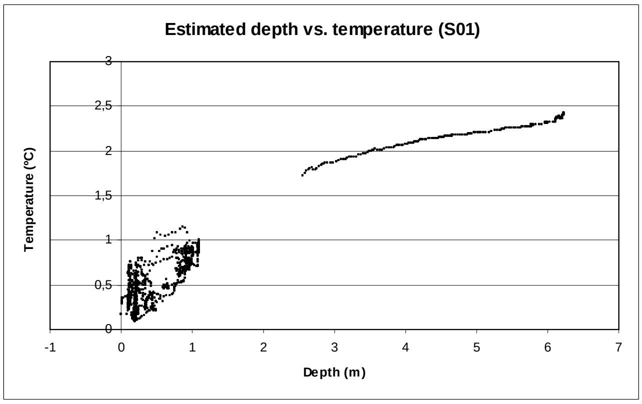
APPENDIX G. Chlorophyll-a

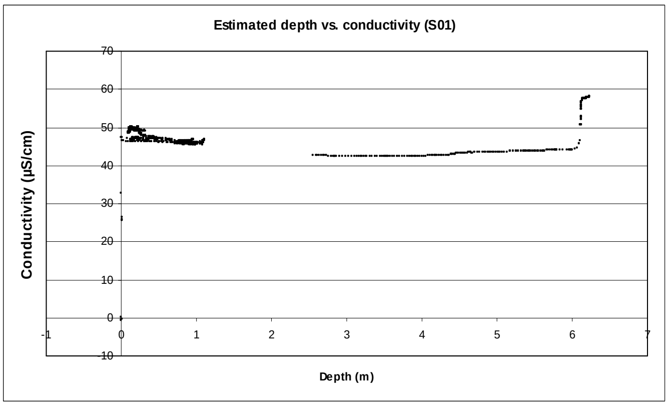
APPENDIX A. Table of results

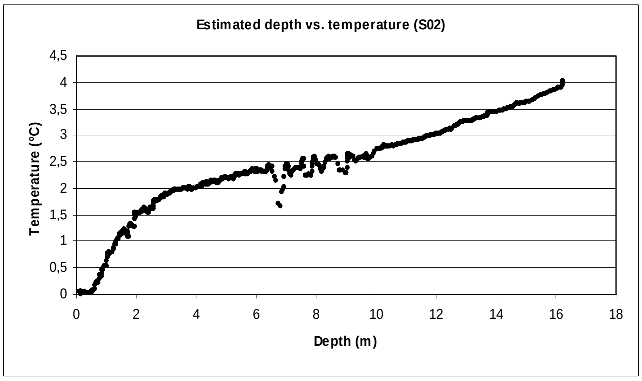
Table 1. Results of analysed variables in every sampling point.

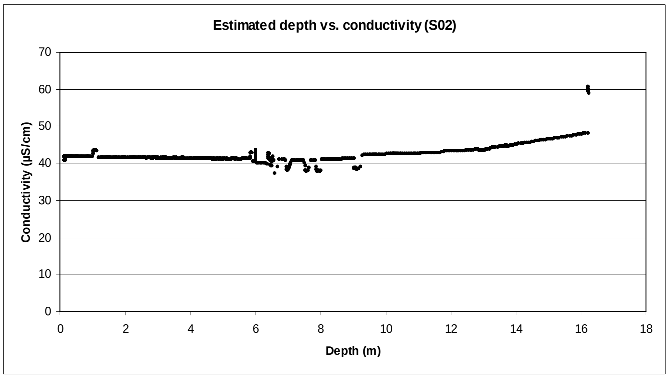
Site name	Depths	Absorbance		pH	Conductivity	Alkalinity	Total suspended solids	Organic suspended solids	Inorganic suspended solids	Tot-P	Free PO4	Org-P	Particualte P	Tot-N	NO3-/NO2--N	NH4+-N	TOC
	m	254nm	400nm		(µS/cm)	mg/L as CaCO3	ppm	ppm	ppm	µg P L-1	µg P L-1	µg P L-1	µg P L-1	mg N L-1	mg N L-1	mg N L-1	mg L-1
S01	0-4	0,413	0,054	6,79	73,7	249	1,68	1,18	0,49	13,9	3,7	4,7	5,5	0,92	0,65	0,02	8,7
S02	0-4	0,41	0,053	6,67	71,3	238	2,24	1,49	0,75	12,4	2,7	5,3	4,3	0,98	0,69	0,02	8,6
	14-16	0,546	0,172	6,42	66,5	257	179,32	23,50	155,81	221,4	156,5	-147,0	211,9	1,58	0,62	0,02	11,5
S03	0-4	0,543	0,085	6,62	72,4	228	6,40	2,38	4,02	10,0	11,0	-4,1	3,2	0,86	0,47	0,13	11,4
S04	0-4	0,552	0,091	6,42	64,9	206	8,64	3,65	4,99	7,8	9,9	-4,1	2,0	0,70	0,44	0,03	11,6
	6-8	0,51	0,088	6,38	67,1	234	5,40	1,69	3,71	7,2	7,7	-1,0	0,5	0,76	0,44	0,02	10,7
S05	0-0	0,678	0,107	6,2	54,9	147	4,50	0,74	3,77	16,9	10,7	-0,1	6,2	0,83	0,52	0,01	14,2
S06	0-4	0,494	0,073	6,48	64	208	1,21	0,74	0,47	10,3	5,9	3,9	0,5	0,90	0,64	0,01	10,4
	30-30	0,559	0,099	6,39	74,8	271	6,00	2,75	3,24	25,7	15,5	2,1	8,1	0,88	0,66	0,01	11,7
S07	0-4	0,475	0,073	6,69	79,8	214	2,15	1,18	0,98	13,8	6,5	3,7	3,6	1,06	0,82	0,01	10,0
	30-30	0,524	0,085	6,48	67,1	798	2,58	1,39	1,20	17,5	8,5	3,8	5,3	0,94	0,68	0,01	11,0
	38-38	1,402	0,364	6,57	115,3	284	9,62	4,86	4,75	66,6	38,4	0,2	28,0	1,65	1,34	0,02	29,4
S08	0-3	0,459	0,073	6,83	96,8	399	2,36	1,08	1,28	16,2	7,8	3,5	4,8	1,42	1,14	0,02	9,6
S09	0-4	0,462	0,071	6,83	70	236	1,74	1,19	0,55	14,8	5,9	4,4	4,5	0,99	0,74	0,01	9,7
	30-35	0,502	0,085	6,65	72,8	255	2,35	1,50	0,85	20,2	9,5	3,9	6,8	0,94	0,66	0,01	10,5
S10	0-2	0,401	0,050	7,01	71,6	252	0,79	0,44	0,35	17,1	7,2	6,8	3,1	x	x	x	8,4
S11	0-2	0,415	0,056	6,63	82,2	332	1,09	0,59	0,49	15,8	6,4	7,5	1,9	x	x	x	8,7
S12	0-4	4,54	0,037	6,84	76,4	250	1,92	1,66	0,26	14,5	5,7	5,3	3,6	1,07	0,78	0,02	95,3
	20-25	0,45	0,044	6,8	75,6	267	2,08	0,87	1,21	15,7	6,4	3,9	5,3	0,97	0,71	0,01	9,5
S13	0-3	0,633	0,095	6,79	109,6	320	2,50	0,95	1,55	22,7	9,7	4,2	8,9	1,17	0,77	0,02	13,3
S14	0-4	0,539	0,081	6,7	81,9	310	2,56	2,49	0,07	14,8	6,7	4,5	3,6	1,01	0,72	0,01	11,3
S15	0-2	0,454	0,067	6,64	77,4	267	2,03	1,09	0,94	14,7	6,5	3,5	4,8	1,18	0,81	0,01	9,5
S16	0-2	0,445	0,065	6,58	74,1	265	2,05	2,00	0,05	13,5	6,2	4,3	3,0	1,04	0,79	0,02	9,4
S17	0-4	0,44	0,062	6,61	74	275	1,33	0,59	0,74	15,3	7,4	4,0	3,9	1,03	0,75	0,01	9,2
S18	0-0	0,439	0,062	6,63	81,3	283	1,58	0,76	0,81	15,2	6,3	4,6	4,4	1,09	0,79	0,01	9,2
S19	0-4	0,447	0,066	6,6	77,1	274	2,15	1,20	0,95	15,2	6,5	4,1	4,6	1,17	0,82	0,01	9,4
S20	0-4	0,978	0,072	6,69	79,1	284	2,10	0,62	1,49	13,2	5,3	6,3	1,6	1,12	0,80	0,07	20,5
	10-12	0,526	0,084	6,52	83,3	280	2,62	0,92	1,69	13,8	6,1	5,6	2,1	0,99	0,72	0,02	11,1
S21	0-2	0,449	0,065	6,59	75,1	269	2,42	2,37	0,05	15,4	6,5	3,8	5,1	1,10	0,79	0,02	9,4
S22	0-1	0,445	0,067	6,44	75,9	274	2,10	1,96	0,15	14,8	6,7	4,6	3,4	1,03	0,72	0,01	9,4
S23	0-2	0,476	0,072	6,81	74,6	245	2,49	0,41	2,08	12,4	5,3	5,4	1,7	1,06	0,79	0,02	10,0
S24	0-3	0,504	0,076	6,73	77,5	259	1,73	0,99	0,74	11,9	5,2	5,3	1,4	0,99	0,77	0,01	10,6
S25	0-3	0,563	0,087	6,58	90	286	2,32	1,18	1,13	16,3	8,1	2,9	5,4	1,18	0,88	0,01	11,8

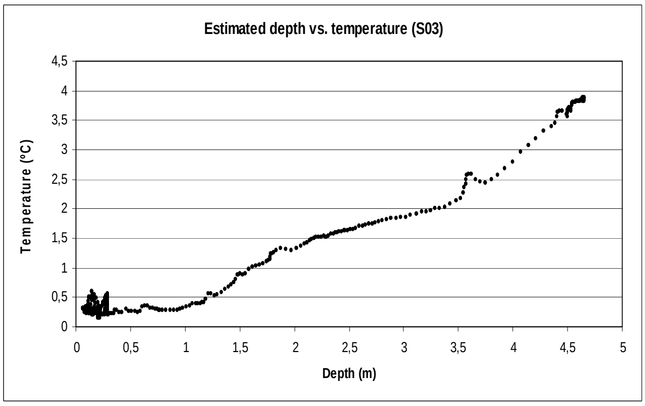
APPENDIX B. CTD plots

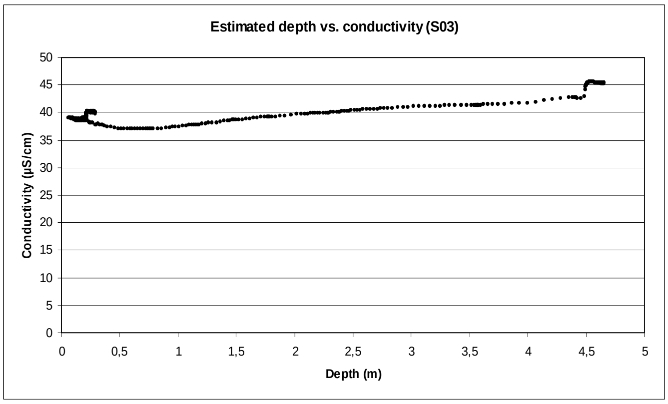


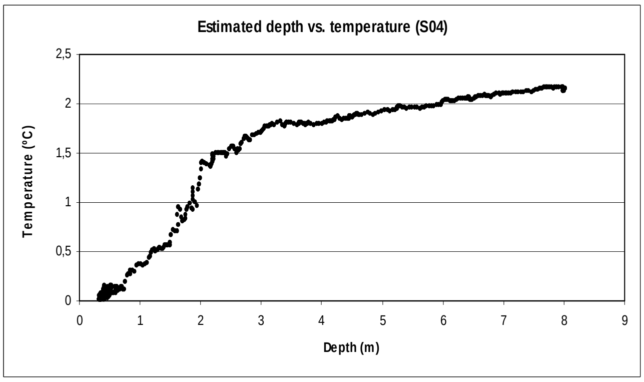


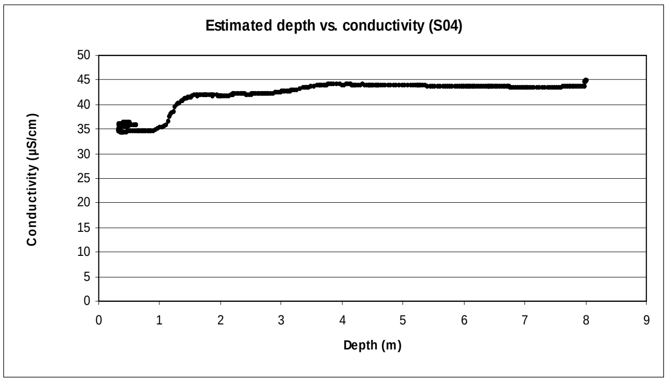


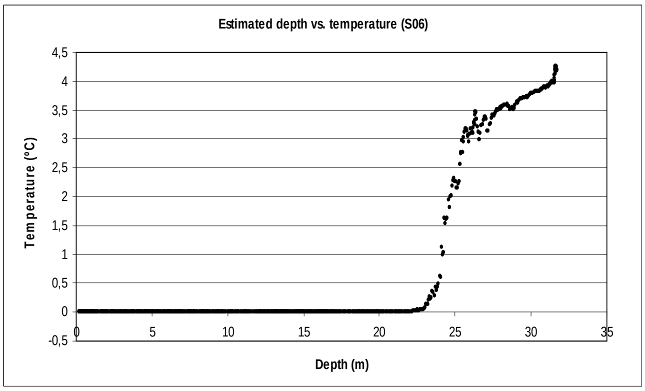


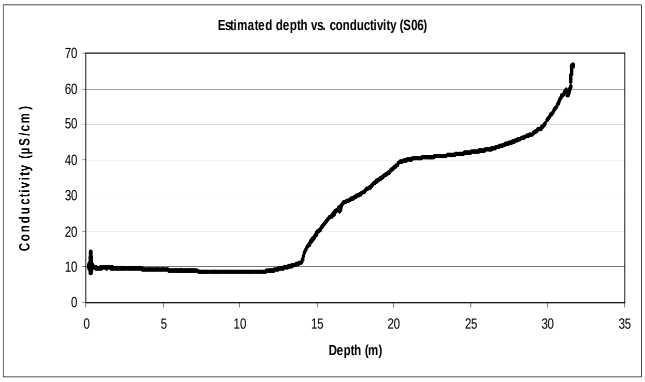


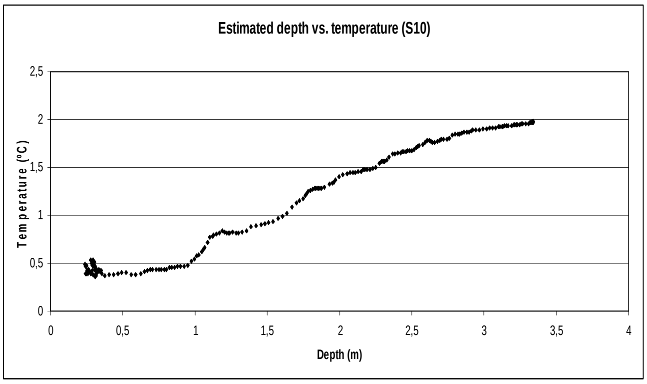


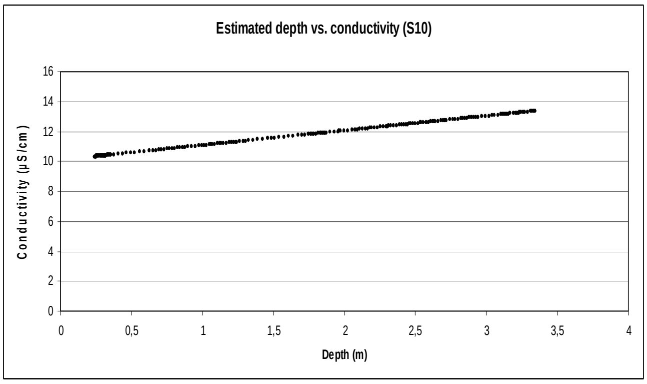


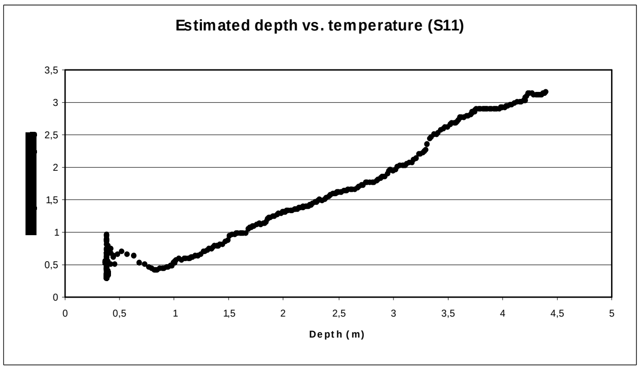


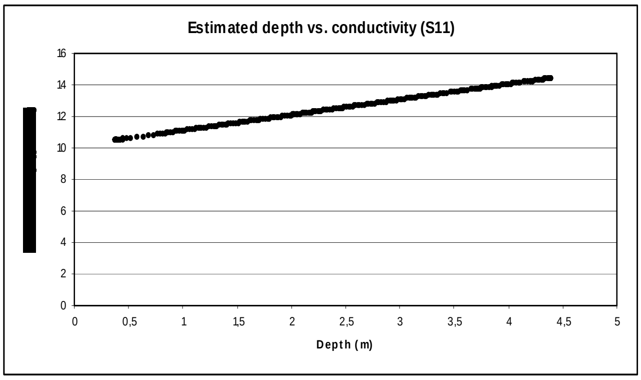

Estimated depth vs. temperature (S06)
Temperature (°C)
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
-0,5
0
5
10
15
20
25
30
35
Depth (m)

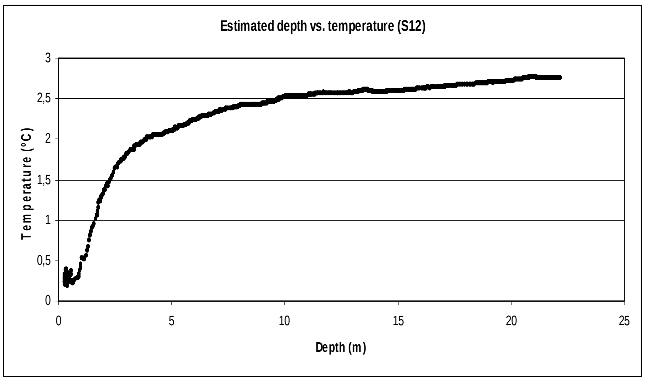

Estimated depth vs. conductivity (S06)
Conductivity (µS/cm)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
Depth (m)

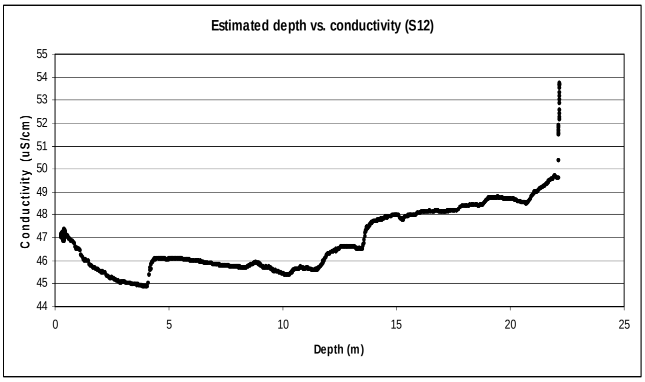

Estimated depth vs. temperature (S10)
Temperature (°C)
2,5
2
1,5
1
0,5
0
0
0,5
1
1,5
2
2,5
3
3,5
4
Depth (m)

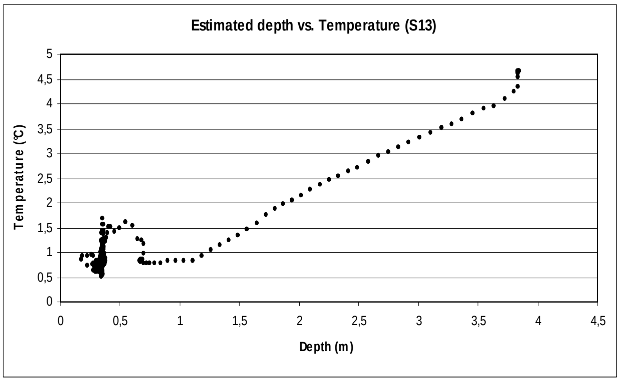

Estimated depth vs. conductivity (S10)
Conductivity (µS/cm)
16
14
12
10
8
6
4
2
0
0
0,5
1
1,5
2
2,5
3
3,5
4
Depth (m)

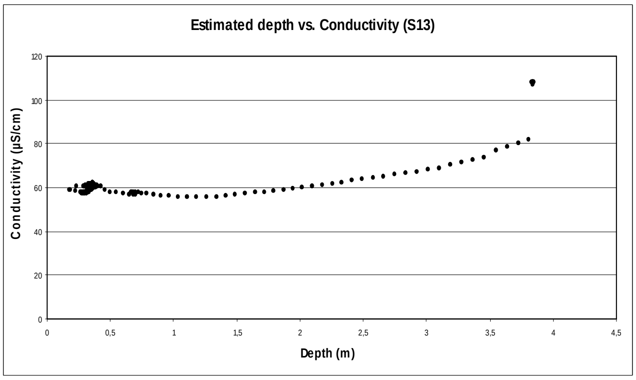

Estimated depth vs. temperature (S11)
3,5
3
2,5
2
1,5
1
0,5
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Depth (m)

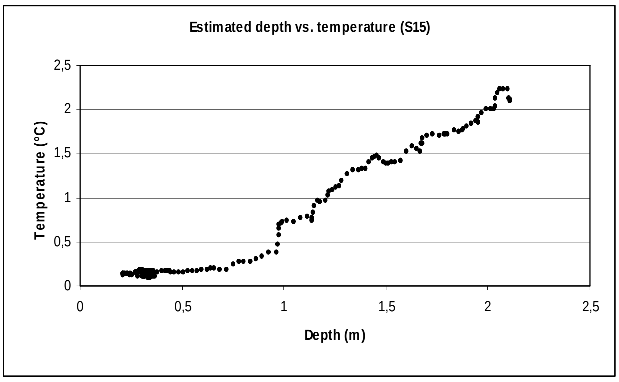

Estimated depth vs. conductivity (S11)
16
14
12
10
8
6
4
2
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Depth (m)

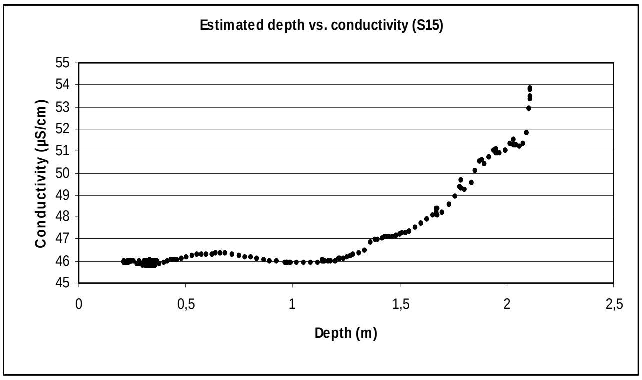

Estimated depth vs. temperature (S12)
Temperature (°C)
3
2,5
2
1,5
1
0,5
0
0
5
10
15
20
25
Depth (m)

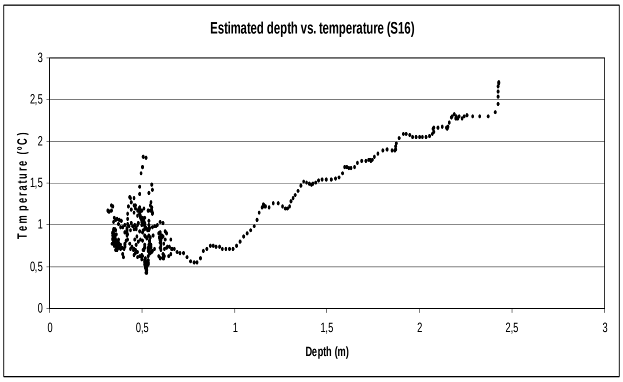

Estimated depth vs. conductivity (S12)
Conductivity (uS/cm)
55
54
53
52
51
50
49
48
47
46
45
44
0
5
10
15
20
25
Depth (m)

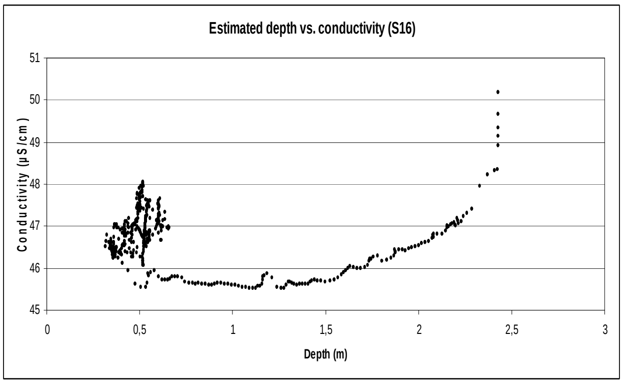

Estimated depth vs. Temperature (S13)
Temperature (ºC)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

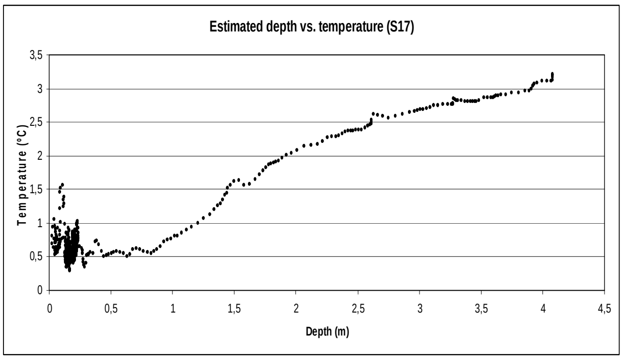

Estimated depth vs. Conductivity (S13)
Conductivity (µS/cm)
0
20
40
60
80
100
120
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

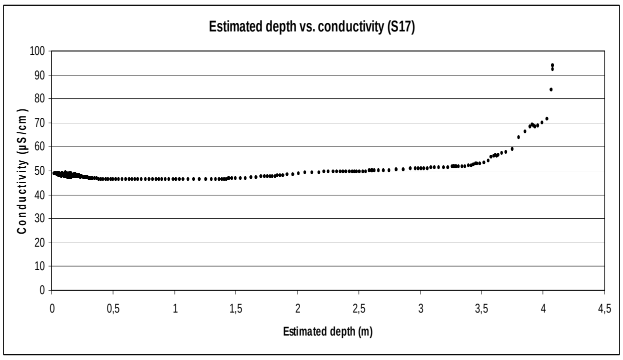

Estimated depth vs. temperature (S15)
Temperature (ºC)
0
0,5
1
1,5
2
2,5
Depth (m)
0
0,5
1
1,5
2
2,5

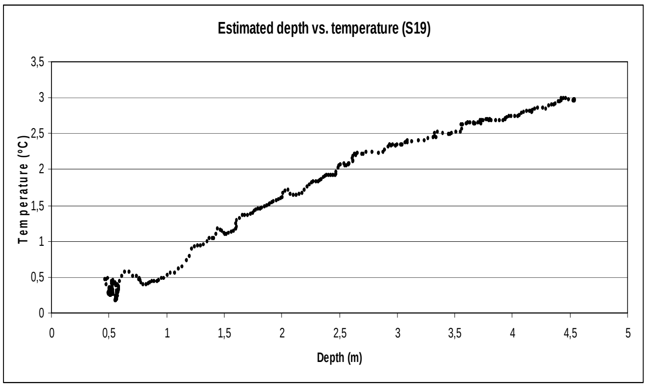

Estimated depth vs. conductivity (S15)
Conductivity (µS/cm)
45
46
47
48
49
50
51
52
53
54
55
Depth (m)
0
0,5
1
1,5
2
2,5

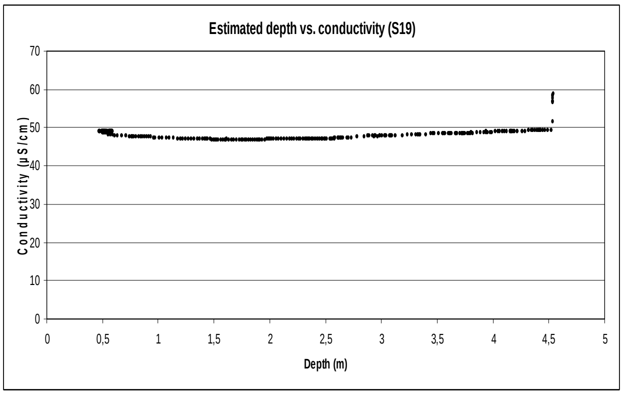

Estimated depth vs. temperature (S16)
Temperature (ºC)
0
0,5
1
1,5
2
2,5
3
Depth (m)
0
0,5
1
1,5
2
2,5
3

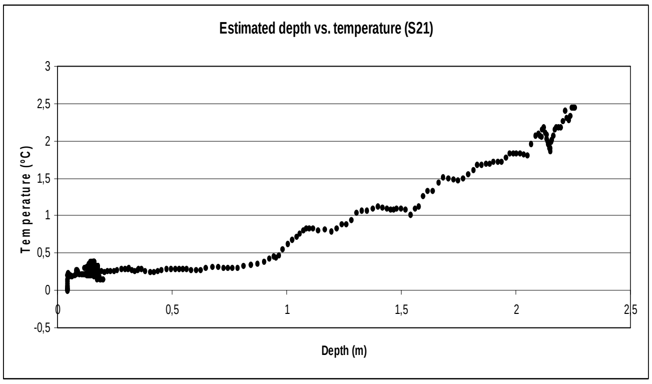

Estimated depth vs. conductivity (S16)
Conductivity (µS/cm)
45
46
47
48
49
50
51
Depth (m)
0
0,5
1
1,5
2
2,5
3

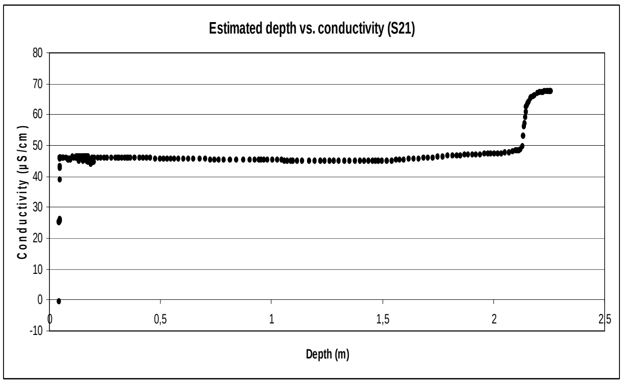

Estimated depth vs. temperature (S17)
Temperature (ºC)
0
0,5
1
1,5
2
2,5
3
3,5
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

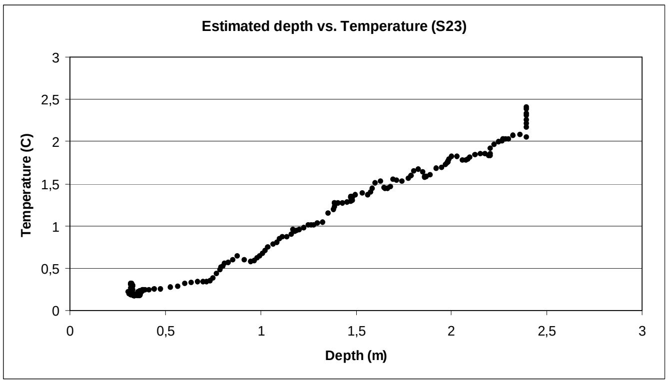

Estimated depth vs. conductivity (S17)
Conductivity (µS/cm)
0
10
20
30
40
50
60
70
80
90
100
Estimated depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

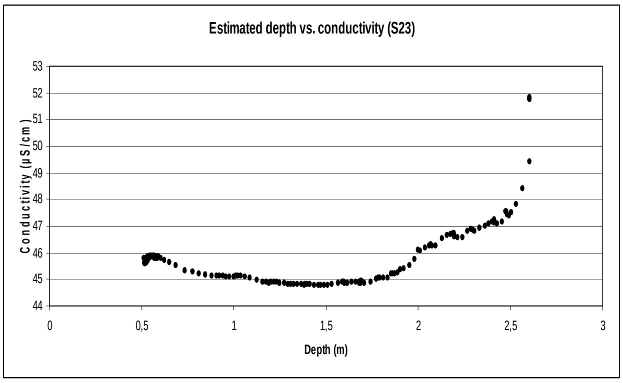

Estimated depth vs. temperature (S19)
Temperature (°C)
0
0,5
1
1,5
2
2,5
3
3,5
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5

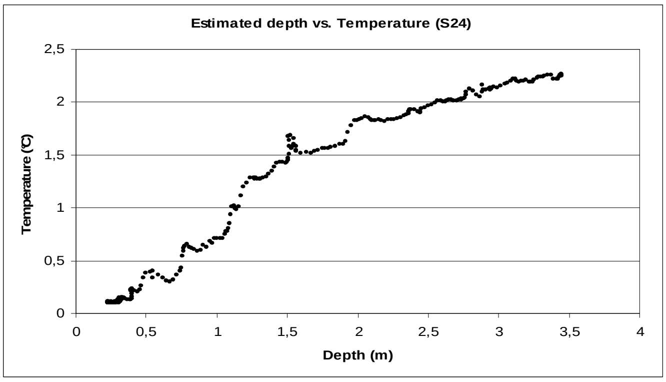

Estimated depth vs. conductivity (S19)
Conductivity (µS/cm)
0
10
20
30
40
50
60
70
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5

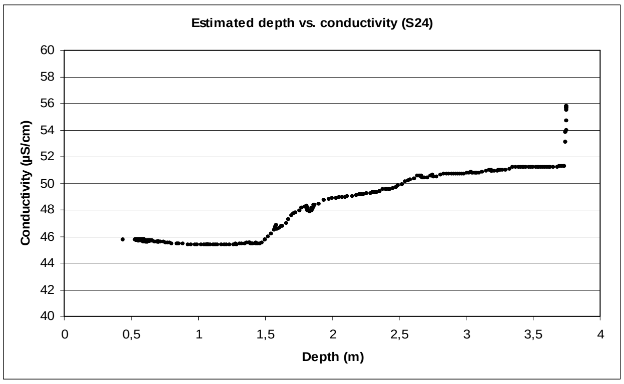

Estimated depth vs. temperature (S21)
Temperature (°C)
-0,5
0
0,5
1
1,5
2
2,5
3
Depth (m)
0
0,5
1
1,5
2
2,5


Estimated depth vs. conductivity (S21)
Conductivity (µS/cm)
-10
0
10
20
30
40
50
60
70
80
Depth (m)
0
0,5
1
1,5
2
2,5


Estimated depth vs. Temperature (S23)
Temperature (C)
0
0,5
1
1,5
2
2,5
3
Depth (m)
0
0,5
1
1,5
2
2,5
3


Estimated depth vs. conductivity (S23)
Conductivity (µS/cm)
44
45
46
47
48
49
50
51
52
53
Depth (m)
0
0,5
1
1,5
2
2,5
3


Estimated depth vs. Temperature (S24)
Temperature (C)
0
0,5
1
1,5
2
2,5
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4


Estimated depth vs. conductivity (S24)
Conductivity (µS/cm)
40
42
44
46
48
50
52
54
56
58
60
Depth (m)
0
0,5
1
1,5
2
2,5
3
3,5
4

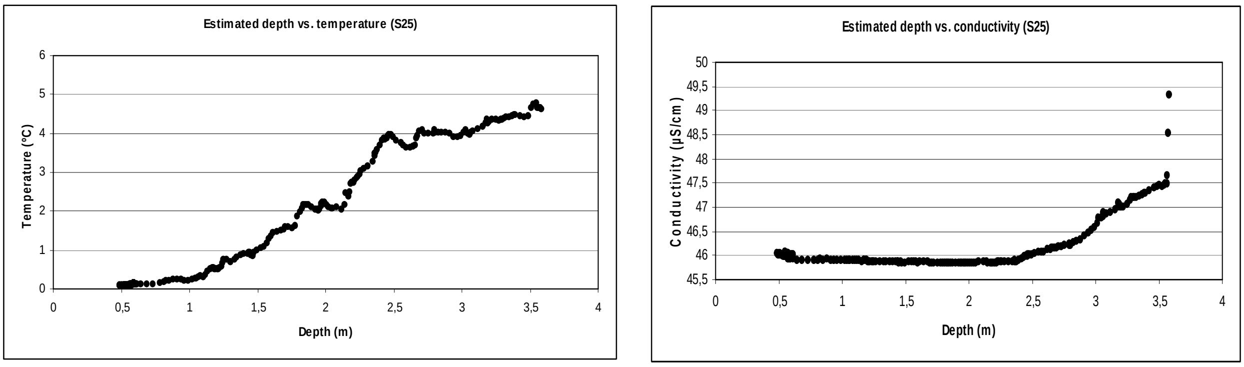


Figure 1. CTD plots (Temperature vs. Depth and Conductivity vs. depth) for all sampling points.

APPENDIX C. pH

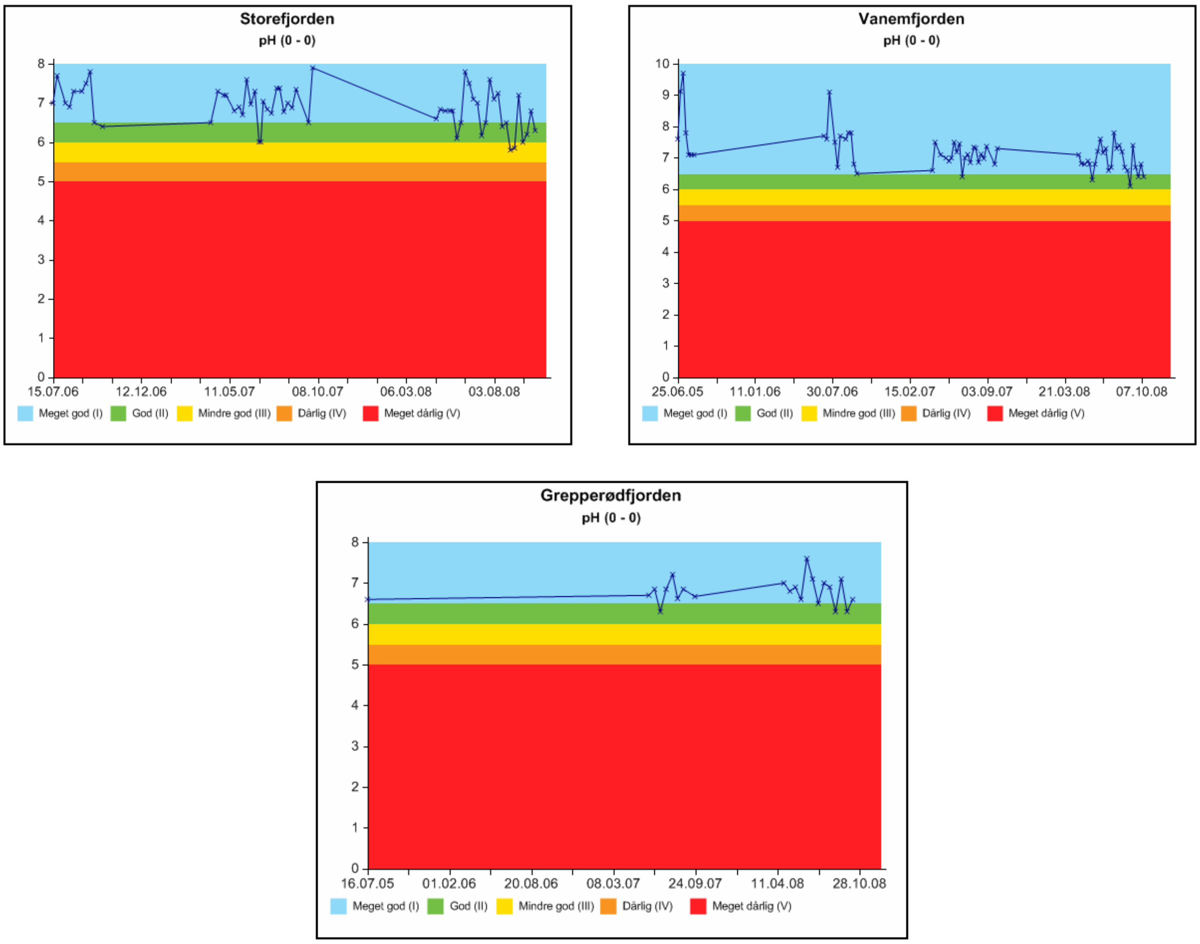


Figure 2. pH results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)

APPENDIX D. Suspended solids

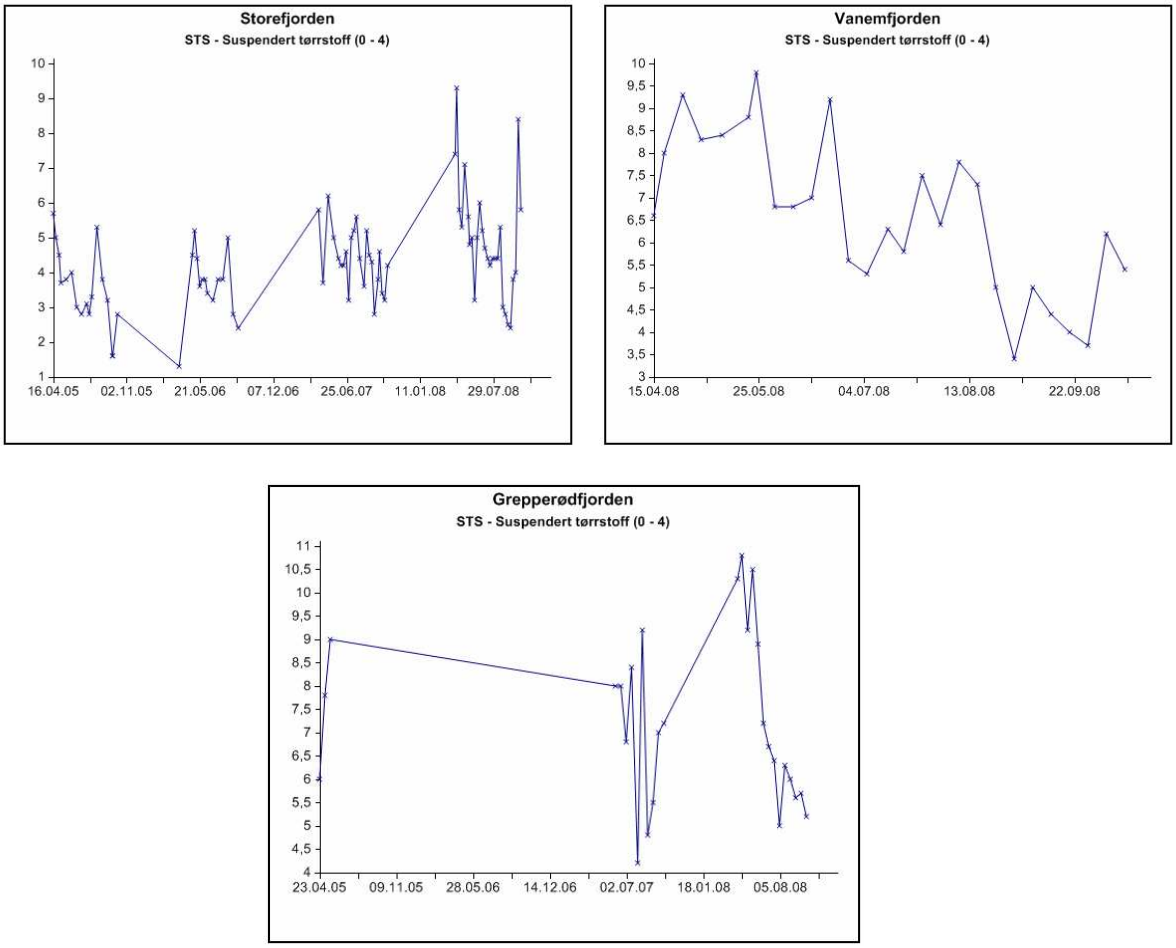


Figure 3. Total Suspended Solids (TSS) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)

APPENDIX E. Phosphorus

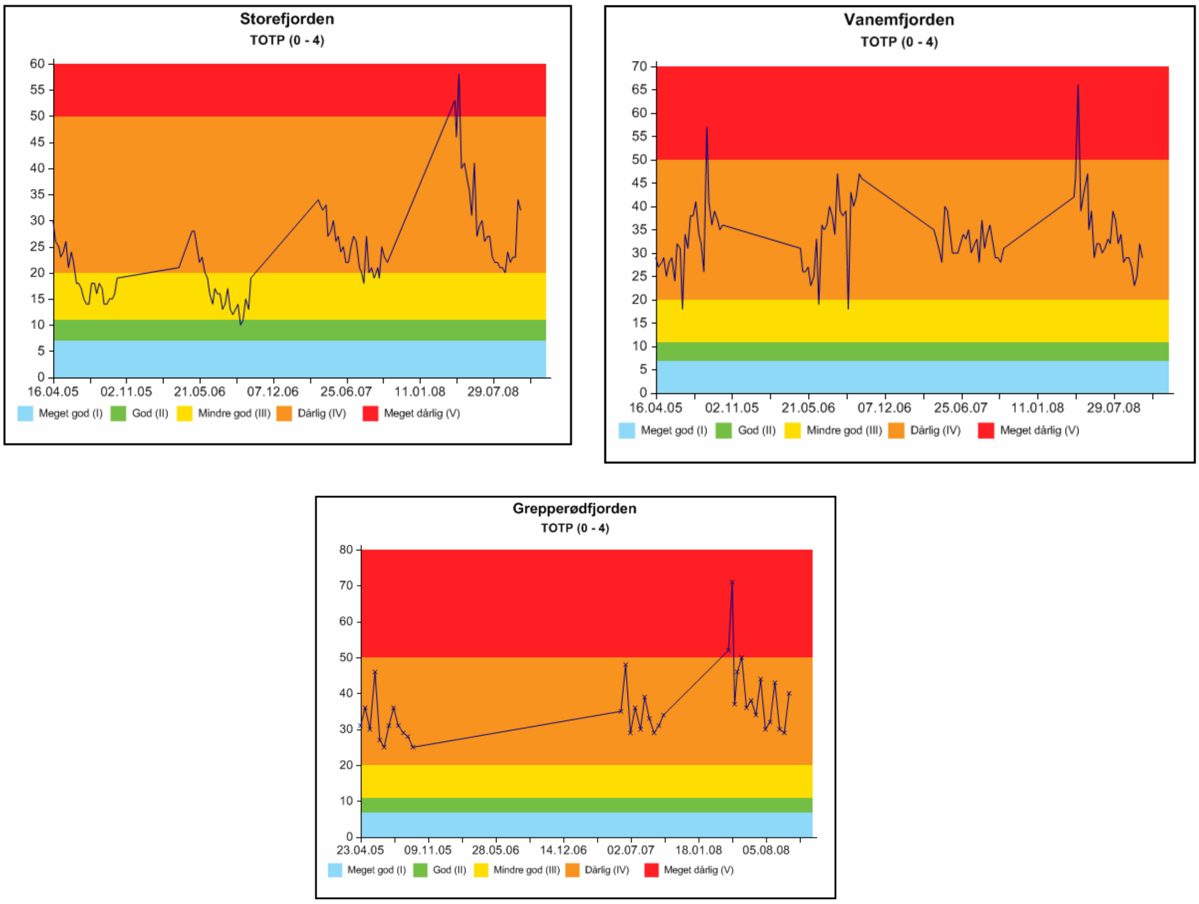
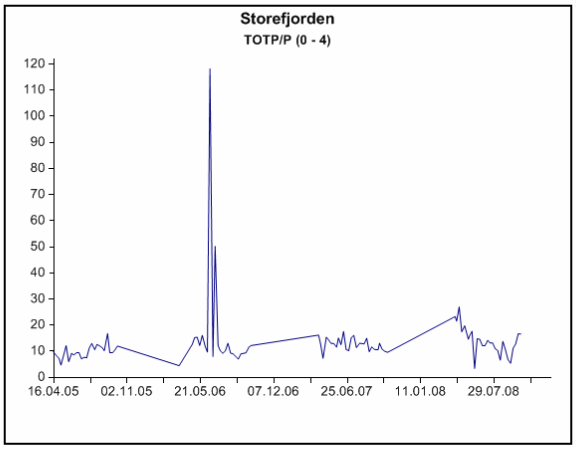
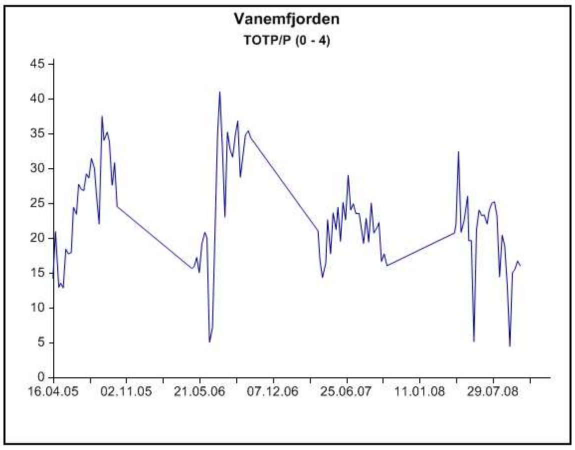


Figure 4. Total Phosphorus (Tot-P) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)





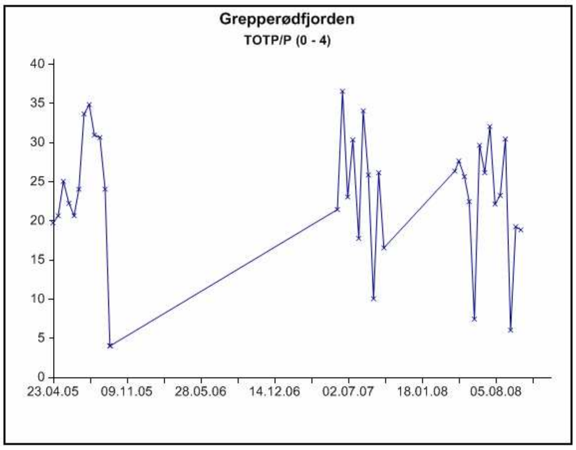


Figure 5. Particulate Phosphorus (Part-P) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)

APPENDIX E. Nitrogen

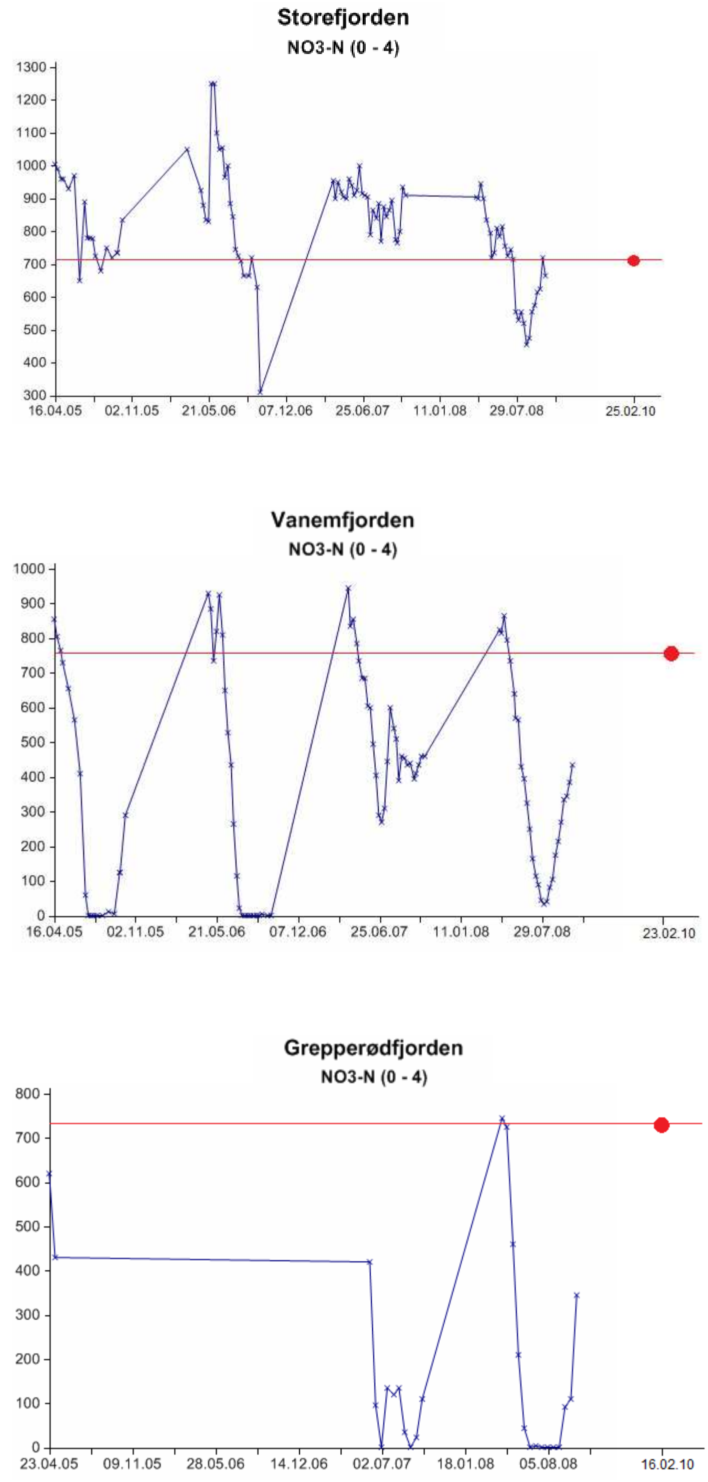


Figure 5. Nitrate (NO_3-N) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)

APPENDIX F. Total Organic Carbon

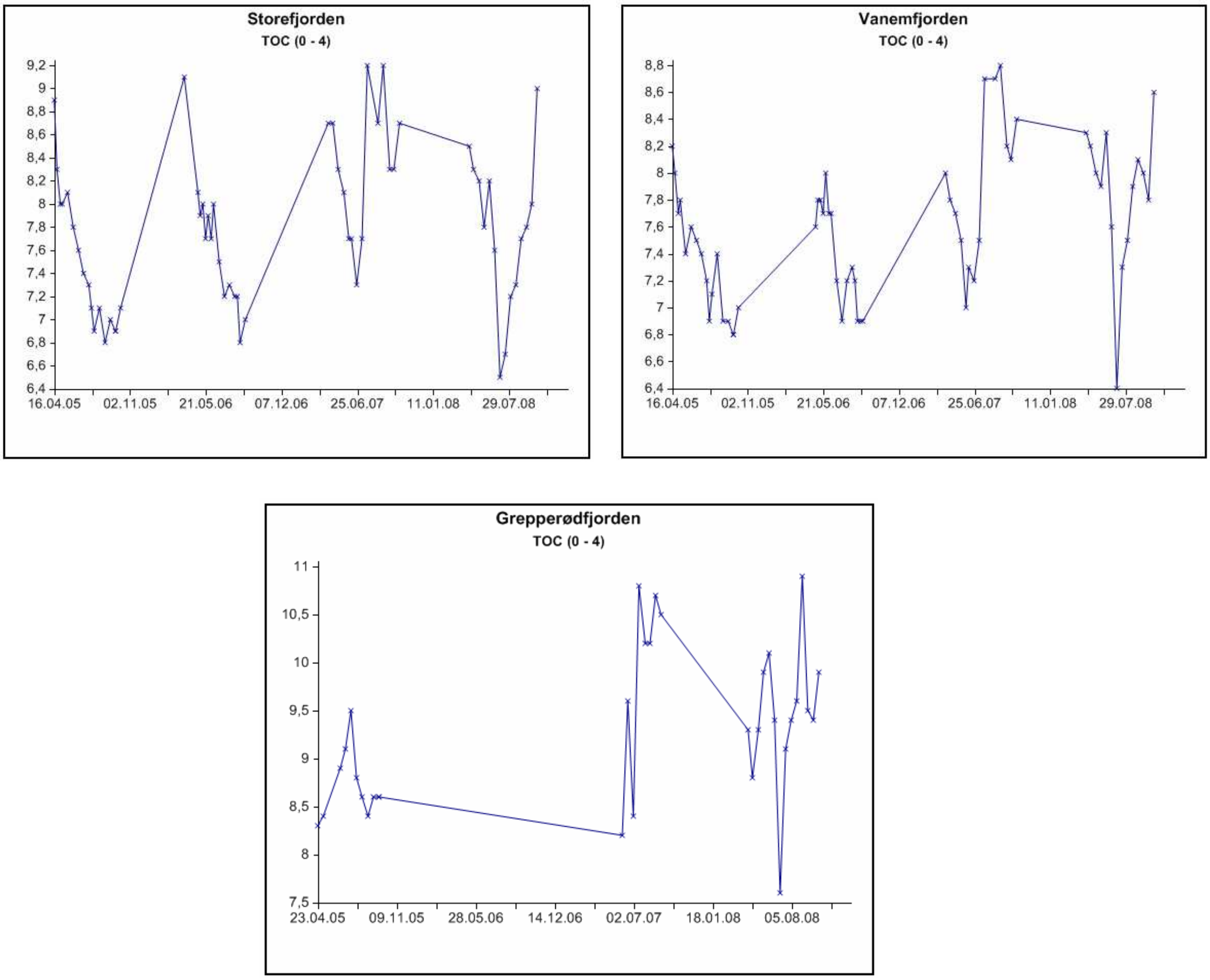


Figure 5. Total Organic Carbon (TOC) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)

APPENDIX G. Chlorophyll-a

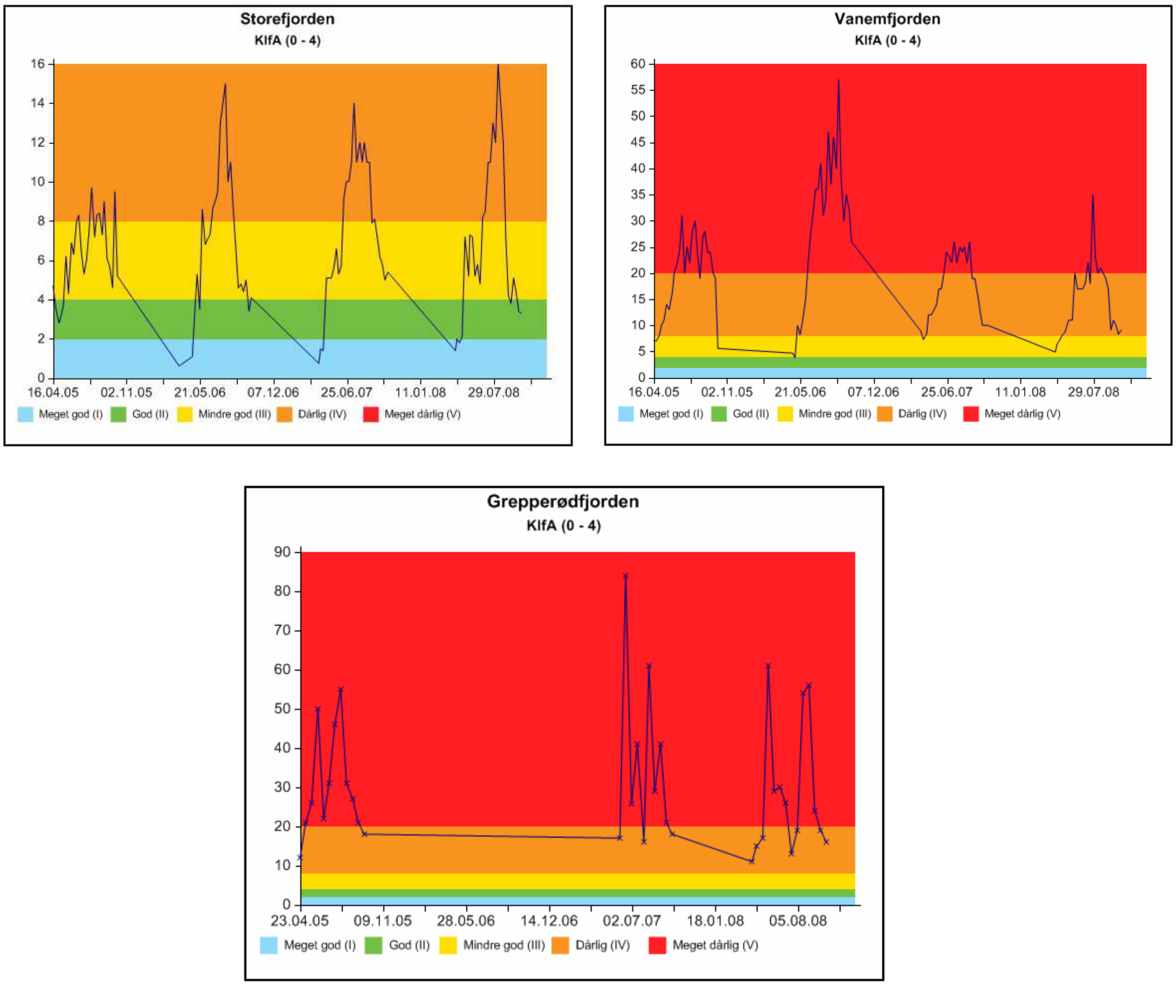


Figure 5. Chlorophyll-a (ChlA) results of 2005, 2006, 2007 and 2008 (Source: Bioforsk Rapport Overvåking Vansjø/Morsa 2008)