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Relation between turbidity and suspended material at different soils, scales and phosphorus levels.

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Abstract

Losses of phosphorous (P) from agricultural soil may cause eutrophication of receiving water bodies. Beside surface runoff, leaching has recently been considered an important P transport pathway. P losses in runoff are associated with eroded clay particles where the highest P accumulation occurs.

This study investigated the use of turbidity measurement as a surrogate method for suspended solids (SS), particulate P (PP) and total P (TP) concentration in leachate water.

Water samples were collected at lysimeter, plot and field scale from the Uppsala lysimeter station and Lanna/Bornsjön experimental field, over a period between January and April 2011. Turbidity and SS were measured on samples from six soils with different soil properties from central and south of Sweden. Total P (TP), dissolved reactive P (DRP) and PP concentration of water samples were measured. Turbidity, SS, PP and TP values obtained were then studied considering the different scales.

The highest values of turbidity and SS were found in a soil with a significant clay content (59%), the correlation between the two parameters returned a r^2=0,67. A significant r-square value (0,57) was also found between turbidity and TP and PP in the same soil. Nevertheless soils with similar condition in clay content did not show the same correlation and behaviors suggesting that parameters and properties such as pH, organic matter content and internal soil structure strongly influence characteristics of leachate water. Furthermore, results from the comparison of scales shown that larger dataset on longer term would improve the quality of the study. Turbidity and total/particulate P did not seem to show a correlation at different P levels according with soil test P (phosphorus content in ammonium lactate extract [P-AL]), therefore water transport mechanisms and subsoil properties seem to influence the P leaching more than soil test P value in the topsoil.

The result of this study suggest that turbidity might be used as a surrogate method to investigate P losses associated with SS at specific intervals, but relying on turbidity measurements without a detailed knowledge of topsoil and subsoil properties is nevertheless not possible.

Keywords: turbidity, suspended solids, phosphorus losses, eutrophication, leaching.

Contents

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Introduction

Eutrophication

Eutrophication, defined as an over enrichment of nutrients resulting from natural or artificial processes (Smith & Schindler, 2009) represents one of the major problems concerning surface water quality in Northern Europe. This phenomenon is caused by an increase in the concentrations of nutrients as phosphorus (P) and nitrogen (N) (Chorus, 2001).

The direct consequences of nutrient loads are a visible reproduction of algae (Figure 1), together with a decrease in dissolved oxygen and therefore the spreading of dead zones in coastal marine water (Diaz & Rosenberg, 2008).

The excess of nutrients is usually utilized by species that are undesirable or harmful (Smith & Schindler, 2009). Furthermore those phytoplankton species change in form or size and modify their utilization by consumers, hence accumulating as intense nuisance blooms (Anderson et al., 2002).

According with Margalef (1974) the degradation of the organic material, originated form the increase in algae amount, causes a severe depletion in the concentration of oxygen therefore low DO concentrations are physiologically stressful or lethal to aquatic organisms (Breitburg et al., 1997).

Phosphorus in water is present in dissolved and particulate form; the dissolved part provides a direct source of nourishment for the phytoplankton whereas the particulate part, which consists of P absorbed to solid particles, can be accumulated in the sediment. Nevertheless, due to different chemical, hydrodynamic and temperature conditions it can be released and re-enter the water column under dissolved form (Gallerano et al., 1993).

According to HELCOM (2007) a shift is occurring in the Baltic Sea since the 1900s, from oligotrophic clear water to eutrophic regime. This is due to an excessive load of N and P coming from activities on land, mainly agriculture.

Although both N and P contribute in the eutrophication process, mitigation measures are focusing more on reducing the second one. Phosphorus has important implications for ecosystem management because it limits the growth of bacteria responsible for the nitrogen-transforming, which affects carbon fixation, storage, and release mediated by plants (Sundareshwar et al., 2003).

Figure 1 Algal bloom in the Baltic Sea (http://www.greenfudge.org/).

Agriculture and nutrients

In modern agriculture, P is an important nutrient and fertilization of crops stands for the largest part of P used in agriculture (Lowell et al., 2002). Agricultural land is considered to contribute a large proportion of the P load from Sweden to the Baltic Sea. Around 40% of the P that reaches the Baltic Sea from Sweden comes from agricultural land and the proportion is largest in the southern part (Ejhed & Brandt, 2003). Diffuse pollution from agriculture is the main source of nutrients (N and P) to surface and ground water (EC & WHO, 2002).

Since 1950 Scandinavian countries introduced a more specialized form of agriculture which was based on the use of pesticides and chemical fertilizers (Larsson & Granstedt, 2010). As a consequence, the load of P to the Baltic Sea increased.

Figure 2 Source of pollution from agriculture http://www.setyoufreenews.com

Phosphorus losses

Most of developed countries have recently registered an increase of P content in agricultural soils due to an excessive use of fertilizers (Djodjic et al., 2004); in Sweden 50% of all arable land has a high P value (Eriksson et al., 1997; Swedish board of Agriculture, 2002), consequently an increase of the soil P pool is leading to a possible increase in P losses from agricultural soils (Djodjic et al., 2004). Moreover, P has been supposed to be stable in soil apart from a few cases such as in organic and very light sandy soil, or after an intensive application of manures (Sharpley et al., 1994).

In order to reduce P concentration in surface water bodies it is necessary to focus on the sources and how P is transported through agricultural soils.

According to Hill (1997), point source pollution is defined as "any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack". In Sweden nutrient pollution from many point sources have been controlled and reduced by the implementation of effective measures; for example advanced wastewater treatment with P reduction was introduced in the majority of the wastewater plants in Sweden in the 1990s, hence the P content of the water was reduced about 92% (Sundberg, 1994).

In contrast, non-point source pollution (NPS) may come from many diffuse sources; "it is generally caused by rainfall or snowmelt moving over and through the soils. Natural and human-made pollutants are detached and carried away by runoff water, they are then left into lakes, rivers, wetlands, coastal waters and ground waters" (US EPA, 2011).

The dominant transport pathways of P are surface runoff and leaching through the soil profile. Runoff is defined as a surface and subsurface lateral movement of water due to the slope of a field whereas leaching considers the passage of compounds from the solid phase to the water one (Haygarth & Sharpley, 2000)

Leaching occurs with different flows; matrix flow is a relative slow and even movement of water and solutes through the soil, obeying the convective-dispersion theory, water follows an average flow path through soil. Preferential flow on the other hand refers to an uneven and often rapid movement of water and solutes through the soil profile, where soils natural structure as wormholes, root holes, cracks stand for the major part of the flow. Depending on the soil type and properties the dominant type of flow will vary, sandy soils for example are generally associated with matrix flow whereas preferential flow often occur in clay soils (Bergström et al., 2007).

Phosphorus losses from surface runoff usually are in the form of dissolved reactive P (DRP) and bound to soil particles (Ulén et al., 1998). Although surface runoff is one of the major principal P pathways (Sharpley & Rekolainen, 1997), other studies consider leaching as an important process of P transport (Culley et al., 1983).

Macro-pores in agricultural clay soils are regarded to be a preferential way of P movement (Ulén & Persson, 1999). Phosphorus passing through large pores in the soil profile does not have enough time to react with sorption sites present in the soil and percolates towards the deeper layers reaching drain tiles. Coarse sandy soils show a high risk of leaching losses due to their sometimes low sorption capacity and high hydraulic conductivity (Sims et al., 1998). Additionally, soils with high organic matter content tend to behave in the same way (Tiemeyer et al., 2009).

Phosphorus is usually transported as PP and dissolved P (DP) (Haygarth et al., 1998); PP is bond to suspended material and can be hence related with soil erosion. Water, during runoff and leaching processes carries along chemicals and other pollutants together with suspended solid from the landscape.

Probst (1984) and Allan (1995) have reported a correlation between suspended material and nutrient level in water bodies, especially P, therefore, assessing how suspended material is concentrated and moves, leads to a better understanding of nutrient pollution dynamics.

Total SS is considered as fine particles of sediment together with pollutants which attaches to them, although SS cannot be considered a measure of pollutants carried by storm water runoff, it can be used as an indicator because its relationship with pollutants. Therefore the transport of SS is of considerable interest regarding the impact of nonpoint source pollutant (Lewis, 1996).

In rivers studies, for example, sediment sampling and load estimation are conventionally based on discharge data, even though turbidity is generally a much better predictor of SS concentration (Lewis, 1996). Also Gippel (1995) writes about relation between turbidity and sediment concentration which can be expected in most cases, therefore turbidity data should be able to return better estimates from infrequent measurement of concentration.

This study aims to investigate and assess the possible use of turbidity as an indirect measurement of SS, PP and TP concentration in leachate water.

Material and methods

Site and Soils description

Swedish soil fertility experiments

Based on the first long fertility studies originally carried out in Great Britain in the middle of the nineteenth century (Johnston, 1997), Sweden started its own experiment in 1957 (Ivarsson & Bjarnason, 1988). The Swedish soil fertility experiment aims to provide information on the long term influence of cultivation measures and natural parameters on crop yields and soil productivity (Carlgren & Mattsson, 2001).

Phosphorus applications follow the principles of replacement; each site has four P input levels. Level A is without P application, P removed with the crop is replaced in level B whereas level C and D consist of high additions of P with the aim to reach slow (C treatment) and fast (D treatment) increases in the soil P status (Carlgren & Mattsson, 2001).

In our study lysimeters taken from the fertility experiments at Kungsängen, Vreta, Ekebo and Fjärdingslöv were used. The soil columns were placed in a lysimeter station in Uppsala and water samples were collected and analyzed. Sites and important soil properties in the topsoil are listed in table 1.

Kungsängen (Figure 3) site is located between the Uppsala-Stockholm railways on route number 255. Kungsängen soil has been formed by the youngest post-glacial sediment from the Baltic ice and is defined as gyttja clay. The two rivers Fyrisån and Sävjaån contributed to the presence of 59% unstratified gyttja clay soil at the site. Concerning earlier uses, grazing was the main activity during the 18^{th} century.

The site had originally a high content of organic matter, which was set underneath the permanent grassland vegetation, but due to crop rotation started in 1907 it has steadily decreased; the fertility experiment began at Kungsängen in 1963.

According to the soil taxonomy described by the Soil Survey Staff (1987) the soil is defined as aquic due to its complete saturation of water during some days of the year (Kirchmann, 1991)

Vreta Kloster (Figure 3) is situated in the Eastern Götaland County in the central part of Sweden; the site is located in a shallow plain in undulating countryside near Lake Roxen. The area is mainly covered by glaciofluvial deposits of varved clay (Fromm, 1976). The top soil is a silty clay (50%) and the subsoil is a clay of free calcium carbonate (Carlgren & Mattsson, 2001).

This site has been cultivated and used for milking cows for 200 years, and cattle manure was applied up until 60 years ago although with small application rates. The area is tile-drained and defined as a fertile area.

Ekebo (Figure 3) farm is located near Fjärjestad church in Skåne county in the south part of Sweden, in a flat countryside area. According to Adrielsson et al. (1981) the bedrock is formed by sediments from the Upper Trias and is covered with quaternary deposits of clayed tills.

It is classified as a coarse-loamy, mixed, mesic Oxyaquic Eutrocrept (Soil Taxonomy) and as a Eutric Cambisol soil (FAO), and the percentage of clay is relatively low at 17%. Due to the absence of calcium carbonate, a low Mg content and dense subsoil (Kirchmann et al., 1999), Ekebo it is one of the less favorable sites for agricultural use (Carlgren & Mattsson, 2001). The site has recurrently been subject to fires in the past to avoid growth of woody vegetation, as the site was mostly used for grazing.

The site of **Fjärdingslöv** (Figure 3) farm is located in the southern part of Sweden, close to Trelleborg, Skåne County. The sample area consists of a slight depression on a flat countryside area. At this site the bedrock is formed by Danian Limestone rich in chert and thickness of 40 m (Daniel, 1977).

It is classified as a coarse-loamy, mixed, mesic Oxyaquic Hapludoll (Soil Taxonomy) and a Haplic Phaeozem soil (FAO). The texture is composed of sand and loam with an increase in clay (19%) and calcium carbonate concentration to a depth of 100 cm (Carlgren & Mattsson, 2001). Agricultural quality is high, this field has been used as arable land for more than 150 years, and small applications of animal manure are recorded to be used during the 20th century.

Experimental fields

The experimental field started in central part of Sweden in the first half of 1900, aimed to study losses of nutrients from agricultural fields. Bornsjön and Lanna, two of the soils studied in the experiment, have separately drained plots, water leachate is collected and then analyzed.

Bornsjön (Figure 3) soil has relatively high percentage of clay, 60% (Ulén, 2011) and according to FAO (1998) is defined as flat and classified as a Eutric Cambisol (Ulén & Persson, 1999). The bedrock is a veined garnet-gneiss with meta-argillite containing much plagioclase, cordierite and biotite (Stålhös, 1968).

The other experimental field studied, **Lanna** (Figure 3) is located at the Lanna station in southwest Sweden by the largest agricultural plain in Sweden (Västgöta plain). The soil is classified as an Uderic Haploboroll (Aronsson & Stenberg, 2010) with a clay percentage of 47% (Ulén et al., 2005). The mean annual temperature of the region is 6.1°C and the mean annual precipitation 558 mm (Lanna, 1961-1990).

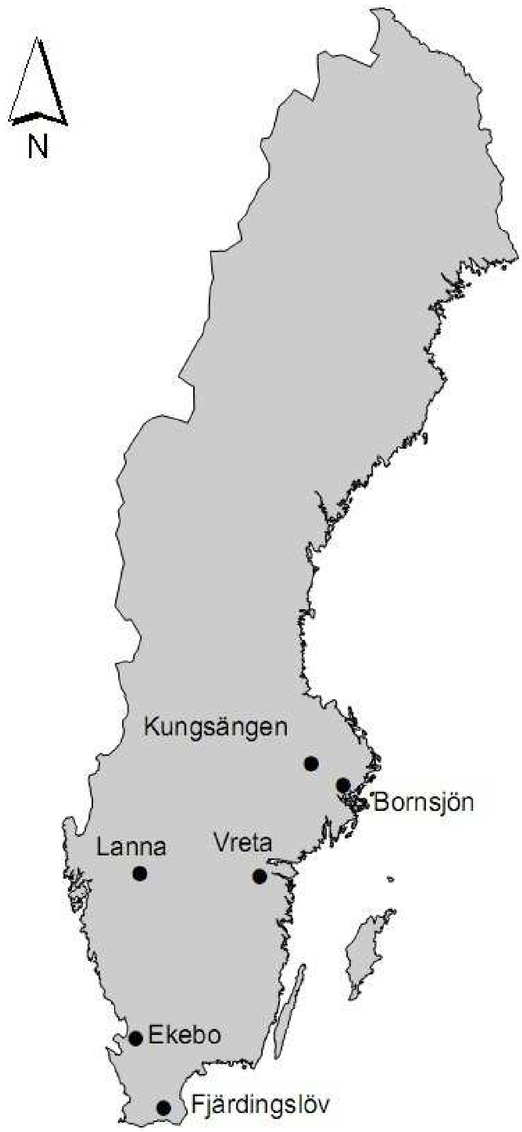

Figure 3 Site locations

Table 1 Soils properties and classification

Site	Classification	Texture §	Clay §	Organic C §	P-AL#	pH§
			%	%		
Fjärdingslöv	Oxyaquic Hapludoll*	Sandy loam	19	1,1	3,3	7,5
Kungsängen	Typic Haplaquept¥	Clay	59	2,3	3,7	6,9
Ekebo	Oxyaquic Hapludoll*	Loam	17	2,2	6,7	6,5
Vreta	Not determined	Silty Clay Loam	50	2,1	6,7	6,7#
Bornsjön Oxelby/OXA	Eutric Cambisol^	Clay	60	(missing)	4,9	6,6^
Lanna	Uderic Haploboroll()	Clay	47	1,9[x]	7,5[x]	7,4[x]

§ Determined according to methods described by (Börling et al., 2001).For clay and inorganic C, n=2.

*(Kirchmann et al., 1999); ¥ (Kirchmann, 1991); # (Carlgren & Mattsson, 2001);

() (Ulén et al., 2005); [X] (Aronsson & Stenberg, 2010)^(Ulén & Persson, 1999)

Lysimeter, plots and field scale experiments

The study was performed using three different scales. The six soils were analyzed at lysimeter scale at the Uppsala lysimeter station. The experimental fields at Bornsjön and Lanna have been studied at plot scale as well. Bornsjön has also been studied at field scale (table 2).

Table 2 Scales used for the different soils

Scale	Site					
	Kungsängen	Vreta	Ekebo	Fjärdinglöv	Bornsjön	Lanna
Lysimeter	x	x	x	x	x	X
Plots					x	X
Field					x	

Lysimeter scale

The soils from the Swedish fertility experiment were sampled in autumn 1999; PVC standard sewage pipes of 0,295 m diameter and 1,18 m long, were lightly lowered into the soil and then by applying drilling methods undisturbed soil columns were taken out (Persson & Bergström, 1991). In order to provide the right gravity drainage, non-sorptive filter material was used to replace 0,07 m of the bottom part of each column. Lysimeter were collected in the same way at Lanna and Bornsjön in 2009. After collection, the lysimeter were placed under ground level at the Uppsala lysimeter station (59°49 N; 17°39 E) (Figure 4).

The mean annual temperature and precipitation in the area are 5,5 C° and 527 mm/yr (Aronsson & Bergström, 2001) and the lysimeters have been exposed to the same climatic conditions as the surrounding soil (Djodjic et al., 2004).

Figure 4 Lysimeter station Uppsala

Plot scale

In 2006 an experimental field, 30 km south of Stockholm and 20 m above sea level, was set nearby the Lake Bornsjön which is one the main water reservoirs of Stockholm. The field consists of 28 drained plots with subsurface runoff collection, each plot measures 20 m x 24 m (0,084 ha). In order to obtain an effective drainage of the soil, drains are located in the center with 8 m of distance. Measuring stations collect the water flow through tilting vessels and record the volume by data loggers which also control the proportion of the flow sampled (Ulén, 2011).

Seven treatments were considered (A-G), A and B compared the results of using mineral P fertilization, C analyses the effect of structure liming and D-E compared methods of P fertilizer application in combination with shallow tillage. Treatment F is an uncultivated and unfertilized plot whereas G comprises an alternative crop rotation (Ulén, 2011).

The other plot scale studied is located at Lanna site, an experimental field with separated tile-drain plots built in 1935. Four drained plots set in an area of 0,40 ha (40x100 m^2) were place at an average depth of 1,0 m. Water from the drainage, sampled according with the proportion of flow, was collected and delivered to measuring wells which record the discharge rate from each plot by a data logger (Aronsson & Stenberg, 2010).

Concerning the treatments of the plots used in the current study, three have been conventionally plowed in the fall, since 2007 whereas one plot is unfertilized and set-aside since 1993 (Ulén et al., 2005).

Field scale

Bornsjön field samples have been collected from an arable land with 4×43 ha with tile drains system which was installed in the late 1940s and 1950s. Drains tiles have topsoil and some gravel backfill and they are situated at 1-1,2 m underneath the ground with irregular spacing. The main drainage line measures 25 cm in diameter. Samples were obtained with a flow proportionally method using an ISCO sampler controlled by a data logger (Ulén & Persson, 1999).

Experimental work

The experimental work was composed of two main procedures: measurement of turbidity and measurement of SS. Water samples, TP, PP and DRP concentration were obtained from the responsible person of each of the experiments from the Soil and Environmental Department at SLU. Data were then collected in tables (Appendix C) and studied together through Microsoft Excel software.

Turbidity

Turbidity is defined by the International Standards Organization (ISO) as transparency reduction of a water sample due to the presence of suspended matter (Lambrou et al., 2009). When a beam of light passes through a solution it is absorbed reducing the intensity of the beam transmitted as solid particles present in the solution reflect and refract the light. Assessing the amount of scattered light measured with a 90° angle from the incident light is defined as the nephelometric method (ISPRA, 2004).
The device used is The Hach Model 2100AN IS* Laboratory Turbidimeter (Figure 5) designed for turbidity and attenuation measurement in accordance with International Turbidity Measurement Standards ISO 7027, DIN 38 404 and NF EN 27027. The Model 2100AN IS is a nephelometer with the capability to measure scattered or attenuated light. It uses the Nephelometric optical system and provides direct measurements in units of NTU (Nephelometric Turbidity Unit, 0-10,000).

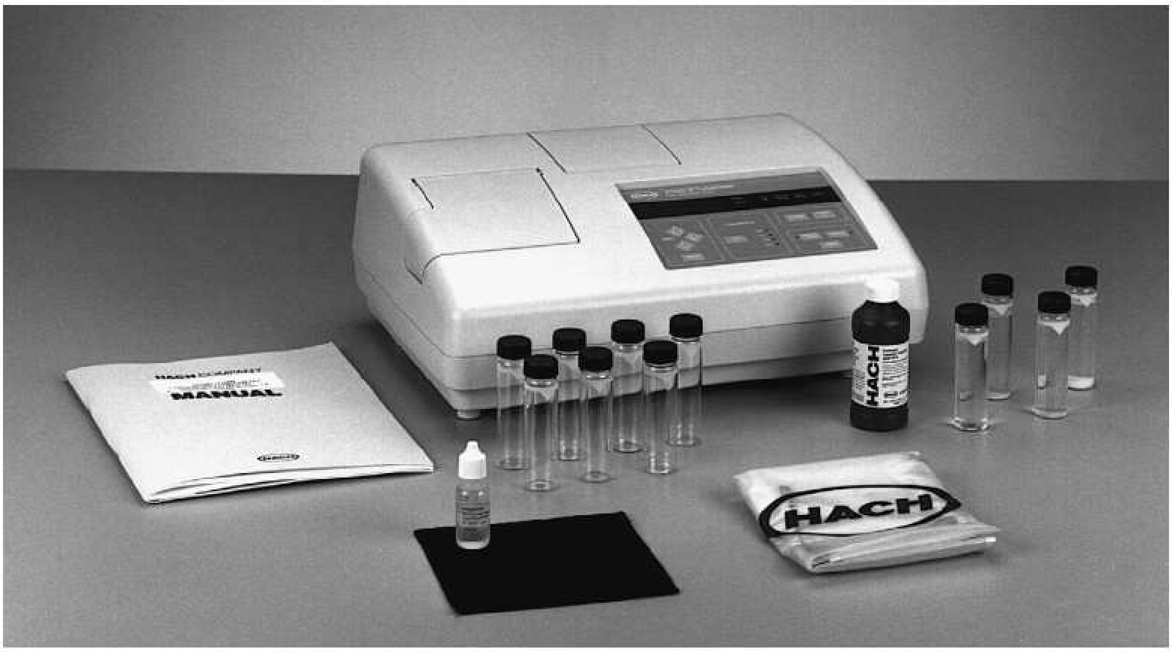

Figure 5 The Hach Model 2100AN IS* Laboratory Turbidimeter (Hach Company, 2008)

Samples were kept at a temperature of 4°C for the entire period in order to reduce interaction between the chemical compounds contained in the water. Samples were shaken in order to disperse the precipitation and homogenize the solution, afterward water samples were poured into a clean container with an approximate volume of 30ml. The calculation time needed by the turbidimeter was generally short.

Suspended solids

Suspended solids are defined as solids removed by filtration from a water sample (Swedish Standard Institute, 2005).

The basis of this analysis is the Swedish Standard SS-EN 872, the methods was slightly modified with the use of Whatman OE 66 Membran 0,2 µm filter instead of 0,5 µm.

The procedure consists of the use of a vacuum or pressure filtration apparatus in order to filter a sample of water through a 0,2 µm membrane filter. Filters were then dried at 105°C±2°C in an oven for at least one hour and subsequently weighted with an analytical balance to measure the mass of the residue retained. Water samples were transferred to a graduated cylinder reaching the volume of 50ml for low turbid sample, 25ml for medium turbidity and 10ml for high turbid sample.

Filters were left in the oven at 105°C for approximately 1 hour and after that they were taken out and let left to gradually come back to room temperature for at least ten minutes. Filters were weighted using the same analytical balance

The content of SS was calculated from this expression:

$$SS = \frac{1000 \times (b - a)}{V}$$

Where

SS is the content of SS (mg/l);

b is the mass of the filter after the filtration (mg);

a is the mass of the filter before the filtration including the subtracted blank value (mg);

V is the volume of the sample (ml)

Concentration of different forms of P

Laboratory analyses were performed at the department of Soil and Environment at SLU. DRP (or "PO_4-P") was measured on filtered samples (0.2 µm Whatman membrane filters). The DRP analysis was performed by flow injection analyses (FIAstar 5000, FOSS Analytical A/S, Denmark) in which the orthophosphate in the samples first reacted with ammonium molybdate which was then reduced to phosphomolybdenum blue in a sulphuric acid medium (ISO 15681-1 revision 4). The intensive blue color was measured at 720 nm. In the total P analysis the samples were digested in an acid persulphate solution before analysis on the FIAstar 5000.

PP was calculated as the difference between total P in unfiltered water and total P in filtered water (0.2 µm Whatman membrane filters).

Results and discussion

Whole dataset study

Turbidity and SS

The entire dataset obtained from the experimental work was then grouped together in scatter plot graphs in order to evaluate possible behaviors and trends within turbidity and SS values.

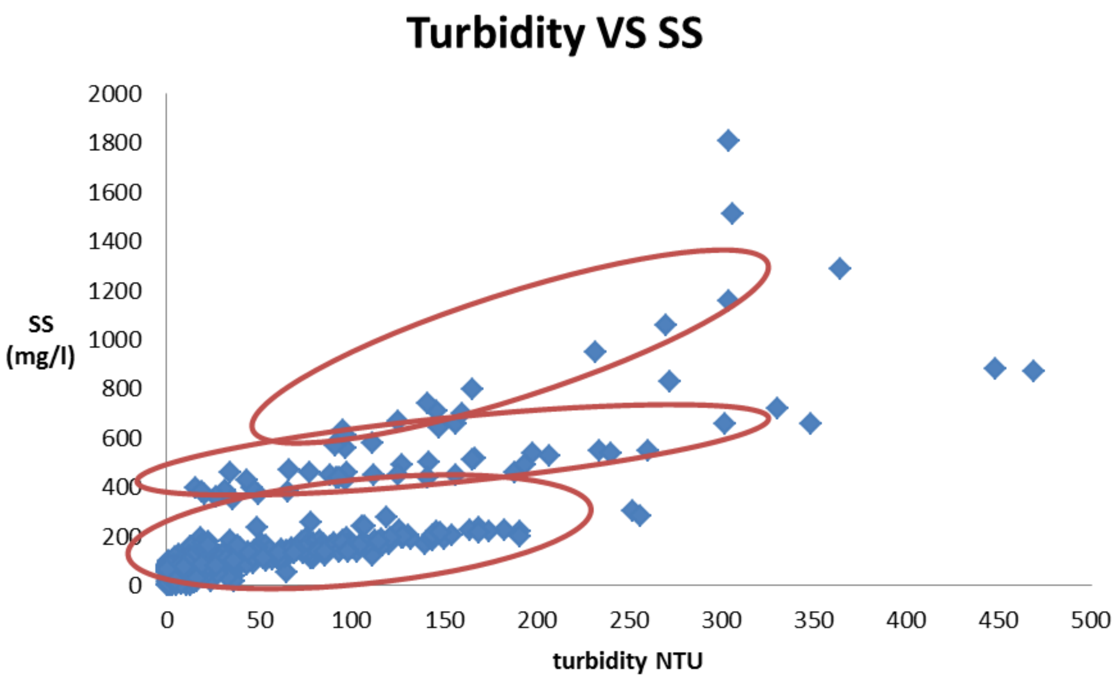

Figure 6 Turbidity versus SS for ALL data, the red ellipses highlight the different trends.

Figure 6 shows all the data for turbidity versus SS collected from different soils and scales. Three clusters are visible, the thickest is formed by values between 0 and 200 of SS and 0 and 250 NTU; a gap is present from 200 and 400 SS and from 400 to 600 there is the second cluster which has fewer values than the first.

Up to 600 SS there is the third cluster, with the least number of values, it is also clear that up to 1400 SS and 400 NTU four outliers are present.

Plotting the whole dataset returned a correlation which could suggest different trends in frequency of values but comparing the graph with the one in figure 7 it is evident that Bornsjön plot dataset largely influence the distribution and it is also clear that lysimeter values are concentrated in the lowest cluster whereas the upper one are formed by part of Bornsjön plot and Bornsjön field.

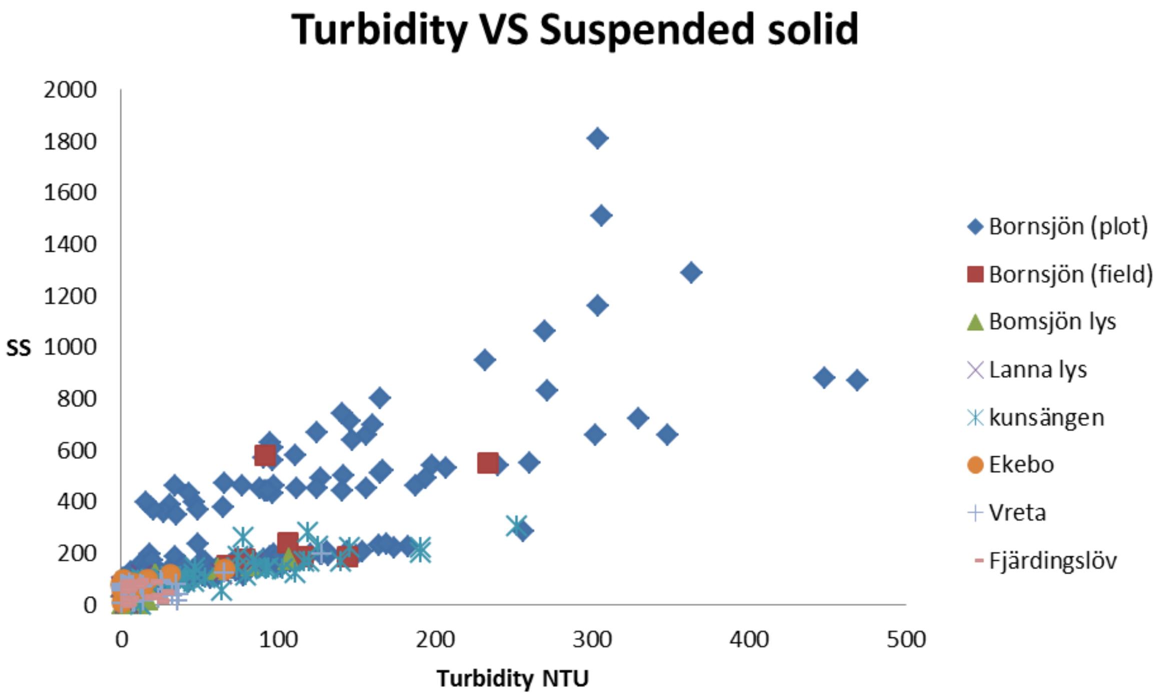

Figure 7 Turbidity versus SS for ALL data

Furthermore according with Bornsjön plot dataset, the three main clusters observed in figure 6 are associated with samples from April and thus a period immediately after the high flow events (Appendix B).

The differences and characteristic between scales and soils will be analyzed and explained later.

The whole dataset was also studied in relation with peaks and drops of discharge volume during the sampling period; therefore, low and high flows were then obtained. According with the data recorded, three weeks from January, February and March 2011 were associated with low flow whereas three weeks from those same months were associated with high flow. Middle values from the other weeks among the sampling period were not considered in these graphs.

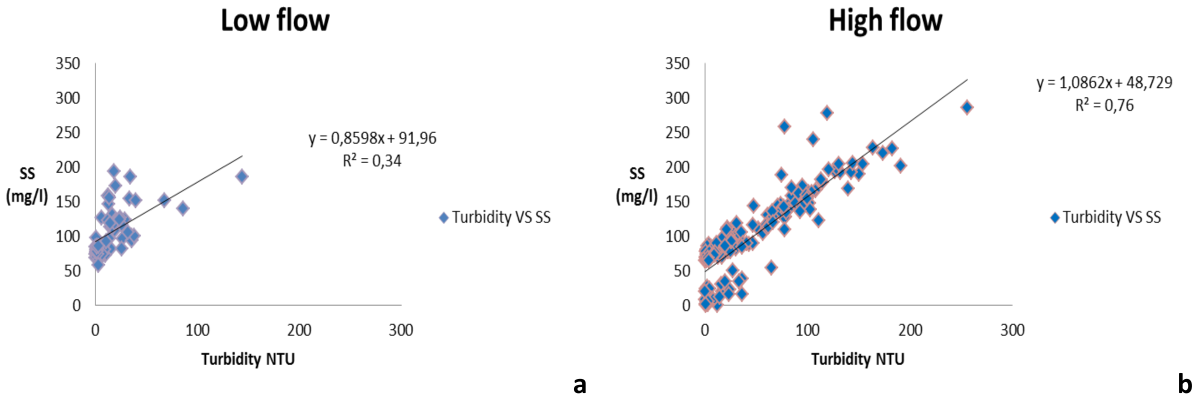

Figure 8 (a) Turbidity versus SS of data collected on week 5 (January 2011), week 6 (February 2011) and week 11 (March 2011). (b) Turbidity versus SS of data from week 4 (January 2011), week 12 (March 2011) and week 13 (April 2011).

Observing figure 8 (a) the correlation between turbidity and SS at low flow is relatively small (0,34), SS values range from 50 to 200 and turbidity clusters between 0 and 50 NTU, nevertheless three outlines values between 50 and 150 NTU are visible.

Figure 8 (b) shows instead the correlation between turbidity and SS during high flow period, the distribution of values in the graph implies a positive and good correlation which is 0,76. It is possible to distinguish two trends, one it is perfectly included between 0-50 mg/l SS and 0-50 NTU and the other one which is wider, shows a linear increase in turbidity with the increase of suspended sediment, highest values do not overcome 300 mg/l SS and 250 NTU. Differences in the graphs suggest that sample from low flow period have globally low values of turbidity but relatively large values of SS, meaning that smaller particles were detached rather than bigger ones. During flow events indeed variation in particles size and sediment properties are known to occur (Richards, 1984; Walling, 1984; Gippel, 1989) and they therefore influence results of the turbidity-suspended sediment relation.

Observing the high flow graph the increase in turbidity associated with an increase in SS can be attributable to the larger amount of water able to carry more soil particles. Other studies focusing on water bodies, especially rivers, also found this relation explaining that the flow rate is one of principal factor influencing turbidity. Fast running water carries more particles and larger-sized sediment and heavy rains detaches more easily sand, silt, clay, and organic particles from the land to the surface (Oram, 2011). Although the water analyzed in this study is leachate from lysimeter a closer comparison can be made with sample from plot and field scale.

Turbidity and TP

Turbidity and TP data were grouped and plotted together in one graph as it was previously done for turbidity and SS.

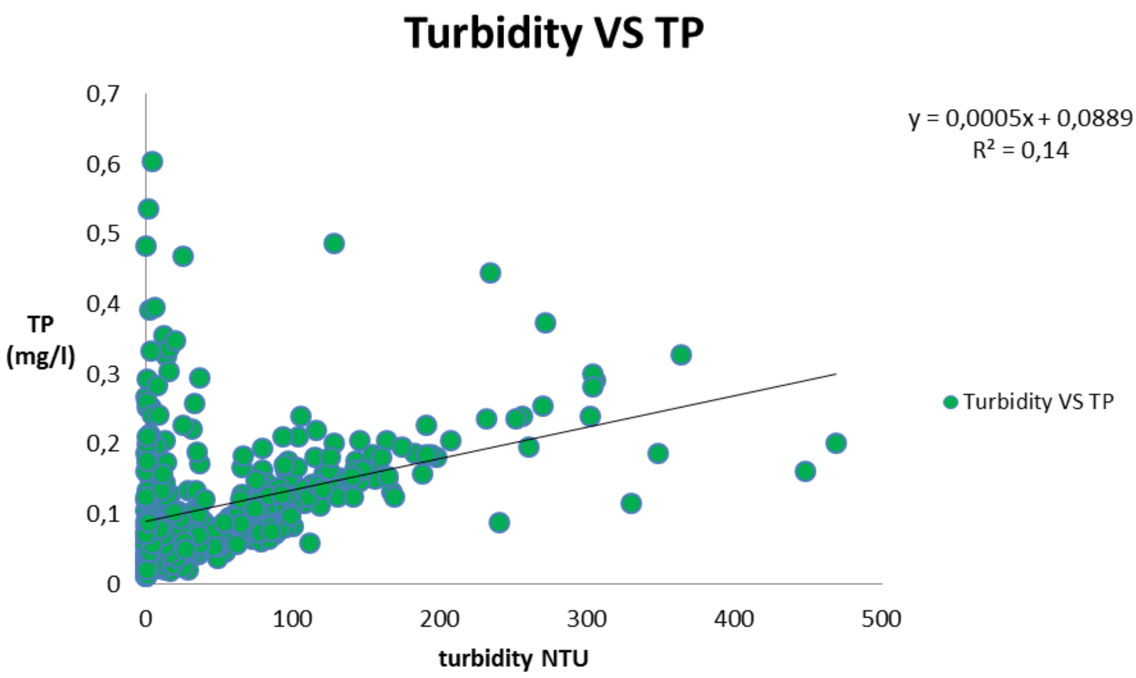

Figure 9 Turbidity versus TP for ALL data

Turbidity and TP do not yield a strong correlation, it appears from the graph in Figure 9 that several samples show a concentration of TP evenly distributed to 0,3 mg/l associated with low value of turbidity. As it occurred in the correlation between turbidity and SS (Figure 6), soil samples from the lysimeter scale are concentrated at low turbidity values, in this case between 0 and 50 NTU. The increase in TP concentration does not seem to be strongly related with an increase in turbidity. Abdou & Flury (2004) observed differences in water flow and solute transport between field and lysimeter stating that solutes move faster in the first one than in the second one, it might be possible that the less erosion processes in the lysimeter columns result in consistent values of P leachate associate with small value of turbidity due to the less detachment and movement of particles. Nevertheless a positive trend, following instead a direct relation, is formed from 50 NTU. This trend is largely influenced by the Bornsjön plot and field sample with a contribution from Kungsängen soil; as it was also found by Jones (2011) in another study, the distribution of the two forms, PP and DP in the different soils influence the correlation of the whole dataset.

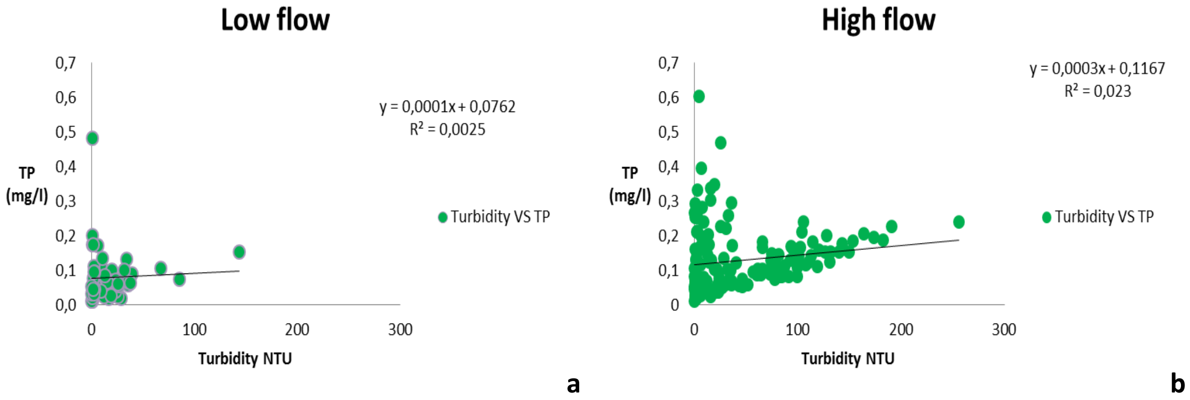

Figure 10 Turbidity versus TP of data collected on week 5 (January 2011), week 6 (February 2011) and week 11 (March 2011) (a). Turbidity versus TP of data from week 4 (January 2011), week 12 (March 2011) and week 13 (April 2011) (b).

Figure 10 shows how TP and turbidity are related with period of low flow (r^2=0,024) and high flow (r^2=0,0025), it is remarkable that above 50 NTU (Figure 10b) an increase in TP is associated with an increase in turbidity. A consistent relation between these variables during high flow events was also found and discussed by Christensen (2002), Ryberg (2006) and Jones et al. (2011).

Turbidity and PP

As well as for TP the whole data set was grouped to study the relation between turbidity and PP, the graph is presented in Figure 11.

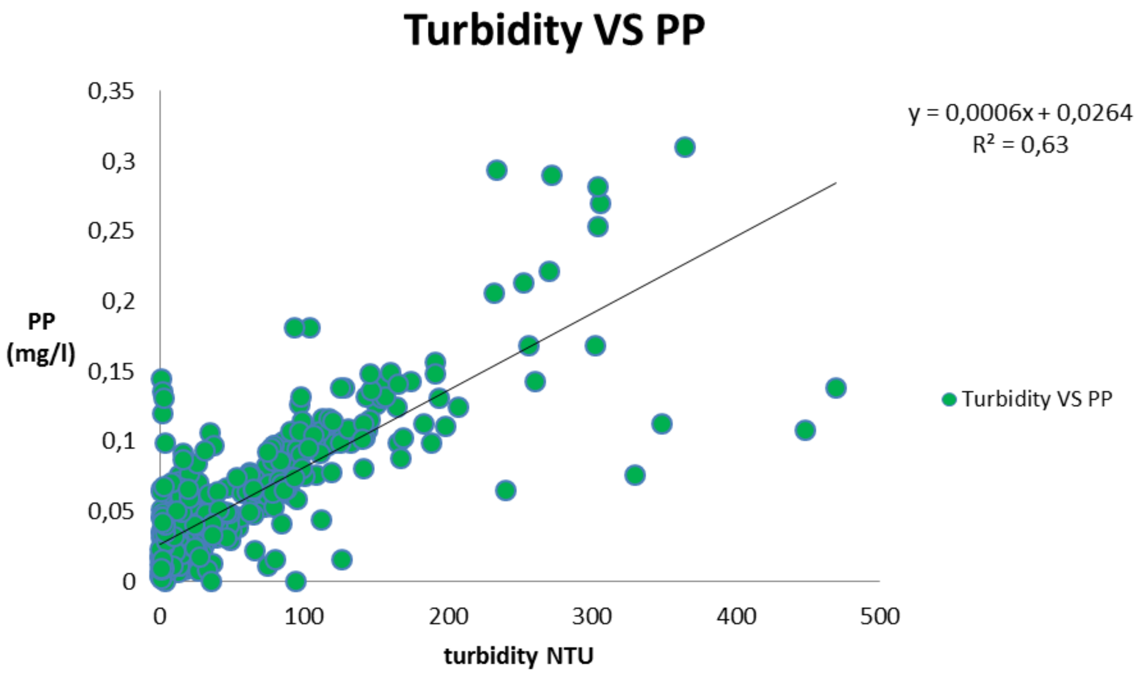

Figure 11 Turbidity versus PP for ALL data

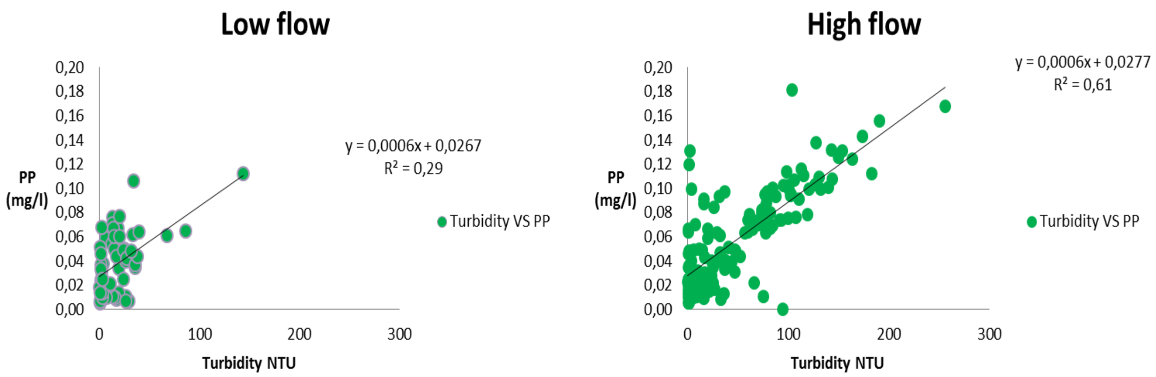

Figure 12 Turbidity versus PP of data collected on week 5 (January 2011), week 6 (February 2011) and week 11 (March 2011) (a). Turbidity versus PP of data from week 4 (January 2011), week 12 (March 2011) and week 13 (April 2011) (b).

Comparing with the plot of TP and turbidity (Figure 9) the correlation in this case (Figure 11) is higher (0,63) and the distribution of sample is following a direct relation with a main cluster between 0 and 200 NTU and 0 and 0,15 mg/l.

Concerning PP and high/low flow the relationship represented by the graphs in Figure 12 shows characteristic and similarities already observed with SS (Figure 8) and TP (Figure 10).

Low flow presents a distribution of sample clustered between 0 and 50 NTU but with large concentration of P whereas high flow has the positive trend with sample reaching high concentration of PP; 0,181 and 0,168 mg/l associated respectively with turbidity values of 104 and 256 NTU.

Scale study

Turbidity and SS

In order to see if and how different scales affect relation with turbidity and suspended solid, graphs from Bornsjön are compared in Figure 13.

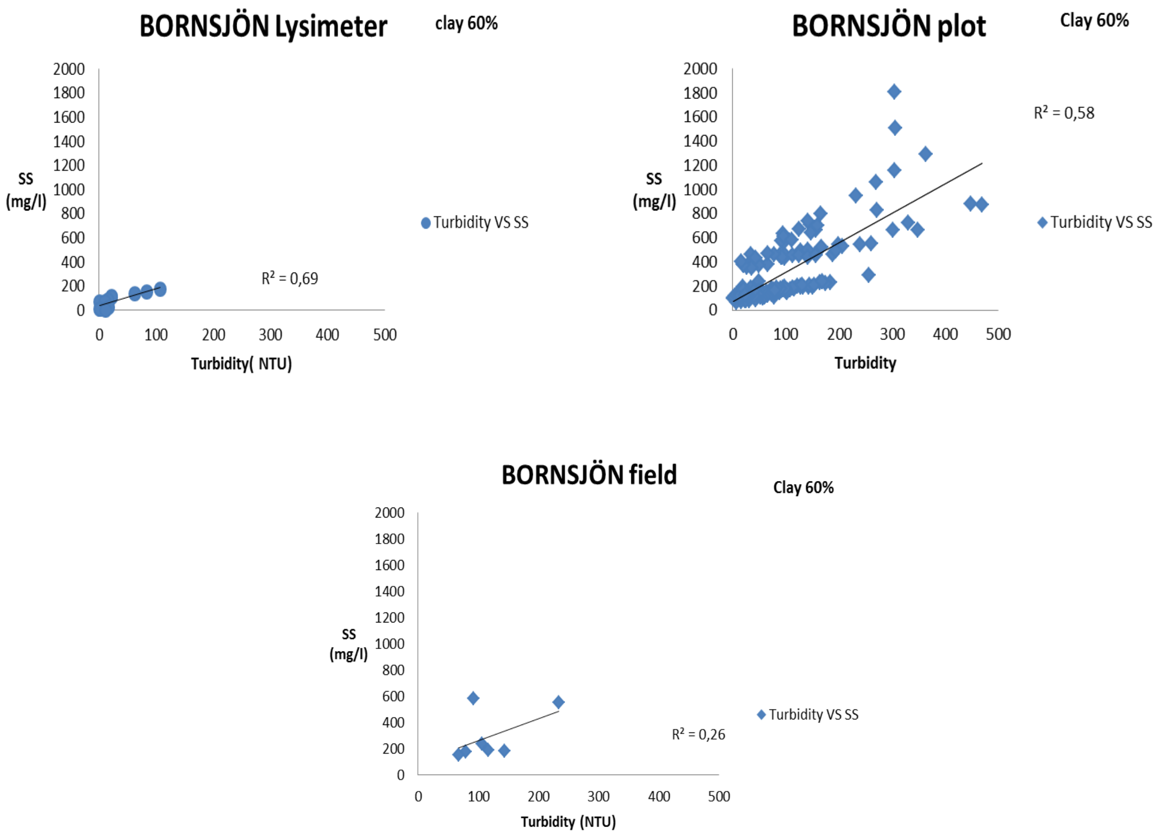

Figure 13 Scatter plots of Bornsjön soil at lysimeter, plot and field.

It appears that increasing the scale size the r^2 decreases; lysimeter shows the highest correlation (0,69), plot the second higher (0,58) and field scale with the lowest (0,26).
Nevertheless lysimeter returns the lowest turbidity and suspended solid values which are between 0,8-107 NTU and 2-174 mg/l.
Bornsjön plot has the larger data set which provides more information regarding trends of turbidity and SS; both values are greatly larger than the plot scale, in fact the largest are 469 NTU and 1810 mg/l even though most of the sample are below 150 NTU and 880 mg/l.
Bornsjön field seems to give the less reliable relation yielding an r^2 of 0,26, which is the lowest although averages of turbidity and SS are the largest (table 3).

In Figure 14 the same comparison is shown for Lanna soil at lysimeter and plot scale.

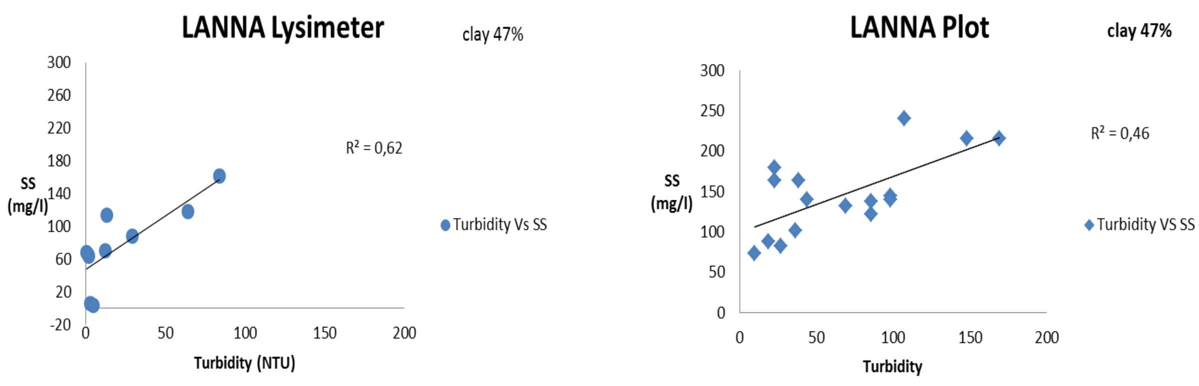

Figure 14 Scatter plot of Lanna soil at lysimeter and plot scale

As the previous comparison, this soils displays similar results, lysimeter scale has a better r^2 value than plot study. Observing the averages values of turbidity and SS in table 3, plot return the larger ones respectively 67,47 NTU and 146 mg/l.

Table 3 Clay content, R-square, turbidity and SS values for Bornsjön and Lanna at lysimeter, plot and field scale.

		Turbidity and SS		
SITE	**Clay %**	**R^2**	**Turbidity (NTU)**	**SS**
Bornsjön(lysimeter)	60	R^2 = 0,69	29,31	78
Lanna(lysimeter)	47	R^2 = 0,62	19,35	76
Bornsjön(plot)	60	R^2 = 0,58	89,69	288
Lanna(plot)	47	R^2 = 0,46	67,47	146
Bornsjön(field)	60	R^2 = 0,26	119,8	296

It is important to specify that lysimeter is an ideal environment of study which might give expected result because is not subject to external and unpredictable influences.
Therefore soil sample contained in lysimeter column were not exposed to surface and subsurface erosion, factor that affects detachment of larger amount of particles.

Larger turbidity and SS values recorded at plot and field scale might be explained because of the stronger mix action of internal erosion and surface erosion which is absent in the lysimeter analysis.

Furthermore it is not possible to draw a correct interpretation because the three scales are not based on the same data set as it is clearly shown in the graphs. Plot has 28 samples each week, whereas lysimeter 1-3 sample, and field only one.

Turbidity, TP and PP

Figure 15 reports the correlation between turbidity and TP at the three scales, increasing the scale, the r-square increases as well as the values of P and turbidity (table 4).

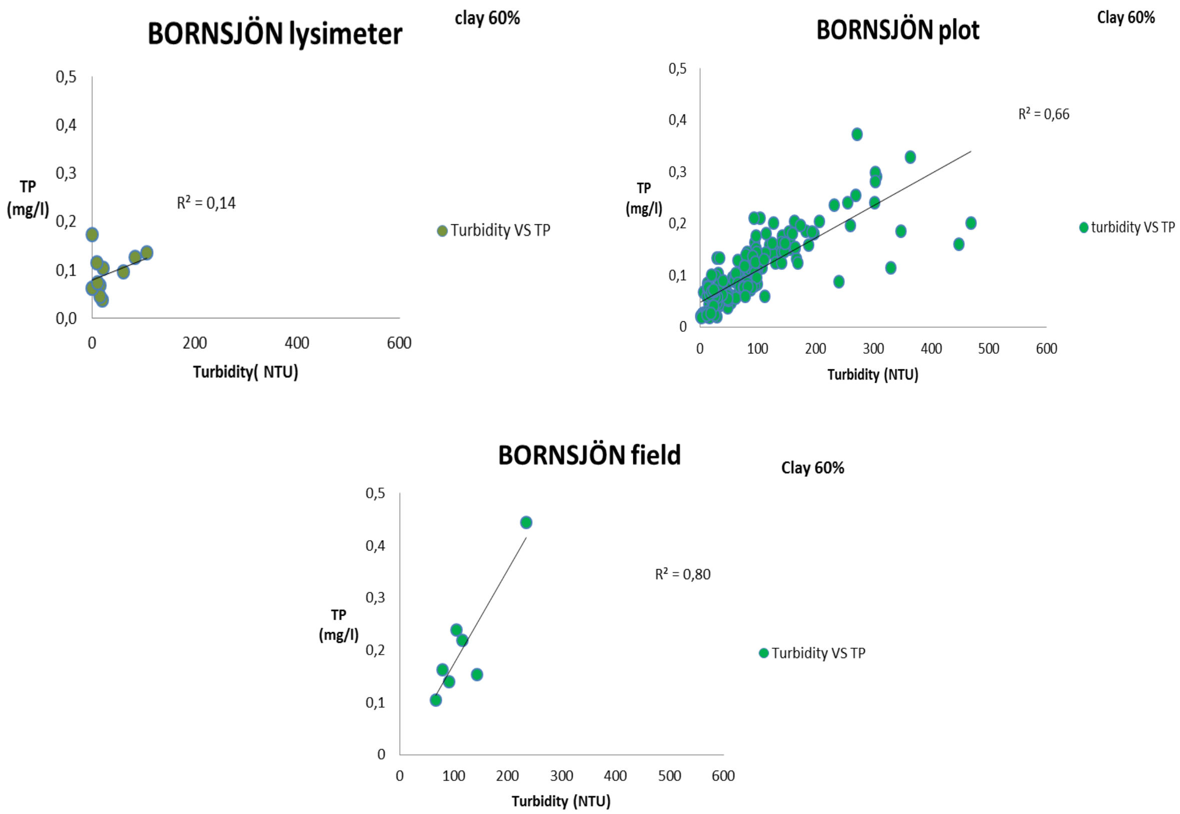

Figure 15 Turbidity and TP scatter plots of Bornsjön soil at lysimeter, plot and field scale

Bornsjön lysimeter returned a direct relation with an increase of P concentration above 20 NTU, nevertheless it is possible to see one clear outlined point with nearly zero turbidity and the highest P concentration (0,174 mg/l). Values in this site reflect characteristic of the lysimeter scale, both TP and turbidity are smaller than the other values found in the other scales meaning that the environment considered is closed and isolated. In the lysimeter, the surface runoff processes are very limited and therefore mobilization of SS is very low. Moreover, all solute is forced to go through the whole 1-m deep soil column and attenuation might be higher. Further, lysimeters are freely and probably better drained than plot and field scale which also may influence mobilization of particles.

The main cluster of points ranges from 0 to 200 NTU and 0 and 0,2 mg/l and afterward sample are slightly spread but globally with an increase in turbidity is associated an increase in total P.

Field scale returned the highest correlation even though it is possible to distinguish a cluster of points between 0,1 mg/l-0,25 mg/l and 50-150 NTU, an outlined point returned the largest concentration of P in the three scales (0,44 mg/l) but not the largest turbidity.

As previously mentioned, the uneven availability of samples from lysimeter and field scale has limited the possibility to draw more conclusions. Nevertheless, plots reflected the more interaction of parameters which occurs in plot and field scale; Stamm (2002) defines this "scaling problem" which is closely linked to the spatial variability of soil properties and water fluxes. The heterogeneity at the plot scale is due to small-scale variability in the pore structure whereas at the field scale, additional factors may dominate the spatial variability.

Table 4 Clay content, R-square, turbidity and TP values for Bornsjön at lysimeter, plot and field scale.

		Turbidity and TP		
SITE	**Clay %**	**R^2**	**Turbidity(NTU)**	**TP(mg/l)**
Bornsjön (lysimeter)	60	$R^2 = 0,14$	29,31	0,09
Bornsjön (plot)	60	$R^2 = 0,66$	89,69	0,10
Bornsjön (field)	60	$R^2 = 0,80$	119,8	0,21

In Figure 16 the three scales of Bornsjön are compared, PP and turbidity were plotted in order to observe R-square of linear regression.

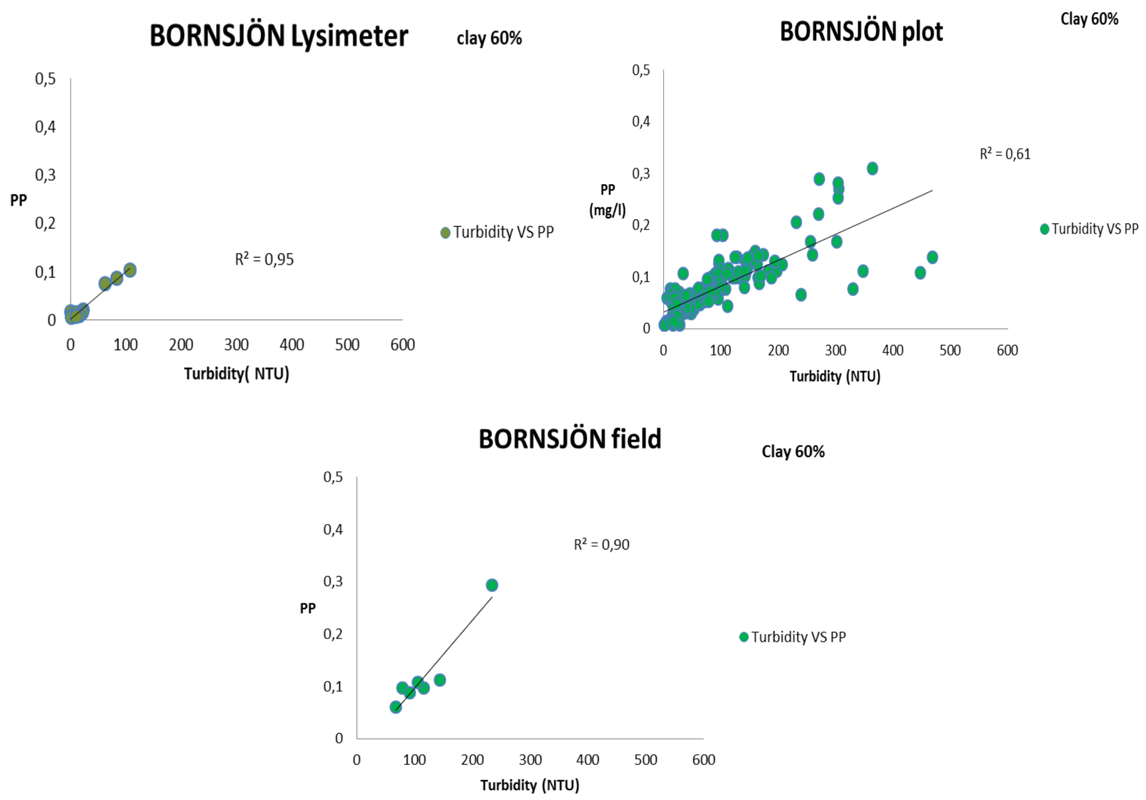

Figure 16 Turbidity and PP scatter plots of Bornsjön soil at lysimeter, plot and field scale

As observed in the comparison with SS and turbidity, lysimeter scale returns the higher correlation r^2 but at the same time with the lower concentration of PP and turbidity.

Two clusters are visible, the lower one ranges from 0,017 mg/l and 0,864 NTU to 0,02 mg/l and 22,2 NTU, the upper one from 0,076 mg/l and 61,9 NTU to 0,104 mg/l and 107 NTU. Averages values recorded are 29,31 NTU and 0,03 mg/l.

Bornsjön plot graph shows a similar trend till 200 NTU and 0,15 mg/l whereas sample are spread at higher PP concentration and NTU.

Bornsjön plot gives also the largest values, turbidity reaches 469 NTU and PP 0,31 mg/l (week 13-15) the averages values are instead comprised between lysimeter and field (table 5). Field scale yielded a good correlation (r^2=0,90) a cluster of sample is included between 67 - 144 NTU and 0,061-0,112 mg/l, only one sample shows greater values (234 NTU and 0,293mg/l). Turbidity and PP of field scale are the largest values (119,8 NTU and 0,12 mg/l).

As it can be seen in table 5, turbidity and PP concentration increase with increasing the size of the scale.

Considering different P forms, at field scale PP form (0,12 mg/l) is twice as high as dissolved P (0,06 mg/l) and the TP is 0,21 mg/l. Similar ratio occurs for the plot scale where PP is 0,08 mg/l and DRP 0,03 mg/l, with TP concentration of 0,10 mg/l . The result obtained differ from Haygarth (2002) who states that generally dissolved reactive P is the dominant form reported at fields scales. On the other hand (Turtola & Jaakkola, 1995) found that particulate P constitute a large fraction of P in artificial drainage from heavy clay soils.

Moreover, size distribution of suspended particles, which was not analyzed in this study, varies spatially depending on the characteristics of the catchment (Walling & Moorehead, 1987), partly explaining why turbidity versus SS concentration relationships tend to be site-specific.

Table 5 Clay content, R-square, turbidity and PP values for Bornsjön at lysimeter, plot and field scale.

		Turbidity and PP		
SITE	**Clay %**	**R^2**	**Turbidity(NTU)**	**PP(mg/l)**
Bornsjön (lysimeter)	60	$R^2 = 0,95$	29,31	0,03
Bornsjön (plot)	60	$R^2 = 0,61$	89,69	0,08
Bornsjön (field)	60	$R^2 = 0,90$	119,8	0,12

Different soils study

Turbidity and SS

The objective in using turbidity to study sediment transportation is to approximate concentration of SS to measured turbidity. This study evaluates the differences and similarities between soils with different soil properties.

Linear regression analysis between turbidity and SS were then performed for all the soils from the different lysimeter.

Figure 17 shows the experimental field soils, Bornsjön and Lanna at lysimeter scale.

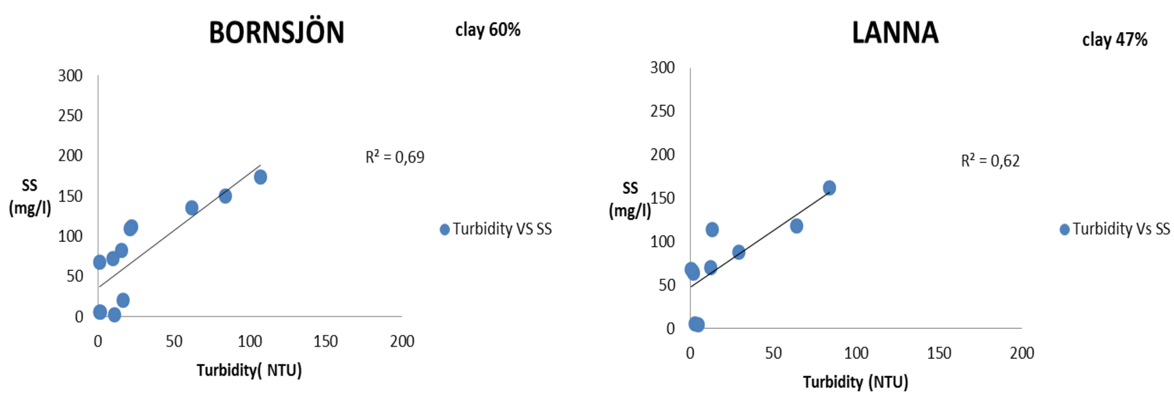

Figure 17 Scatter plots of soils from the Experimental field

According with the clay content respectively 60% and 47% the two soils show a good correlation, R-square values are respectively 0,69 and 0,62. Values of turbidity range from 0 to 107 NTU. Bornsjön samples returned a good correlation and relatively high values of SS and turbidity, soil profile is characterize by deep cracks formed by shrinkage or by freeing-thawing cycles (Ulén & Persson, 1999) and macro-pores which cause preferential flow and thus detachment of particles. Lanna profile presents macro-pores structure as Bornsjön and preferential flow which causes internal erosion (Bergstrom et al., 1994).

Figure 18 shows soils from the Swedish long term fertility experiment included in the lysimeter study.

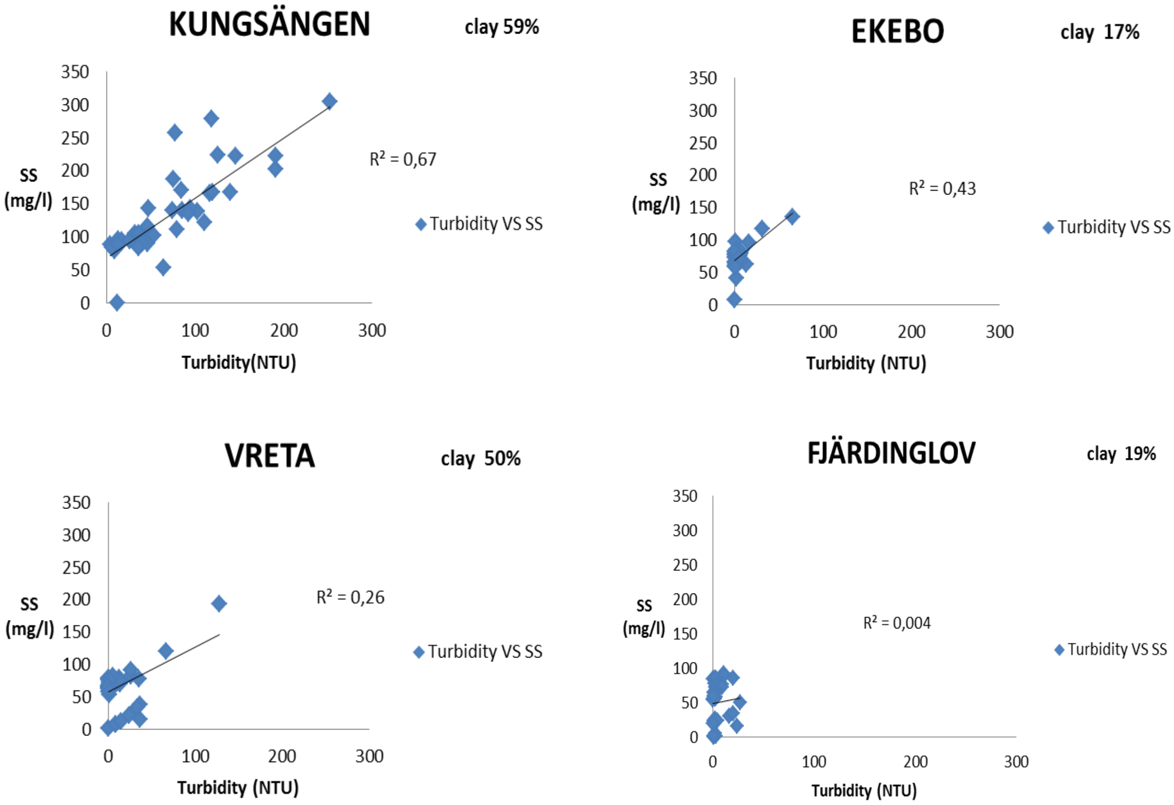

Figure 18 Scatter plots of soils from the Swedish Long Term Fertility Experiment

Kungsängen yielded an r^2 of 0, 67 together with the highest values of turbidity 252 NTU and the highest value of SS (304); its high clay content 59% partly explain the significant values of turbidity and SS obtained but other factors need to be considered.
Its structure for instance promote high porosity due to large channels and pores (Kirchmann, 1991), therefore a strong internal erosion could be responsible of the particles losses in the water samples. Further, Kungsängen has a high concentration of illite which increase downward the subsoil profile (Kirchmann, 1991) and according to Seta & Karathanasis (1996) this type of mineral with a high negative charge is known to slake and disperse fine clay particles. As well as the illite concentration, low pH in the subsoil (Kirchmann, 1991) affects stability of soil particles.
According with Figure 18 Ekebo displays few values of turbidity above 50 NTU and extremely low values of SS; it is also possible to see that only two samples show significant turbidity values related with larger concentration of suspended material. The general trend on the other hand shows that SS concentrations are mostly distributed between 0 and 100 mg/l associated with turbidity values not bigger than 16, 3 NTU.

According to (Gippel, 1995) for the same concentration and particle size, organic particles may attenuate to turbidity values two to three times higher than mineral particles (table 1) Ekebo has the highest organic content which might also explain the low value of turbidity.

Besides the clay and organic content the small losses could also be attributable to the permeability which is significantly reduced in the first layer of subsoil (0,3-0,5 cm) (Kirchmann et al., 1999).

Fjärdingslöv's samples form an homogeneous cluster of points with turbidity and SS values which do not exceed 27, 1 NTU and 92 mg/l.

Looking at table 6 and comparing Ekebo and Fjärdingslöv values, turbidity is nearly the same whereas SS values are higher in the first soil; according to (Campbell & Spinrad, 1987) few particles may account for a large portion of the suspended matter weight, but very little of the beam attenuation, thus affecting turbidity values.

Vreta samples display a remarkable behavior; the r^2 obtained is low in spite of 50% of clay content in the soil profile but it is possible to clearly distinguish two trends of values which affect dispersion of data and therefore the low r^2 value.

The lower one, with SS values between 2-38 and 0, 5-36, 5 NTU, corresponds to sample collected in January and beginning of March where soil was frozen and thus unlikely to release particles. The upper one with SS between 54-194 and 0, 7-128 NTU corresponds to end of March and April where snow begun to melt and thus to carry larger particles which resulted in an increase of turbidity and SS values.

Although this phenomena is not clear and visible in all the graphs, looking at the dataset it is possible to see an increase in turbidity and suspend solid values during the snow melt period in week 12 (sample from the 2011-03-24) and week 14 (sample from 2011-04-04). According to (Kirchmann et al., 2005), rather small macro-pore volume present in Vreta soil excludes the occurrence of preferential flow which might explain the low values of turbidity and SS.

It is also important to consider that reason behind some poor correlations associated with turbidity data measured in the laboratory may have been associated particle agglomeration in the sample container. Furthermore, standard glass fibre filters allow colloids and fine clay-sized material with high specific turbidity to pass through. Therefore the interpretation of turbidity data in terms of SS concentration can be precarious (Gippel, 1995).

Table 6 Clay content, pH, R-square and averages turbidity and SS values for each soil.

			Turbidity and SS		
SITE	**Clay %**	**pH**	**R^2**	**Turbidity(NTU)**	**SS**
Kungsängen	59	6,9	R^2 = 0,67	70,86	133
Bornsjön	60	6,6	R^2 = 0,69	29,31	78
Lanna	47	7,4	R^2 = 0,62	19,35	76
Ekebo	17	6,5	R^2 = 0,43	5,29	76
Vreta	50	6,7	R^2 = 0,26	10,21	65
Fjärdingslöv	19	7,5	R^2 = 0,004	5,19	50

Turbidity and TP

Linear regressions were performed also for each soil to evaluate relationship between turbidity and TP.

Figure 19 shows the two graphs based on data from lysimeter study from experimental field sites from Bornsjön and Lanna.

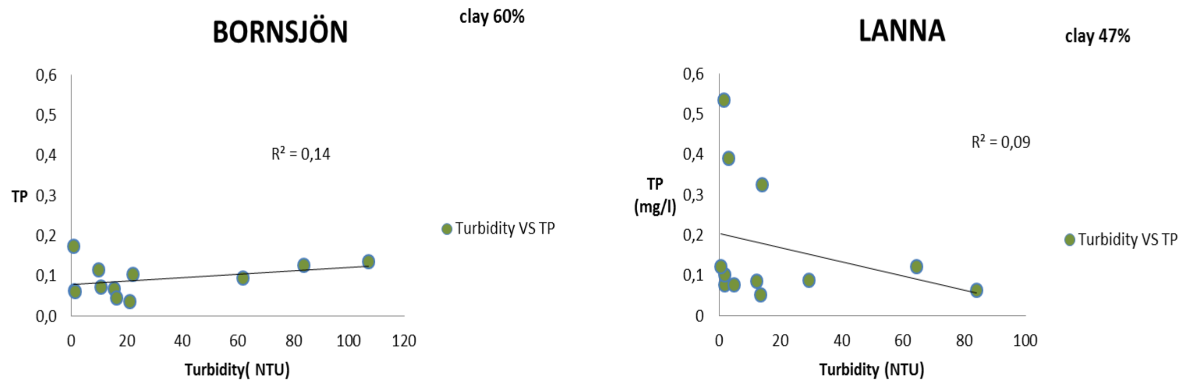

Figure 19 Scatter plots of soils from the Experimental field.

Bornsjön returned a small correlation of 0,14 with an homogenous distribution of sample, some of them having extremely low value of turbidity associated with high concentration of TP. As stated before, forms of P influence the correlation with turbidity; high concentration of DRP recorded for Bornsjön (0,05 mg/l), which is higher than PP (0,03 mg/l) cannot be associated with turbidity (Uusitalo et al., 2000).

Same situation occurred for Lanna soil where the even higher average concentration of DP 0,14 mg/l on the TP (0,17 mg/l) returned a negative correlation.

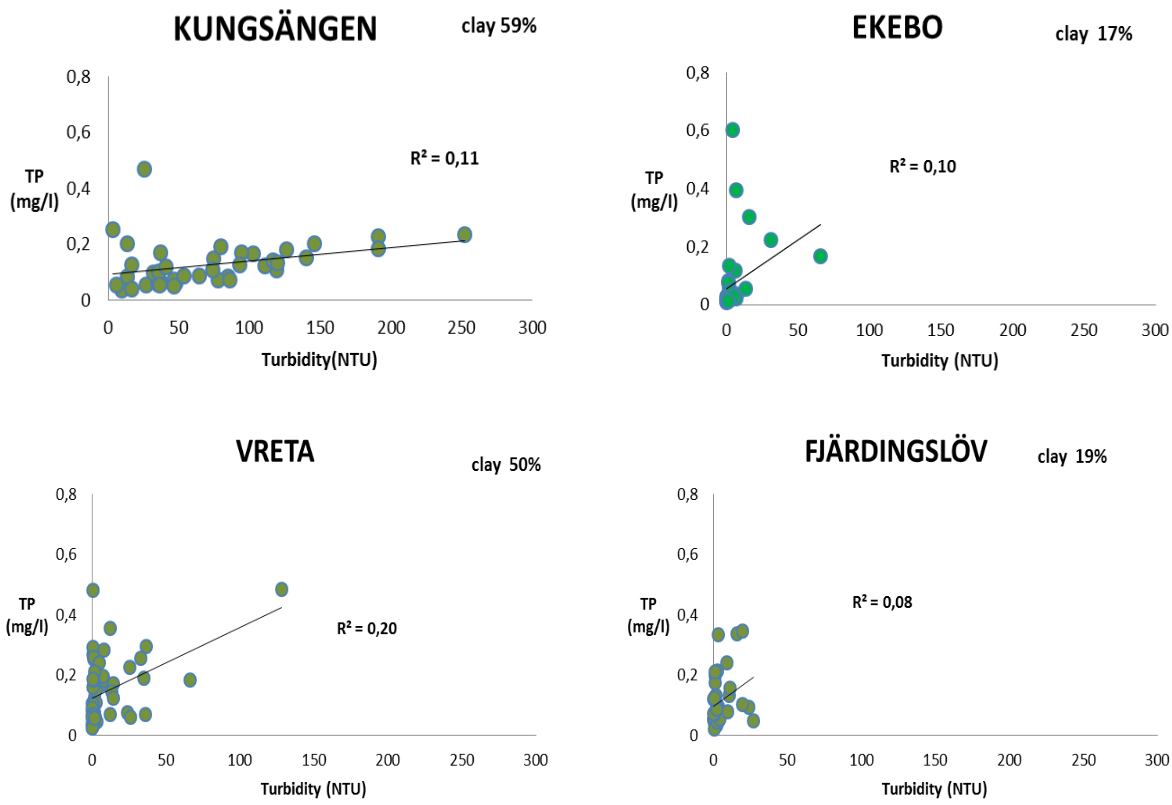

Figure 20 scatter plots of soils from the Swedish Long Term Fertility Experiment

In Figure 20 the scatter plots of the 4 soils from the Swedish long term fertility experiment are represented; Kungsängen shows a positive trend due the average amount of PP (0.06 mg/l) which is slightly higher than the concentration of DP (0.05 mg/l). Nevertheless, the r-square is low mainly due to the outline point with 0,468 mg/l. The highest value of turbidity 252 NTU related with the third largest concentration of TP (0,236mg/l) was recorded for this soil.

Even though the low P-AL in the topsoil (3,7), Kungsängen return high TP losses of 0,13 mg/l probably due to the fact that water and solute percolate quicker in the soil profile because of the presence of macro-pores, where short contact time between water and soil circumvent the P sorption capacity (Djodjic et al., 2004).

Ekebo samples do not show a visible trend and it also seems that the correlation is negative. There is a cluster between 0 and 10 NTU and 0 and 0,1 mg/l of total P and at higher values of P concentration are not associated with higher values of turbidity. Indeed, the largest value of turbidity (66 NTU) corresponds to 0,1666 mg/l of TP which is a relatively low concentration, furthermore water samples from Ekebo lysimeter have the lowest P concentration (0,07 mg/l) even though its P-AL in the top soil is one of the highest (6,7 mg P /100 g soil, table 1). This might be associated with small leachate volume of water, high sorption capacity and sub-soils properties observed in other studies (Djodjic et al., 2004).

Fjärdinglslöv 's plot presents similar characteristic with Ekebo, the r-square is lower and sample are evenly distributed without visible trends. In both soils the losses of TP are dominated by DP therefore relationship between turbidity and TP are not reliable. Fjärdinglslöv 's low P sorption (Börling et al., 2001) might explain the relatively high average losses of dissolved P; furthermore this could occur because of chemical and physical properties of soils such as smectite mineral in the subsoil which facilitate shrinkage, formation of cracks and thus reduction of P-sorption (Kirchmann et al., 1999).

Vreta yielded a r^2=0,20 and it has a large number of sample with consistent concentration of P associated with nearly void NTU and a cluster of values between 0 and 60 NTU and 0 and 0,3 mg/l, nevertheless there is not a significant trend in the distribution of sample.

Looking at the four plots the different clay content does not particularly affect TP losses, other properties discussed above and mentioned later on seem to be more important.

Turbidity and PP

Linear regression and therefore comparison of r^2 was performed also to evaluate relationship between turbidity and PP concentration.

Figure 21 shows the two plots from the experimental field soils at lysimeter scale Bornsjön and Lanna.

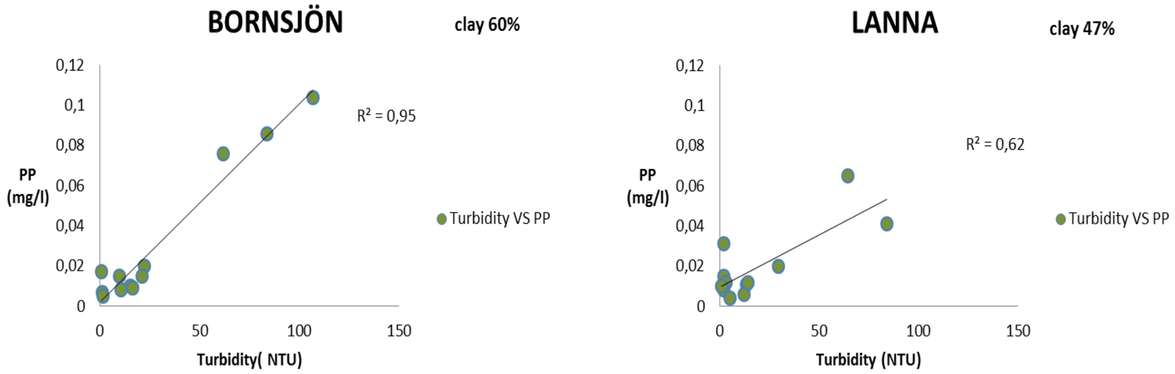

Figure 21 scatter plot of soils from the Experimental field

Bornsjön returns an high correlation (0,95) but values are not evenly distributed; two cluster are present, the first group does not exceed 10,7 NTU and 0,017 mg/l whereas the second formed by three sample has turbidity values which range between 61,9-107 NTU and PP concentration within 0,076-0,104 mg/l. Nevertheless the PP average concentration is 0,03 mg/l which is not a very high value (table 7).

Lanna shows a lower r^2 of 0,62; two cluster can be identified as well but with globally lower values than Bornsjön.

The lower cluster has PP concentration and turbidity between 0,004-0,015 mg/l and 0,6-29 NTU. The upper cluster reaches 84,2 NTU with PP of 0,041 mg/land 64,4 NTU with 0,065 mg/l. Although the correlation is one of the highest, the average PP concentration is one of the lowest (0,02 mg/l).

Figure 22 shows the correlation of the four soils from the Swedish long term fertility experiment.

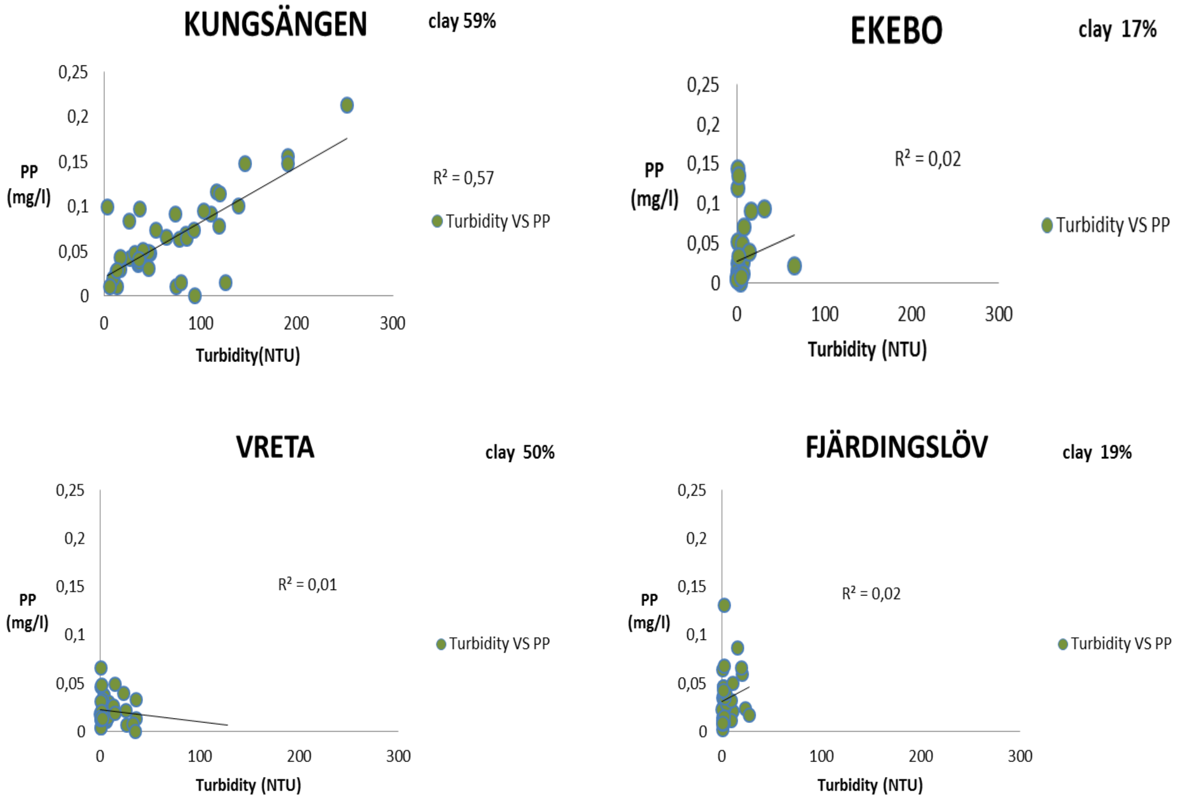

Figure 22 Scatter plots of soils from the Swedish Long Term Fertility Experiment

Table 7 Clay content, pH, R-square, P-AL and P concentration forms, Turbidity and SS averages values for correlation between PP and turbidity for each soil.

SAMPLE ID	CLAY %	pH	P-AL	TP (mg/l)	DRP (mg/l)	PP (mg/l)	r^2	TURBIDITY (NTU)	SS
Bornsjön	60	6,6	4,9	0,09	0,05	0,03	0,95	29,31	78
Kungsängen	59	6,9	3,7	0,13	0,05	0,06	0,57	70,86	133
Vreta	50	6,7	6,7	0,15	0,12	0,02	0,03	10,21	65
Lanna	47	7,4	7,5	0,17	0,14	0,02	0,62	19,35	76
Fjärdingslöv	19	7,5	3,3	0,12	0,09	0,04	0,02	5,19	50
Ekebo	17	6,5	6,7	0,07	0,05	0,03	0,02	5,29	76

Kungsängen returned the best correlation 0,57 and the largest values of PP (0,213 mg/l) and turbidity (252NTU). Furthermore it has the largest average PP concentration of 0,6 mg/l.

Observing the fractions of DRP and PP in table 7, this soil shows an even ratio which according to (Jensen et al., 2000) might be explained by the profile structure and presence of macro-pores and preferential flow through soil profile.

Schoumans (2002) for example states that preferential flow creates a flow of water with a low ionic strength through the soil, which can mobilize colloidal P forms.

Furthermore the total absence of calcium in the profile (Kirchmann, 1991) could explain the higher concentration of PP rather than dissolved P.

Considering the PP averages concentration (table 7), the highest one (0,06 mg/l) is recorded in Kungsängen samples, where also turbidity and SS have shown the highest values. According with the relatively good r^2 yielded (0,57), PP losses are related with the highest turbidity values recorded, similar observation are also stated in a study made by (Jones et al., 2011).

Ekebo and Fjärdingslöv on the other hand yielded the lowest r^2=0,02, but the turbidity values are low with one exception for Ekebo (66 NTU).

Concentrations of PP range between 0 and 0,09 mg/l whereas turbidity vary between 0,04 and 13,7 NTU.

Even though both of them have low average of turbidity Ekebo 5,29 NTU and Fjärdingslöv 5,19 NTU they have significant averages values of PP concentration respectively 0,03 and 0,04. Even though Bornsjön and Ekebo show, in table 7 the same ratio of PP and DP (0,05-0,03) which doesn´t different significantly ,the two soils have different properties.

Factors such as pH and chemical composition of soils influence partitioning of P forms.

According with Schoumans (2002), changes in pH have a large influence on the solid phase of the soil, since pH determines the surface charge of Fe/Al-hydroxides, the main sorption medium of P. An increase of the pH reduces the positive charge of hydroxides, and mobilizes anionic P-forms like ortho-P. Lanna soils for example has the highest concentration of dissolved P ratio which might be explained by the high pH (7,5), although this soil is also rich in Al and Fe.

In spite of its high clay content Vreta does not return a strong correlation, a cluster of values is clearly included between 36,5 NTU and 0,066 mg/l and only one sample shows a turbidity value (128 NTU) out of that range.

Vreta has the lowest PP concentrations (0,02 mg/l). According to table 7 Vreta has the second highest average DRP concentration standing for 80% of the total P concentration. The absence of preferential flow due to the rather small macro-pore volume, the presence of illite and vermiculite with both high concentration of Al and Fe and a pH range from 6,6 to 7,4 (Kirchmann et al., 2005) strongly influence PP losses and therefore partitioning of the two form. Hence, relying only on Vreta high clay content would lead to wrong conclusion regarding its vulnerability against losses of SS and PP.

Although all soils were exposed to the same condition and therefore same external input, it is possible to see differences in P concentrations in water samples, especially in the distribution of P forms (PP and DRP). Looking at the averages it is noticeable that DRP constitutes the larger form of P in leachate, conclusion also found previously by Djodjic et al. (2004).

Furthermore each soil has a different P soil concentration which clearly influences total P found in water samples.

Relation between turbidity and TP/PP at different P-levels

Total P and PP obtained from the four Swedish soils were studied in relation with suspended solid where even four soil P levels and fertilizer application strategies described previously were considered. It was expected to see differences in the P leached from different P levels.

Previous studies (Williams & Saunders, 1956; Sharpley & Syers, 1976; Sharpley, 1980) focused on finding relation between enrichment ratios of P in soils subjected to different addition of P. They concluded that large amount of P might be leached even though there are no additional applications, most likely because the clay fraction is enriched in native inorganic and organic P.

Looking at the averages of P concentrations in table 8, only Fiärdingslöv has the lowest TP concentration in level A and larger amount in the levels C and D which was also found by Djodjic et al. (2004). Here the higher soil P levels resulted in higher P concentrations. Other three sites do not show this patter which was explained by the fact that subsoil in this deep lysimeter (1 m) is more important than the soil P content in the topsoil.

Ekebo instead has the largest concentration found in level A 0,12 mg/l and a decrease in P in C level (0,05 mg/l) and slightly larger (0,06 mg/l) in D. The associated SS value for Ekebo follow the same trend, the largest concentrations in level A (84), a decrease in C (71) and a small increase in D (73). For Vreta soil, TP and SS concentrations are higher in level C, whereas B level has the second highest SS concentration (67) but the lowest losses of P leachate (0,10 mg/l).

Kungsängen shows the highest concentration of P in the D level but at the same time the second highest at A level.

Furthermore Vreta and Kungsängen have the same TP concentrations in level A which is 0,14 mg/l but Vreta has half of Kungsängen's SS concentration meaning in this case that relatively large losses of P can occur even with low SS losses.

Sharpley (1985) stated that "the enrichment ratio of particles in runoff could be predicted by the amount of SS transported" .

Considering that this study was performed at lysimeter scale, the results in table 8 partly agree with Sharpley's study. The largest SS averages values are mostly associated with largest percentage of PP found in the water samples.

Kungsängen and Ekebo has the largest SS concentrations, respectively 145 and 84 mg/l, associated with the largest losses of PP, 84% and 45%, which occurred in level A rather than level D.

Vreta has the largest SS concentration in level C but the highest percentage of PP in level B, obviously the relatively high difference between leachate influence this relation (0,10 mg/l level B and 0,20 in level C).

However, Kungsängen, Ekebo and Fjärdinglsöv have the highest amount of PP leachate in the A level treatment which does not imply any P application.

Therefore regarding P leaching, the subsoil's ability to retain P, which is influenced by chemical and physical properties, might be more important than P content in the topsoil (Djodjic et al., 2004).

Table 8 Averages values of suspended solid and related TP concentration and PP percentage at A, B, C and D level of P application.

	SS (mg/l)				**TP (mg/l)**				**PP (%)**			
P-application	A	B	C	D	A	B	C	D	A	B	C	D
Kungsängen	145	135	117	135	0,14	0,12	0,08	0,17	84	59	65	30
Ekebo	84		71	73	0,12		0,05	0,06	45		44	30
Vreta	63	67	70	59	0,14	0,10	0,20	0,15	13	17	13	8
Fjärdingslöv	49	51	46	54	0,06	0,10	0,16	0,15	97	35	25	23

Conclusion

Turbidity is a straightforward and cheap method to estimate quality of water sample. However according with the result obtained, it cannot be considered an absolute measure because relation are strongly influenced by the many confounding effects present in the natural soils-water systems.

The results suggested that between values of 30 NTU and 250 NTU SS is relatively well associated with turbidity. Low values of turbidity are globally difficult to interpret, being associated with both high and low SS concentrations. On the other hand a dispersion of SS generally occurred at high values, above 250 NTU.

Bornsjön, Lanna and Kungsängen returned the best correlations in term of turbidity/SS reliability, nevertheless other soils with similar properties did not show the same results.

Physical and chemical parameter of soil such as structure, mineral composition, organic matter content and pH need to be accurately known in order to totally understand turbidity and associated SS values.

Differences in water flow through the soil profile due to chemical and physical properties resulted to strongly influence the amount of SS and associated P.

Significant relations between turbidity and P-levels in soils were not found; this implies a considerable influence of the sub-soil processes and characteristic which affect P leaching.

However larger dataset and long term analysis on flow rates were not available. Further analysis such as particles size distribution, which has been reported to strongly influence result of turbidity, would be necessary to clarify the results obtained.

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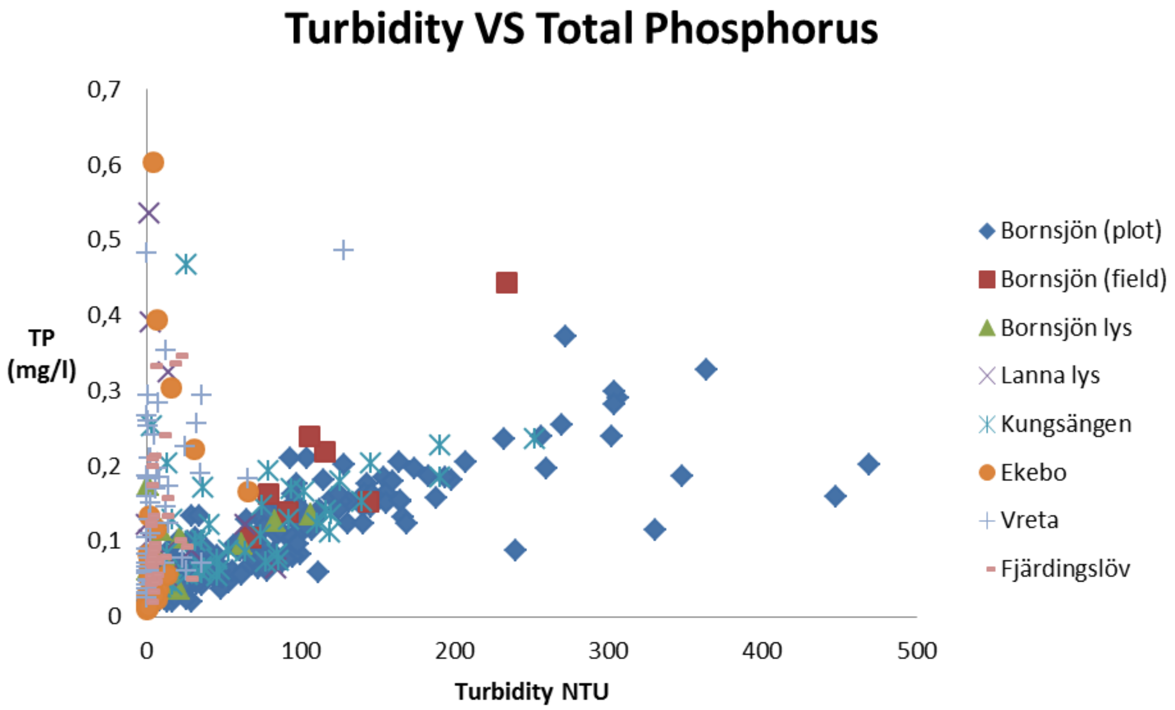
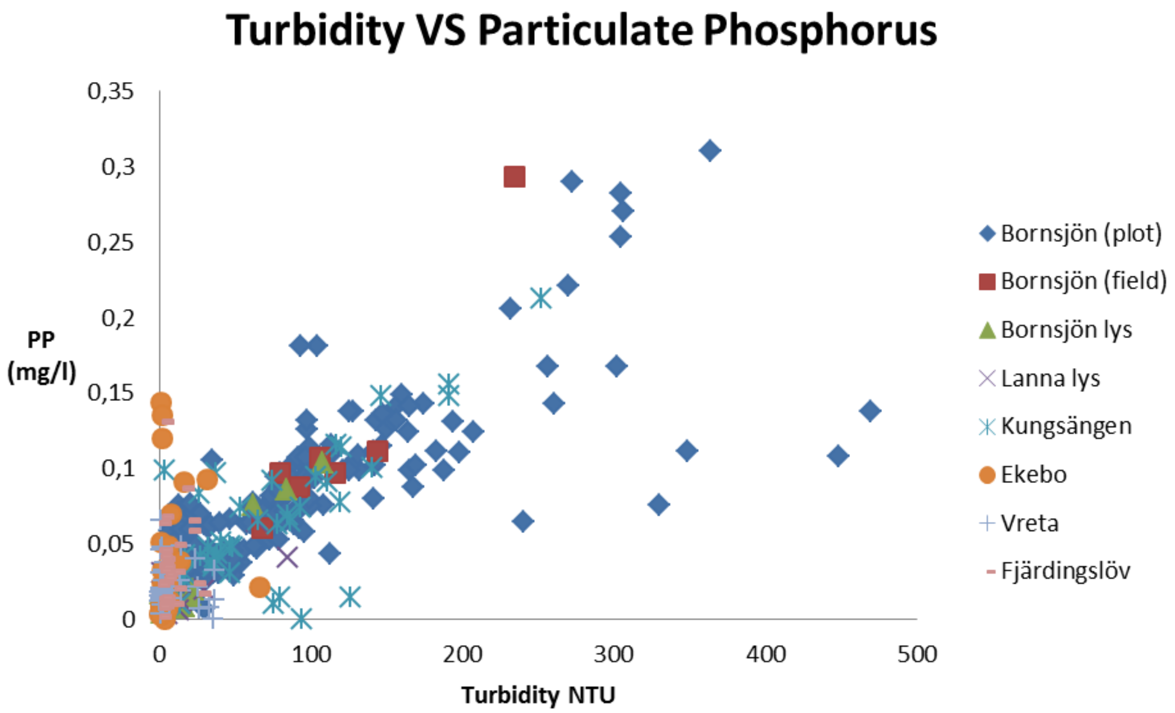
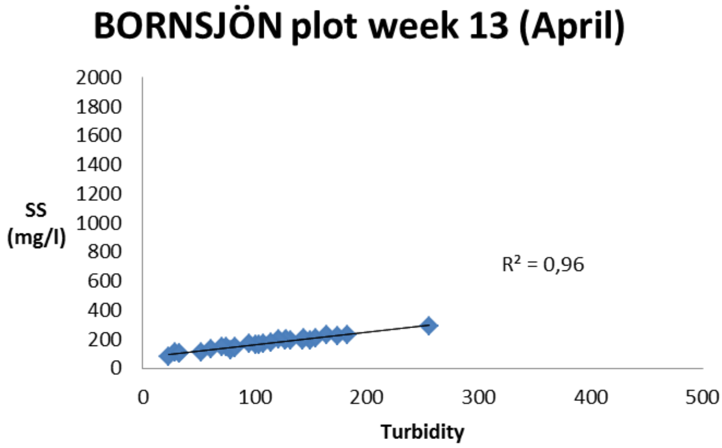
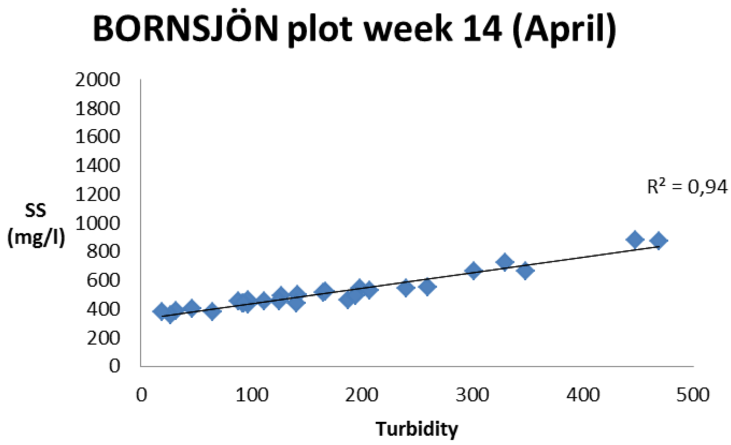
Appendix A

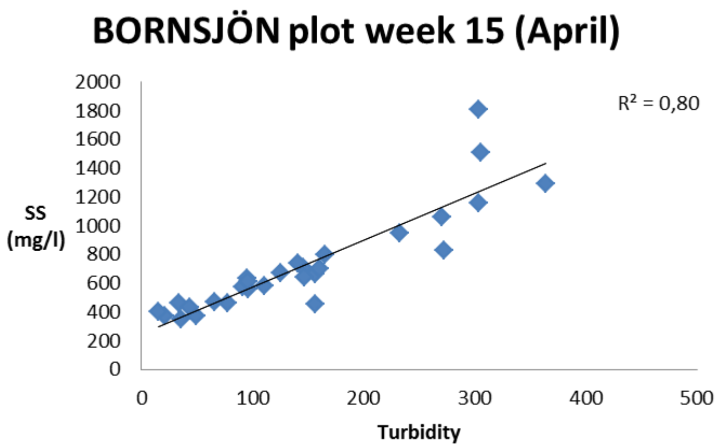

Turbidity VS Total Phosphorus
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
TP (mg/l)
0
100
200
300
400
500
Turbidity NTU
Bornsjön (plot)
Bornsjön (field)
Bornsjön lys
Lanna lys
Kungsängen
Ekebo
Vreta
Fjärdingslöv


Turbidity VS Particulate Phosphorus
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
PP (mg/l)
0
100
200
300
400
500
Turbidity NTU
Bornsjön (plot)
Bornsjön (field)
Bornsjön lys
Lanna lys
Kungsängen
Ekebo
Vreta
Fjärdingslöv

Appendix B


BORNSJÖN plot week 13 (April)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
SS (mg/l)
R² = 0,96
0
100
200
300
400
500
Turbidity


BORNSJÖN plot week 14 (April)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
SS (mg/l)
R² = 0,94
0
100
200
300
400
500
Turbidity


BORNSJÖN plot week 15 (April)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
SS (mg/l)
R² = 0,80
0
100
200
300
400
500
Turbidity

Appendix C

week	TURBIDITY(NTU)	FIRST FILTER WEIGHT(mg)	AFTER FILTER WEIGHT(mg)	VOLUME(ml)	SS	DISCHARGE(mm)	DRP(mg/l)	TP (mg/l)	PP (mg/l)
Week 3	79	74	82,7	50	174	6,4	0,042	0,162	0,097
Week 4	116	81,2	90,6	50	188	25,4	0,071	0,219	0,097
week 5	144	78,9	88,2	50	186	3,5	0,033	0,153	0,112
week 6	67,5	81,4	89	50	152	5,6	0,024	0,105	0,061
week 13	106	79,2	85,2	25	240	55,2	0,111	0,239	0,107
week 14	234	81,2	86,7	10	550	23,9	0,110	0,444	0,293
week 16	92	80,6	86,4	10	580	4,5	0,039	0,139	0,088
AVERAGES	119,8				296	18	0,06	0,21	0,12