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Analysing the Cleaning Capacity of Lake Hammarsjön and the Origin of Brownification in Helgeån's Drainage Basin

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A. Economic Valuation of Wetland Services

1. Introduction

The Millennium Ecosystem Assessment showed that human activities have a wide impact on ecosystems. This is true for the present times more then ever before. Ecosystems underlie a rapid change, a large amount of habitat is lost. The report also showed that wetland ecosystems are particularly affected by these changes. It will be a challenge to articulate the need to stop these changes and implement protection strategies into local planning processes in the future (McInnes 2007, p. 7).

One way to create a broader understanding of the functions of wetlands and the benefits humans gain from it is to evaluate the ecosystem services economically. Nature is often looked at as a common good that can be exploited without any specific costs for society. On the contrary some people might think that nature is unused capital that has to be transformed to yield a profit. There is no incentive for conservation. The recognition of the importance of ecosystems can be increased by emphasizing the services that wetlands provide for humanity. Associating these services with specific monetary values helps to improve the position of conservation in decision processes and to establish a method of attributing costs to ecosystem loss (Constanza et al 1989).

1.1 Types of Wetland Services

There are many different ecosystem services that wetlands provide. Some services are also provided by other ecosystem types while others are unique to wetlands. It is possible to achieve some of these services with man-made substitutes. The costs of substitution however fluctuate. They depend on the type of service that shall be substituted and on local conditions. To determine the costs of substituting an ecosystem service is one way to valuate it. Other types of ecosystem services need to be valuated with different measures. It has to be decided case-by-case, which method needs to be applied.

In every case it is important to identify all services of the examined wetland when starting with a valuation. In some cases may be enough to valuate the most important benefits to see that the costs of loss are higher than the gains of alternative usage. In other cases all services may need to be valuated in order to be able to judge about their worthiness (Barbier et al 1997).

To identify all benefits of a wetland it is helpful to review what others have identified as ecosystem services of wetlands. The Millennium Ecosystem Assessment report identified four general categories of wetland services: provisioning functions, regulative functions, cultural functions and supporting functions. All categories include services that have both direct and indirect effects on human well-being. A more detailed list of Ecosystem services provided by wetlands can be found in table 1.

Not all of these services are present in wetlands worldwide. The list shall rather be regarded as an inspiration and guideline for own research. For every specific case there may be services whose presence can be affirmed or negated from the beginning, while the presence of other services has to be verified in detail. Subsequently it has to be determined which services are most important and which are easiest to valuate. This includes a choice of valuation methods for each service. If the execution of an own valuation is too expensive benefit transfers might be an alternative (see Box 1)

Table 1. Ecosystem Services Provided by or Derived from Wetlands

Services	**Comments and Examples**
Provisioning	
Food	production of fish, wild game, fruits and grains
Fresh water	storage and retention of water for domestic, industrial and agricultural use
Fibre and fuel	production of logs, fuelwood, peat, fodder
Biochemical	extraction of medicines and other materials from biota
Genetic Materials	genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows	groundwater recharge/discharge
Water purification and waste treatment	retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	retention of soils and sediments
Natural hazard regulation	flood control, storm protection
Pollination	habitat for pollinators
Cultural	
Spiritual and inspirational	source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	opportunities for recreational activities
Aesthetic	many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	opportunities for formal and informal education and training
Supporting	
Soil formation	sediment retention and accumulation of organic matter
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients

(Source: Millennium Ecosystem Assessment 2005, p.2)

Box 1. Benefit Transfers

The practice of using results of a study that already exists to estimate the value of another ecosystem is referred to as a “benefit transfer”. They can be useful when there is insufficient data available or there is no budget available for an own assessment. Whether a benefit transfer can be applied successfully depends on different factors. First of all, the two sites need to have certain similarities. These similarity can be characteristics of the site, but also of their markets and users. Some benefits are easier to transfer than others. For example the valuation of health impacts of the ecosystem is easier to transfer than the recreation values, as recreation values highly depend on the individual visual characteristics of the site. Incorporating measuring results from the own ecosystem makes it easier to apply benefit transfers. It is helpful if there were detailed notes about the recording and valuation process in the original study, so that the quality and appropriateness of the source data can be evaluated. If the valuation report contains more informations it also makes it easier to compare it with the data from the own ecosystem and estimate if a benefit transfer can be accessed successfully. (Barbier et al 1997)

1.2 The Case of Lake Hammarsjön

The river Helgeån is situated in the south of Sweden. His drainage basin's northern end is near Rydaholm in Jönköping County. The southern end is about 130 km in the south where Helge å flows into the Baltic Sea. The biggest city in the drainage basin is Kristianstad with about 30,000 inhabitants. This is a city surrounded by wetlands, notably the lakes Araslövssjön, Råbelövssjön and Hammarsjön. Helgeån runs through lake Araslövssjön upstream Kristianstad and lake Hammarsjön downstream Kristianstad. It can be assumed, that the value of the surrounding wetlands for humans in the city in close proximity is exceptionally high.

One aspect of water management that is definitely affected by the city of Kristianstad is the water quality. The concentrations of nitrogen and phosphor in the outlet of the sewage treatment plant for example are considerably higher than the concentrations in the main stream of the river. It is of interest for the community, if lake Hammarsjön possesses a water purification and waste treatment function that can compensate these inputs. This document will focus on an analysis of concentrations of nutrients and pollutants before and after lake Hammarsjön. With creation of balance sheets the extent of this function shall be determined, in order to allow an economic valuation afterwards.

2. Material and Methods

The aim of this analysis is to compare the concentrations of nutrients and pollutants in the water flowing into lake Hammarsjön with the concentrations in the water flowing out of lake Hammarsjön. The first step is to collect the necessary data for this analysis.

Image 1: Sampling Stations Near Lake Hammarsjön. Source: Google Earth

To determine the concentrations in the outflow of Hammarsjön only one data set is necessary. The inflow however needs a more detailed research. There are several sources of water flowing into Hammarsjön. The main source is the river Helgeån, which leaves lake Araslövssjön a few kilometres further north, passes Kristianstad and then enters lake Hammarsjön. However, no data is available for the river Helgeån downstream Araslövssjön for recent years. Sampling at Långebro ended in 1999. Therefore data from a station before Araslövssjön has to be used. This entails that a lower percentage of the incoming water is captured. For a partially compensation of this deficit more data can be included. There is another operative station at the river Vinnö å, directly before the inflow into lake Araslövssjön. The data set from this station is an important addition to the total inflow data set that has to be created.

Other sources of water are the six pumping stations of Kristianstad and three smaller streams that enter lake Hammarsjön directly. There is no recent data available for these sources. However, recordings exist for the outflow of the sewage treatment plant of Kristianstad. The water from there flows into Hammarsjön through the pumping station Pynten. Additionally, rain water and ground water enter the lake.

The data from the stations “Helgeån at Torsebro (Torsebro)”, “Vinnöån, before entering Araslövssjön (Vinnöån)” and “Helgeån, downstream Hammarsjön (Outflow)”, as well as the data from the non-active stations “Helgeån at Långebro (Långebro)”, Råbelövskanalen in Nosaby, Kristianstad (Nosaby)” and “Pumping Station 'Pynten' (Pynten)” are taken from the project “SRK, Helge ån vattendrag” by the “SLU – Institutionen för vatten och miljö”. Data from the Station “Sewage Treatment Plant of Kristianstad (STP)” was recorded by the Sewage Treatment Plant of Kristianstad. All data is available on a monthly basis.

Data from the STP was only available for discharge, total nitrogen and total phosphor. All other analyses had to be done with only two datasets for the inflow. These substances were sulfate, chloride, iron, total organic compounds (TOC) and colour.

In order to create the total inflow dataset the monthly discharge data of each station is combined for each month. The data for nitrogen and phosphor are combined in a ratio according to the percentage of discharge (compared to total discharge) that month at the respective station. For months where no discharge data is available, but nutrient or nitrogen data was measured, the percentage of total discharge at that station was used. When a value was missing in one of the data sets, the whole month was omitted in the statistics.

Due to the low distance to the Baltic Sea there was also the question if seawater enters the lake and distorts the results. To eliminate this distortion an analysis of Conductivity was performed. As conductivity is an indicator for high salinity and therefore for seawater, months with increased values were also excluded from the whole analysis.

3. Results and Discussion

In this chapter the results of the analysis are presented and an interpretation is provided directly.

3.1 Conductivity

While the conductivity in the total inflow dataset was relatively constant (mean value: 14,87 mS/m, peak value: 35,91 mS/m), there were huge outliers in the outflow (mean value: 48,60 mS/m, peak value: 1060 mS/m). This is an indication for water from the Baltic Sea entering lake Hammarsjön. As a result of this, every value that was higher than 50 mS/m was considered unnaturally high and taken out of the dataset. Every value higher than 35 mS/m that was measured in a month following a month with an unnaturally high value was also omitted. This lead to an exclusion of 51 values in total. After the values were taken out, the mean conductivity in the outflow was at 18,0 mS/m, which is a more realistic value for a freshwater ecosystem.

The tendency for water entering form the Baltic Sea is decreasing. There is a correlation between high conductivity and low discharge. This indicates that water from the Baltic Sea can flow upstream and enter lake Hammarsjön in months when the general water level of the river Helgeån is low.

3.2 Discharge

The discharge of the inflow was calculated based on datasets from Torsebro, Vinnöån and the STP. It showed that the water from Torsebro was the main source of water, with a mean percentage of 93,11 % of the total inflow. Data was not available for all years, but in the period where it was available (1979-1996, 2000-2004) the linear regression was obviously negative, starting at 45,09 m³/s in 1979 and ending at 27,57 m³/s in 2004. This means there has been a decrease in discharge recently.

The data from Vinnöån showed a mean percentage of 6,23 % (2,58 m³/s) and no visible trend towards increase or decrease. The discharge at the STP was very low, with only 0,66 % of the total inflow. However, a constant increase was visible over the years, with the linear regression starting at 0,22 m³/s in 1976 to 0,3 m³/s in the end of 2008. The total inflow dataset includes 86,43 % (41,47 m³/s) of water compared to the discharge that was measured in the outflow of lake Hammarsjön (47,98 m³/s). This means that about 13,5 % of the incoming water come from other sources and are not captured in this study. Without the water from the STP the mean inflow is at only 85,86 % (41,19 m³/s) of the outflow value.

The discharge at the outflow of lake Hammarsjön has a decreasing tendency, but not as high as the discharge at Torsebro. This means that part of the decrease of water in Helgeån is compensated by the increase of water from other sources, for example from the STP.

3.3 Total Nitrogen

In the case of lake Hammarsjön the origin of nitrogen can be determined as follows: the concentration in the river Helgeån is the lowest of all examined sources with a mean value of 1,5 mg/l. The concentration of nitrogen in Vinnöån is significantly higher, with 4,6 mg/l. However, extreme values can be measured at the STP. With a mean value of 17,0 mg/l the concentration there is more than ten times as high as in Helgeån before entering lake Araslövssjön.

Due to the extremely high concentrations in the water of Vinnöån and the STP these sources have a significant influence on the total inflow concentration, although the discharge is much lower than that of river Helgeån at Torsebro. This becomes clear if the results are compared to the outflow values. With 1,6 mg/l at the outflow the concentration is slightly above the 1,5 mg/l at Torsebro. If all inflow values are combined however, the total inflow is with 1,8 mg/l above this value. This is a surplus of 13,42 % and indicates a cleaning function of the lake.

As there still is the possibility that the sources that were not captured have lower nitrogen concentrations, this can not be valid as a proof. Instead it is necessary to convert the mean values of the dataset [mg/l] into total values [mg]. This shows that 205 t of nitrogen enter lake Hammarsjön monthly, while 214 t of nitrogen flow out of the lake. The amount of nitrogen in the inflow equals 95,73 % of the nitrogen in the water flowing out of lake Hammarsjön. These results still do not demonstrate completely that lake Hammarsjön has a cleaning function. But the inflow concentration almost equals the outflow concentration, while still 13,57 % of the water is missing in the equation. This means, that the concentration of the water that is remains not covered has to be lower than 0,54 mg/l to not exceed the outflow value. When comparing this to the other local sources, it seems rather unlikely that the concentration would be that low. Therefore it can be assumed, that nitrogen is consumed while the water passes lake Hammarsjön.

3.4 Total Phosphor

Similar to the results of total nitrogen, the results for phosphor at the inflow are lowest at the station in Torsebro (35,71 µg/l), high at the station at river Vinnöån (130,78 µg/l) and extremely high at the outflow of the STP (352,01 µg/l). This results in a higher mean concentration for total phosphor in the inflow of lake Hammarsjön (44,46 µg/l) than in the outflow (43,37 µg/l). With 2,51 % this surplus is relatively small. When adding it up to a total phosphor amount per month, the inflow (4,6 t) is only at 81,52 % of the outflow (5,7 t).

3.5 Other substances

For all other substances there is no available data for the STP. That reduces the percentage of incoming water covered by the analysis from 86,43 % to 85,86 %. While this may seem like only a minor change, the previous chapters have proven that concentrations in the outflow of the STP can be high enough to have a significant influence of the total constitution of water in lake Hammarsjön. Because of this, the following results may be an underestimate of the real substance concentrations in the inflow of lake Hammarsjön.

Other substances that were analysed were colour, sulfate, iron and total organic carbon.

Concerning colour, the mean concentration of the inflow (143,43 mg Pt/l) is above the concentration of the outflow (131,70 mg Pt/l). This is a surplus of 8,84 %. When the monthly rate is calculated however, a negative result comes out. Here the inflow (15755,51 t Pt) is 8,13 % below the outflow rate (17150,22 t Pt). This can be attributed to the missing data from other sources. It can be assumed, that the real inflow rate may be above and that the water may get cleaner while it flows through lake Hammarsjön.
It is also apparent, that the colour in the lake is increasing, whereas the concentrations in the inflow (linear regression = 0,45x + 74,17) are rising faster than those in the outflow (linear regression = 0,38x + 61,72).

An analysis of sulfate was possible for the time between January 2000 and December 2008. In this period there was a strong surplus of mean concentration in the outflow (13,6 mg/l), compared to the inflow (10,72 mg/l). This is equivalent with 20,96 % and is not caused by outliers, but by a consistent surplus of sulfate in the outflow. A mean concentration of about 31 mg/l in the uncovered sources would be necessary to equal the concentration in theoutflow. That this is a possible figure is shown by the fact that the mean concentration of sulfate in Vinnöån is 31,13 mg/l. However, it is impossible to determine if the concentrations are higher than that. Therefore on the basis of recent knowledge it can not be stated that the wetlands of lake Hammarsjön clean the water from sulfate.

Data for iron was available for the period between January 2000 and November 2006. With the beginning of 2003 the values started to become very inconsistent, so that in total there were only 53 single figures good enough to include in this analysis. What can be said from these is, that the mean concentration of iron in the inflow (1,76 mg/l) is slightly above the mean concentration of iron in the outflow (1,70 mg/l). But it is not high enough to declare a cleaning function of lake Hammarsjön for this substance.

Records for total organic carbon are present for the period between January 1990 and December 2008. The mean concentration in the inflow of lake Hammarsjön (16,42 mg/l) is slightly above the mean concentration in the outflow (16,10 mg/l). However, due to the uncovered sources no definite conclusions can be made concerning a cleaning function of the wetlands.

4. Conclusions

Because of the incomplete dataset for the inflow of lake Hammarsjön it is impossible to certify the cleaning function of lake Hammarsjön. It is relatively secure to assume that the concentration of total nitrogen flowing into the lake is higher than that in the outflow which indicates a cleaning function of the lake, at least regarding nitrogen.

For the other substances the concentration in the inflow is either not high enough to bridge the gap in data or is even lower than the concentration in the outflow. To fill the gap is difficult, as the available data is measured over a long period of time and single measurements will not do justice to the accuracy needed for this kind of analysis. Monthly measurement would have to be performed for a longer period at all pumping stations and the ditches that enter lake Hammarsjön directly. As this would be a project with high expenses, alternatives have to be considered.

The validation of the cleaning capacity of lake Hammarsjön was chosen as an example how to validate an ecosystem function because it seemed to be one of the easiest ecosystem services to validate in the beginning. In the progress it has turned out to be rather complicated.

As the economic validation of this singular benefit from the ecosystem turns out to be cost-intensive it can be assumed that a validation of all services of this wetland could exceed the gains of knowledge taken from an analysis. A validation of all wetlands of the whole Vattenriket biosphere reserve would be many times over that. Hence alternative methods have to be considered.
One alternative could be a benefit transfer.

Box 2. Sewage Treatment Plant Kristianstad

From the sewage treatment plant of Kristianstad data is available for four different issues: discharge at the outflow of the STP, nitrogen concentrations in that outflow, phosphor concentrations in that outflow and precipitation data.

The discharge at the outflow of the STP increases over the time from 1968 to 2008. Linear regression gives us a trend line with an average increase of 0,16 l/s per month, starting at a discharge of 0,22 m³/s in 1968 and ending up at approximately 0,3 m³/s in 2008.

The nitrogen data shows a clear decrease, the linear regression shows a decrease of 55,9 µg/l for each month. The trend line starts at 27159,8 µg/l in 1978 and ends at about 5000 µg/l in 2008. A major break can be observed at the end of 1992. Beginning with 1993 the nitrogen level is clearly below the level previous to the break. The mean value is at 16747,6 µg/l.

The data for phosphor shows a distinctly lower mean value of 477,0 µg/l. The average decrease in linear regression is at 3,5 µg/l per month, which is a significant decrease, compared to the lower mean value. The trend line starts at 1163,72 µg/l in 1976 and turns negative in 2003. This is due to some extreme outliers, mainly in the first period of measurement. Without these outliers the monthly decrease would only be at 1,1 µg/l.

Due to the increased discharge at the outflow of the STP the influence of this source is growing. It is a success that the concentrations of nitrogen and phosphor in the water have decreased in a larger matter than the increase in flow. However, the concentrations of these substances are still a lot higher than in the main stream of river Helgeån and it can be expected these are not the only substances with unnaturally high concentrations there.

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B. Colour In the Drainage Basin of River Helgeån

1. Introduction

Over the last two decades an increase in watercolour in the lakes and rivers in the south of Sweden has occurred. This increase is mainly inflicted by an increase in humic substances, which absorb light. These substances emerge from decaying plants and other organisms. (Kaién 2007a)

A widely debated, but still unanswered question is what caused this increase in colour. Different theories about causes for the brownification exist. They include change in land-use patterns, developments related to climate change (e.g. change in precipitation patterns), change in water origin and decrease in sulphuric rain and because of that the recovery from acidification. Eventually, it is a combination of all of those factors playing together (Kaién 2007b, p.3-4).

To gain further insights into the origin of watercolour this study focusses on the drainage basin of river Helgeån. Data from measuring stations at different points of the river are used to analyse the development of colour between 1969 and 2008. Spatial and temporal data is included. The aim of the study is to find out where the increase in watercolour was biggest.

1.1 Helgeån's Drainage Basin

The river Helgeån is situated in the south of Sweden. His drainage basin's northern end is near Rydaholm in Jönköping County. The southern end is about 130 km south where Helge å flows into the Baltic Sea. The biggest city in the drainage basin is Kristianstad with about 30,000 inhabitants.

Helgeån emerges from lake and flows through lake Möckeln, which is also fed by the streams Agunnarydsån and Målenån. In its further course the streams Vissjöån, Prästebodaån, Verumsån, Drivån, Killingaån, Olingeån, Almaån, Bivarödsån, Vinnöån, Vramsån, Mjöån and Vittskövleån flow into river Helgeån. In Kristianstad six pumping stations pump water into the river. This water comes from the drained and colonized wetlands under the city, the nearby lake Råbelövssjön and the local sewage treatment plant.

There are measuring stations located at the major inflows of these streams into river Helgeån and at other significant points of the river's course. Additionally, some measuring stations are located at significant points of the streams flowing into river Helgeån.

2. Material and Methods

The objective of this analysis is to find out if there are parts of the drainage basin where the watercolour has increased faster than in others. This could indicate if there are any regions where the colour in the water comes from in particular. For this study data from every measuring point of the project “SRK, Helge ån vattendrag” by the “SLU – Institutionen för vatten och miljö” was analysed. There was a great amount of stations that didn't supply any data for recent years. There even were some stations that were only operational for three years and solely during the 1970s. These stations were included in parts of the analysis in order to see any abnormal characteristics and to give some hints where further observation is necessary. However, they were omitted in the main analysis of the brownification. Only stations that are still active were included, as the increase in colour is a phenomenon that has occurred mainly during the last decade.

For each station a profile was created, including the period of observation, the development of the values, the trend, the maximum value and the mean value. A comparison of the mean values between the different measuring stations was performed. To minimise the influence of the different starting years of the stations the datasets were edited to all start in 1990. The mean values were also attributed to a map of the catchment area to see where the highest loads appear. Linear regression was performed for every dataset and the gradient of the trend line was used to determine the specific increase in colour for every station. Those increases were compared to one another. The mean values of the non-active stations were analysed to find out more about which regions are particularly affected by brownification.

The highest value in each dataset was used as a “maximum value”. These maximum values were compared between the different stations. The results were compared to the results from the analysis of the mean values to find out if there would be any similarity. It was analysed if there were any years in which watercolour was particularly high in several streams and rivers. The results were compared to precipitation data from Kristianstad's sewage treatment plant to find out if major rain events have an influence on the watercolour.

3. Results and Discussion

In this chapter the results of the analysis are presented and an interpretation is provided directly.

3.1 Mean Colour

The values for mean colour were analysed for all stations. A special focus is given to the stations that were still active at the end of 2008. Those were 20 stations in total of which one was launched in 1969, twenty-two were launched in 1976, five in 1983 and two in 1991. The stations were summed up in a table (6. Appendix, Table 1) according to the size of their mean colour concentrations.

If the order of the stations in the table is analysed it becomes obvious that the stations that were launched after 1976 have an above average mean value for colour. If all stations are divided into the two categories “old” (started 1976 or earlier) and “new” (started after 1976) this observation is confirmed. Six of the seven “new” stations are among the ten highest positions in the table. There are two possible explanations for this:

(a) it is due to the increase in colour that the values measured in the 1970s were lower than more recent values. Because of that they diminish the mean values of their specific stations and so the “old” stations have a lower mean values than the “new” stations.
(b) the “new” stations are located at points where a higher colour can be expected anyway.

To identify which theory is true, two methods can be applied. One is to reset the start of all datasets to 1990. If the mean values of the “old” stations increase after the reset, it is proof for explanation (a). The other method is to compare the “old” and “new” stations on a map to determine if there is a resemblance between a later launch and the geographical position. This would be proof for explanation (b).

3.1.1 Reset of the datasets

After the datasets were reset to start in 1990 (except the two datasets which start in 1991) the results were summed up in a table similar to the first one (6. Appendix, Table 2). In addition, the change in mg Pt/l was calculated.

The table itself shows only a small difference to the first table. Still six of the “new” stations are among the ten stations with the highest mean values. The change in mg Pt/l in comparison to the old values however shows a clear tendency. For all datasets there has been an increase. While the mean change for the “new” stations is + 4,33 mg Pt/l, the mean increase for the “old” stations is +

18,99 mg Pt/l. This shows that explanation (a) is correct, but can not be hold accountable to be the only reason for the above-average mean values of the “new” stations. The phenomenon can not be explained in its whole extent. An analysis of the geographical distribution has to be performed in order to validate explanation (b).

3.1.2 Geographical Distribution

To see if the geographical distribution of the “new” stations has anything to do with their high colour content, it is necessary to find out if colour has an even geographical distribution or if there are regions of the catchment area where colour is more apparent than in others. To do so, all stations are divided into five groups, according to their mean concentrations of colour in mg Pt/l. Each station is marked on a map of the area (Image 1), the colour content is indicated by different colours. In this analysis all stations are included, even the ones that are not active any longer.

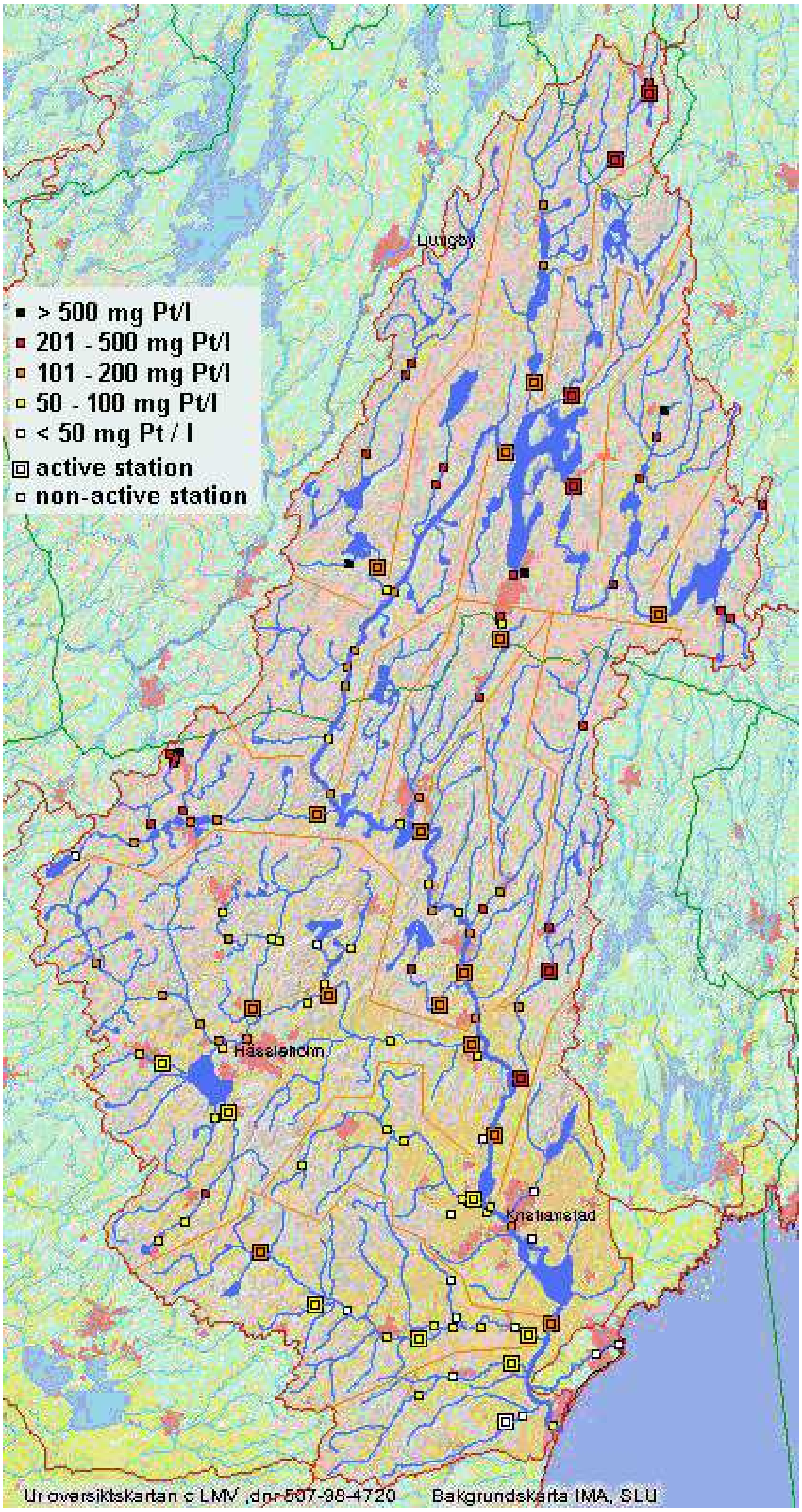

Image 2: Map of Mean Colour (All Stations). Source: SLU

It is noticeable that colour is higher in the northern streams and rivers. High values can be seen at the rivers and streams upstream of Lake Möckeln and the catchment areas of Prästebodaån, Vissjöån, Verumsån, Drivån, Klingaån and Bivarödsån. A major change in colour content can be seen at Almaån's catchment area, where only one mean value of more than 200 mg Pt/l has been measured. This tendency continues with the streams and rivers in the far south of Helgeån's catchment area. Vinnöån, Vramsån, Mjöån and Vittskövleån all have moderate mean values for colour content.

The stations that are still active seem to be well-distributed. There is an active stations at most inflows of small rivers into bigger rivers and at other significant locations. A tendency that the mean values of these stations are slightly higher than those in the immediate surrounding can be observed. However, there are no active stations where the colour has been extremely high over the whole period of time. All four stations with a mean value of more than 500 mg Pt/l were only operational in the 1980s.

Considering these results it seems likely that the position of the measuring stations could be an explanation for the differences between the "new" and the "old" stations.

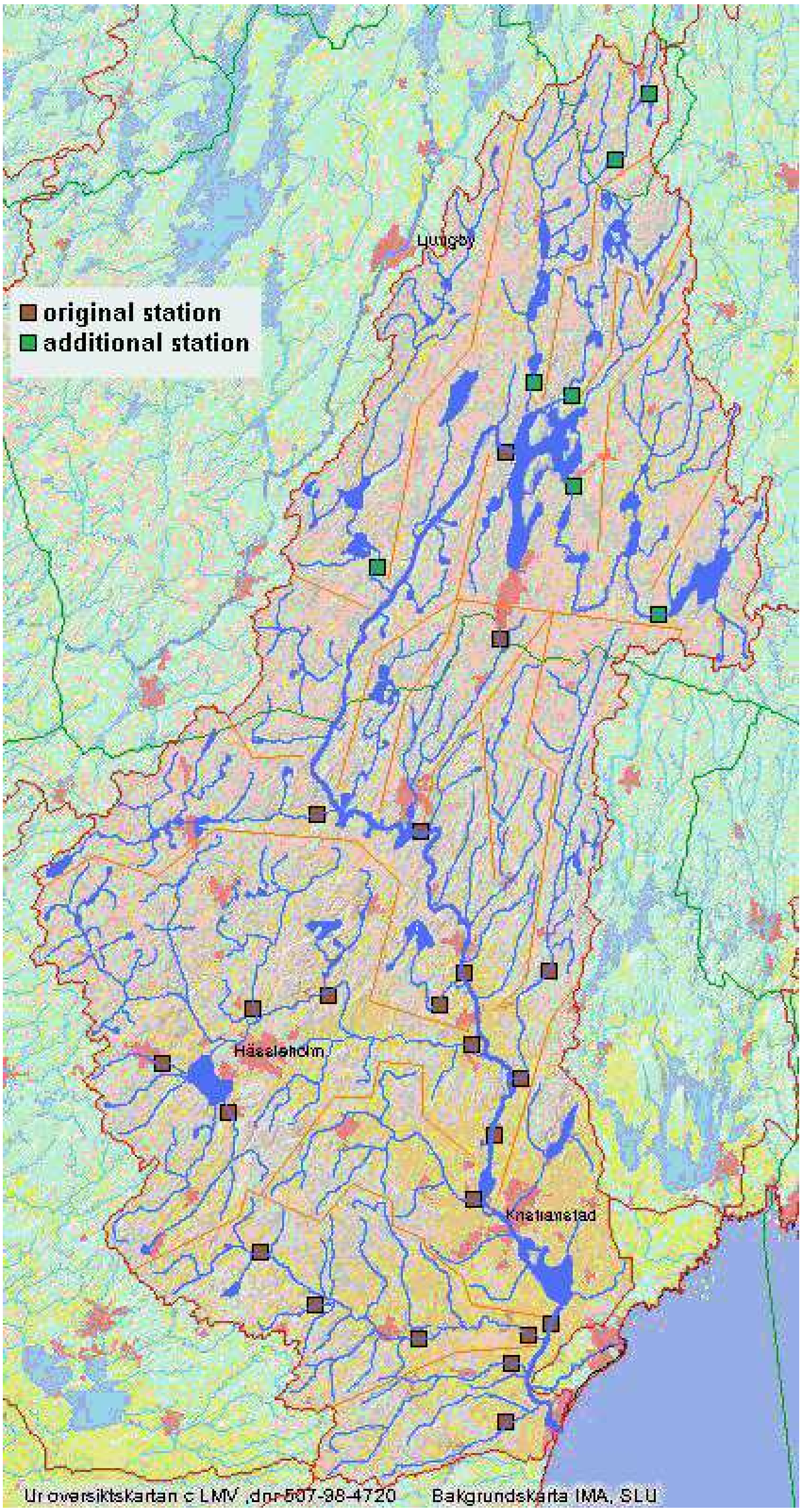

Image 3: Map of "Old" and "New" Stations. Source: SLU

To proof that explanation (b) is true, the map of the catchment area was edited. This time the "old" and "new" stations are marked with different colours. Considering that watercolour has been proven to be most apparent in the north, it can be expected that the "new" stations are located in the north of the drainage basin.

As Image 2 shows, this assumption is true. All "new" stations are located in the northern part of Helgeån's drainage basin. Most of them at the streams flowing into lake Möckeln. As seen in Image 1, this is the part of the drainage basin where colour is most apparent. Therefore it is possible to draw the conclusion that this also contributes to the above-average values of the "new" stations. Explanation (b) is true.

Altogether it can be said that the higher colour at the additional stations (observed in 2.2) can be attributed to explanation (a) and (b). A general increase in colour since the 1980s has occurred and the "new" stations are located in areas where there already are high concentrations of colour.

3.1.3 Tendency

For the corrected datasets linear regression was performed for each station. The gradient of the trend line was used to see where the increase in colour was fastest. The results were added to table 2 (6. Appendix).

The gradient – which expresses the mean increase per year – is higher at stations with a high mean value. This can be seen in Diagram 1. The higher the position in Table 2, the higher the gradient. The lower the position, the lower the gradient. This means that brownification increases fastest in regions where a high amount of watercolour is already apparent.

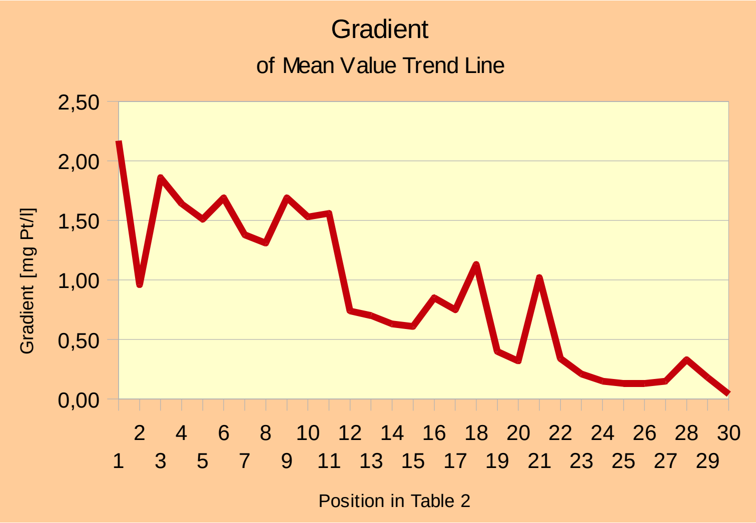

Diagram 1: Gradient

The station where the increase in colour is fastest is “Bivarödsån, vid Hylta” with an average monthly increase of 2,17 mg Pt/l. This is also the station that has the highest mean value for colour anyway. The station where the has the lowest gradient is “Vittskövleån, bakom fotbollsplanen” with an average monthly increase of only 0,04 mg Pt/l.

If the gradients of all datasets are combined the mean increase of colour for the whole drainage basin can be calculated. The tendency is a clear increase, with an average monthly gain of 0,87 mg Pt/l. This confirms the description of a brownification that can be found in Kaién 2007a.

3.1.4 Non-Operational Stations

Although there is a good number of stations that are still active at the moment, the majority of all measuring stations has already been closed. As the increase in colour has occurred recently, there was no sense in including data from those stations in the previous analyses about brownification. However those values are helpful to find out where the colour comes from in detail and which sections of the drainage basin have the highest mean values measured.

The mean values of all stations, operational and non-operational, were combined to one joint table (6. Appendix, Table 3). The result shows that there are non-operational stations where the mean value for colour is higher than the highest value measured that was represented in the past analyses (Bivarödsån vid Hylta). Thirteen stations in total had a higher mean value than this station. The first station (Enerydabäcken uppstr. Eneryda) is a vast outlier with an almost double as high mean value as the second station, Klockareån nedstr. Göteryd. Another remarkable result is that two streams appear several times in this statistic. These are Sågmöllebäcken (4x) and Enerydabäcken (2x). As seen in Image 1, the majority of the measuring stations with high colour values is located in the north of Helgeån's drainage basin.

3.2 Maximum Colour

The maximum value from each dataset is the value in the dataset where the content of colour (in mg Pt/l) was highest. Although this peak value is not as conclusive as the mean value of a dataset, some details about the development of colour can be derived from it.

3.2.1 Comparison to Mean Value

If the stations that are still active are listed in a table according to their maximum value (6. Appendix, Table 4), there are certain similarities to the table created for the mean values of each dataset. The two stations with the highest mean values are the same as the two stations with the highest single values that were measured (“Bivarödsån, vid Hylta” and “Bivarödsån, före utlopp I Helgeån”). Apart from that, the maximum values for the “new” stations are divided more evenly among the table. This is an indication that the high mean values of colour in these datasets are less influenced by outliers than the “old” ones and that the colour content is consistently high at these stations.

3.2.2 Annual Comparison

Insights into the development of colour can be gained by analysing in which year the maximum values occurred. Table 4 shows that there are two years in which especially high colour contents were measured: 1998 and 2007. Of all thirty stations that were included in this analysis, thirteen had their peak value in 2007 and ten in 1998. This means that most stations had their maximum values in the second half of the whole period under observation. That indicates an increasing trend.

If the mean maximum values for 1998 and 2007 are calculated, this trend is confirmed. While the ten maximums that occurred in 1998 have an average level of 445 mg Pt/l, the thirteen stations of 2007 have an average value of 643 mg Pt/l.

The question remains why in 1998 and 2007 such high values for colour were measured, but not in the years in between. An explanation could be, that in these years a particularly high precipitation occurred. A comparison with rain data could confirm this explanation (c).

3.2.3 Precipitation Data

A closer look at the years 1998 and 2007 shows that in both years the colour peak was mainly between August and October. Precipitation data from the sewage treatment plant (STP) in Kristianstad shows that in July 2007 very high precipitation was measured. This could be a proof that explanation (c) is correct. However, there is no similar event in 1998. Also, in August 2006 the value for precipitation was even higher but there was no comparable increase in colour at that time. So it may as well be possible that explanation (c) is not true at all and it was only coincidentally that the increase in 2007 was directly after a major precipitation event.

4. Conclusions

The results from the analysis have shown that there is a constant increase in the concentration in the drainage basin of river Helgeån. This increase appears in all rivers and streams of the drainage basin, although in some regions stronger than in others. Brownification has been fastest in Bivarödsån and in the north in the streams around lake Möckeln, where the water has already had quite a high colour content. In the streams in the south west of Kristianstad on the opposite the increase has been moderate and the overall colour of the water has been low from the beginning.

Among the stations that are not active any longer are some that had very high mean values during their running time. For further research it can be suggested to investigate the surroundings of the streams Sågmöllebäcken and Enerydabäcken, especially the conditions at the station “Enerydabäcken uppstr. Eneryda” where the by far highest mean value of the whole drainage basin was measured. Although it is unfortunate that these stations have been closed in the past it can be said that it is a positive development that seven stations that are still active have been launched there additionally in 1983 and 1991.

Some conclusions can be drawn from the analysis of the maximum values. An increasing tendency of watercolour can be confirmed as the highest maximum values occurred in 2007, towards the end of the period under review. The stations with the highest mean values also lead the list with the highest single content of colour that was measured. However, it remains unclear why most peak values were in 1998 and 2007. While a major precipitation event could be the explanation for the colour maximums in 2007 no similar event occurred in 1998. A major precipitation event in 2006 however had no consequences for the colour content.

5. Sources

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6. Appendix

Table 1. Mean Colour Values of All Active Stations

Station Name	Mean Value	Period of Review
Bivarödsån, vid Hylta	317,77 mg	1976 – 2008
Bivarödsån, före utlopp i Helgeån	235,96 mg	1976 – 2008
Målenån	232,74 mg	1991 – 2008
Sågasnässjöns utlopp	231,05 mg	1983 – 2008
Agunnarydsån, nedströms Stammaderna	223,60 mg	1983 – 2008
Agunnarydsån, Ryssbysjöns utlopp	207,86 mg	1983 – 2008
Verumsån, före utfl i Helgeån	198,81 mg	1976 – 2008
Prästebodaån, uppströms Delary	188,69 mg	1991 – 2008
Agunnarydssjöns utlopp	188,60 mg	1983 – 2008
Farstorpsån, före utflöde i Almaån	177,35 mg	1976 – 2008
Drivån, nedströms Älmhults AR	155,85 mg	1976 – 2008
Helgeån, utlopp ur Osbysjön	149,88 mg	1976 – 2008
Nöbbelöv kraftverksdamm	143,30 mg	1976 – 2008
Helgeån, vid Torsebro	140,66 mg	1976 – 2008
Almaån, nedströms Lillåns tillflöde	123,70 mg	1976 – 2008
Almaån, före utflöde i Helgeån	111,86 mg	1976 – 2008
Möckelns utlopp	110,63 mg	1976 – 2008
Femlingens utlopp	110,37 mg	1983 – 2008
Helgeån, nedstr. Hammarsjön	109,83 mg	1969 – 2008
Olingeån i Gryt	109,76 mg	1976 – 2008
Vramsån, uppströms Rickarum	100,46 mg	1976 – 2008
Svartevadsbäcken, nedströms Tyringe	82,09 mg	1976 – 2008
Tormestorpsån, före inlopp i Finjasjön	72,81 mg	1976 – 2008
Vramsån nedströms Tollarps AR vid Hommentorp	70,56 mg	1976 – 2008
Vramsån före utflöde i Helgeån	68,05 mg	1976 – 2008
Almaån, utlopp ur Finjasjön	66,10 mg	1976 – 2008
Vinnöån, före inlopp i Araslövssjön	58,00 mg	1976 – 2008
Lindebäck, vid Ullarp	56,86 mg	1976 – 2008
Mjöån, nedströms Everöds AR	51,47 mg	1976 – 2008
Vittskövleån, bakom fotbollsplanen	36,59 mg	1976 – 2008

Table 2. Mean Value and Gradient 1990-2008

Station Name	Mean Value	Change to Total	Gradient
Bivarödsån, vid Hylta	333,19 mg	+ 15,42 mg	2,17
Bivarödsån, före utlopp i Helgeån	266,79 mg	+ 30,83 mg	0,96
Sågasnässjöns utlopp	240,22 mg	+ 9,17 mg	1,86
Målenån	232,74 mg	± 0,00 mg	1,64
Verumsån, före utflöde i Helgeån	230,90 mg	+ 32,09 mg	1,51
Agunnarydsån, nedströms Stammaderna	230,00 mg	+ 6,40 mg	1,69
Agunnarydsån, nedströms Rydaholms ARV	215,76 mg	+ 7,90 mg	1,38
Farstorpsån, före utflöde i Almaån	206,93 mg	+ 29,58 mg	1,31
Agunnarydssjöns utlopp	193,62 mg	+ 5,02 mg	1,69
Prästebodaån, uppströms Delary	188,69 mg	± 0,00 mg	1,53
Nöbbelöv kraftverksdamm	177,70 mg	+ 34,40 mg	1,56
Helgeån, utlopp ur Osbysjön	173,53 mg	+ 23,65 mg	0,74
Drivån, nedströms Älmhults AR	170,33 mg	+14,48 mg	0,70
Helgeån, vid Torsebro	165,23 mg	+24,57 mg	0,63
Helgeån, nedstr. Hammasjön	149,21 mg	+ 39,38 mg	0,61
Almaån, nedströms Lillåns tillflöde	145,72 mg	+ 22,02 mg	0,85
Möckelns utlopp	135,94 mg	+25,31 mg	0,75
Olingeån i Gryt	134,91 mg	+ 25,15 mg	1,13
Almaån, före utflöde i Helgeån	133,07 mg	+ 21,21 mg	0,40
Vramsån, uppströms Rickarum	115,58 mg	+ 15,12 mg	0,32
Femlingens utlopp	112,20 mg	+ 1,83 mg	1,02
Svartevadsbäcken, nedströms Tyringe	96,53 mg	+ 14,44 mg	0,34
Tormestorpsån, före inlopp i Finjasjön	84,27 mg	+ 11,46 mg	0,21
Vramsån nedströms Tollarps AR vid Hommentorp	80,39 mg	+ 9,82 mg	0,15
Vramsån före utflöde i Helgeån	79,37 mg	+ 11,32 mg	0,13
Almaån, utlopp ur Finjasjön	74,75 mg	+ 8,65 mg	0,13
Vinnöån, före inlopp i Araslövssjön	68,30 mg	+ 10,30 mg	0,15
Lindebäck, vid Ullarp	67,30 mg	+ 10,44 mg	0,33
Mjöån, nedströms Everöds AR	56,56 mg	+ 5,09 mg	0,18
Vittskövleån, bakom fotbollsplanen	38,64 mg	+ 2,05 mg	0,04

Table 3. Other Stations

Station Name	Mean Value	Period of Review
Enerydabäcken uppstr. Eneryda	1160,42 mg	1983 – 1990
Klockareån nedstr. Göteryd	684,38 mg	1983 – 1990
Sågmöllebäcken, korsning m väg	625,48 mg	1989 – 1999
Bäcken från Äskya till Möckeln	534,57 mg	1983 – 1999
Bivarödsån, nedströms Hökön	482,39 mg	1976 – 1999
Sågmöllebäcken, 500 m nedströms diket	478,23 mg	1989 – 1999
Enerydabäcken nedstr. Eneryda	449,69 mg	1983 – 1990
Sågmöllebäcken 50 m uppstr. infl. fr. Dike	435,56 mg	1989 – 1990
Dike från Gotthard Nilsson AB till Möckeln	417,24 mg	1983 – 1999
Sågmöllebäcken	381,54 mg	1976 – 1985
Emmaljungabäcken	336,32 mg	1976 – 1999
Prästebodaån nedstr. S:a Ljunga	319,69 mg	1983 – 1990
Härlenbäcken uppstr. Häradsbäck	319,23 mg	1983 – 1990
Bivarödsån, vid Hylta	317,77 mg	1976 – 2008

Table 4. Maximum Values of All Active Stations

Station Name	Maximum	Year of Maximum	Period of Review
Bivarödsån, vid Hylta	1500 mg	1984	1976 – 2008
Bivarödsån, före utlopp i Helgeån	1000 mg	2007	1976 – 2008
Agunnarydsån, nedströms Stammaderna	900 mg	2007	1983 – 2008
Drivån, nedströms Älmhults AR	800 mg	1987	1976 – 2008
Almaån, utlopp ur Finjasjön	800 mg	1998	1976 – 2008
Målenån	800 mg	2007	1991 – 2008
Farstorpsån, före utflöde i Almaån	750 mg	2001	1976 – 2008
Sågasnässjöns utlopp	720 mg	2007	1983 – 2008
Almaån, nedströms Lillåns tillflöde	700 mg	1998	1976 – 2008
Olingeån i Gryt	700 mg	2000	1976 – 2008
Agunnarydsån, nedströms Rydaholms ARV	700 mg	2007	1983 – 2008
Verumsån, före utflöde i Helgeån	700 mg	2007	1976 – 2008
Helgeån , nedstr. Hammarsjön	620 mg	2007	1969 – 2008
Almaån, före utflöde i Helgeån	600 mg	1998	1976 – 2008
Agunnarydssjöns utlopp	570 mg	2007	1983 – 2008
Helgeån, utlopp ur Osbysjön	560 mg	2007	1976 – 2008
Helgeån, vid Torsebro	550 mg	2007	1976 – 2008
Femlingens utlopp	520 mg	2007	1983 – 2008
Prästebodaån, uppströms Delary	500 mg	1998	1991 – 2008
Svartevadsbäcken, nedströms Tyringe	500 mg	1998	1976 – 2008
Nöbbelöv kraftverksdamm	500 mg	2007	1976 – 2008
Möckelns utlopp	450 mg	1999	1976 – 2008
Tormestorpsån, före inlopp i Finjasjön	300 mg	1998	1976 – 2008
Vramsån, uppströms Rickarum	300 mg	1998	1976 – 2008
Mjöån, nedströms Everöds AR	280 mg	2001	1976 – 2008
Vinnöån, före inlopp i Araslövssjön	250 mg	1998	1976 – 2008
Vramsån nedströms Tollarps AR vid Hommentorp	250 mg	1998	1976 – 2008
Vramsån före utflöde i Helgeån	250 mg	1998	1976 – 2008
Vittskövleån, bakom fotbollsplanen	220 mg	2001	1976 – 2008
Lindebäck, vid Ullarp	220 mg	2007	1976 – 2008