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Analysing temporal and spatial variations in DOC concentrations in Scanian lakes and streams, using GIS and Remote Sensing

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Abstract

During the last two decades the watercolour have increased dramatically in southern Sweden. The watercolour is manly determined by the DOC (Dissolved Organic Carbon) concentration. DOC affects the raw water quality, and because of the increasing trends, the cost for producing drinking water of high quality has risen considerably. It is therefore of great interest for society to understand what will happen with the DOC concentrations in the future and to be able to point out lakes that are in he risk zone of experiencing higher watercolour.

This study takes a catchment-scale approach, trying to explain both spatial and temporal variations in DOC concentrations. This is done by correlation analysis using different map parameters such as land-use and stream length. Second, possible factors driving the increase in DOC concentrations are examined, focusing on land-use change.

The results shows that in the 15 lakes and streams investigated, the watercolour has increased with an average of 3 % per year during the period 1983-2005. Size of catchment area, slope and land-use proved to be insufficient predictors of both present day and yearly increase in watercolour. Instead water pathways (expressed as Drainage Density$_{fm}$) proved to be the best predictor. Land-use change can most likely not be the driving factor behind the increase in watercolour. Instead, recovery from acidification was correlated to watercolour and could well be the driving factor. In the future, changes in precipitation patterns can lead to an increased leakage of DOC from soils.

Sammanfattning

Under de två senaste decennierna har vattenfärgen ökat dramatiskt i södra Sverige. Vattenfärgen bestäms främst av koncentrationen av humuspartiklar. Humus påverkar råvattenkvalitén och kostnaden för att producera dricksvatten har ökat markant p.g.a. de ökande humushalterna. Det är därför av stort intresse för samhället att kartlägga vad som kommer hända med DOC koncentrationerna i framtiden och peka ut sjöar som är i riskzonen för ökande vattenfärg.

I den här studien analyseras både spatiala och temporal variationer i DOC koncentrationer. Detta görs genom korrelationsanalyser mellan olika kartparametrar och vattenfärgsvärden. Möjliga förklaringar till vad som kan vara den drivande faktorn bakom vattenfärgsökningen undersöks, med fokus på förändrad markanvändning.

Resultaten visar på att i de 15 sjöar och vattendrag som undersökts har vattenfärgen ökat med i genomsnitt 3 % per år under perioden 1983-2005. Storlek på avrinningsområdet, lutning samt markanvändning visade sig ha låg förklaringsgrad, både vad gäller årlig ökning i vattenfärg samt aktuell vattenfärg. Istället visade sig vattnets flödesvägar i avrinningsområdet (utryckt som Drainage $\text{Density}_{\text{fm}}$) ha den bästa förklaringsfaktorn. Detta resultat visar på att dikning av skog- och myrmark starkt påverkar vattenkvaliteten, vilket är vikigt att ta hänsyn till vid framtida rensningar och dikningar

Förändrad markanvändning, från öppen mark till skogsmark, kan med störst sannolikhet inte vara den drivande faktorn bakom vattenfärgsökningen. Dock har andelen skogsmark ökat och kan väl ha bidragit till en del av ökningen i vattenfärg. Istället verkar minskat svavelnedfall vara den faktor som driver förändringen, detta genom att göra DOC - partiklarna mer lättrörliga och på så sätt öka läckaget. Den stora ökning i vattenfärg som observerats kanske är en ”ursköljningsprocess” av kol som varit starkare bundet när svavelnedfallet var högre. Resultaten visar också på förändringar i vattnets ursprung mellan 1980- och 2000 talet, med ett större inslag av regnvatten. Orsaken till detta skulle kunna vara ökad nederbörd eller förändrade nederbördsmönster, men också djupare och/eller fler dikningar i skog och myrmark. Framtida klimatförändringar spår både ökade nederbördsmängder och förändringar i nederbördsmönster, något som kan leda till ökat läckage av DOC till sjöar och vattendrag.

1. Introduction

There is overwhelming evidence that the watercolour has increased during the last two decades across Europe and North America (Evans 2004). The same trend is observed in southern Sweden (Lövgren 2003). The average watercolour in Sweden has increased with ~3% each year during the two last decades (SLU). The watercolour is mainly determined by the content of humic substances (the Swedish Environmental Protection Agency 1999), which originate mainly from decomposition of organisms, mostly decaying plants. Humic substances absorb light, giving water rich in humus a high watercolour (Evans 2004).

In Sweden approximately 25% of the people receive their drinking water from groundwater, 25 % from artificial filtration of surface water, and 50 % gets their water from lakes and streams (Lövgren 2003). The main difference between groundwater and surface water is their variation in humic substances. Groundwater contains very low values while surface water exhibits large variations both in time and space (Thurman 1985). Humic substances create huge problems for water treatment plants trying to produce drinking water of high quality. Since humic substances is a source of energy for micro organisms it can contribute to bacterial growth in the water distribution systems, causing diseases and giving the water bad taste and odour (Lövgren 2003). Humus and added chlorine can form chlor-organic compounds that are very carcinogenic (Sibelle 1988). The increase in watercolour means that the cost for producing drinking water of a high quality has risen dramatically. Some municipalities even evaluate the possibility of switching to other water supplies with better quality, e.g. ground water supplies or other surface water supplies with lower humic content. Because of this it is of great interest for society to understand weather the humus concentrations will continue to raise, level out or return to more acceptable values (Lövgren 2003). It is also interesting to identify lakes that can be experiencing increasing humic content in the future (SLU a)

According to the EUs water framework directive (established in 2000) all surface waters shall have a “good ecological status” in the year of 2015. Organic matter influences almost every process in the aquatic environment (Thurman 1985). Since it plays a significant role in aquatic food webs, transports of nutrients and metals, and modifies the optical properties of water bodies (Findlay and Sinsabaugh 2003) it is of great interest to understand why the watercolour increases. There are many theoretical hypotheses on these trends. The three hypotheses examined in this work can be summed to three major areas; a) changes in land-use (LUSTRA 2002), b) climate related changes such as precipitation and temperature (Neal et al., 2005) and c) recovery from acidification (Evans et al. 2006).

1.1 Aim

Inland water functioning is tightly linked to the characteristics of their catchment areas (Kalff 2002). This study will take a catchment scale approach; first trying to explain spatial variations, and second temporal variations in watercolour.

This thesis aims to give the answer to the following questions:

1. Is the increase in watercolour for the data used in this work of the same magnitude as reported in literature?
2. How accurate is a catchment area modelled using a DEM (Digital Elevation Model) compared to drawing it using the topographic map?
3. Which map parameter can best explain the spatial and temporal variation in watercolour?
4. Can land-use change be the driving factor behind the increased watercolour?
5. Can changes in precipitation, sulphur deposition or changes in water origin explain the increased watercolour?

2. Theoretical background

2.1 What is watercolour?

Total Organic Carbon (TOC) is the sum of all organic carbon species found in water, from methane to larger and more complex humic substances. TOC can be divided into Particulate (POC) and Dissolved Organic Carbon (DOC) by filtration through a 0.45 µm net. The majority of the DOC are polymeric organic acids, also called humic substances (Thurman 1985)**.** Humic substances absorb visible light, most strongly at the blue end of the spectrum, thus giving waters rich in DOC a characteristic brown colour (Evans 2004).

2.2 How is watercolour measured?

The most common method to measure watercolour is based on a visual comparison between the water sample and a solution containing Potassium Hexachloroplatinate (K_2PtCl_2 unit mg Pt L^{-1}) (Brönmark and Hansson, 2005). The method used for the data in this work is based on absorbance measurements. The measurements are made at the wavelength 420 nm in a 5 cm cuvette on filtrated water (0.45 µm) (SLU b). This method is supposed to be a measure of humic substances, but the absorbance measurements can be influenced by several other factors, such as; ionic strength, pH, light scattering and the presence of other light absorbing substances, mainly iron/ manganese-oxides and nitrate (Temnerud 2005). Since iron (and most other metals) bond with dissolved organic molecules (Kalff 2002) an increase in DOC content will lead to an increase in iron (and other metals). How much these other factors influence the absorbance values is not well known and it falls outside the aim of this work. However, according to the Swedish Environmental Protection Agency (report 4913, 1999) a high humic content gives higher absorbance. In the report they also conclude that absorbance measurements are an objective and more accurate method than the one based on visual comparison. Throughout this work it is supposed that a higher DOC/humic- content gives a higher absorbance and thereby higher water colour.

2.3 Where does DOC come from?

DOC is generated by the partial decomposition of, or exudation from, organisms (Evans et al 2004). The DOC produced in the lake or stream is referred to as autochthonous sources, and DOC produced outside the lake or stream is referred to as allochthonous sources. The major of the DOC in streams and small to moderate-size rivers comes from allochthonous sources (Thurman 1985).

The allochthonous sources can mainly be divided into two categories, organic matter from soils and organic matter from plants. The organic matter from soil has decomposed for a longer time and is of older age than the organic matter from plants

(Thurman 1985). Radiocarbon studies have shown that most of the DOC in streams and lakes is derived from material of much younger age than the organic soil material. This means that most of the DOC in lakes and streams is derived from resent terrestrial primary production. Leaching from fresh deciduous litter may explain the seasonality in the concentration of DOC in discharge from forested catchments. This because deciduous leaf litter imparts high DOC concentrations in the autumn, while coniferous litter and organic soils release DOC more evenly. (Hongve 1999).

The organic carbon content is highest in the upper soil layers and decreases with depth. The O-horizon consists of ~ 20 % organic carbon and the C-horizon less than 2 %. Interstitial water (water between pores) easily solubilize organic matter from the litter layer (O-horizon). The organic matter dissolved is mostly DOC originating from decaying processes of plants and soil. The interstitial water carries the DOC into the A and B-horizons. Because of adsorption and decaying processes in soil, the content of DOC in interstitial water decreases with depth (Figure 1) (Thurman 1985). This gives a sharp attenuation of DOC as water moves from upper soil horizons to lower soil horizons and in to the saturated zone (Cronan and Aiken 1984). This means that water transported only through the upper soil layers have a higher concentration of DOC, compared to water transported further down in soil.

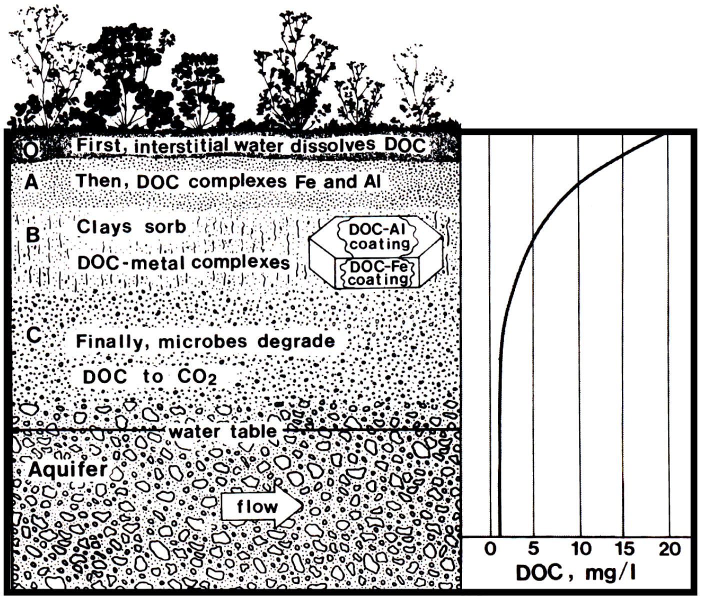

Figure 1. The DOC content of interstitial water decreases rapidly with depth. This is due to low decreasing carbon content as well as adsorption and degradation process in soil (From Thurman 1985).

2.4 The magnitude of carbon exported from catchments

On a global scale, one percent of terrestrial NEP (Net Ecosystem Production) is exported to rivers and lakes (Kalff 2002). According to Worral et al. (2006) the leakage from a catchment area mostly covered by peat can range between 4.0 to 7.0 g C m^{-2} yr^{-1}. Lövgren (2003) reported values between 1 to 20 g C m^{-2} yr^{-1} for alpine and boreal catchments in the Nordic region.

It is mostly the concentration of humic substances that relegate the emission of CO_2 from lakes (Vetenskapsrådet), thereby would an increase in DOC concentrations give an increase in the amount of CO_2 evaded from lakes and streams. Dillon and Mollot (1997) compared their catchment export rates with NEP for American forests (data from Edwards et al.1981; Whittaker et al. 1979). By doing this they estimated that up to 5 % of NEP from a forest can be returned to the atmosphere as CO_2 through lake evasion. Jonsson et al. (2006) investigated the export of terrestrially fixed carbon to aquatic systems in a boreal catchment in northern Sweden. They concluded that approximately 3 % of the terrestrial NEE (Net Ecosystem Exchange) is evaded as CO_2 in lakes and streams.

2.5 Parameters effecting watercolour

Several possible explanations on factors in a catchment area that cause high water colour have been discussed. Among these, the following factors have been investigated in this work:

Land-use: The Land-use in the catchment area is often used to explain DOC concentrations in lakes and streams. According to Lövgren et al. (2003) high humus concentrations is found in catchments with large soil pools of carbon, such as peat and frosted areas, and short water retention times. According to Dillon and Mollot (1997), the percentage of peat coverage in a catchment area is positively correlated to the DOC concentrations. This is because DOC is probably readily leached from peat lands because of the persistent moisture saturation, and the high carbon content (Kalff 2003).

Drainage Density: By summarizing the total length of streams in a catchment area and dividing it by the size of catchment area, the drainage density is calculated. A low drainage density means that a particle has to travel further to reach a stream before it can be exported (Kalff 2003). Or expressed in another way, drainage density gives a measure of the average lateral flow path length through soil to the stream network (Dahlström 2005). A long flow path would mean that the water floats at lower depths in soil, and DOC will then be adsorbed and the concentration of DOC in water will decrease (according to the theory discussed in section 2.3). This argument is in line with the work of Hope et al. (1994) where they suggest that concentrations of DOC in stream water are usually strongly linked to catchment hydrological pathways. Hongve (1999) argues that the water pathways through the soil probably are the most important factor determining the DOC concentrations in lakes and streams.

Slope and size of catchment area: The slope of the catchment area is usually correlated to the amount particles exported. If a catchment area has a high average slope, particles (in this case DOC) leave land at higher rate per unit area. A small catchment area usually has a higher average slope (Kalff 2001).

2.6 Possible factors driving the increase

The cause of the increase in watercolour has been discussed widely in the literature. Roulet and Moore (2006) concludes that the increasing trends in DOC concentrations has to do with either an increase in net DOC production in terrestrial ecosystems, or increases in leaching of DOC. This study focuses on three explanations on why the watercolour increases:

Land- use change: Planting forest on agricultural land increases the humic content in the upper part of the soil (LUSTRA 2002); this would lead to an increase in DOC exported to lakes and streams. During the last decades there has been an observed increase of carbon content in the upper soil parts (Vetenskapsrådet), this raises the question whether the increased forest production can be coupled to the increasing absorbance values.

Precipitation: Long-term increases in precipitation will raise the groundwater level so it comes in contact with the organic soils and transports DOC to lakes and streams. (Lövgren et al. 2003). An increase in stream discharge gives an increase in DOC concentrations, due to a “flushing effect” in the upper soil layers (Hope et al. 1994).

Recovery from acidification: Today, the average sulphur deposition in Sweden has decreased to approximately one third of the levels in 1988 (SLU 2007). DOC solubility is suppressed by high soil water acidity and ionic strength. Thereby would a decline in sulphur deposition lead to increased release of DOC from soils (Evans et al. 2006).

3. Method

The method can be divided into five main steps. 1) Compilation of absorbance data for 15 different test points, 2) generating of catchment areas for the fifteen test points, 3) quantification of land-use and other map parameters in the catchment areas, 4) interpretation of aerial photographs to test if land-use change can be the driving factor behind the increased watercolour and 5) test other possible explanations of what can be the driving factor behind the increased watercolour (Figure 2).

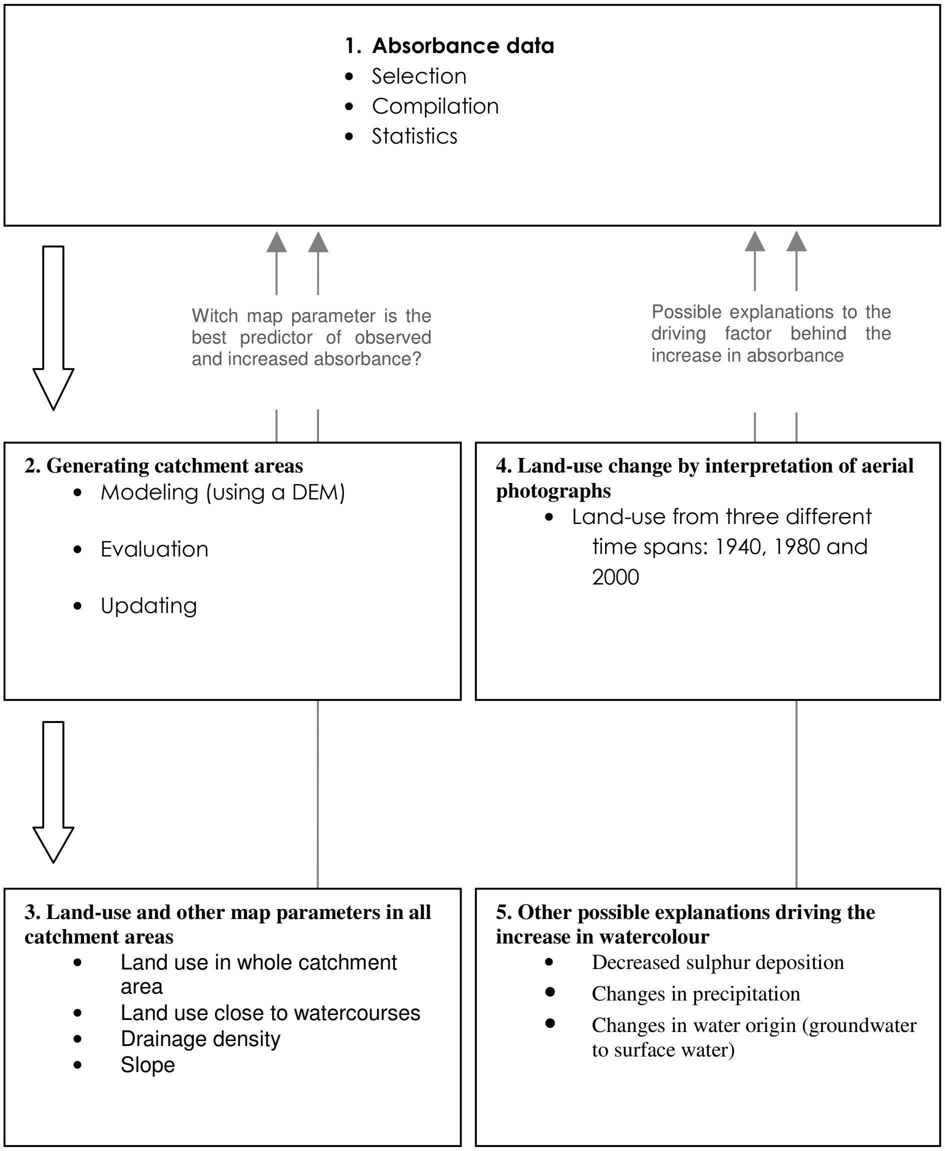

Figure 2. Conceptual model of the general steps used in the method.

3.1 Absorbance and water chemistry data

SLU (Sveriges lantbruksuniversitet) has a commission from the Swedish government to run continuous environmental analysis, as a part of the National and Regional environmental surveillance. The commission is divided into ten different areas; of witch lakes and streams is one. This part of the program aims to follow variations between years and changes over time. The test points selected for the program are a representative (for Sweden) selection of lakes and streams that are not directly affected by emissions or intensive land-use. The result is to be used as a reference in comparison with more affected lakes and streams. All water chemical data used in this work (absorbance, chlorine (Cl^-), calcium (Ca^{2+}) and conductivity) is downloaded from the SLU website (http://www.ma.slu.se/).

3.1.1 Selection of lakes and streams

In Scania there are over 100 test points included in the environmental analyses. Not all of these were examined in this work. To be used in this work the test points had to fulfil the following criteria's.

- Since the main objective of the work is focusing of explaining temporal change based on spatial parameters the test points had to have time series longer than 15 years.
- Since this work is done in cooperating with the County Administrative board of Scania, and since the data used for land-use and map parameters only covers Scania the catchment area for the lake/stream had to be inside (or close to) the Scanian borders.

These criteria's gave a total of 15 test points, 8 lakes and 7 streams. (Figure 3)

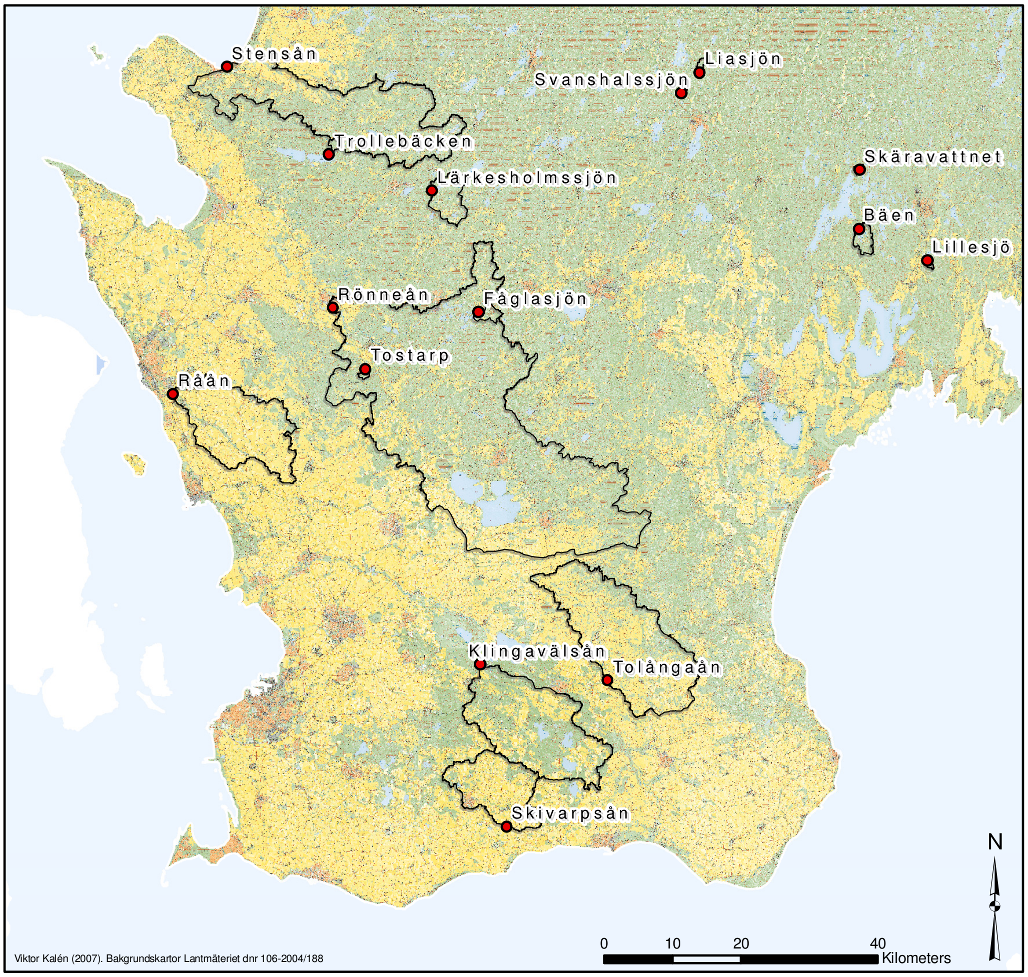

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Figure 3. The 15 test points and their catchment areas (for method generating catchment areas, see section 3.2).

3.1.2 Compilation and statistics for absorbance values

The downloaded measurements of absorbance for the 15 different test points where taken at a depth varying between 0.5-2.3 meters and measured between and 4-12 times per year (evenly distributed over the year). In this work, the first step was to calculate an average absorbance value for each year and test point. Out of the average absorbance per year, three different values for absorbance were created:

- **Initial value** was calculated as average absorbance for the period 1984-1989, (except for the test points Trollebäcken and Tostarpsbäcken where, the average was calculated for the period 1989-1994, due to shorter time series).
- **Present day absorbance** was calculated as average absorbance for the period 2000-2005.
- **Yearly increase** was calculated by correlation analysis (Pearson's correlation coefficient). If the test point had a significant ($p < 0.05$) change in yearly absorbance during the years 1984-2005, the slope of the line was assumed to be the yearly change in absorbance value. If it had no significant increase ($p > 0.05$) the yearly change was set as 0.

3.2 Generating the catchment areas

The catchment area of a lake or a stream is defined as the land area that drains towards the limnic system (Kalff 2002). It is possible to model a catchment area by using a DEM (Digital Elevation Model). In order to separate the different steps in the catchment area processes, the catchment area created just using the DEM is referred to as a *modelled* catchment area. After evaluating and updating, it is referred to as a *generated* catchment area.

3.2.1 Modelling the catchment areas

A DEM is a raster representation of a continuous surface, were every cell represents an elevation value (Eklundh 2000). In this work a DEM was used with a resolution of 50*50 m, (the average geometric accuracy in z-led is at most 2.5 m, LMV GSD-höjddata), and the program ArcGIS 9.1, with the extension ArcHydro Tools, was used to model the catchment areas.

The theory of modelling catchment areas using a DEM is based on calculating the flow direction. The flow direction is the direction that water, due to gravitation, is spread through a non-permeable surface (Eklundh 2000). The algorithm used in the program assumes that the water in one cell only can flow in one direction, which is the adjacent cell with the lowest elevation value. By summarizing all the cells draining to one specific cell, the catchment area of that specific cell is defined.

3.2.2 Evaluation and updating of the catchment areas

To evaluate how accurate the modelled catchment areas where, the modelled result from the test point Lake Liasjön was compared to the same catchment area drawn from the topographic map (scale 1:50 000). The drawing was made by Anna Hagerberg at the County Administrative Board of Scania, and the result was seen as the “true” catchment area of Lake Liasjön. The information used from the topographic map was primarily the height from contour lines, but also the location and drainage direction of wetlands, small waters and streams.

The information of drainage direction of wetlands and flow directions of streams gave additional information that could not be modelled only using the DEM as input (see results, section 4.2). To get the catchment areas as correct as possible these parameters had to be taken into account. Thereby, the modelled catchment areas had to be controlled and sometimes adjusted. As a help with controlling and updating the catchment areas, borders from SMHIs sub catchments were used. The modelled areas where controlled and adjusted by controlling each line segment by the following process:

- If the line segments of the modelled result agreed with SMHIs boundaries, and if there were no obvious errors (e.g. streams running across the border of the catchment area), the line segments were accepted as correct modelled.
- If the line segments of the modelled result where close to SMHIs borders, a comparison was made with the topographic map, to see if the modelled result or SMHI had the best fit.
- Most of the time the line segment were far away from the SMHI boarders. In these cases the catchment areas were compared to the topographic map. If there where no obvious errors, the line segments were classed as correct modelled.

3.3 Map parameters in the catchment areas

Three different main groups of map parameters were created for correlation analysis with absorbance values; these where Land-Use, Drainage Density and Size/Slope.

3.3.1 Description of land-use data (SMD-data)

To quantify the land-use in all the 15 catchment areas, SMD-data (Svensk Marktäckedata) was used. This is a database containing national land cover and land use data that is based on EUs classification system for CORINE Land Cover. The difference between CORINE-data and SMD-data is that the SMD database is suited for Swedish conditions and land cover (total 57 classes). The main data source for the database is multispectral satellite images (Landsat TM) and therefore the geometric resolution of the database is 25*25 m. The thematic accuracy for the SMD-data is 75 % and the geometric accuracy is 25 m (one pixel). The database is produced in the reference system RT90, and produced raster data and then converted to vector data, which is used in this project (LMV-produktspecifikation).

3.3.2 Land use in all 15 catchment areas

The SMD-database was clipped according to the borders of the catchment areas. In order to make comparisons easier, the 57 different land-cover classes were merged and combined in different ways (e.g. coniferous forest of different height were merged to just coniferous forest). In this way 5 different land-use classes and 5 land-use groups were created for correlation analysis with absorbance values (Table 1). The selection and combination of classes were made based on the hypothesis that it is forested areas and/or areas covered by mire that influences the watercolour. The total area for each land-use class and land-use group in each catchment area was calculated in ArcGIS 9.1. and the percentage for the different land-use classes was calculated.

Table 1 The 10 different land-use classes created from the SMD data for correlation analysis with absorbance value.

Land-se classes	Coniferous forest
	Mixed forest
	Deciduous forest
	Clear-cut
	Lake area
Land-se groups	Mire (inclusive forest on mire)
	Mire + wetland + peat
	Total Forest (inclusive clear-cut)
	Total Forest (inclusive clear-cut) + mire
	Coniferous forest + mire + clear-cut

3.2.3 Land use in the near- and surrounding of streams and watercourses

According to Bishop (1994) the riparian zones has a large impact on the DOC concentrations. To test if the land-use close to lakes and streams has bigger influence on the watercolour then the land-use in the whole catchment, two buffer zones (for each catchment) were created with the distance of 0-30 m respective 0-200 m from streams and water courses (zone definition according to Halldén et al. 2000). Two GIS-layers where used to create the buffer zones; one containing digitized streams (lines) and one containing digitized lakes (polygons). Both layers are digitised from the Swedish economic map, scale 1:10000 (LMV GSD). Not all lakes were used to create the buffer zones; the water in lakes and small water bodies that are not connected to the stream system will probably not reach the stream system as surface water, instead it will percolate down to the groundwater which means that DOC will be absorbed before reaching the stream network (see section 2.3). Because of this, lakes without a line segment within 30 m from the stream network were excluded before creating the buffer zone.

The SMD-data was clipped according to the buffer-zones. The total area for each land-use class in the buffer-zones and catchment area was calculated in ArcGIS 9.1 and the percentage for the different land-use classes was calculated.

3.2.4 Drainage density

Drainage density is the total length of streams divided by size of catchment area (unit m/km^2). Drainage Density was calculated by using a database containing all streams in Scania (LMV GSD). This database only included streams with a width < 6 meters. Because of this, streams wider than 6 meters had to be digitised from the economic map. Two different measures of drainage density where calculated; Total Drainage Density and Drainage Density$_{fm}$, which is drainage density for streams running through forest and mire. A catchment area with a high percentage forest and mires will, in most cases, get a higher Drainage Density $_{fm}$ and this value can be considered as a combination of Drainage Density and land-use.

3.2.5 Slope

The slope was calculated in ArcGIS 9.1 using a DEM (described in section 3.2.1). The slope is defined as the maximum change between each cell and its neighbours. This gives each cell a slope value; a cell with a low slope value has a flat terrain. Two different measurements of slope were created; 1) average slope calculated for all cells in each of the 15 catchment areas, and 2) average slope for all cells covered by forest in each of the 15 catchment areas.

3.2.6 Statistical analysis – map parameters

The land-use classes generated from the SMD-data were tested for correlations with absorbance value. Both yearly increase in absorbance and present day absorbance value were tested. The same was done for the other map parameters; Size of catchment area, average Slope in catchment area, average Slope in forested areas, Drainage Density and Drainage Density$_{fm}$. This gives that a total of 34 map parameters were tested for correlations with absorbance values. The statistical method used was Pearson's Correlation Coefficient.

3.3 Quantifying land-use change by aerial interpretation

To investigate if land-use change could be the driving factor behind the increased absorbance values, interpretation of aerial photographs were used. Compared to satellite images, the higher resolution aerial photograph makes it possible to detect small areas where the land-use has changed and it is possible to go further back in time.

3.3.1 Selecting catchment areas for interpretation

Out of the 15 test-points, 5 lakes were chosen for interpretation (Table 2). The reason for selecting these five lakes were that they differ a lot in absorbance, both present day value and yearly increase but have small (< 10 km^2) catchment areas. Interpreting larger areas would have been too time-consuming.

Table 2 The 5 lakes selected for interpretation. They all have small catchment areas, but differ in absorbance value.

Test point	Size C.A (km^2)	Present day AbsF	Yearly increase in AbsF
Liasjön	2.1	0.826	0.0242
Fåglasjön	6.1	0.267	0.0045
Svanshalssjön	0.7	0.125	0.0019
Lillesjö	1.1	0.023	0.0007
Skäravattnet	1.1	0.019	0.0005

3.3.2 Aerial photographs

Aerial photographs from three different time spans were used to quantify the land-use change. These pictures were from the time spans 1940-47, 1981-1986 and 2000-2005. From now on these series will be named 1940-, 1980- and 2000-pictures. The reason to use pictures from 1940 was based on that that it takes ~70 years before the carbon content in the upper soil part and biomass has reached its maximum (LUSTRA 2002). Based on this, it would take ~70 years before the land-use change would have "maximum" effect on the absorbance values.

The series from 1940 and 2000 were available at the County Administrative Board of Scania as digital black and white ortophotos (dnr- 106-2204/188). The 1980 series were ordered from Lantmäteriverket and were delivered as digital IR-photos (Appendix 2).

3.3.3 Georeferencing the 1980-pictures

The digital IR-pictures were only central projected, which means that the surface is projected as a photography through a convex lens. The IR-pictures therefore had to be linked to the same map projections as the two other orthophotos. This can be done in two ways. The best result is achieved by a 3-dimensional correction with an adjustment to a Digital Elevation Model (ortophoto production). This is a very expensive method and was therefore not used in this work. Instead, a 2-dimensional adjustment was chosen. This was done by determining transformation parameters by locating so called Ground Control Points (GCPs). GCPs are points that can be clearly identified in the image and in a source; which is in the required map projection system (in this case the black and white orthophoto from 2000 in RT 90). Examples of GCPs can be road intersection and house corners (Janssen and Hurnemann 2001).

Based on the set of GCPs, the pictures were transformed using a best fit procedure (Janssen and Hurnemann 2001). The errors that remain after the transformation are called residual errors. By summarizing these errors an RMS (Root Mean Square error) value is calculated. This is an indicator of the quality of the transformation. The RMS error is only valid for the area bounded by the GCPs, and therefore it is important to select points close to the edge of the image (Janssen and Hurnemann 2001). After the transformation, the pictures were geocoded by resampling the pictures. The interpolation method used was nearest neighbour.

One picture (covering lake Liasjön) was already rectified in another project (Andersson, thesis nr 110). For 3 of the 4 pictures rectified in this work, a 2nd order polynomial transformation was used and the number of GCPs varied between 40-60. The exception was the picture covering Lake Lillesjö. The lake (and it's catchment area) is situated on a height, which gives distortions in the geometric relationship caused by terrain differences, so-called relief displacement (Janssen and Hurnemann 2001). Another factor causing problems was the non even distribution of possible GCPs. Because of this few (24) GCPs and a 3rd order polynomial was used (Appendix 2). This gave a very bad fit in the outer parts of the picture, so-called Runges phenomena (Eklundh 2001) but it gave the best possible fit for the area of interest.

3.3.4 Interpretation of the aerial photographs

The interpretation was made by identifying and digitising homogenous objects (e.g. areas with coniferous forest), in ArcGIS 9.1. As a help during the interpretation the SMD-data as well as the other two aerial photos from the different time spans were used. The land-use classes interpreted are shown in Table 3

Table 3 The land-use classes used in the aerial interpretation.

Artificial ground
Coniferous Forest
Mixed Forest
Clear cut/Young forest
Deciduous Forest
Mire
Water
Field/Open land

In this way three different databases, one for each time span, were created for each catchment area. The total area for each land-use class and time span was calculated in ArcGIS 9.1. and the percentage for the different land-use classes was calculated.

3.3.5 Field control and thematic accuracy

Two field controls where made (13 and 24 of April 2007). The first time, areas where the interpretation was uncertain were visited (training areas). The second time, evaluation points where collected. The evaluation points where used to calculate the thematic accuracy of the interpreted map. A stratified sample method was used where it was made sure that all classes had evaluation points. Two kinds of selections were made on the points; first, they had to be close to roads (<100 m) in order to get as many points as possible and second, classes that were estimated as easy to interpret (e.g. water) got fewer point. The evaluation values were calculated in three different ways, according to Eklundh (2000):

- **User Accuracy (A_i)** is the probability that a random point on the map is correct classified.
- **Producer accuracy (B_i)** is the probability that a random point in the reality is correct classified.
- **Kappa value (Kappa)** gives a number between –1 to 1 and expresses to what extent the points in the evaluated map differ from a random class. For example a Kappa value of e.g. 0.5 means that the interpretation is 50 % better than chance.

3.4 Precipitation and sulphur deposition

The data for precipitation and sulphur deposition was downloaded from the IVL, Svenska Miljöinstitutet, website. The data is included in the same National environment surveillance as the absorbance and water chemistry data. The data is delivered as average per hydrologic year (the hydrologic year starts in October and ends in September). Because of this the absorbance values for Lake Bäen were recalculated to average absorbance for each hydrologic year (although, in the results the hydrologic year is presented as one year value, e.g. 1988/1989 is presented as 1988). The sulphur deposition measurements were made as both wet and dry deposition (IVL).

The station Arkelstorp (RN 1382500: 6212500) had the longest time series of sulphur measurements (1989-2005) and was selected for correlations with absorbance values. The catchment area closest to this station is the one for Lake Bäen (distance 11 km^2) and it was chosen for comparison between yearly absorbance values and sulphur deposition and precipitation.

3.5 E.C. – I.R. diagram

It is possible to determine the origin of water by calculating the relationship between the ions chlorine (Cl^-) and calcium (Ca^{2+}). Chlorine originates from the atmosphere and calcium from the lithosphere. A higher proportion of chlorine means that the water is more strongly influenced by atmocline water; a higher proportion of calcium means that it is more affected by groundwater (lithosphere). The relationship is called Ion Ratio (I.R) and is calculated as:

$$I.R. = \frac{0.5 * Ca^{2+}}{(0.5 * Ca^{2+}) + Cl^{-}} \qquad \text{Eq. 1}$$

The I.R. value is then plotted against conductivity ($E.C._{25}$ $\mu S\ cm^{-1}$) in an E.C – I.R. diagram. A water with high conductivity is influenced by seawater (Van Virdeen 1979).

E.C-I.R diagram was calculated for all 7 lakes. In order to see if there has been any changes in water origin an initial (1984-1989) value and a present day (2000-2005) value of I.R. was calculated.

4. Results

Eleven out of fifteen test points showed a significant increase in absorbance between the years 1983-2005. Only three (Klingavälsån, Råån, and Tolångaån) showed no significant increase and one (Skivarpsån) showed a small (but significant) decrease (Appendix 1). On an average, the absorbance value has increased with 3.2 % between 1983-2005 for the 15 test points.

4.1 Comparison between initial and present day values

When comparing the initial absorbance values and present day values, there is a clear trend that the absorbance generally has increased. As many as five test points have changed from considerably to strongly coloured water (according to the assessment scale of the Swedish Environmental Protection Agency assessment (1999). Lake Liasjön differs from the other test point and is therefore treated as an outlier and is excluded in all results presenting correlations (Figure 4).

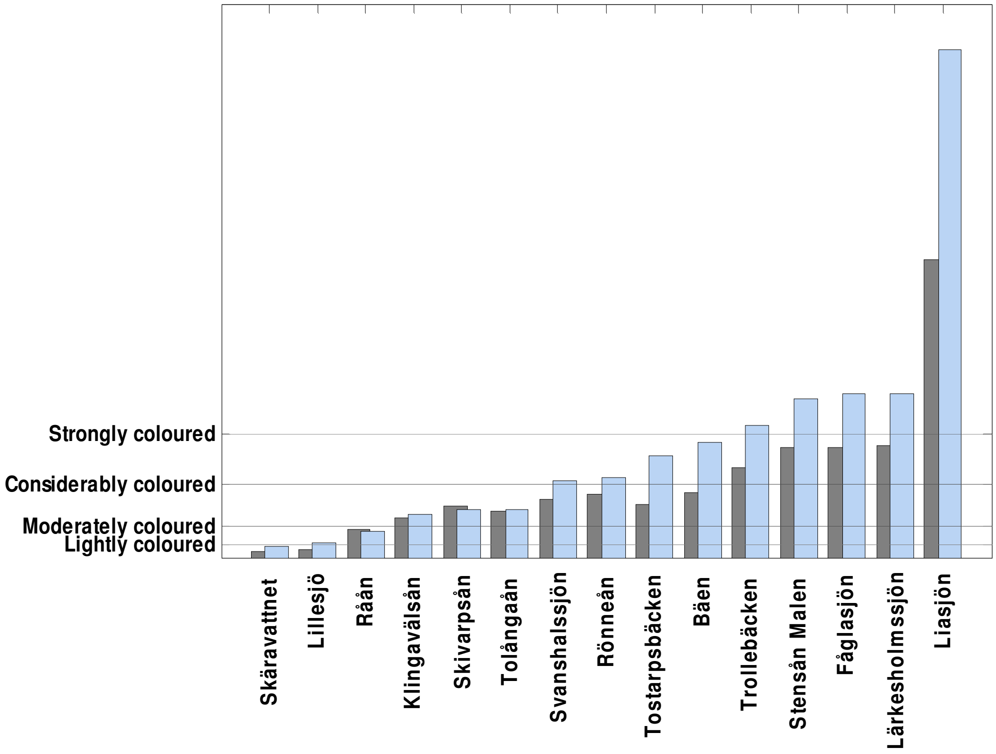

Figure 4. Initial (grey) and present day (blue) absorbance values for the 15 test points. Several of the test-points have increased one step according to the assessment scale of the Swedish Environmental Protection Agency (1999).

4.2 Evaluation of the generated catchment areas

The modelled catchment area of Lake Liasjön (size 3.0 km^2) was overestimated with 43 % compared to the one drawn from the topographic map (2.1 km^2). This shows that the additional information about drainage and flow direction of lakes and streams is crucial to get as a correct estimation of the catchments area as possible (Figure 5 a and b).

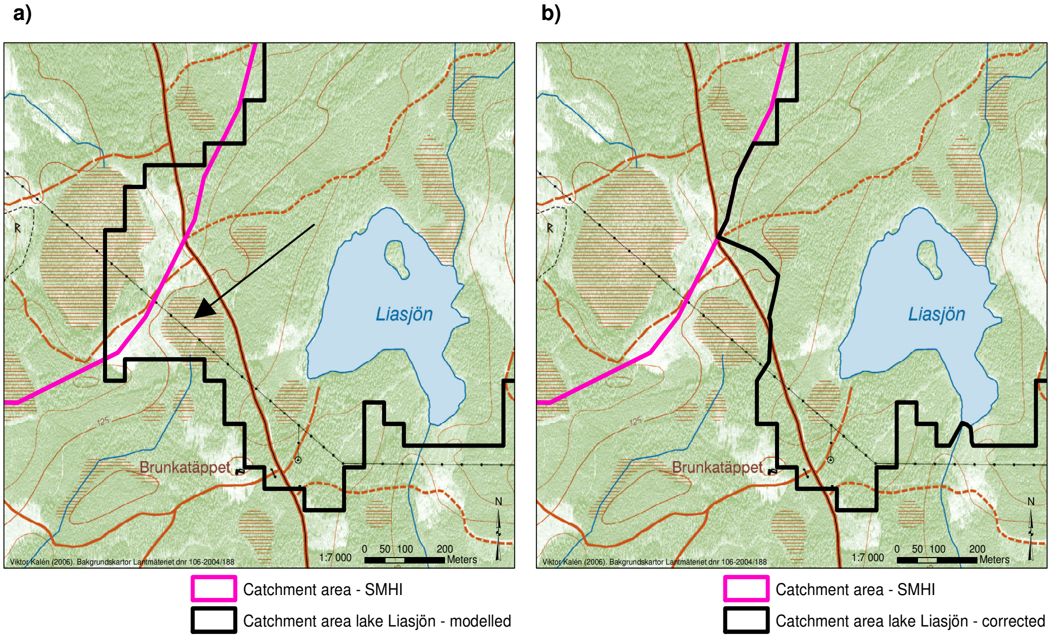

Figure 5 a) Shows the a part of the modelled result of the catchment area of lake Liasjön The black arrow shows a wetland area that is drained out of the modelled catchment area. **Figure 5 b)** shows the same area but with the borders of catchment area corrected and updated.

4.3 Correlations between map parameters and absorbance

Of the 34 parameters tested, size of catchment area, slope and land-use all proved to be bad predictors of both present day absorbance and yearly increase. Due to the low sample size (n= 14) a normal distribution of the test-points cannot be assumed, and therefore the p-values have to be interpreted with caution.

4.3.1 Present day absorbance

All map parameters correlated to present day absorbance are presented in Table 4. No significant correlations were found for present day absorbance vs. size of catchment area or slope.

Interestingly only one land use class (percentage mire, wetland and peat, zone 0-30 m) was correlated to present day absorbance values (Figure 6). The correlation is significant at the 0.05 level but with a low degree of explanation ($R^2 = 0.44$) The best predictor of present day absorbance value was Drainage Density$_{fm}$. The correlation is significant at the 0.01 level and has a fairly high degree of explanation ($R^2 = 0.66$) (Figure 7).

Table 4 The map parameters that were positively correlated to present day absorbance (Sorted falling by degree of explanation). Drainage Density and Drainage Density$_{fm}$ both have fairly good degrees of explanation, while the only significant land-use parameter has a low degree of explanation.

Parameter	**n**	**p**	**R^2**
Drainage Density$_{fm}$	14	0.01	0.66
Drainage Density	14	0.01	0.60
Percentage mire, wetland and peat (zone 0-30 m)	14	0.05	0.44

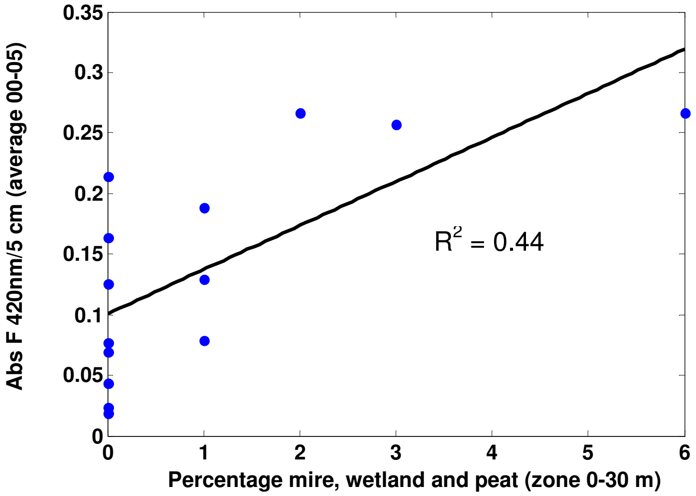

Figure 6. Average absorbance vs. percentage mire, wetland and peat cover in the zone 0-30 m from all watercourses. There is a weak correlation with a low degree of explanation ($p=0.05$, $R^2 = 0.44$, $n=14$).

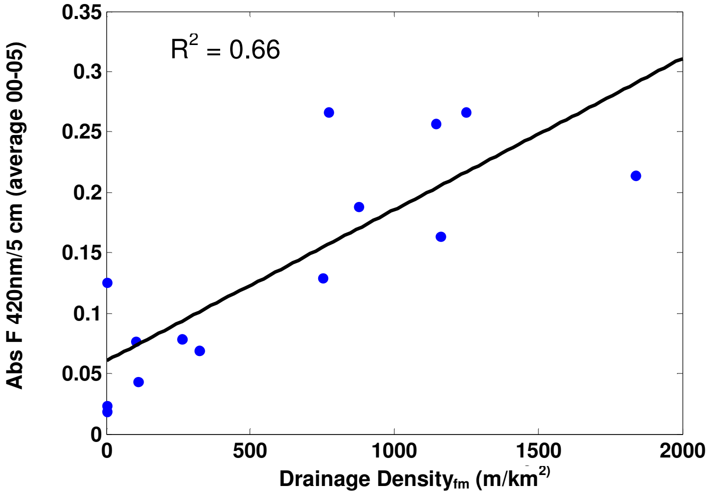

Figure 7. The best parameter to explain present day absorbance was Drainage Density$_{fm}$ The correlation is significant at the 0.01 level.

4.3.2 Yearly increase in absorbance

The significant correlations between increased absorbance and map parameters were similar as the ones for present day absorbance. All map parameters correlated to increase in absorbance are presented in Table 5 No significant correlations were found for increased absorbance vs. size of catchment area or slope.

The best land–use class to predict the increase absorbance was total percentage forest and mires (zone 0-30 m) (Figure 8). The correlation is significant at the 0.05 level, but the degree of explanation is weak ($R^2 = 0.41$). Again, Drainage Density$_{fm}$ proved to be the best predictor. The correlation is significant at the 0.01 level and the degree of explanation is high ($R^2 = 0.82$) (Figure 9)

Table 5 The five map parameters that were correlated to yearly increase in AbsF. Drainage Density has a very good degree of explanation, while all the land-use parameters have low degrees of explanation.

Parameter	**p**	**R^2**
Drainage Density$_{fm}$	0.01	0.82
Drainage Density	0.01	0.52
Total percentage forest + mires (zone 0-30 m)	0.05	0.41
Total percentage forest + mires (zone 0-200 m)	0.05	0.36
Total percentage mires (including forest on mires)	0.05	0.29

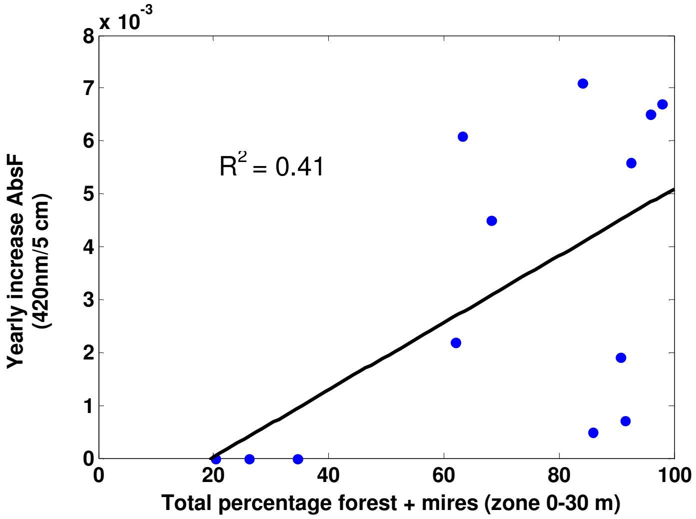

Figure 8. Yearly increase in AbsF was poorly correlated to any land use-parameter. The best degree of explanation was found for Total percentage forest + mires in the zone 0-30 m. (p=0.05, R^2 = 0.41, n = 14)

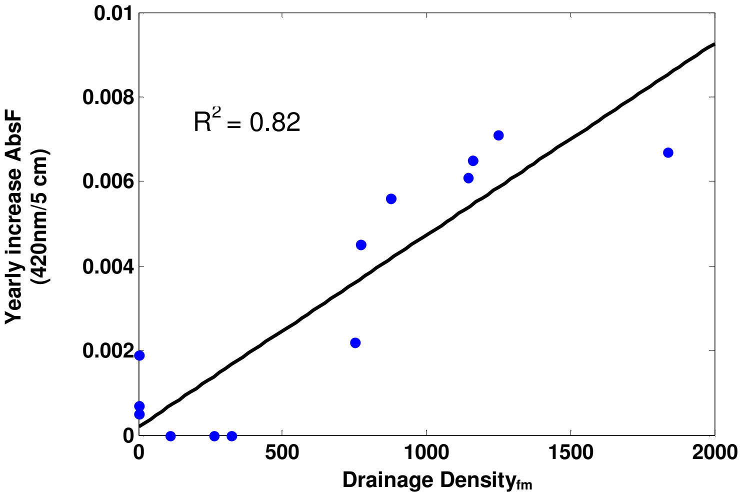

Figure 9. The best parameter to explain the increased absorbance values was Drainage Density$_{fm}$ The correlation is significant at the 0.01 level. At the bottom of the graph there are three points with a Drainage Density$_{fm}$ of zero. These are all small lakes without connecting streams.

4.4 Land use change

To test if land-use change could be the driving factor of the increased absorbance, five catchment areas were selected; Lake Skäravattnet Lake Lillesjö, Lake Svansshalssjön, Lake Fåglasjön and Lake Liasjön. Aerial pictures from three different time periods were interpreted (1940, 1980 and 200). Unfortunately there was no aerial photograph from 1940 covering the catchment area of lake Liasjön.

4.4.1 Cross-table evaluation points

Of the 51 points visited in field, 41 were correctly classified, as seen in the cross-table below (Table 6). Unfortunately there was a problem with the classes *mixed forest* and *coniferous forest*. All points interpreted as mixed forest were classed as coniferous forest, and 3 out of 9 coniferous point where classed as mixed forest.

Table 6 The interpreted result was compared to field observations. Of 51 visited points, 41 were correctly classed.

	Field Observation								
Aerial interpretation	Artificial ground	Coniferous Forest	Mixed Forest	Clear cut/young forest	Deciduous Forest	Mire	Water	Field/Open land	Number (interpretation)
Artificial ground	**4**	0	0	0	0	0	0	0	**4**
Coniferous Forest	0	**4**	0	2	1	0	0	0	**7**
Mixed Forest	0	3	**0**	1	0	0	0	0	**4**
Clear cut/Young forest	0	0	0	**8**	1	0	0	0	**9**
Deciduous Forest	0	2	0	0	**5**	0	0	0	**7**
Mire	0	0	0	0	0	**6**	0	0	**6**
Water	0	0	0	0	0	0	**2**	0	**2**
Field/Open land	0	0	0	0	0	0	0	**12**	**12**
Number (field)	**4**	**9**	**0**	**11**	**7**	**6**	**2**	**12**	**51**

4.4.2 Thematic accuracy

The overall agreement between the interpretation and field observation was acceptable with a Kappa value of 0.76 (which means that the interpretation is 76 % better than if the classes were randomly selected). *Artificial ground*, *Mire*, *Water* and *Field/Open land* all had Kappa values of 1.00 and C*lear-cut* had 0.86. The land-use classes *Deciduous forest* and *Coniferous forest* had low Kappa values, 0.67 and 0.48 respectively. *Mixed forest* was lacking evaluation points and had a Kappa value of 0. This makes the interpretation uncertain, but if all forest classes are merged to just one class, the Kappa value for that class would be 1. Thematic accuracy is presented as User accuracy (A_i) Producer's accuracy (B_i) and Kappa (Table 7).

Table 7 User accuracy (A_i) Producer´s accuracy (B_i) and Kappa value for the 8 classes.

	A_i	B_i	Kappa
Artificial ground	100	100	1,00
Coniferous Forest	57	44	0.48
Mixed Forest	0	0	0.00
Clear cut/Young forest	89	73	0.86
Deciduous Forest	71	71	0.67
Mire	100	100	1.00
Water	100	100	1.00
Field/Open land	100	100	1.00

4.4.3 Land use change – interpretation of aerial photographs

The results shows that the land-use change, both looking at total percentage forest and changes within forest classes, is small (no data where available for lake Liasjön for the 1940-period) the total percentage of forest has increased slightly between 1940-1980. The increase is biggest for lake Fåglasjön (17 %) and smallest for lake Skäravattnet (4 %). Between 1980-2000 there has been almost no change in total percentage forest (Figure 10 and Table 8).

Within the different forest classes there are some interesting trends. In Lake Lillesjö a large area of mixed forest has changed to *Coniferous forest*. The *Clear-cut* areas have increased since 1940 for lake Skäravattnet, lake Svanshalssjön and lake Lillesjö. No other clear trends can be seen (Figure 10). Due to the low Kappa values of mixed forest and coniferous forest, these results have to be evaluated with caution.

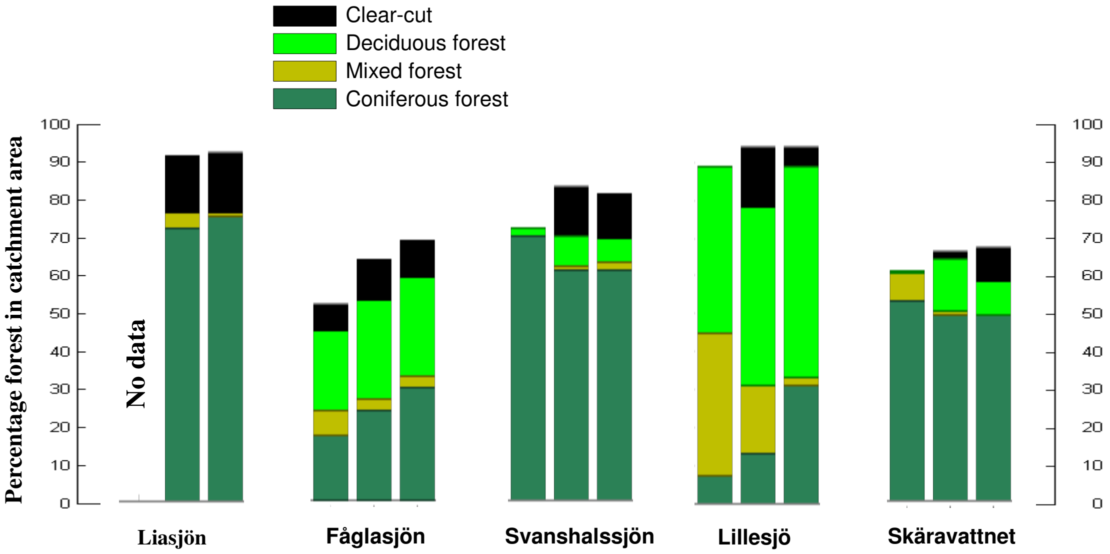

Figure 10. Percentage of forest in the catchment area for the three different periods 1940- 80 and 00. Since 1940 the total percentage forest has increased in all the interpreted areas. However, the increase is fairly constant between the lakes. Between 1980 and 2000 the percentage forest is almost constant.

Table 8 Percentage forest, clear-cut and mires for the periods 1940-, 80- and 00. The 5 test-points are sorted by yearly increase in absorbance (* = missing data).

	Liasjön	Fåglasjön	Svanshalssjön	Lillesjö	Skäravattnet
1940	*	52	72	89	62
1980	95	63	83	94	66
2000	95	69	82	94	68
Change in % 1940-1980	*	11	11	5	4
Change in % 1980-2000	2	6	-1	0	2
Abs F (yearly increase)	0,0242	0,0045	0,0019	0,0007	0,0005

4.5 Other possible explanations driving the increase in absorbance

There seems to be a trend that higher initial absorbance values give higher yearly increase. The correlation between these to parameters, has a fairly high degree of explanation ($R^2 = 0.59$) and is significant at the 0.01 level (Figure 11).

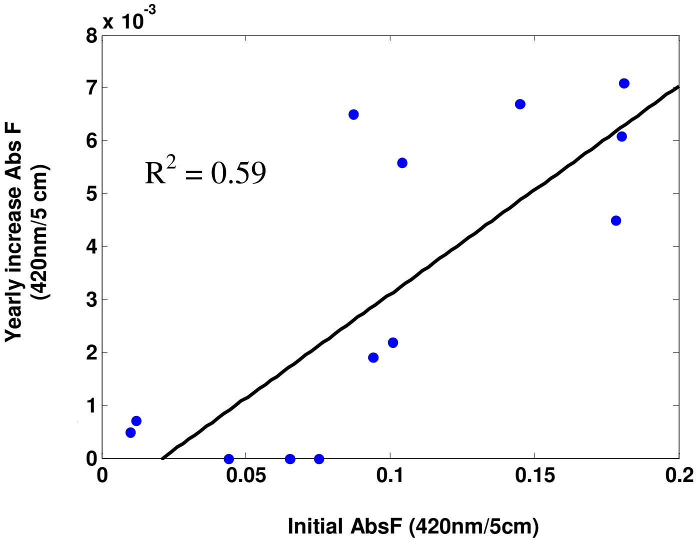

Figure 11. Yearly increase in absorbance vs. initial absorbance. The correlation is significant at the 0.01 level.

4.5.1 Precipitation and sulphur-deposition

Both precipitation and sulphur deposition shows significant changes during the period 1988-2004. The precipitation has increased slightly but significantly (n = 16 p=0.05 R^2 = 0.36). The sulphur deposition has decreased dramatically (n = 16 p=0.01 R^2 = 0.91) (Figure 12 a). The first absorbance value is extremely high and is treated as an outlier. In Figure 12 b the whole absorbance serie (1983-2005) is plotted and showing that the year 1988 was an extreme.

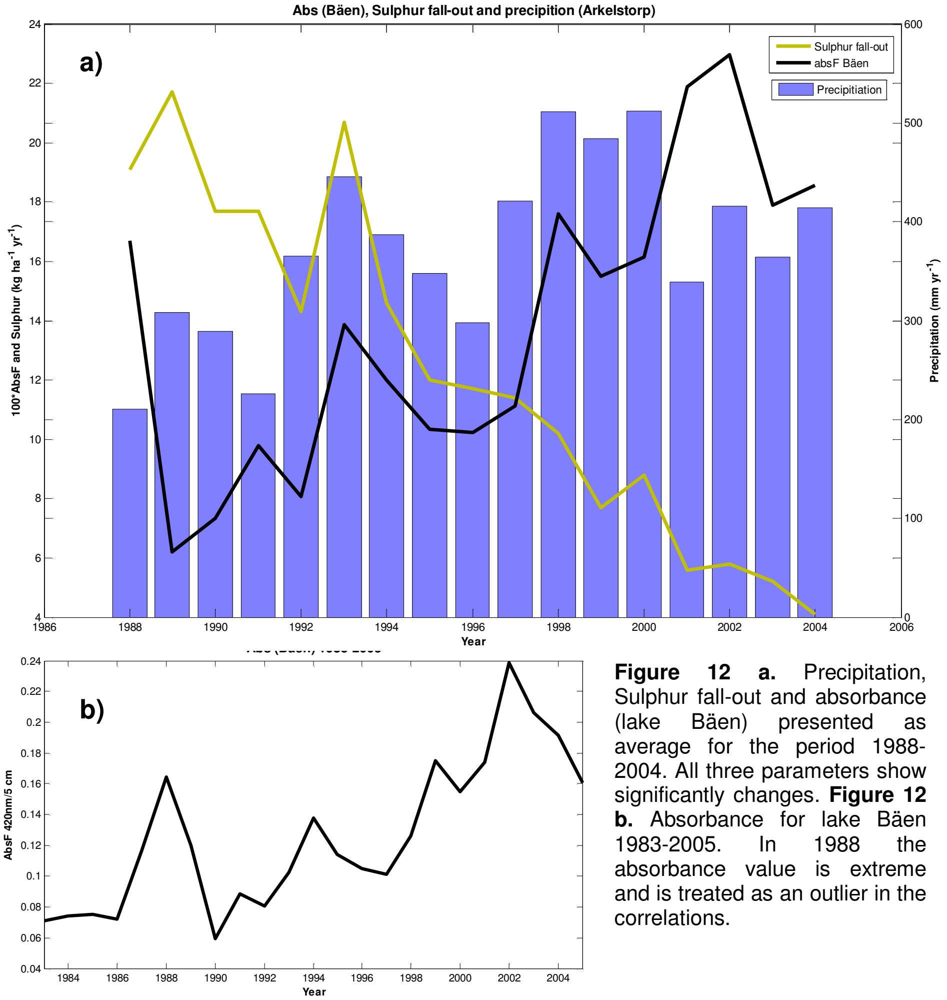

Figure 12 a. Precipitation, Sulphur fall-out and absorbance (lake Bäen) presented as average for the period 1988-2004. All three parameters show significantly changes. **Figure 12 b.** Absorbance for lake Bäen 1983-2005. In 1988 the absorbance value is extreme and is treated as an outlier in the correlations.

The correlation between absorbance and precipitation was significant at the 0.05 level. But the degree of explanation was very low ($R^2 = 0.26$) (Figure 13).

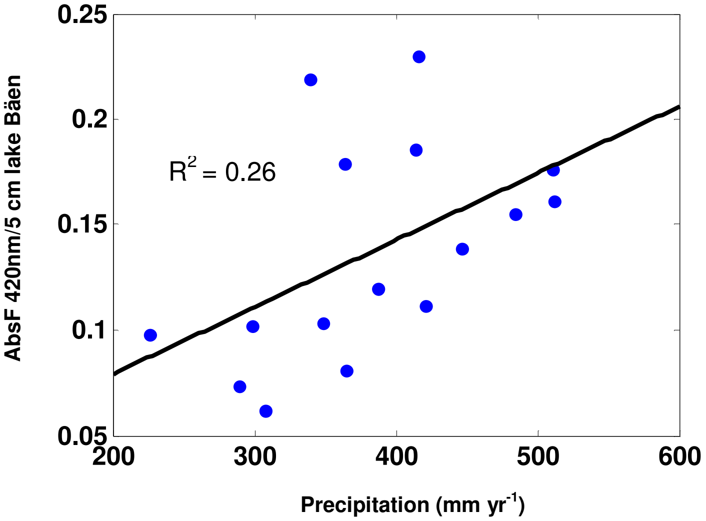

Figure 13. Absorbance value for Bäen (average for each year) was poorly correlated to yearly precipitation (n=16)

The correlation between absorbance and sulphur deposition was significant at the 0.01 level. The degree of explanation was better than for precipitation ($R^2 = 0.62$) (Figure 14).

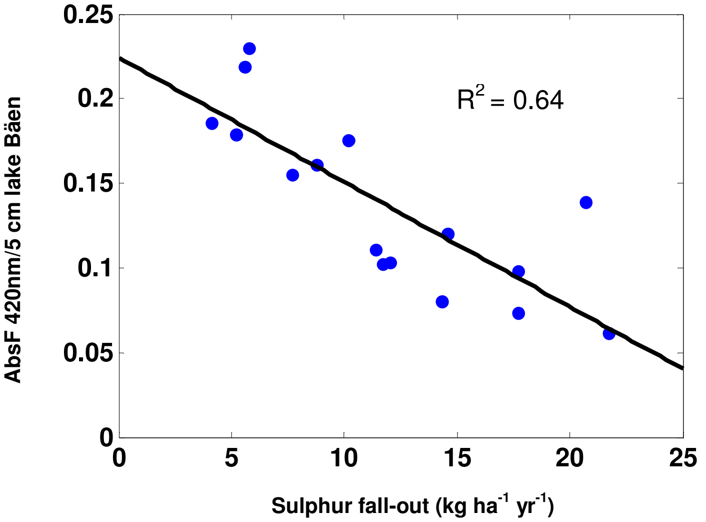

Figure 14. Absorbance value for Bäen (average for each year) vs. sulphur fallout (n=16)

4.5.2 E.C.-I.R. Diagram

The E.C.-I.R. diagram shows that all lakes are mostly supported by atmocline (rain) water (Figure 15 a). When comparing E.C.-I.R. diagram between 1980 and 2000 there is a trend that the water in most of the lakes are more atmocline in 2000 compared to 1980. This can be an indicator of changes in hydrology parameters. No correlation was found between I.R. –value and yearly increase or present day value absorbance value (Figure 15 b).

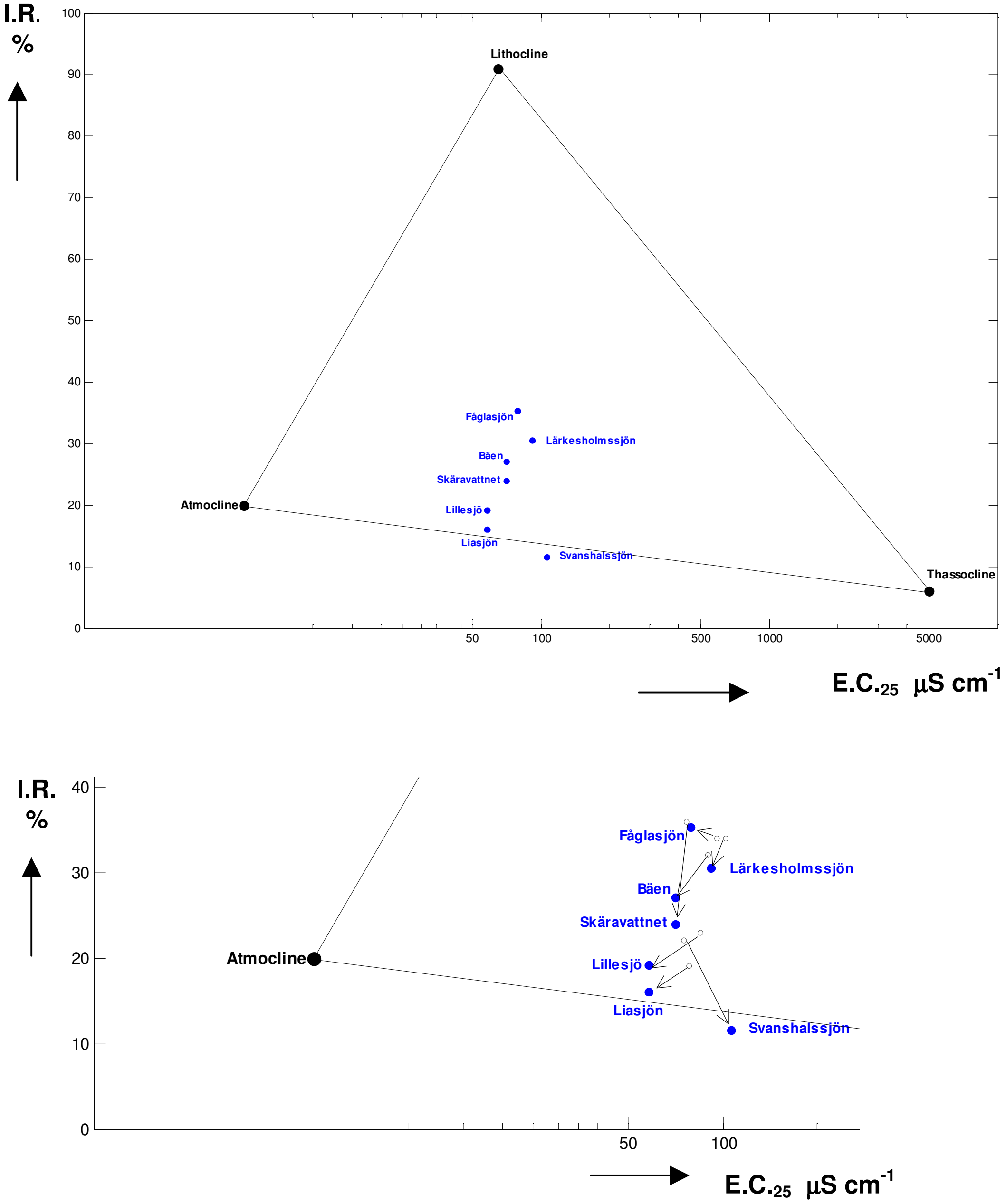

Figure 15 a. E.C. – I.R. Diagram for the 7 lakes. All lakes are mostly supported by atmocline water . In **Figure 15 b** the EC-IR value from 1980 is plotted as grey circles and the black arrow shows the change from 1980-2000. All lakes (except Lake Lärkesholmssjön) have changed and in I.R value. This can be an indicator of that the water are less of Lithocline (groundwater) origin.

5. Discussion

5.1 Absorbance values

The increase in absorbance value (~3 % per year) in the analysed data is of the same magnitude as reported in the literature (SLU). If just looking at averages between initial and present day values, as many as 5 out of the 15 test points are in 2000 classified as strongly coloured, in 1980 the same number was one. According to the statistical results it is clear that the watercolour has increased in most of the streams and lakes investigated. There is one source of error within the statistical method used; the observations between years are not independent and the lack of independency can affect the outcome of the correlation (Rogers 2001).

Looking at the number of test points, n = 14 (Lake Liasjön excluded), a higher number of observations is always desired. Since all test points (in Scania) included in the National Environmental Survey and with a long time series were chosen this is the largest sample size available using data from the same source and analysed in the same way. The study of Vourenmaa et al.(2006) had a similar approach as this work and their sample size was only n=15. For future studies, more test points can be added just looking at present day values of absorbance and correlations to map parameters.

5.2 Map parameters

Size, Slope, and the Land-Use of a catchment area all proved to be insufficient predictors of both the present day values and the increased absorbance values. Instead Drainage Density, and especially Drainage Density$_{\text{fm}}$, proved to be the best predictors. These results shows that the carbon reaching the lakes and streams originates from forest and mires, but the water flow pathways are more important than the actual percentage forest and mires. The higher up in soil the water flows, the higher the DOC content. This is in line with the work of Hongve (1999) where he proposes that the effect that mires sometimes have on DOC concentrations may depend more on their influence on water pathways than on leaching of DOC from the peat, and that the water pathways in the catchments probably are the most important factors determining DOC concentrations in lakes and streams. One parameter not examined in this study that could be the interesting for future studies is the permeability of soils. According to Hongve (1999) a higher degree of impermeable soils would give a higher surface runoff and thus higher DOC concentrations.

The absorbance measurement is a measure of the loading of DOC. According to Kalff (2001) the amount of DOC exported from a catchment area is highly correlated to percentage peat and forest. The actual loading is more dependent of residence time and water renewal times, because of removal processes such as sedimentation, microbial decomposition and photo oxidation. This can be one explanation to the low correlations between land-use and absorbance values recorded in this work. Drainage density can be considered as a type of substitute measurement for water renewal times, because a high drainage density probably gives a shorter residence time in a catchment area. This would give yet another explanation to why Drainage Density was such a god predictor of watercolour.

Due to the small sample size (n=14) the test-points cannot be assumed to be normal distributed. This gives a high uncertainty when evaluating the p-values. For future studies better statistical methods were the data is tested for normal distribution is preferred. Another approach would be to add more test points so that normal distribution can be assumed ($n > 30$). Probably, the correlations for land-use parameters are not normal distributed, this in combination with the bad R^2 values and the high p-values (p close to 0.05) shows that land-use parameters not can explain the observed absorbance values.

5.3 Land-use change

As the parameter Land-Use proved to be an insufficient predictor of present day absorbance values as well as increase in absorbance. This must lead to the conclusion that a change in land-use from open land/cultivated land to forest does not necessarily give higher increase in absorbance values. As can be seen in Figure 8 there are catchment areas with a high percentage forest and mires, but still a very small increase in absorbance value. However, the total percentage forest has increased in all interpreted areas. Of the 4 lakes interpreted, the two with the highest yearly increase in absorbance (lake Fågasjön and Lake Svanshalssjön) also have the biggest increase in total percentage forest between 1940-2000. The increase in forest has probably increased the total carbon content in the catchments, and can well contribute to a small part of the increase in watercolour. But that it would be the driving factor is very unlikely. The fact that between 1980 and 2000 there has been almost no change strengthens this theory. Larger changes in land-use and a stronger relationship between present day absorbance and percentage forest is required to explain the observed increase in watercolour. This study just focused on percentage changes in land-use, not were the land-use took place. On interesting thing for future studies would be to look at land-use changes close to streams, if a forest were planted close to a stream, the parameter Drainage Density$_{fm}$ would increase.

The changes within forest classes are rather small. The catchment of lake Lillesjö is the one that experienced the largest change between forest classes; ~35 % mixed forest had become (mostly) coniferous forest. This is a change that could contribute to an increase in absorbance value, but the absorbance increase in Lake Lillesjö is very small. Due to the low thematic accuracy of mixed forest and coniferous forest, comparisons between different forest classes have to be made carefully. However, there are explanations to the low accuracy values. The number of evaluation points is small and not evenly distributed between classes. The reason for this is the time/cost of being in field and the fact that several points that were planned to be visited were unreachable due to closed roads. Another source of error is due to limitation- and scale problems. Looking at an aerial photography, one area can be classed as mixed forest, but when the evaluation point is visited in field there is a chance that there is only coniferous forest surrounding the point. This problem can be overcome with better field preparations and stricter definitions of sizes of objects. These two explanations point to that the interpretations of mixed forest and coniferous forest probably are better than the thematic accuracy values expresses.

5.4 Other explanations driving the increase

Instead the driving increase seems to be o f a more widespread phenomenon. Evans et al. (2004) found a strong positive correlation ($R^2 = 0.7$) between the rate of annual DOC increase and initial DOC concentrations. Due to this they argued that mean DOC release per unit of soil organic carbon had increased, which implies a driving mechanism operating at a large scale. Vourenmaa et al. (2006) also reported on a correlation between annual TOC change and average present day values of absorbance. The results from this work also show a correlation between yearly increase and initial absorbance value, although a bit weaker ($R^2 = 0.59$, $p = 0.01$). Since lakes and streams with a high initial absorbance value increases the most, the driving factor seems to accelerate an already existing processes.

The correlations between sulphur deposition, precipitation and absorbance values are just to be seen as a brief guidance to what can be the driving factor behind the increasing absorbance values. Just looking at lake Bäen, both precipitation and sulphur deposition have changed and both of them correlate to absorbance value for Lake Bäen, therefore it is possible that both of these can have influenced the amount of DOC exported to the lake. The facts that sulphur deposition has the highest degree of explanation, that it is working on a large scale, and that the deposition has decreased dramatically in Sweden during the examined period (SLU 2007) all points to that this could be what drives the increase in watercolour. When comparing data in this way, it is important to remember that a strong linear relationship does not necessarily imply that there is a causal connection between the two variables (Rogersson 2001). More data and statistical analysis are required to be able to sort out and determine what drives the increase.

An interesting thing to investigate would be changes in precipitation patterns. It can be so that there are more dry periods followed by more heavily rainfall. In this more water would flow higher up in the soil layers due to saturated soils (Hope et al. 1994). The results from the E.C-I.R. diagram can be an indicator of this. The water seems to be more of atmocline origin, which means that either the amount of atmocline water has increases, or the amount of groundwater decreases. According to SGU (2007) no big trends of changes in groundwater level have been recorder in Scania during the examined period. Instead changes in the amount of precipitation and/or precipitation pattern could be an explanation to the changes in the E.C.- I.R. diagram.

Lövgren et al. (2006) Investigated three lakes that had watercolour measurements going back to 1945. He concluded that the watercolour in 1940-1950 for these three test points was of the same magnitude as today. The lowest watercolour values were recorded in the middle of 1970. Lövgren explains these trends with changes in climatic parameters. It is interesting to couple his results to the sulphur theory. Probably, the sulphur deposition was fairly low during the 1940-1950. As showed in this work, it was high in 1980a after which it decreased rapidly.

Changes in precipitation and sulphur deposition can be linked to the results of Drainage Density$_{fm}$ and the result that high initial absorbance gives a big yearly increase. If more DOC is released because of decreasing sulphur-deposition it will be absorbed in the lower soil horizons in those catchments were the water has to travel a long way to reach a stream. In a catchment with high a Drainage Density the DOC will be transported more quickly to the stream network, thus affecting watercolour. The higher the Drainage Density, the higher would the effect be, giving an accelerating affect.

5.5 Lake Liasjön and drainage of forested areas

Lake Liasjön is extremely interesting though to its high absorbance value and its large increase. Visited in field it is obvious that the water in the lake is very dark. The extreme absorbance values gave such a strong influence on the correlations (both strengthening and weakening), that Lake Liasjön was treated as an outlier in the correlation analysis. A good example of this is the correlation between yearly increase in absorbance and Drainage Density$_{fm}$. If Lake Liasjön is included, the R^2 value goes down from 0.82 to 0.53 (although still significant at the 0.01 level). There is an explanation for this; in field, a lot of drainage ditches (Figure 16) were noticed in the catchment area of Lake Liasjön. These ditches were not drawn on the topographic map, although they were of the same size as the streams present in the map. If the length of these ditches had been included in the calculations, Lake Liasjön would have had a much higher Drainage Density$_{fm}$ value, and the correlation would probably have been even stronger.

Figure 16. One of the drainage ditches in Lake Liasjön. The water was highly coloured. Photo Viktor Kalén.

Another observation made in the catchment area of Lake Liasjön was that the soil had sunk. It looked like many of the trees were "standing on their on roots". The explanation to this can be that the drainage ditches has lowered the water table. When the water table is lowered, the soil is oxygenated which will enhances the microbial activity and increase the breakdown in soil (Wallace 2006). Most likely this leads to an increase in the amount of DOC exported. The effect would probably be the same if already existing ditches were made deeper or wider. Recently a study where made at the County administrative Board of Scania. The study aimed to control if a number drainage ditches in Scania were according to the depth and width that the duty allows. The results show that the majority of the drainage ditches examined where either to deep, to wide or both to deep and wide according to what the duty allows (Grosen 2007, unpublished data). This can well contribute to a higher leakage of DOC to the water systems. Because of this and because of the correlations between Drainage Density$_{fm}$ and watercolour it is of great interest to discuss how the drainage of forested areas will be done in the future. This also raises the question if increased drainage can be the driving factor of the watercolour? This is most unlikely since this factor is not working on a large scale, and due to the fact that since 1986 there is a prohibition against drainage in Scania. Although exemption can be given, it is not likely that the drainage have increased enough to explain the observed trends and being the driving factor behind the increased watercolour.

5.6 What will happen in the future?

According to literature, approximately 1-5 % of NPP is returned to the atmosphere as CO_2 by evasion of DOC in lakes and streams. Since the concentration of DOC is regulating the rate of CO_2 evaded (Vetenskapsrådet), an increase in DOC also means an increase in CO_2 emission. According to Dillon and Mollot (1994) the net annual accumulation of carbon based on NEP may be overestimated because of export of carbon to lakes and streams.

The main issue concerning DOC trends is whether it will continue increase, stabilize or return to lower values. If sulphur is the driving factor it could be so that what is observed is a flushing effect. During the acidification the DOC particles have been bound up, and is now flushed trough the water systems. If so, the absorbance values can return to more acceptable values, but since DOC still is more easily leached compared to when sulphur deposition was high the water colour will not go back to the values experienced in the 1980s. Other things that can keep the watercolour at a high level is increases/changes in precipitation due to climate change. e.g. storm events gives significant changes in flow paths and makes water float higher up in the soil layers (Hope et al. 1994). According to SMHI (© Rossby Center SMHI 2007) there will be an increase in both precipitation and extreme precipitation in Scania of ~ 5 to 10 % during the two next decades. If decreased sulphur deposition is the explanation to the increased watercolour, this would lead to a very interesting conclusion; by solving the environmental problem of acidification, another problem appears.

6. Conclusions

- The increase in watercolour for the data used in this work is of the same magnitude as reported in literature.
- Generating catchment areas just using ArcGIS and a DEM (resolution 50*50 m) is not a sufficient method. If an as good results as possible is desired the location and flow direction of streams, wetlands and lakes has to be taken into account. Instead, the modelling should be viewed as a very helpful tool, especially if many catchment areas are to be generated.
- Drainage Density$_{fm}$ proved to be the map parameter best explaining both present day values and increased absorbance values. Land-use proved to be an insufficient parameter explaining absorbance values.
- Land-use change can most likely not be the driving factor behind the increased watercolour.
- Decreased sulphur deposition tends to be the driving factor behind the increased absorbance values. But increased precipitation and/or changes in precipitation pattern can also be an explanation.

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7. References

Articles

Bishop, K., Pettersson, C., Alard, B., Lee, Y-H. (1994). Identification of the riparian sources of aquatic dissolved organic carbon. Environmental International , 20(1), pp. 11-19

Cronan, C.S., Aiken, G.R, (1984). Chemistry and transport of soluble humic substances in forested watersheds of the Adirondack Park, New York Geoehimica et Gosmochimica .&a Vol. 49, pp. 1697-1705

Dahlström, N., (2005). Function and dynamics of woody debris in boreal forest streams. Doctoral Thesis, Umeå University, Umeå, 21 pp

Dillon, P.J and Molot, L.A., (1997). Dissolved Organic and Inorganic Carbon Mass Balances in Central Ontario Lakes. Biogeochemistry, Vol. 36, No. 1, Dissolved Organic Carbon as an Integration of Global Stresses on Freshwater., pp. 29-42.

Edwards NT, Shugart HH Jr, McLaughlin SB, Harris WF & Reichle DE., (1981). Carbon metabolism in terrestrial ecosystems. In: Reichle DE (Ed) Dynamic properties of ecosystems (pp 499-536). Cambridge University Press, New York

Evans,C. D., Chapman, P. J., Clark, J.M., Monteith, D.T., Cresser, M.S., (2006). Alternative explanations for rising dissolved organic carbon export from organic soils. Global Change Biology 12 (11), pp. 2044–2053.

Evans, C.D., Monteithb, D.T., Cooper D.M., (2004). Long-term increases in surface Water dissolved organic carbon: Observations, possible causes and environmental impacts, Environmental Pollution 137., pp. 55-71

Hope, D., Billet, M.F., Cresser, M.S., (1994). A review of the export of carbon in river water: fluxes and processes. Environmental Pollution 84. pp. 301-324

Hongve, D., (1999) Production of dissolved organic carbon in forested catchments. Journal of Hydrology 224, pp. 91–99

Jonsson, A., Algesten, G., Bergström, A.-K., Bishop, K., Sobek, S., Tranvik. L.J. and Jansson, M., (2006). Integrating aquatic carbon fluxes in a boreal catchment carbon budget. Journal of Hydrology 334: 141-150.

Lövgren, S., Forsenius, M., Andersen, T. (2003), Climate induced water colour increase In Nordic lakes and streams due to humus. Nordic Council of Ministres, Brochure (12 pp)

Neal, C., Robson, A.I., Neal, M., Reynolds, B., (2005) Dissolved organic carbon for upland acidic and acid sensitive catchments in mid-Wales. Journal of Hydrology 304 (2005) pp 203–220

Roulet, N., Moore , T.R., (2006). Browning the waters. NATURE 444, pp. 283-284.

Sachse, A., Henrion, R., Gelbrecht, J., Steinberg, C.E.W. (2005),. Classification of Dissolved organic carbon (DOC) in river system: Influence of catchment characteristics and autochthonous processes, Organic Geochemistry 36 (2005), s. 923–935

Sibelle, I., Biological stability in drinking water distribution systems: a review, Année Biole 78. pp. 117-161

Temnerud, J., Spatial Variation of Dissolved Organic Carbon Along Streams in Swedish Boreal Cathcments. Örebro University, University Libraries, 2005, www.ub.oru.se

Van Wirdum, G. (1980). Simple description of water quality changes during a hydrological cycle for use in nature protection. In: Hooghart JC (Ed). Wayer quality in groundwater systems. Report nr 5. Commission of hydrological research TNO, Den Haag, The Netherlands (In Dutch)

Vuorenmaa, J., Forsius,M., Mannio, J., (2006). Increasing trends of total organic carbon concentrations in small forest lakes in Finland from 1987 to 2003, Science of the Total Environment 365 47–65

Wallace, Z.E., Holden, J., McDonald, A.T., (2006). Drain blocking: An effective Treatment for reducing dissolved organic carbon loss and water discolouration in a drained peatland, Science of the total environment 367 (2006), pp. 811-821

Worrall, F., Burt, T.P., Adamson, J., (2006). The rate of and controls upon DOC loss in a peat catchment, Journal of Hydrology 321, s. 311–325

Whittaker RH, Likens GE, Bormann FH, Eaton JS & Siccama TG (1979) The Hubbard Brook ecosystem study: forest nutrient cycling and element behaviour. Ecol. 60. pp. 203-220

Books

Brönnmark, C.,Hansson, L-A., (2005), The Biology of Lakes and Ponds, Second Edition,Oxford University Press Inc., New York, pp

Eklundh, L., (2000), Geografisk informationsbehandling, Metoder och tillämpningar. Stockholm, Byggforskningsrådet: pp. 348

Grootjans, A.B., (1985), Changes of groundwater regime in wet meadows. Casparie Heerhugowaard b.v., pp. 146

Findlay, E.G., Sinsabaugh, R.L., 2003, Aquatic Ecosystems Interactivity of Dissolved Organic Matter. Academic Press, pp 512

Janssen, L. F. L., and Huurneman, C. G., (2001), Principles of remote sensing. The international Institute for aerospace survey and earth sciences (ITC), Netherlands, pp. 410

Kalff, J., (2002), Limnology: inland water ecosystems, Prentice-Hall, Inc, pp. 592

Rogersson, A.R., (2001), Statistical methods for Geography. SAGE Publications LTD., pp. 236

Thurman, E.M., (1985), Organic Geochemistry of Natural Waters. Martin Nijhoff/Dr W junk Publishers, Dordrecht., pp. 497

Internet sources

SLU a., Article downloaded from http://www.slu.se/?id=965&puff=13 (downloaded 2007-05-30)

SLU b.,Water chemistry data downloaded from http://info1.ma.slu.se/ma/www_ma.acgi$Project?ID=StationsList&P=All – (downloaded 2007-04-27)

© Rossby Center SMHI 2007., Climate data http://www.smhi.se/cmp/jsp/polopoly.jsp?d=8785&l=sv -downloaded 2007-06-17

Personal Communication

SGU (2007). Thunholm, B.,

Reports

Naturvårdsverket. Bedömningsgrunder för miljökvalitet. Sjöar och vattendrag. Rapport 4913.

Lantmäteriet - Svenska CORINE Marktäckedata Produktspecifikation Dokumentnummer SCMD-0001 2002.

LUSTRA-programmet 2001-2002 (www-lustra.slu.se/rapportermm/pdf/2002.pdf)

SLU 2007, Miljötrender Nr 2, pp 11

Vetenskapsrådet: Omsättning och effekter av humusämnen i sjöar, vattendrag och Havsområden - abstracts

Used data

Svenska Marktäckedata SMD Vektor. Version 2.2 (2002-06-03) LMV
LMV Fastighetskartan Hydrografi Linje 2006 – LMV GSD
LMV Fastighetskartan 2003 Sjöar – LMV GSD
LMV GSD-Höjddata

Topographic map, Economic map © Bakgrundskartor Lantmäteriet, dnr 106-2004/188

Appendix 1 - The 15 test-points

Table A 1. Size of catchment area, yearly increase in absorbance with p- level and R^2 value and time series for data used in analysis for all 15 test points (sorted falling by yearly increase in absorbance)

Name – test point	Size catchment area (km^2)	Yearly increase AbsF 420nm/5cm	Significance Level yearly increase	R^2	Time serie for analysis
Liasjön	2.1	0.0242	**	0.65	83-05
Lärkesholmssjön	29.4	0.0071	**	0.39	83-05
Trollebäcken	3.1	0.0067	**	0.53	89-05
Tostarpsbäcken	1.4	0.0065	**	0.50	89-05
Stensån Malen	284.8	0.0061	**	0.48	83-05
Bäen	9.4	0.0056	**	0.60	83-05
Fåglasjön	6.1	0.0045	**	0.42	83-05
Rönneån	975.7	0.0022	**	0.49	83-05
Svanshalssjön	0.7	0.0019	*	0.36	83-05
Lillesjö	1.1	0.0007	*	0.40	84-05
Skäravattnet	1.1	0.0005	**	0.43	83-05
Klingavälsån	214.1	0	-	0.06	83-05
Råån	157.0	0	-	0.06	83-05
Tolångaån	260.5	0	-	0.06	83-05
Skivarpsån	101.7	-0.0001	*	0.15	83-05

* Significant at the 0.05 level
** Significant at the 0.01 level
\- No correlation

Appendix 2 - Aerial pictures

Table A 2. The 5 interpreted aerial pictures, number of GCPs, polynomial and RMS value for georeferencing

	Picture name	Number of GCP:s	Polynom	RMS Error	Georeferenced by
Svanshalssjön	814_04210_44	53	2nd	4.1	This project
Liasjön	814_04129_46	59	2nd	3.8	This project
Lillesjö	244_03268_28	20	3rd	5.6	This project
Skärvattnet	844_03480_05	45	2nd	4.5	This project
Fåglasjön	3C40_21	39	2nd	9.5	Andersson, 2004

Lunds Universitets Naturgeografiska institution. Seminarieuppsatser. Uppsatserna finns tillgängliga på Naturgeografiska institutionens bibliotek, Sölvegatan 12, 223 62 LUND. Serie startade 1985.

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden.
Report series started 1985.

79. Ullman, M., (2001): El Niño Southern Oscillation och dess atmosfäriska fjärrpåverkan.
80. Andersson, A., (2001): The wind climate of northwestern Europe in SWECLIM regional climate scenarios.
81. Lalloo, D., (2001): Geografiska informationssystem för studier av polyaromatiska kolväten (PAH) – Undersökning av djupvariation i BO01-området, Västra hamnen, Malmö, samt utveckling av en matematisk formel för beräkning av PAH-koncentrationer från ett kontinuerligt utsläpp.
82. Almqvist, J., Fergéus, J., (2001): GIS-implementation in Sri Lanka.
    Part 1: GIS-applications in Hambantota district Sri Lanka : a case study.
    Part 2: GIS in socio-economic planning : a case study.
83. Berntsson, A., (2001): Modellering av reflektans från ett sockerbetsbestånd med hjälp av en strålningsmodell.
84. Umegård, J., (2001): Arctic aerosol and long-range transport.
85. Rosenberg, R., (2002): Tetratermmodellering och regressionsanalyser mellan topografi, tetraterm och tillväxt hos sitkagran och lärk – en studie i norra Island.
86. Håkansson, J., Kjörling, A., (2002): Uppskattning av mängden kol i trädform – en metodstudie.
87. Arvidsson, H., (2002): Coastal parallel sediment transport on the SE Australian inner shelf – A study of barrier morphodynamics.
88. Bemark, M., (2002): Köphultssjöns tillstånd och omgivningens påverkan.
89. Dahlberg, I., (2002): Rödlistade kärlväxter i Göteborgs innerstad – temporal och rumslig analys av rödlistade kärlväxter i Göteborgs artdataarkiv, ADA.
90. Poussart, J-N., (2002): Verification of Soil Carbon Sequestration - Uncertainties of Assessment Methods.
91. Jakubaschk, C., (2002): Acacia senegal, Soil Organic Carbon and Nitrogen Contents: A Study in North Kordofan, Sudan.
92. Lindqvist, S., (2002): Skattning av kväve i gran med hjälp av fjärranalys.
93. Göthe, A., (2002): Översvämningskartering av Vombs ängar.
94. Lööv, A., (2002): Igenväxning av Köphultasjö – bakomliggande orsaker och processer.
95. Axelsson, H., (2003): Sårbarhetskartering av bekämpningsmedels läckage till grundvattnet – Tillämpat på vattenskyddsområdet Ignaberga-Hässleholm.
96. Hedberg, M., Jönsson, L., (2003): Geografiska Informationssystem på Internet – En webbaserad GIS-applikation med kalknings- och försurningsinformation för Kronobergs län.
97. Svensson, J., (2003): Wind Throw Damages on Forests – Frequency and Associated Pressure Patterns 1961-1990 and in a Future Climate Scenario.

98. Stroh, E., (2003): Analys av fiskrättsförhållandena i Stockholms skärgård i relation till känsliga områden samt fysisk störning.
99. Bäckstrand, K., (2004): The dynamics of non-methane hydrocarbons and other trace gas fluxes on a subarctic mire in northern Sweden.
100. Hahn, K., (2004): Termohalin cirkulation i Nordatlanten.
101. Lina Möllerström (2004): Modelling soil temperature & soil water availability in semi-arid Sudan: validation and testing.
102. Setterby, Y., (2004): Igenväxande hagmarkers förekomst och tillstånd i Västra Götaland.
103. Edlundh, L., (2004): Utveckling av en metodik för att med hjälp av lagerföljdsdata och geografiska informationssystem (GIS) modellera och rekonstruera våtmarker i Skåne.
104. Schubert, P., (2004): Cultivation potential in Hambantota district, Sri Lanka
105. Brage, T., (2004): Kvalitetskontroll av servicedatabasen Sisyla
106. Sjöström., M., (2004): Investigating Vegetation Changes in the African Sahel 1982-2002: A Comparative Analysis Using Landsat, MODIS and AVHRR Remote Sensing Data
107. Danilovic, A., Stenqvist, M., (2004): Naturlig föryngring av skog
108. Materia, S., (2004): Forests acting as a carbon source: analysis of two possible causes for Norunda forest site
109. Hinderson, T., (2004): Analysing environmental change in semi-arid areas in Kordofan, Sudan
110. Andersson, J., (2004): Skånska småvatten nu och då - jämförelse mellan 1940, 1980 och 2000-talet
111. Tränk, L., (2005): Kadmium i skånska vattendrag – en metodstudie i föroreningsmodellering.
112. Nilsson, E., Svensson, A.-K., (2005): Agro-Ecological Assessment of Phonxay District, Luang Phrabang Province, Lao PDR. A Minor Field Study.
113. Svensson, S., (2005): Snowcover dynamics and plant phenology extraction using digital camera images and its relation to CO2 fluxes at Stordalen mire, Northern Sweden.
114. Barth, P. von., (2005): Småvatten då och nu. En förändringsstudie av småvatten och deras kväveretentionsförmåga.
115. Areskoug, M., (2005): Planering av dagsutflykter på Island med nätverkanalys
116. Lund, M., (2005): Winter dynamics of the greenhouse gas exchange in a natural bog.
117. Persson, E., (2005): Effect of leaf optical properties on remote sensing of leaf area index in deciduous forest.
118. Mjöfors, K., (2005): How does elevated atmospheric CO2 concentration affect vegetation productivity?
119. Tollebäck, E.,(2005): Modellering av kväveavskiljningen under fyra år i en anlagd våtmark på Lilla Böslid, Halland
120. Isacsson, C., (2005): Empiriska samband mellan fältdata och satellitdata – för olika bokskogområden i södra Sverige.
121. Bergström, D., Malmros, C., (2005): Finding potential sites for small-scale Hydro Power in Uganda: a step to assist the rural electrification by the use of GIS

122. Magnusson, A., (2005): Kartering av skogsskador hos bok och ek i södra Sverige med hjälp av satellitdata.
123. Levallius, J., (2005): Green roofs on municipal buildings in Lund – Modeling potential environmenta benefits.
124. Florén, K., Olsson, M., (2006): Glacifluviala avlagrings- och erosionsformer I sydöstra Skåne – en sedimentologisk och geomorfologisk undersökning.
125. Liljewalch-Fogelmark, K., (2006): Tågbuller i Skåne – befolkningens exponering.
126. Irminger Street, T., (2006): The effects of landscape configuration on species richness and diversity in semi-natural grasslands on Öland – a preliminary study.
127. Karlberg, H., (2006): Vegetationsinventering med rumsligt högupplösande satellitdata – en studie av QuickBirddata för kartläggning av gräsmark och konnektivitet i landskapet.
128 Malmgren, A., (2006): Stormskador. En fjärranalytisk studie av stormen Gudruns skogsskador och dess orsaker.
129 Olofsson, J., (2006): Effects of human land-use on the global carbon cycle during the last 6000 years.
130 Johansson , T., (2006): Uppskattning av nettoprimärproduktionen (NPP) i stormfällen efter stormen Gudrun med hjälp av satellitdata.
131 Eckeskog, M., (2006) Spatial distribution of hydraulic conductivity in the Rio Sucio drainage basin, Nicaragua.
132 Lagerstedt, J., (2006): The effects of managed ruminants grazing on the global carbon cycle and greenhouse gas forcing.
133 Persson, P., (2007) Investigating the Impact of Ground Reflectance on Satellite Estimates of Forest Leaf Area Index
134 Valoczi, P. (2007) Koldioxidbalans och koldioxidinnehållsimulering av barrskog I Kristianstads län, samt klimatförändringens inverkan på skogen.
135 Johansson, H. (2007) Dalby Söderskog - en studie av trädarternas sammansättning 1921 jämfört med 2005