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Ecological Changes in Lake Risten, Sweden, caused by Anthropogenic Influences

A Theoretical and Practical Study

Cristina Sendra Díaz
Peder Österlöf

Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University

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Authors:
Cristina Sendra Díaz
Peder Österlöf

Supervisor: Rolf Larsson
Co-supervisor: Lena Vought
Examiner: Linus Zhang

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Abstract

The ecological status in lake Risten, Sweden, is important in many ways. The lake is with its size a huge resource for recreation all around the year, since it provides good opportunities for activities like swimming, fishing and camping.

Lake Risten is the first big lake in the river system downstream the deposits of the former copper mine in Bersbo, which has been affecting its downstream recipients over many years, although a very successful restoration was accomplished during 1987-1989. The fish from the lake is to a high extent used for consumption, and therefore comprehensive investigations has been necessary to check if the concentrations of metals in the fish are low enough not to make out a risk for human health when consuming it. It has been discovered, from a literature study, that the nutrient status of a lake is crucial for the uptake of metals in fish.

Another problem in lake Risten, which has been more recently noticed by the local people, is an early stage of eutrophication. In the whole lake, but especially close to local nutrient sources from agriculture, an increase in under water vegetation and bottom sediment is occurring, which in turn is resulting in a change of habitats affecting the fauna of the lake. One species, which can be seriously affected by such a change, is the crayfish, and the fact is that the crayfish population has decreased over the last years. Whether the eutrophication is the main reason for the decrease or not cannot be stated without further investigations.

This thesis is based on a combination of analysis of a thorough literature study and practical work, in form of water sampling for measuring of nutrient values in the inlet- and outlet streams of the lake and measurements of physical parameters of those streams. The report presents the situation in which the lake is found today and its history, but more importantly it presents how its ecological status could be improved in the future by application of suggested solutions. The results from the measurements can not give a totally accurate answer, but it can hopefully give an idea of the situation and tell if further investigations are needed or not.

Sammanfattning

Den ekologiska statusen i sjön Risten är viktig på många sätt. Sjön utgör på grund av sin storlek resurs för rekreation året runt eftersom den har förutsättningar för aktiviteter såsom bad, fiske och camping.

Sjön Risten är den första stora sjön av sjöar nedströms gruvpedonierna efter den nedlagda koppargruvan i Bersbo som har påverkat sina nedströms recipienter under många år, även om en framgångsrik restaurering genomfördes åren 1987-1989. Fisken i sjön används i hög grad för konsumtion och omfattande undersökningar har därför varit nödvändiga för att klarlägga att metallhalterna i fisken inte är höga nog att utgöra en risk för människors hälsa vid konsumption. Det har, under en literaturstudie, noterats att näringsstatusen I en sjö är avgörande för upptaget av metaller i fisk.

Ett annat problem som på senare tid uppmärksammats i sjön Risten, av närboende personer, är ett tidigt stadium av övergödning. I hela sjön, men framför allt nära lokala näringskällor från jordbruk, sker det en ökning av bottenslam och undervattensvegetation, vilket i sin tur resulterar i en förändring av habitat som påverkar sjöns fauna. En art som kan bli allvarligt påverkad av en sådan förändring är kräftan, och faktum är att just kräftpopulation har minskat under de senaste åren. Huruvida övergödningen är huvudorsak till minskning eller inte kan inte fastställas utan vidare undersökningar.

Det här examnensarbetet är baserat på en kombination av grundliga literaturstudier och praktiskt arbete i form av insamling av vattenprover för mätning av näringsvärden i de in- och utgående dikena från sjön samt mätningar av dessa dikens fysikaliska parametrar. Rapporten beskriver den situation som sjön befinner sig i idag och dess historia, men framför allt så beskriver den hur sjöns ekologiska status kan förbättras i framtiden med de lösningar som föreslås. Resultaten från mätningarna kan inte ge en helt korrekt bedömning, men de kan förhoppningsvis ge en bild av situationen och avgöra om vidare undersökningar är nödvändiga eller ej.

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1 Introduction

Risten is an oligotrophic lake of approximately 5.7 km^2, located about 10 km north of the municipality of Åtvidaberg in the county of Östergötland, Sweden, and 200 km south-west of Stockholm. The lake is quite deep, with an average depth of 11 meters and a maximum depth of 33 meters. It therefore also contains a great volume of water, about 60 million cubic meters (Mm^3). It is draining an area of 91 km^2 and has a theoretical residence time of 4.5 years (Ledin et al. 1996). Lake Risten is a part of the river system Söderköpingsån (Vattenmyndigheterna, 2013). A map showing the location of lake Risten within Sweden can be seen in Figure 1, represented with a red dot. Figure 2 shows a more detailed location of lake Risten.

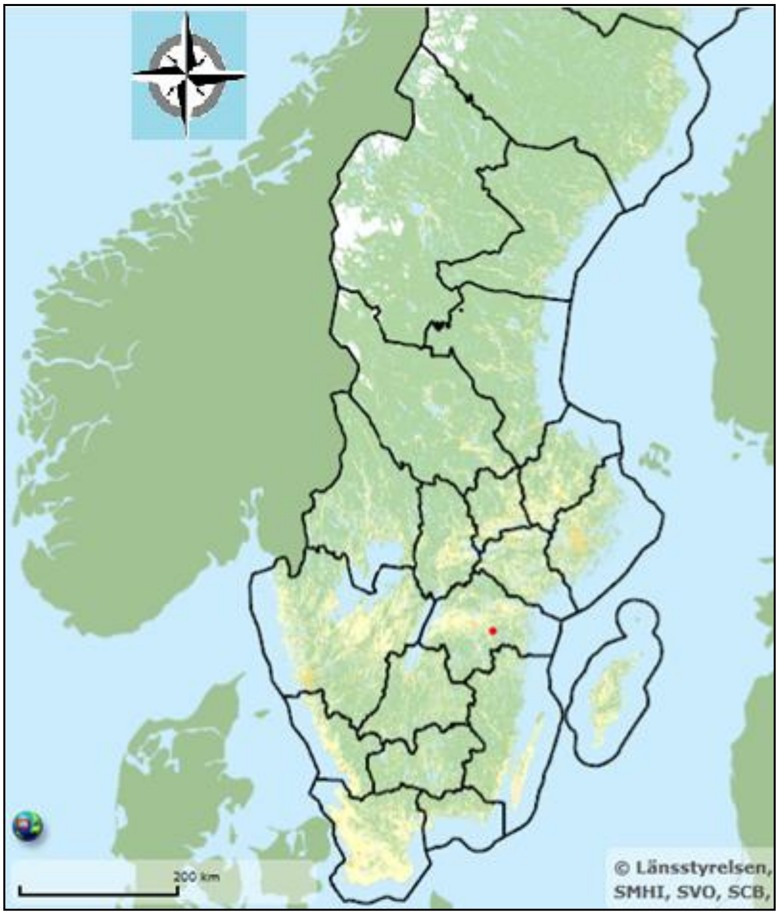

Figure 1 Map of Sweden, where lake Risten is represented with a red dot. Vattenmyndigheterna, 2013

Figure 2 Detailed location of lake Risten. Vattenmyndigheterna, 2013

2 Background

This report is focusing on the area around lake Risten; Byrum stream in the north part of the lake, Mulstad stream in the north-west part, Missmyra stream in the east part, the outlet of lake Risten and the inlet of lake Såken are locations chosen for field studies. In Figure 3, the locations for the field studies are marked out with names, as well as the location of the Bersbo mine. To have a clear view of the effects of the mine along the water system, information about lake Risten and how the metals are transported all the way down from the upstream lakes is given in section 5.6.

Figure 3 Lake Risten and Bersbo mine. Vattenmyndigheterna, 2013

The copper mine of Bersbo was started up approximately 500 years ago (Karlsson & Bäckström, 2002). It was of great importance for the region during the decades 1850-1870 and closed in 1902. There has always been some contamination from the mine, but logically it increased from the 1850s until it was closed. It was not until the second world war when some processing of the pollutant waste was made (Bäckström & Sartz, 2011). The water quality of lake Risten has during the last centuries been affected by the mine in Bersbo, about 4 km south of lake Risten. (Ledin et al. 1996) The mine was in use until the beginning of the 20th century (Karlsson & Bäckström, 2002) and the waste from the mine was deposited in connection with the mine, but it was not until the 1970s, that the effect that the mine activity had had on the river system downstream Bersbo was noticed. Higher concentrations of heavy metals, e.g. Copper (Cu), Zinc (Zn) Lead (Pb) and Cadmium (Cd), than normal and acidification were the results from these deposits, and it could be seen in samples from groundwater, surface water and sediment (Länsstyrelsen Östergötland, 2013).

During 1987-1989, the waste deposits from the mine were covered to reduce the leakage. It was the first attempt of its kind for after treatment of mine waste in Sweden and one of the first in the world. The result of the restoration was, after an investigation made by the county board of Östergötland in 2004, shown to be a reduction in total leakage of 90%. However, the leakage from the Bersbo mine was still greater than the leakage from all the other mines in the county together (Länsstyrelsen Östergötland, 2013). The county board received money from Naturvårdsverket (The Environmental Protection Agency) to put all the facts from the mine activity together to get an idea of the total situation for the environment around Bersbo (Länsstyrelsen Östergötland, 2013). This was done in 2005 and it was decided that there was still need of information regarding pollution of the downstream recipients. Therefore the county board made a further study during 2006-2007. The investigated area can be seen in Figure 4 below.

Figure 4 Investigated area and red dots for the three deposits: Storgruveupplaget, Steffenburgsupplaget and Grönhögern. Börjesson & Ekholm, 2007

Besides the investigation of the recipients, measurements of the metal concentrations in fish were also done. Its purpose was both to analyze its ecological status and to see if the fish was suitable for consumption. The highest concentrations of most of the metals were found in fish from

Risten, but the fish was still considered to be suitable for consumption there and the values were, though higher than natural concentrations, not higher than in other similar lakes in south of Sweden. This was the case for e.g. Mercury (Hg) concentrations in pike and perch, which were higher than they would be in natural conditions but still lower than the limits put by Livsmedelsverket (National Food Administration) as well as the European Union (EU) regarding the consumption of fish. The reproduction of fish in lake Gruvsjön, which is located upstream Risten and very close to the mine, seemed however to be severely affected since almost no fish was found there (Länsstyrelsen Östergötland, 2013).

Another problem for the lake, which also has been discovered during the investigation of lake Risten, is that it is in an early stage of eutrophication. The ecological status is however considered to be good at the moment (Vattenmyndigheterna, 2013). In some parts, especially in the north-west, Risten is surrounded by agricultural areas which are drained into the lake. Locally lake Risten has been changing a lot during the last decades, probably because of nutrients led in by the streams draining those agricultural areas. The changes can be seen especially in form of a huge increase in underwater vegetation, especially close to the outlets of the streams, but also far away from them, along the shorelines. It is of great interest for the landowners around the lake to keep a good lake water standard, since fishing for crayfish is an important tradition in the area, but it is also important for the people in the nearby villages, since it is a popular place for swimming during summer and on a bigger scale because it is affecting the downstream lakes (Interviews and observations, 2013).

The sediment is probably a result of incoming particles from the streams, but also of decomposing underwater vegetation. There is especially one big stream located at the farm Mulstad at the north-west shoreline of lake Risten, and this one seems to be one of the main sources for the early stage of eutrophication, since an extreme increase in under water vegetation can be seen locally. The stream has its origin from a drainage system, draining about 20 hectares of agricultural land, and since the farmers are ploughing very close to the edges of the stream it can be assumed that a lot of nutrients are entering the stream directly via surface water runoff (Interviews and observations, 2013).

3 Objectives

The aim of this project is to find out in which way the lake Risten has been changing ecologically during the last decades, and which methods can be used to improve the situation. This was done by trying to get an answer for the following questions:

1. How has the lake been affected by the metals, which has been and still, but in reduced amount are, entering from the mine deposits situated in Bersbo?
2. Are the agriculture fields surrounding lake Risten eutrophicating it just locally?
3. Is there a relation between metal concentrations and nutrient concentrations in a lake, and moreover is it good to increase the nutrient concentration in lake Risten to get rid of metals in the water?
4. Is there a reduction of crayfish in the lake, and could this be a result of the increased amount of water vegetation along the shorelines?

If it is found that the lake in some senses is changing in a negative way, a suggestion of how to solve the problems causing those negative changes will be provided.

4 Methodology

The methodology of this study is divided into three parts, where the first part is a literature review, the second part is interviews with people from the area, people at the county board and landowners, and the third part is an analysis of the water sampling and measurements carried out on 21st until 25th of April 2013, within the study area.

4.1 Literature

A number of reports and scientific papers were studied to identify the main practical and theoretical issues of lake Risten, its catchment area and the mine in Bersbo. Several papers, partly facilitated by the county board and the municipality, were analysed to get a better understanding of the change in ecological status of the lake during the last decades.

4.2 Interviews

Some people employed by the county board, having knowledge in the field of limnology, were consulted by phone about the ecological status of the lake and the connection between metal- and nutrient levels in the lake. Local landowners were also contacted directly in person to get information about the changes in the results from their fishing for crayfish, hear about their observations of the vegetation status of the lake and most importantly to see what their thoughts are in the matter. These testimonies were used to verify and contrast the already analysed information.

4.3 Measurements

The measurements took place in April 2013, right after the snow melting period, since this is the time of the year when most of the nutrient transport from the fields into the streams occurs (Sandén et al. 1997). The measurements were taken in Mulstad stream, Missmyra stream, Byrum stream, in lake Risten and the outlet from lake Risten into lake Såken. Sub-catchments for the three inlet streams (Mulstad, Byrum and Missmyra) were created with the software Silverlight facilitated by Vattenmyndigheterna (2013). The measurements were compared with the data obtained from the county board and from the municipality. The results were analysed in the laboratory to show a possible tendency of the nutrient levels and to understand where the majority of the nutrients come from and their effects in the lake.

5 Literature Review

A complete and long analysis during almost three months was done, with lake Risten being the topic directly or indirectly related. Reports were studied and analysed, where for example the mine located in Bersbo, was mentioned. The relation between the nutrients in lake Risten and the metals in the water system, coming from the mine in Bersbo to the downstream lakes, were mentioned in many sources and understood to be important.

5.1 Fish, Metals, Nutrients and pH

In eutrophicated lakes, the metals are spread over the great biomass, which exists because of the nutrients, compared to less nutritive lakes where the biomass is not that big, and this is often referred to as bio-dilution. One result of this bio-dilution is that the fish in a lake with high nutrient status, and thereby high bio-dilution, will have a low uptake of metals and vice versa. The uptake of metals in fish are however complicated systems, not depending only on the amount of nutrients in the water. The uptake can also be affected by ions, which are competing with the metals about the possibilities to bind in the fish bodies. When the phosphorus level in the water is lower than 20μg/l, the level of Hg is quite constant, but for nutrient rich lakes the Hg levels can be 50-75% lower. The concentration of Cd can be as much as 50 times higher in a less nutritive lake compared to a very nutrient rich lake. Pb is different from the other metals in the way that the level in perch liver is totally independent of the nutrient characteristics of the water. It is probable that there is an antagonism between Zn and Hg, and since Zn in the water is a common result of close by upstream mine deposits, low levels of Hg are often found with a mine present (Länsstyrelsen Dalarnas län, 2010).

The levels of metals in freshwater is very dependent on the pH of the water and vice versa. Mine waste lower the pH in water, but there are other factors that affect pH in freshwater ecosystems, i.e. acid rain. The ions affect the pH which should be in a range of 6-8 to be considered as neutral. When the pH in the water is low, the solubility of the metals is high and therefore the bioavailability of the metals increase, and thereby the bioaccumulation to primary producers. A high pH on the other hand, lowers the solubility of metals in the water (Leventhal & John, 1995).

The pH and the concentrations of metals are extremely connected in water ecosystems. A pH lower than 6 is considered to be too low to maintain a high biodiversity in freshwater ecosystems (Brönmark & Hansson, 2005). The pH in lake Risten is, as can be seen in the results from the measurements and from the data obtained from the county board, seen in Table A3-1, around 7.8, which means a quite neutral pH.

It has been found that for lakes, which are rich in P, the Hg levels are often remarkably low. If a lake, which is rich in P, also has high levels of metals, then the Hg levels in fish from the lake can be extremely low, as for example if the lake is located downstream mine deposits. This relation points out a kind of competition between Hg and other metals, especially Zn, of the uptake in fish. When it comes to Zn, Cu, Cd and Pb , those metals are opposite to Hg not taken up in the muscles of the fish, but instead in the liver. The values pointing out that were mostly taken from small perches, so perhaps it is not for sure that this can be stated. It has been noticed that the relation between the metal levels in fish and the metal levels in water, where the fish exist, is very weak, even though it has also been noticed that there is a connection between metals entering downstream recipients and the concentrations of some metals in fish liver. High amounts of nutrients in the water do however reduce the metal concentrations in fish liver as well, especially the Cd- concentration (Länsstyrelsen Dalarnas län, 2010).

5.2 Eutrophicated Lakes

Eutrophication is a process of increasing nutrients for primary producers, which makes them grow faster. During 1950-1960 a dramatic increase of algae blooms were observed in lakes, which untreated water was discharged into and which had surrounding agriculture lands where fertilisers were used (Brönmark & Hansson, 2005). The causes were not discovered until sometime later, when a study was carried out in Canada, demonstrating that phosphorus is the limiting factor when it comes to primary production in freshwater ecosystems (Schindler, 1974). This experiment consisted in adding phosphorus, nitrogen and carbon to the lakes, proportional to the amounts from the incoming sources. When phosphate (PO_4-P) and nitrate (NO_3-P) were added to the lakes, the changes in eutrophication could be seen within weeks. When nitrogen and carbon were added to one of the lakes, and phosphorus and carbon to another lake, it had different effects. The lake in which nitrate were put did not change much, but the lake in which phosphate were put showed a big difference, which could be clearly seen due to the increase of algae. When the adding of phosphate stopped, the conditions slowly went back to normal (Schindler, 1974). This experiment showed clearly the relation between the addition of phosphorus to freshwater ecosystems and the fast increase of algae blooms.

The consequences of eutrophication in lakes are mentioned by Brönmark & Hansson (2005) to be "reduction of water transparency due to the increase of algae that do not allow sunlight to pass through the water; this increase of organisms produces an increase of matter accumulated as sediments on the bottom of the lake". Finally bacteria use this organic matter, and due to this they need big amounts of oxygen, which leads to a decrease in oxygen. These effects make the lake less suitable for organisms to live there (Lake Scientist, 2013).

Eutrophication is also a natural process, but it can be seen that the eutrophication due to human activities, like agriculture and industry, is much faster than the natural eutrophication. Nowadays the concern about eutrophication in Swedish lakes, and especially in the lakes found in southern Sweden, is very big due to the huge changes within those lakes and in the Baltic Sea. There are many techniques to decrease anthropogenic eutrophication. For example, the textile detergents with more than 0.2% phosphates are prohibited in Sweden since 2008 (KEMI, 2011).

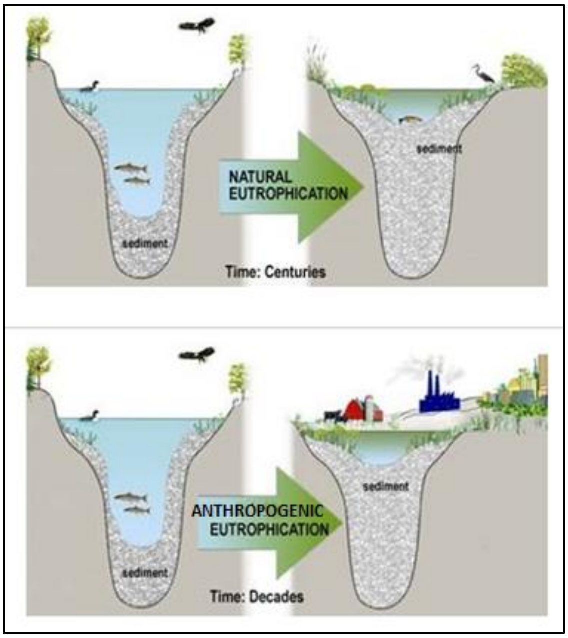

Figure 5 Time scale in natural and human-induced eutrophicated lakes. Lake Scientist, 2013

In Figure 5 to the left the difference in time scale between a natural and an anthropogenic eutrophication can be observed. In the picture showing the natural eutrophication, the lake is enriched slowly, and it may be noticed after centuries. In the human-induced eutrophication, the lake is enriched quickly and the changes may, as it is mentioned by Schindler (1974), be seen within weeks.

At present in the area surrounding the Baltic Sea, the discharges of phosphorus comes mainly from point sources as treatment plants and secondly from agriculture land as showed in Figure 6 (SMHI, 2013). In the case of lake Risten, P is mostly coming from agricultural sources.

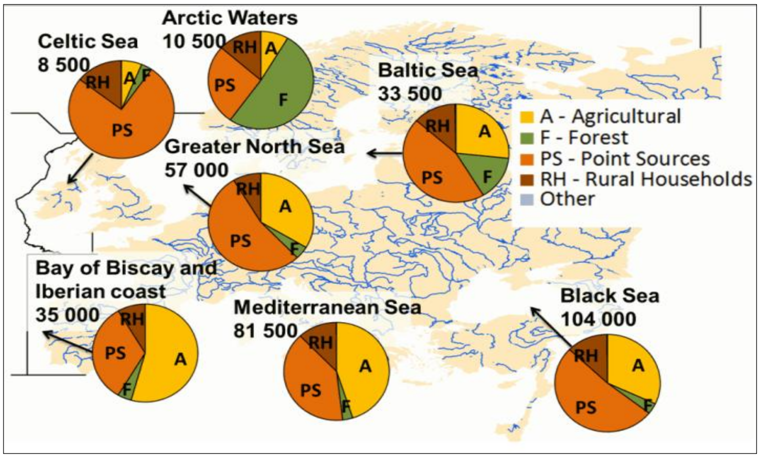

Figure 6 Total amount and division of sources of phosphorus discharge from land to the seas around Europe. A = Agriculture, F = Forestry, PS = Point sources (such as treatment plants and industrial operations), RH = Rural Households, Other. SMHI, 2013

Eutrophication causes a lot of changes in the habitats of a lake, often making the survival hard for many species living there.

5.2.1 Transport of Phosphorus and Nitrogen

Phosphorus has an ability to bind easily to soil particles, and is therefore mainly entering streams by surface runoff. Nitrogen on the other hand, is mainly entering streams by subsurface flow into channelized streams, crossing agricultural fields, often via drainage pipes (Vought et al. 1994). Since phosphorus usually is the limiting nutrient when it comes to freshwater systems, the surface runoff must be the first thing to consider when trying reducing the eutrophication of downstream recipients in such systems. (Schindler, 1974)

5.2.2 General Methods used to decrease the Nutrient Transport

The following four methods are very valuable solutions to reduce the amount of nutrients reaching downstream lakes, or finally the sea, by increasing the sedimentation and the uptake.

5.2.2.1 Buffer strips

It is a good idea to leave some space on the side of a stream crossing an agriculture land, to have a zone which is covered by vegetation all around the year and which has the ability to take up most of the nutrients flowing from the agriculture land towards the stream. Such an area is referred to as a buffer strip. Apart from catching nutrients, mostly phosphorus attached to soil particles, before they are ending up in a stream with surface runoff, a buffer strip also has the advantage that it stabilizes the sides of the stream, and thereby reduces the risk for erosion, and also that it provides a habitat for various species which otherwise could not exist. Not just phosphorus but also pesticides are binding to particles, and therefore buffer strips are also contributing to a reduction of pesticides in the water. A buffer strip which is shadowing a stream, for example with trees and bushes, also has the advantage that it decreases the primary production, i.e. production of for example algae, in the stream (Vought et al. 1994).

From experiments it has been found that a buffer strip of 16 meters width can remove 95% of the PO_4-P coming with surface runoff, with the highest removal taking place during the first meters and then exponentially decreasing. A buffer strip of just eight meters is enough to reduce the amount of PO_4-P with 66%. NO_3-N on the other hand seems to be reduced linearly with the distance from the source, with a reduction of 50% coming from the surface runoff when having a buffer strip of 16 meters. The reduction of NO_3-N from subsurface flow is both a result of vegetation uptake and denitrification. Denitrification stands for the biggest part of the reduction, and it takes place during carbon rich and anaerobic conditions. When a buffer strip is 20-25 meters wide the reduction does not seem to increase so much when increasing the width of the buffer strip (Vought et al. 1994).

5.2.2.2 Sediment trap

A sediment trap is a deepening in the bottom of a stream, which has the ability to trap sediments carried by the water flow. The location of a sediment trap, seen in Figure 7, should be for example after a stream has passed through some agriculture fields, since the water then probably carries big amounts of nutrient- and pesticide rich sediments. To have a really good result from the sediment trap the water velocity should be as low as possible over this distance. To achieve a low water velocity a widening of the river could if possible be done where the sediment trap is located. The deeper part of the river, being a result of the creation of the sediment trap, can except from trapping the sediments also provide a variation in the habitat, and thereby increase biodiversity (Gioutlakis et al. 2012).

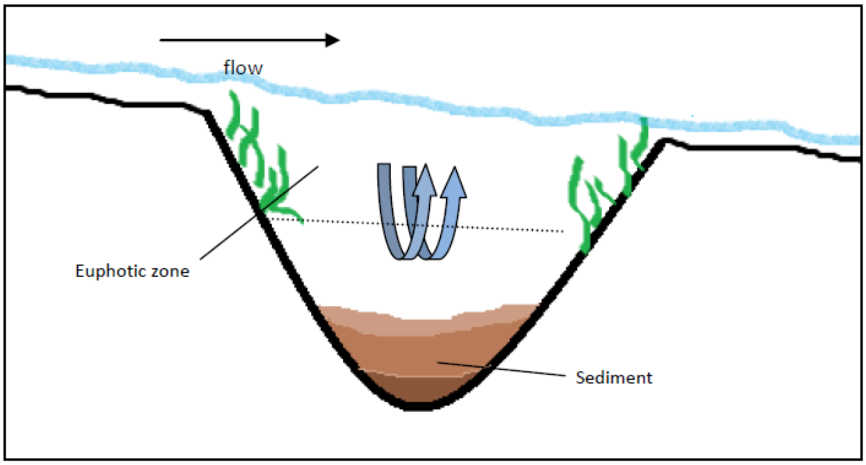

Figure 7 Representation of a sediment trap. Method of trapping phosphorus and pesticides bound to particles. Gioutlakis et al. (2012)

5.2.2.3 Meandering

Meandering, i.e. the bending of a river into curves is the natural structure of a river. Agricultural streams are on the other hand straightened out to make the land use as efficient as possible. A straight channel results in less friction and higher water velocity, while the opposite appears in a meandering river. Therefore meanders are good to increase the sedimentation of particles to the stream bottom and preventing them from reaching sensitive downstream recipients. (Vought & Lacoursiére, 2010)

When meanders are designed the proportion of the lengths between a straight river and the same river meandered should not be less than 1:1.5 (Hooke, 1990). The meanders should also have amplitude 10-14 times bigger than the river width, when the river is filled to the top of the banks (Madsen, 1995).

5.2.2.4 Vegetation

Vegetation is important in a stream since it increases the roughness and therefore decreases the velocity of the water as well as it provides habitats for other aquatic species, decreases erosion and reduces the nutrient levels in the stream by increasing sedimentation and nutrient uptake. When it comes to vegetation on the sides of the stream it can be a good solution to introduce bushes with deeper root systems reducing the risk of erosion along the stream (Vought & Lacoursiére, 2010).

5.3 Crayfish

Noble crayfish (Astacus astacus), the indigenous crayfish species around Europe decreased, first because of a crayfish plague, and then by introduction of signal crayfish (Aphanomyces astaci) in the early 1900s. The invasive species was brought from North America into Sweden in the 1960s, since the noble crayfish was suffering severely from a plague, and since it had been noticed that the signal crayfish was occupying a similar niche in America. It was however not noticed until afterwards that the signal crayfish was a carrier of the very same plague as the noble crayfish had been affected by before. The introduction of the signal crayfish resulted in an even faster decrease of the noble crayfish, not just because the signal crayfish was carrying the plague, which it itself was immune to, but also because it was the most dominant species of the two (Johnsen & Taugbøl, 2010). Noble crayfish is therefore rarely found in lakes of Sweden nowadays (Brönmark & Hansson, 2005).

The crayfish in lake Risten is signal crayfish, and their food is based on macrophytes, periphytic algae, detritus and benthic macroinvertebrates. Therefore they are considered mainly omnivorous; while they are often eaten by fish, as for example perch in lake Risten (Brönmark & Hansson, 2005).

The crayfish population has decreased considerable the last years in lake Risten, as interviewed landowners from the area mentioned when they were asked. Their habitats are freshwater ecosystems like lake Risten, and their preferences are to live surrounded by rocks or tree roots (Brönmark & Hansson, 2005).

Crayfish in lake Risten may be affected by metals due to its food habits, since it eats macrophytes, which might be affected by metals from Bersbo mine, but moreover because its habitat changed during the last decades because of the increase of nutrients in lake Risten that resulted in a higher sediment rate in the lake. This sedimentation is making the refugees around rocks unavailable for the crayfish.

5.4 Earlier Investigations

5.4.1 Review of the Compilation of the Ecological status of the Bersbo Area made by the County Board

In 2005, the County Board of Östergötland did a compilation of all the investigations of Bersbo. It was then decided that regarding further investigations to be done, it was of biggest concern to continue the measurements of metal concentrations in the downstream recipients. Because of this a decision was made by the County Board to do parts of a main study to try to make clear which, if any, threats are to be found for humans living in the area and for the environment. The responsibility for these studies was given to the consulting company SWECO VIAK. The purpose was not just to make clear if there are any threats, but also if it was necessary and possible to do something to lower the risk, and if it was necessary to follow up with more detailed investigations (Börjesson & Ekholm, 2007).

The investigated area, which can be seen in Figure 4, mostly consists of forest, but also some wetlands, grazed fields and agriculture fields. Both permanent houses and summer houses are to be found in the area. There are no red listed aquatic species in the Bersbo area, but on land, species of special interest have been found (Börjesson & Ekholm, 2007).

The restoration of the mine deposits turned out to be really efficient with a decreased transport of sulphate (SO_4^{2-}), Cd, Cu and Zn in all parts of the investigated area. During the first eight years after the restoration of the deposits the amount of Zn going into lake Risten decreased to one fourth and the decrease of Cd in the same place decreased to one fifth (Börjesson & Ekholm, 2007).

Figure 8 Marshland between Strålången and Gruvsjön marked with pink. Ternsell, 2007

As can be seen, when looking carefully at Figure 8, there is an area with marshland, pink colour, located between Gruvsjön and Strålången. This area is a complex system working as a source, as well as a trap, for metals. During oxidative circumstances Cd and Cu are released from the sediment and during reducing circumstances Zn is released from the sediment. The oxidizing and the reducing capacity is dependent on the groundwater level, which means that the area will probably stay alternating between being a source and a trap for metals as long as the hydrological circumstances are the same. However, a possible climate change can lower the groundwater level, resulting in permanent oxidizing circumstances. This could also be the result of creating new streams draining the land. In such a case it is probable that high amounts of metals would be released and spread further downstream This process is however believed to take about 10-100 years, which is such a long time that other factors must be taken into consideration as well (Börjesson & Ekholm, 2007).

Since there is a possibility that the situation for the lakes and streams in the Bersbo area under some circumstances will deteriorate, it cannot be clearly ascertained that the suggested arrangements from the study will be enough. The marshland has probably got a high capacity for retaining metals, but it also makes up a big uncertainty regarding the risk analysis, since it, under changed conditions, also could release great amounts of metals affecting the downstream recipients. Therefore this part of the main study suggests further investigations of the actual processes going on in the marshland, and in which ways they are affecting the metal transport. (Börjesson & Ekholm, 2007)

It has been suggested that further sanitation and risk reduction is needed in the area to secure that a negative effect on health and environment will be avoided. The biggest reason for this is that the ecosystem of Gruvsjön is seriously damaged, and the biggest concern regarding that is to find the source for the alkaline water entering Gruvsjön, and to discover if this source is infinite or finite. This will namely be determining for Gruvsjöns's function as a metal trap in the future (Börjesson & Ekholm, 2007).

To sum up with, the parts of the main study which has been made suggests more detailed investigations regarding the structure and the status of the ecosystems in the investigated area, since there seems to be a need of that. For example, analysis of the metal uptake in crayfish and further analysis of the metal uptake in fish would be good to make sure that the previous conclusion, meaning that intake of crayfish and fish from lake Risten does not affect the human health, is true (Börjesson & Ekholm, 2007).

5.4.2 The Deposits from the Bersbo Mine and the Restoration

The deposits from the Bersbo mine have been affecting both surface water and groundwater in the catchment with leakage of metals, especially, Cu, Cd and Zn, over the years. During 1987-1989, a restoration of the deposits took place. The restoration was one of the first of its kind in the world and the idea was to reduce the leakage from the deposits. This was done by covering the two deposits, Storgruveupplaget and Steffenburgsupplaget, with Cefyll, i.e. concrete stabilised carbon fly ash, and clay and to empty the third deposit, Grönhögen, of waste and then lime treat it with limestone and cover it with moraine (Börjesson & Ekholm, 2007). The three deposits and the investigated area can be seen in Figure 9.

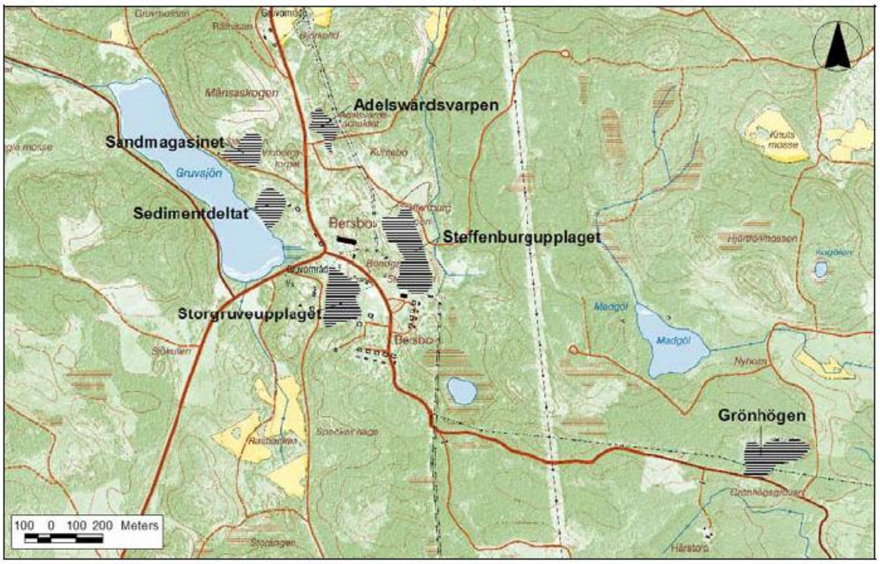

Figure 9 Six waste deposits from mine Bersbo, of which the three to the right later on are described in the text. Börjesson & Ekholm, 2007

5.4.3 Description of the Lakes in the studied Area

The reviewed literature provided information about the surroundings of the mine located in Bersbo, although this report focuses mainly on lake Risten. Following in this section there is a summary of the lakes affected by the former copper mine. These are: Gruvsjön and Strålången on the west-north part from Bersbo, and Båtviksgölen and Risten on the east-north part from the mine, as can be seen in Figure 10 below. The water flows from Gruvsjön, where there is one leaching deposit from the mine to Strålången, and from Strålången to lake Risten. Besides there is a weir connecting the other deposit in Bersbo with lake Risten. A bit further from this location there is a third deposit leaching to Båtviksgölen, and from Båtviksgölen to lake Risten.

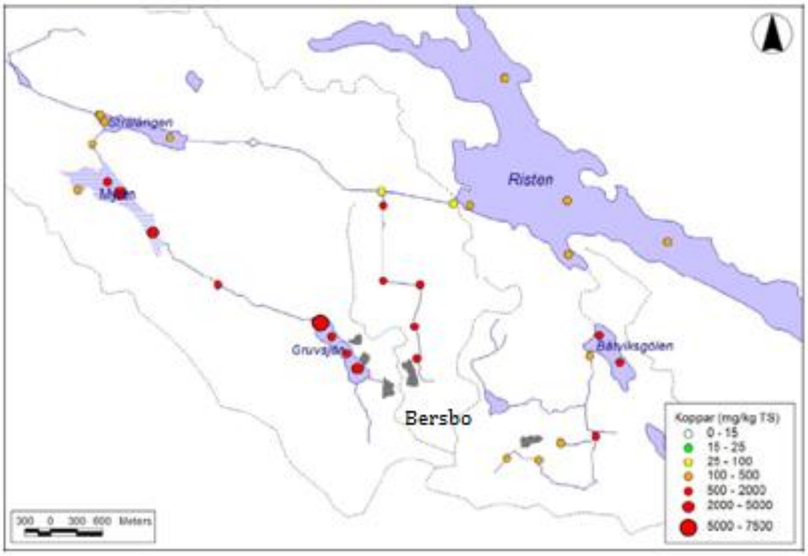

Figure 10 Lakes surrounding Bersbo Mine September 2006. Börjesson & Ekholm, 2007

5.4.3.1 Gruvsjön

Lake Gruvsjön is the closest lake to the mine, located on the west side of Bersbo, and this lake is the first one in the river system affected by the mine waste. From the investigation of the bottom fauna made in 2006 it could be seen that Gruvsjön was poor regarding individuals as well as species, indicating that it is strongly affected by high levels of metals in the bottom sediment. In both surface water and sediments the metal levels are so high that there is a risk of affecting the aquatic life severely. The lake is almost empty of fish and the bottom fauna is disturbed. An increase in amount of species has though been discovered when comparing with older investigations of the bottom fauna, being a result of the restoration of the mine deposits. Sometimes the lake is visited by people who go there for swimming (Börjesson & Ekholm, 2007).

5.4.3.2 Strålången

Strålången is the next lake in the river system receiving metals from the mine waste deposits. Strålången is a very shallow and nutritive lake, which is of high interest of reservation because of its birdlife. It is seldom used for fishing or swimming, since it does not fit those purposes and because it is a bit hard to get there. The lake is rich in individuals and species, and any clear effect on the ecosystem cannot be seen, but the levels of metals in the sediment are high enough to indicate a risk for it. At present time the lake is considered to be acting as a metal trap (Börjesson & Ekholm, 2007).

In the same way as for the marshland upstream, Cu could be released from the sediment during oxidizing conditions, while Zn and Cd mainly could be released during reducing conditions. Any signs of a change in the lake's redox condition has, however, not been shown. No signs of influence from metals can be seen on the fish from Strålången, probably because of the nutrient levels in the lake, since the high nutrient levels are reducing the bioavailability of the metals (Börjesson & Ekholm, 2007). According to (Leventhal & John, 1995), bioavailability is defined as "the proportion of total metals that are available for incorporation into biota (bioaccumulation)".

5.4.3.3 Båtviksgölen

The small lake Båtviksgölen, situated downstream the deposit Grönhögen and upstream Risten, is used for both swimming and fishing by the local people. The metal levels in the sediments are indicating a risk for the aquatic life, but no risk for human health can be seen from the results of the measurements in Båtviksgölen. From fish sampling 1988 it was discovered that the growth and the condition of the fish was not as good as normal, probably because of lack of nutrients in the lake. Båtviksgölen serves as a metal trap, and there are no indications showing that this function is about to change (Börjesson & Ekholm, 2007).

5.4.3.4 Risten

Risten has, because of its size and availability, a very high recreational value and is often used for swimming in summer and fishing all around the year. The levels of metals in the sediments indicate a risk for the aquatic life. After an investigation of the bottom fauna made in 2006 the metal concentrations in the lake were, however, estimated to have very low effect on the lake, and no risk for human health can be seen as a result of the measurements in Risten. From fish sampling 1988 it was discovered that the growth and the condition of the fish was not as good as normal, probably because of lack of nutrients in the lake. Since the restoration during 1987-1989, the metal concentrations have been decreasing remarkably in the surface water both at the inlet and at the outlet. The levels at the outlet are also much lower than the values at the inlet, mostly depending on the sedimentation of a big part of the metals. A result of the decreased metal transport into the lake is that sediment with lower metal concentrations has covered the old sediment, having very high concentrations, and therefore Risten is presently said to be a metal trap (Börjesson & Ekholm, 2007). In Table 1 below, average values for pH and metal concentrations from 1983 to 2002 during summer season can be seen.

Table 1 Average values for pH, sulphate and metals from July-September during 1983-2002. Karlsson and Bäckström (2002)

	Period	pH	SO_4 ppm	Cd ppb	Cu ppb	Pb ppb	Zn ppb
Leachate	1983-86	3.36	603	197	9643	35	66000
	2002	2.87	307	69	5368	22	30470
Weir	1983-88	3.93	333	89	4282	14.3	28116
	1989-97	5.47	123	26	793	2.3	5550
	2002	6.21	10	0.71	55	1.49	700
Inlet Lake Risten	1983-88	6.86	29	4.46	90	0.48	1107
	1989-97	6.74	22	0.44	16	0.49	201
	2002	6.67	4	0.02	5.6	0.49	20
Outlet Lake Risten	1983-88	7.39	24	0.03	11	b.d	117
	1989-97	7.55	22	0.05	6.4	b.d	50
	2002	6.77	16	0.23	6.1	0.36	25

5.4.3.5 Metals in the River System

There are no criteria existing for metal concentrations in freshwater fish, which means that the analysis of the fish in the Bersbo catchment was carried out concerning the criteria for salt water fish. The highest values of Cu, Hg and Zn have been found in the livers of the fish from Risten, probably because Risten is less nutritive than the upstream lakes and therefore has a lower bioavailability (Ternsell, 2007).

According to the criteria for salt water, the level of Cu was evaluated as high in Båtviksgölen and very high in Risten. For the level of Cd it was the other way around, high in Risten and very high in Båtviksgölen. Regarding Zn, the values are considered as very high in all the lakes in the catchment, possibly because the criteria for salt water are not valid for freshwater. The reason for finding the highest levels of metals in the water of Risten could be a result of the lack of nutrients in this lake compared to the others, resulting in a high concentration of metals in the water. When the metal concentrations in the water are high and the concentration of the biological matter, which the fish eats, in the water is low there will be higher amounts of metals binding to every unit of these biological matter, for example zooplankton, and a higher amount of metals will be eaten by the fish (Ternsell, 2007).

The highest levels of Hg have been found in perch from Risten, one of them having a concentration of 0.506 mg/kg Total Solids (TS) in the muscles being just on the limit set to 0.500 mg/kg TS by Livsmedelsverket for regular consumption. Important to notice is that the fishes measured in Risten were much bigger than they normally are for this study. Instead of a weight of 0.05-0.1 kg, which is common when doing the study, the fishes from Risten had weights of 0.5-1.2 kg. Older fishes have higher metal values than younger, and the reason for the fishes from Strålången to have the lowest values was perhaps that they were the youngest. Because of this it is also possible that the values measured in Risten cannot be compared to values measured in fish from other lakes (Ternsell, 2007).

In average the level of Hg were higher in the perch than in the pike in Risten. Since Risten is furthest away from the mine deposits of the lakes in the investigated area it was suspected to hold the fishes with the highest levels of metals, but the result turned out to be the opposite. Maybe this can be explained by the fact that Risten is less nutritive than the other lakes (Ternsell, 2007).

It is very rare that a high level of metals in the liver implies high level of metals in the muscles. Just if the liver is damaged or if there is an extreme amount in the fish’s environment there are also high levels in the muscles. Therefore the fish is usually good for consumption even if the liver values are high. There is however one exception and that is Hg, which is stored in a higher amount in the muscles than in the liver (Ternsell, 2007).

The highest levels of Hg were found in the perches from Risten. The level of Cd is normal in Risten and low in Strålången, when comparing those lakes to similar lakes in the country. The natural level of Hg in Swedish pikes is around 0.2 mg/kg. This can be compared with the level of 0.45 mg/kg measured in Risten. The average for Swedish lakes is however 0.6 mg/kg, meaning that fish from Risten is not particularly affected. The value is also under the value set by the Livsmedelsverket for consumption of pike (Ternsell, 2007).

5.5 Area E23

Area E23 is an area of 739 hectares, of which 398 hectares are agriculture area, being part of an environmental monitoring program, financed by Naturvårdsverket. This monitoring program is trying to analyse the leakage of phosphorus and nitrogen from agriculture land to its water recipients in different parts of Sweden. Area E23 is located in the catchment of the Söderköping stream, where lake Risten also is located (Forsberg et al., 2013). Even though the phosphorus concentrations are quite high in the area, the transport of phosphorus is not so high because of the relatively dry climate. Not just the climate but also the soil properties of Area E23 are very similar to the catchments surrounding Risten, making data from the place very useful for comparison with the streams around Risten. This will give a reference to the report for the evaluation of the results, seen in Figure 12.

Table 2 Annual average values for 2011-2012 and 16-year annual average values, of for example PO_4-P and NO_3-N. In brackets, values for flow proportional samples can be seen. Forsberg, et al. 2013

	Årsmedelhalt 2011/2012	16-årsmedel, manuell provt. *(3-årsmedel, flödespr. provt)*
Tot-N (mg/l)	3.7 *(3.0)*	5.4 *(4.0)*
NO_3-N (mg/l)	2.5 *(2.5)*	4.2 *(3.4)*
Tot-P (mg/l)	0.32 *(0.30)*	0.22 *(0.29)*
PO_4-P (mg/l)	0.16 *(0.14)*	0.10 *(0.12)*
Part-P (mg/l)	0.12 *(0.14)*	0.10 *(0.14)*
Susp mtrl (mg/l)	65 *(101)*	88 *(139)*

6 Measurements

One of the biggest reasons for the early stage of eutrophication in lake Risten is thought to be the incoming nutrients from agriculture. Because of that, measurements were done of the water quality in the incoming water from Mulstad stream, Byrum stream and Missmyra stream and in lake Risten as well as in the outgoing water. In that way one could estimate in which amount Mulstad stream and the other streams were affecting the water quality of the lake. As usual when it comes to streams like the one in Mulstad it was constructed in a time when people did not have knowledge about how it could change ecological values of a downstream lake. It is totally straight, has very sharp edges on the sides and very little space for buffer zones on the sides of the stream.

The field measurements took place from 21st to 25th of April 2013, starting up at Mulstad farm, and the conditions of the land were not the usual ones for this time of the year. The last winter 2012-2013 had been longer and later than normal, and the atmospheric temperature was very low, resulting in a late, but very intensive snow melting of about 0.5 meters of snow. The amount of water was far more than expected in all locations, and it was difficult to reach some of them. The material brought for measuring consisted of a pH-meter, a velocitymeter, 20 empty bottles to save the water samples (half of the number of bottles for phosphorous samples and the other half for nitrogen samples), a tool for measuring the angles of the sides of the streams and a tool for measuring the depth and width. Most of the material was facilitated by the department of Water Resources Engineering and the department of Ecology at Lund University.

The field measurement consisted in taking samples from ten different points distributed in the catchment area of lake Risten. Four samples were taken from Mulstad farm, two from Byrum farm, one from Missmyra stream and two in the stream combining Risten with its downstream lake Såken. The last measurement was taken in the middle of lake Risten. The farms of Mulstad, Byrum, and Missmyra all have inlets to lake Risten, while the stream into lake Såken is the only outlet from lake Risten. Figure 11 below, shows the three sub-catchment areas of Mulstad-, Byrum- and Missmyra streams.

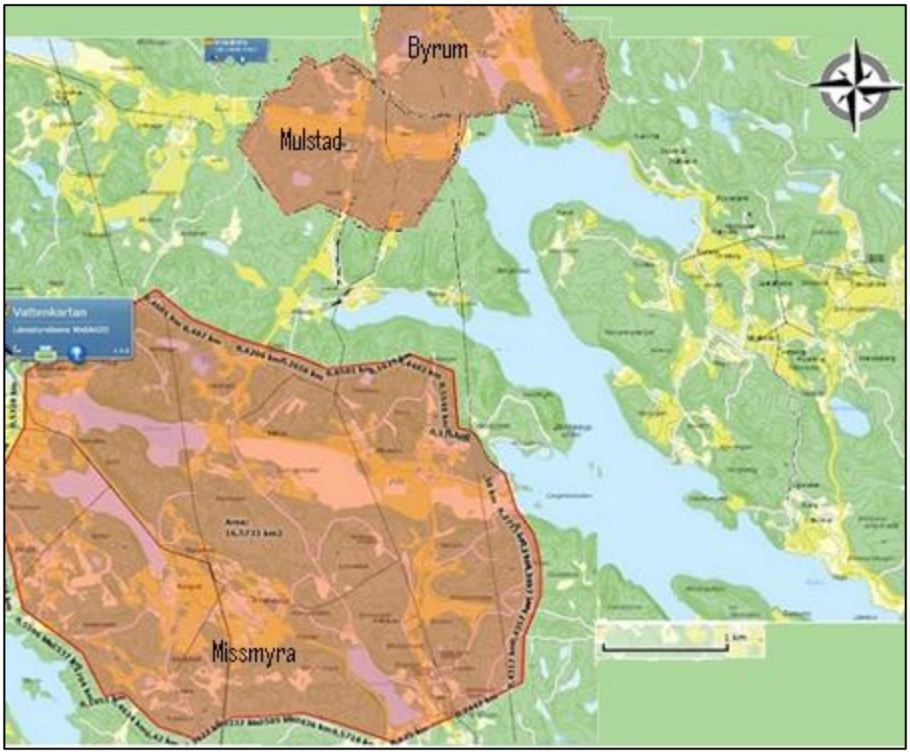

Figure 11 Sub-catchment areas.

At Mulstad farm, water samples were collected to analyse the concentrations of PO_4-P and NO_3-P in four different locations. The first sample in Mulstad was taken five meters away from the inlet pipe, the second sample from a drainage pipe approximately 22 meters downstream the first point, the third sample from another drainage pipe 45 meters downstream the second position, and finally the last sample 270 meters downstream the third point. The last point corresponds to the inlet of lake Risten. In the Byrum stream two samples were taken, one in the inlet and the other one in the outlet of the stream. The distance between the points is approximately 700 meters; the first 200 meters upstream being surrounded by agriculture fields and the downstream 500 meters crossing a wetland area. In Missmyra stream, being more of a wetland for the moment of the measurements, only one sample, near to the outlet, was taken since the possibilities to measure in different locations were limited. In the stream connecting Risten and Såken, two samples were taken, one at the outlet of Risten and one at the inlet of Såken. Finally one last sample was taken in the middle of lake Risten to be compared with the incoming waters.

Material used to measure the following characteristics:
1. pH-meter: pH and temperature of the water
2. Velocitymeter (seen in figure 12 on the left): velocity of the water
3. Carpenter's rule: width and depth
4. Angle meter: slope of both sides of the streams
5. 20 small bottles: water samples for measurements of PO_4-P and NO_3-P

Figure 12 Velocitymeter used. Sendra Díaz and Österlöf, 2013

6.1 Procedure for the measurements in each location

The following procedure applies to all the locations. The first step was to take the water sample, since it is very important not to change the concentration by bringing up bottom matter. One sample was used to measure the NO_3-N and the other to measure the PO_4-P. This procedure was important to do it in the opposite direction of the flow, as before not to contaminate the samples.

The next step was to measure the velocity of the water in the same locations where the samples were taken. To do this, the velocitymeter was put into the water for ten seconds, and then the revolutions of the device were noticed. If the n (revolutions/second) <0.76, the formula used was *v=0,2392n + 0,016 (m/s)*. If n>0.76 the formula used was *v=0,2552n+0,004 (m/s)*. After this, it remained to measure the temperature of the water, the pH of the water, the angles of the sides, the water depth and the water width. For measuring the angles of the sides, a special tool for measuring the angles was used. The pH-meter was calibrated, using tap water of pH 8.5. This whole procedure was repeated in all the streams except for the stream between Risten and Såken, where just water samples were taken.

The chemical analysis of water samples were carried out by our co-supervisor Lena Vought, Senior Lecturer in Ecological Engineering in Kristianstad. After the compilation of the samples, the locations were divided into three sub-catchments: Mulstad, Missmyra and Byrum, where the sampling had taken place. To do this the software Silverlight (Vattenmyndigheterna, 2013) was used. These sub-catchments were drawn by following, perpendicularly, the height curves, to represent the water divides. Following are the three sub-catchments represented in Figure 13 for Mulstad stream, Figure 14 for Byrum stream and Figure 15 for Missmyra stream.

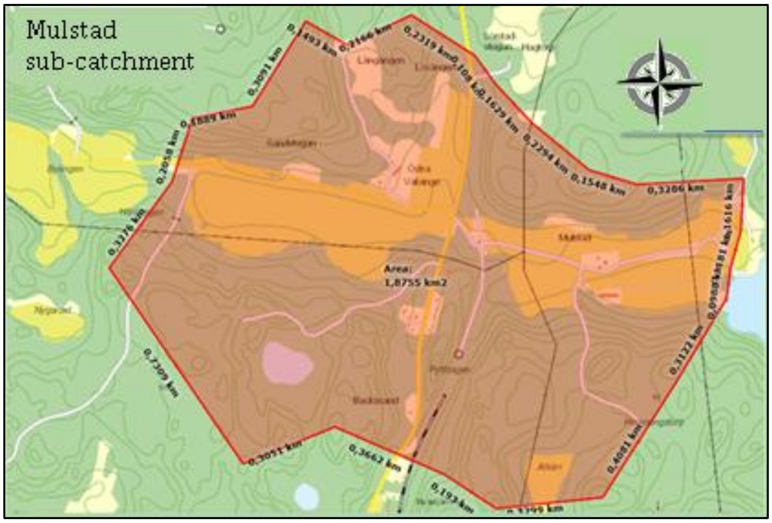

Figure 13 Mulstad stream.

Figure 14 Byrum stream.

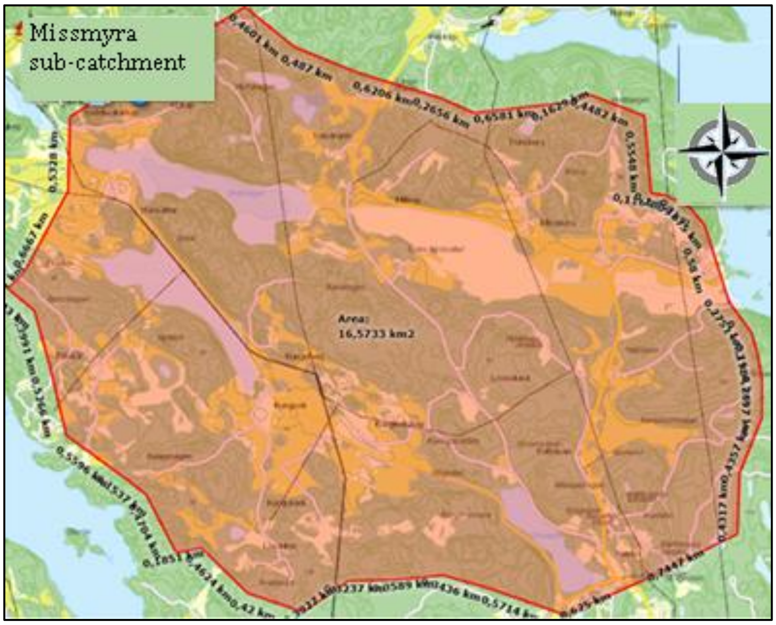

Figure 15 Missmyra stream.

7 Results

The main objective of this report is to analyse the ecological changes which has appeared in lake Risten during the last decades. The most important hypothesis was that the increase of underwater vegetation in the lake is a result of very nutrient rich waters entering the lake with the incoming streams, especially the one located in Mulstad farm. The results try to give an answer to this hypothesis. A map showing the locations where the samples and measurements were taken can be seen in Figure 16 with red dots.

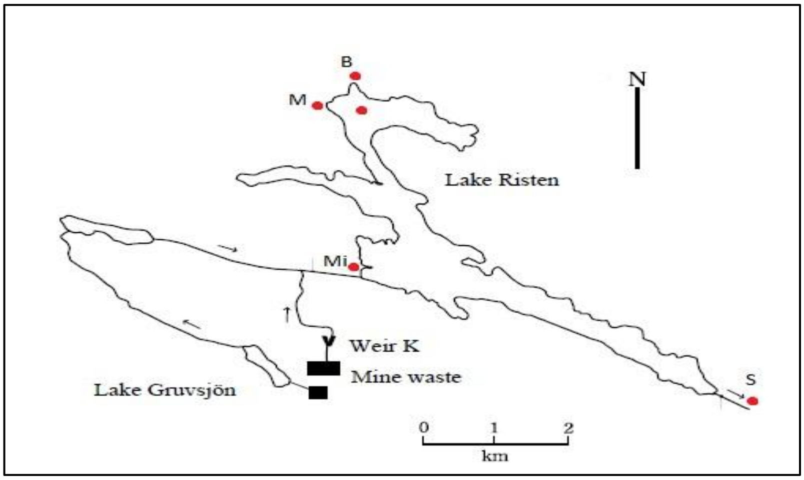

Figure 16 Map showing the locations for the sampling (B=Byrum, M=Mulstad, Mi=Missmyra and S=outlet to lake Såken). Karlsson & Bäckström, (2002), slightly modified

7.1 Summary of the measurements

Table A2-1 shows the data from Mulstad stream solely. The samples were taken in four locations in this stream. These are: MI, which is the Mulstad inlet, MP_1 where the first pipe within the stream was found, MP_2 where the second pipe within the stream was found, and MO, which is the Mulstad outlet. In every of those locations, the pH, the temperature of the water and the distance from the former location was measured. There is no relation between the distances because the pipes are situated randomly one from the other.

Since in Mulstad stream, the main objective is to restore the stream, to avoid the increase of nutrients entering from the stream to lake Risten, Figure A2-1shows also the necessary data for the cross sections. In this case the distance between each location is equal to 50 meters.

The samples were taken at the 21st to 25th of April, and since the snow was melting very quickly, there could be huge differences in the concentrations of nutrients during short time periods, which may be resulting in some errors. The values for the streams were compared with the values of our reference area E23 represented in Table 2. The 16-year annual average was used for the comparison, since it is more representative than the 2011/2012-value.

7.1.1 Data analysis for Mulstad stream

Before the water reaches Risten from Mulstad stream, the stream receives water from the main pipe and from some drainage pipes within the stream.

The highest values were, as mentioned before, found at the location MO. The incredible flooding of the whole area when the measurements took place makes the unusual results more understandable. However, it can be seen that there is no buffer strip existing at all along the Mulstad stream, making the phosphorus leakage very high during this time of the year. The nitrogen is also highest at this point, although the value may be ranged within standard values. The drainage system is considered to be old and in need of restoration, since just two drainage pipes could be found along the whole stream, and the others therefore may be understood to not work properly. The nitrogen is usually coming to the stream with pipes draining the surrounding agriculture lands, but in this case the water seems to have to come through the soil, resulting in more saturated soil and probably a higher surface runoff. The ground was also very saturated because of the great amount of melt water in spring and could not absorb all the water, resulting in flooding. Due to this flooding there is a possibility that the nitrogen reached the stream also through surface runoff, which could explain the high value of nitrogen at MO. In Table 3, values of PO_4-P and NO_3-N for all locations in Mulstad stream can be seen. Figure 17 is showing a picture of MP_1.

Table 3 Obtained values of PO_4-P and NO_3-N for Mulstad stream

Station	PO_4-P (mg/l)	NO_3-N (mg/l)
MI	0,059	0,6
MP_1	0,054	0,529
MP_2	0,039	0,236
MO	1,59	0,921

Figure 17 MP_1 in Mulstad stream.

7.1.2 Data analysis for Byrum stream

In Table 4 the values of PO_4-P and NO_3-N in Byrum stream can be seen. Byrum stream is, as mentioned before, a more natural stream, which could be one reason why the values of the nutrients are lower than the standard values in both Byrum stream inlet (BI) and Byrum stream outlet (BO). The increased value of PO_4-P in BO compared to BI can be explained by the existence of agriculture land along the first 200 meters downstream BI. In Table A2-2, all the measurements for Byrum stream are compiled. Figure 18 shows a picture of the most turbulent part of Byrum stream.

Table 4 Obtained values of PO_4-P and NO_3-N values for Byrum stream

Station	PO_4-P (mg/l)	NO_3-N (mg/l)
BI	0,021	0,865
BO	0,084	0,757

Figure 18 Byrum stream.

7.1.3 Data analysis for Missmyra stream

As mentioned before, the great amount of water from the snow melt made it very difficult for the ground to absorb all the water, and therefore there was a big flooding in the area. The values for PO_4-P and NO_3-N were measured close to the outlet of Missmyra stream (MiO), which can be seen in Table 5 to be very moderate and close to the values found in area E23. This is possibly due to a wetland upstream Missmyra, which increases the sedimentation and the uptake of the nutrients before entering Missmyra stream. Figure 19 shows a panoramic view of Missmyra stream more similar to a wetland than a stream. The full compilation of the measurements in Missmyra stream can be found in Table A2-3.

Table 5 Obtained values of PO_4-P and NO_3-N for Missmyra stream

Station	PO_4-P (mg/l)	NO_3-N (mg/l)
MiO	0,035	0,749

Figure 19 Missmyra stream.

Figure 20 shows the outlet of lake Risten (R), where the stream enters lake Såken. The nutrient concentrations are increasing a bit between the outlet of Risten (RO) and the inlet of Såken (SI), probably since there are agriculture fields along the stream connecting the lakes. The concentrations of PO_4-P and NO_3-N for R, RO and SI can be observed in Table 6 below. The values for the measurements of Risten, Risten outlet and Såken inlet are compiled in Table A2-4. However, the results are still below the values in area E23.

Table 6 Obtained values of PO_4-P and NO_3-N for Risten and Såken stream

Station	PO_4-P (mg/L)	NO_3-N (mg/L)
R	0,036	0,333
RO	0,02	0,331
SI	0,067	0,562

Figure 20 Outlet of lake Risten.

To get a better idea of the proportions of the nutrient transport by the incoming streams, Table 7 below shows the calculated load of PO_4-P and NO_3-N from all three streams into the lake in mg/s. It can be seen that even the load of PO_4-P is much higher in Mulstad than in Byrum and Missmyra, despite the much lower water flow in Mulstad.

Table 7 Concentrations and loads of PO_4-P and NO_3-N as well as the water flows for MO, BO and MiO

	PO_4-P (mg/l)	NO_3-N (mg/l)	Q (m^3/s)	PO_4-P (mg/s)	NO_3-N (mg/s)
MO	1.59	0.921	0.06641	106	61.2
BO	0.084	0.757	0.1596	13	121
MiO	0.035	0.749	1.037	36	777

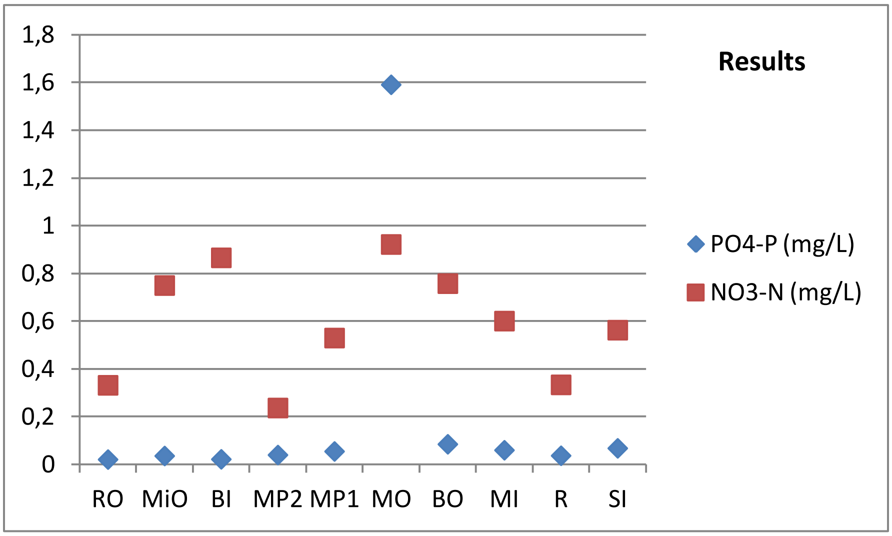

Figure 21 Compilation of values for PO_4-P and NO_3-N in mg/L

Figure 21 shows that the amount of nutrients in the streams are lower than expected, except for the outlet of Mulstad (MO), where the value is extremely high, and it may be the cause for the early stages of eutrophication along lake Risten shorelines. It is possible that the values are not so accurate, since they were measured only once and since the period when they were measured perhaps was not the most favourable.

This shows that certainly Mulstad stream is the most eutrophicated of the three analysed (Mulstad, Byrum and Missmyra), but it is not very accurate to make a statement just from one measurement, and it is recommended to continue measuring phosphorus- and nitrogen values in the same areas for a longer period of time to have more trustable data to analyse. As mentioned before, Mulstad stream is surrounded by agriculture fields and it is an artificial stream with a quite straight shape.

8 Discussion

Lake Risten is of high importance for the inhabitants of the area because of its natural sources, and the recreational and ecological value. This report is a review of several reports from, for example, the county board and the municipality to study the ecological changes in lake Risten during the last decades. Lake Risten has been affected by leakage water from mine waste deposits until now, but it was in 1987 when the restoration of the area started. The restoration was a success, and although high concentrations of metals can still be found in all the lakes downstream the mine, the metal concentrations are much lower than some decades ago. Moreover lake Risten is, since some years, experiencing an early stage of eutrophication because of the surrounding agricultural activities, decreasing the water quality in the lake. This has been confirmed by observations and by the statement from Vattenmyndigheterna (2013). The effects can be seen clearly by the increase of underwater vegetation along the shorelines in the lake, especially close to the sources, and this may be the cause of the decreasing amount of crayfish in the lake.

The main objective of this report was to understand the ecological changes in Risten by investigating how the lake has been affected by contaminated water from the mine in Bersbo and from agriculture, and moreover to analyse the results from the field measurements during 21st to 25th April 2013 to find out which of the streams is the most pollutant in the studied area. The results showed, as thought from the beginning that the most pollutant stream is the one located in Mulstad farm, having nonexistent buffer strips, resulting in very high concentrations of PO_4-P in the runoff water.

When analysing the literature, a very interesting discovery about the relation between metals and nutrients in lake Risten and the other lakes downstream the mine in Bersbo was noticed. When a lake has a low amount of nutrients and a relative big amount of metals, there is not so high amount of organic matter for the metals to bind to and settle with as sediment, and instead the metals stay in the water. On the other hand, when the amount of nutrients is higher, it results in a higher amount of organic matter available for the metals to bind to, and the concentration of metals in the sediments will be lower. The sedimentation enhances bioaccumulation of metals into the macrophytes, and since these are the primary producer in the food chain, the other species can be affected by the metals.

As some people in the area confirmed during interviews, there is a decrease in the number of crayfish in the lake Risten. From our study, the cause of the decrease cannot be stated, but further studies regarding the increase of nutrients into the lake must be taken very seriously into consideration.

With the results from the water samples, it is not possible to confirm that lake Risten is being eutrophicated mostly by Mulstad stream, since the amount of samples is insufficient and the measurements were just done during a short time of the year. To have an accurate result, measurements should be done all around the year and also during many years since the weather conditions may be different from year to year. The reason for just collecting a few samples is economical since the cost for analysis is high. However, the results for Mulstad stream are alarming and should be enough to consider further investigations.

After analysing the present situation in the lake, some possible methods to mitigate the problems of eutrophication are mentioned and explained to in the future be used, when considering a restoration of the stream located in Mulstad farm. Moreover two possible restoration plans for Mulstad stream, with modification of the actual cross-section, are added to the report to provide one economical restoration and one restoration with a more attractive plan for recreational purposes.

The economical restoration includes methods to decrease the amount of nutrients in the lake as: a) buffer zones located on the sides of the stream of 5 meters width along it to collect most of the nutrients from the agriculture land before they reach the stream; b) bushes along the stream to avoid erosion and to collect nutrients; and c) a sediment trap located at the end of the agriculture stream, 20 meters before the stream enters lake Risten. These three methods are recommended to be used besides the modification of the stream cross section, taking into consideration the 10-year flood and the lowest flow probable as well as the average flow. This suggestion gives z=4 and b=1 meter, giving a quite wide cross section with a very mild slope on the sides. This will result in a very good uptake of nutrients, but also that the stream possibly is without water during the dry season.

The option of the recreational restoration includes: a) buffer zones along the sides of the streams of 5 meters width along it to collect most of the nutrients from the agriculture land before they reach the stream; b) trees along the stream in the buffer zones to avoid erosion, collect nutrients before they reach the stream and provide shadow for recreational purposes in the area; c) a sediment trap located at the end of the agriculture stream, 20 meters before the stream enters lake Risten; and d) meandering of the stream to reduce water velocity and thereby increase sedimentation. These methods are meant to be used with the suggested cross-section modification along the stream taking into consideration the 10-year flood and the lowest flow probable as well as the average flow. When giving values of z and bottom width for this suggestion it is considered that it could be nice to have a stream with flowing water all around the year. Therefore the values z=3 and b=0.5 meters was given after some trial and error in calculating the water depth. The reason for having lower values than in the previous suggestion is that a steeper slope and a narrower bottom width result in a smaller cross section, and thereby higher water depth.

Moreover this report encourages the county board and the municipality to continue their investigations of the Bersbo area and its river system, due to its ecological and recreational importance. The suggestions included in this report are meant to be put into practice and used in a near future to increase the water quality in Mulstad farm, but they might also be used for other streams facing similar problems.

9 Conclusion

Risten is moderate when it comes to both individuals and species. The conclusion, as it can be understood from the literature review, is that there are generally no remarkable signs of influence by metals on the bottom fauna in the lake. The metal concentrations in the lake have increased remarkably, as a result of the restoration taking place during 1987-1989.

In lake Risten, the concentration of metals in fish is higher than natural, and although the values are below the limits, it is recommended to continue the investigations of the fish to see if the values are changing. However, according to Livsmedelsverket, the fish in the lake is suitable for consumption and making out no risk for human health. The reason for finding high metal concentrations in fish in Risten is that the lake, even though it is eutrophicated locally, overall has a low nutrient status.

The crayfish population has decreased during the last years, maybe due to a change of their habitat following as a result of the increase in vegetation and bottom sediment. This increase is in turn probably an effect of increased leakage of nutrients from the agricultural activities around the lake, although this is not totally possible to conclude after compiling information about lake Risten and the surroundings, and analysing the results of the measurements, since the amount of measurements is insufficient.

However, observations and analysed reports have demonstrated the fact that lake Risten has changed ecologically during the last decades, in a positive way due to the restoration of the mine deposits nearby, but also in a negative way because of the incipient eutrophication along the shorelines of the lake.

It is recommended to continue with the investigation of metals in lake Risten and of nutrients in the Mulstad stream. If it is found that the values for Mulstad stream are very high, also during a long period, it is strongly recommended to do a restoration of Mulstad stream taking into consideration all the solutions presented in this report.

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Annexes

Annex 1: Calculations

N	Catchment area (km^2)
Q	Water flow (m^3/s)
Q	Specific water flow ($l/s \cdot km^2$)
S	Total lake surface within the catchment (km^2)
Sk	Lake surface of the closest upstream lake in the catchment (km^2)
T	Retention time (months/year)
Pk	Corrected lake percentage (%)
HHQ_{10}	Highest probable water flow during a 10 year period (m^3/s)
MHQ	Mean water flow of the highest yearly water flows (m^3/s)
MQ	Mean water flow over the year (m^3/s)
Mq	Specific mean water flow ($s \cdot km^2$)
MLQ	Mean water flow of the lowest yearly water flows (m^3/s)
LLQ	Lowest probable water flow (m3/s)

Mulstad Stream

Calculation of HHQ

$$N = 1.8755\ km^2$$

$$S\ (total\ lake\ surface\ within\ the\ catcment) = 0.0142\ km^2$$

$$S_k\ (lake\ surface\ of\ the\ closest\ upstream\ lake\ within\ the\ catchment) = 0.0142\ km^2$$

$$P_k = \frac{(S + S_k)}{N} * 100 = \frac{(0.0142 + 0.0142)km^2}{1.8755km^2} * 100 = 1.514\ \%$$

Mq from Figure 2.3 in the Swedish Road Authority is given to 6 l/(s*km^2)

$$MQ = Mq * N * 10^{-3} = 6 * 1.8755 * 10^{-3}\ {m^3}/{s} = 0.01125\ {m^3}/{s}$$

MHQ/MQ =12 according to diagram 2.4 in the Swedish Road Authority (Vägverket, 2008)

This gives:

MHQ=12*MQ=12*0.01125 m^3=0.1350 m^3

MHQ is then multiplied with the correction factor, found as 1.2 since it is on the border between 1.0 and 1.3, from Figure 2.2 in the Swedish Road Authority Document (Vägverket, 2008):

$$MHQ_{corrected} = 1.2 * 0.1350 \, {}^{m^3}/_{s} = 0.162 \, {}^{m^3}/_{s}$$

Figure 2.5 in the Swedish Road Authority Document (Vägverket, 2008) is used to find the maximum discharge:

It is enough to calculate for 10 year flood since the safety is not as big concern in an agricultural landscape as it is in an urban area.

T=10 years:

$$\frac{HHQ_{10}}{MHQ_{corrected}} = 2 \rightarrow HHQ_{10} = 2 * MHQ_{corrected} = 2 * 0.162 \, {}^{m^3}/_{s}$$
$$= 0.324 \, {}^{m^3}/_{s}$$

Calculation of LLQ

Formula 212 in the Swedish Road Authority Document (Vägverket, 2008) gives:

Formula 212 $MLQ = MQ(0.036 + 0.0007 * N + 0.005 * P_k) = 0.01125(0.036 + 0.0007 * 1.8755 + 0.005 * 1.514) \, {}^{m^3}/_{s} = 5.049 * 10^{-4} \, {}^{m^3}/_{s}$

LLQ is approximately 0.5*MLQ for big areas giving:

$$LLQ = 0.5 * 5.049 * 10^{-4} \, {}^{m^3}/_{s} = 2.525 * 10^{-4} \, {}^{m^3}/_{s}$$

Design of cross section

Manning equation is given as:

$$Q = A * R^{2/3} * S^{1/2} * \frac{1}{n}$$

Where n is Manning Coefficient which should be something around 0.03 in our case, R=A/P is the hydraulic radius, A is the cross section, P is the perimeter and S is the bottom slope which is calculated from S=Δz/L.

n= 0.03 (assume fine sand) (US Army Corps of Engineers, 2010)

$$A = (b + z * y)y$$

$$P = b * 2 * y * sqrt(1 + z^2)$$

Calculating S from the Manning Equation

S is calculated for all the eight points in the stream to be able to calculate an average value of S for the whole stream. Below the, point called "Upstream 1" is chosen as an example to show the procedure, and the S-values for all points are later presented in Table A1-1.

Upstream 1

$$z = 0.92$$

$$b = 0.80m$$

$$y = 0.08$$

$$v = 0.693\, {}^{m}/_{s}$$

$$A = (b + z * y)y = (0.80m + 0.92 * 0.08)0.08 = 0.070m^2$$

$$Q = A * v = 0.070 * 0.693 = 0.049\, {}^{m^3}/_{s}$$

$$P = b + 2 * y * sqrt(1 + z^2) = 0.80m + 2 * 0.08 * sqrt(1 + 0.92^2)$$

$$0.049 = (0.80m + 0.92 * 0.08)0.08 * \left(\frac{0.80m + 0.92 * 0.08}{0.80m + 2 * 0.08 * sqrt(1 + 0.92^2)}\right)^{2/3} * \frac{sqrt(S)}{0.03} \rightarrow S = 0.00054$$

Table A1- 1 Summary of the parameters for the eight points

Upstream	z	b (m)	y (m)	v (m/s)	A (m^2)	Q (m^3/s)	S
1	0,92	0,8	0,08	0,693	0,07	0,049	0,00049
2	1,7	1,05	0,23	0,361	0,33	0,12	0,00018
3	1,5	1,35	0,17	0,332	0,27	0,09	0,00013
4	2,7	1,65	0,16	0,285	0,33	0,095	0,000097
5	1,9	1,9	0,21	0,285	0,48	0,14	0,000083
6	2,7	1,7	0,23	0,183	0,53	0,098	0,000043
7	1,9	1,8	0,28	0,136	0,65	0,089	0,000023
8	1,7	1,8	0,33	0,112	0,78	0,087	0,000016

Either the parameters used to calculate the cross sections, i.e. z, b and y, or/and the velocity seem to have been improperly measured in Upstream

2 and Upstream 5 since the flow is increasing a lot in those points and after that decreasing again. However, it can be seen from the measured velocities that the decrease in velocity is quite stable along the stream, and therefore the problem seem to be more related to the cross sections.

Calculation of average S

$S(mean) =$

$= {(0.00054 + 0.00018 + 0.00013 + 0.000097 + 0.000083 + 0.000043 + 0.000023 + 0.000016)}/{8}$

$= 0.00014$

Economical restoration design with focus on nutrient transport

Depth calculated for 10-year flood

$$S = 0.00014$$

$$HHQ_{10} = 0.324\, {m^3}/{s}$$

$$z = 4 \text{ (Lacoursière et al, 1992)}$$

$$b = 1m$$

$$A = (b + z * y)y = (1m + 4 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 1m + 2 * y * sqrt(1 + 4^2)$$

$$0.324\, {m^3}/{s} = (1m + 4 * y)y * \left(\frac{1m + 4 * y}{1m + 2 * y * sqrt(1 + 4^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.43m$$

Depth calculated for LLQ

$$S = 0.00014$$

$$LLQ = 2.525 * 10^{-4}\, {m^3}/{s}$$

$$z = 4$$

$$b = 1m$$

$$A = (b + z * y)y = (1m + 4 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 1m + 2 * y * sqrt(1 + 4^2)$$

$$2.525 * 10^{-4} = (1m + 4 * y)y * \left(\frac{1m + 4 * y}{1m + 2 * y * sqrt(1 + 4^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.0010\ m$$

Depth calculated for MQ

$$S = 0.00014$$

$$MQ = 0.01125\ {m^3}/{s}$$

$$z = 4$$

$$b = 1m$$

$$A = (b + 4 * y)y = (1m + 4 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 1m + 2 * y * sqrt(1 + 4^2)$$

$$0.01125 = (1m + 4 * y)y * \left(\frac{1m + 4 * y}{1m + 2 * y * sqrt(1 + 4^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.027m$$

Restoration design with focus on nutrient transport and recreational values

Depth calculated for 10-year flood

$$S = 0.00014$$

$$HHQ_{10} = 0.324\ {m^3}/{s}$$

$$z = 3$$

$$b = 0.5m$$

$$A = (b + z * y)y = (0.5m + 3 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 0.5m + 2 * y * sqrt(1 + 3^2)$$

$$0.324\, {m^3}/{s} = (0.5m + 3 * y)y * \left(\frac{0.5m + 3 * y}{0.5m + 2 * y * sqrt(1 + 3^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.56m$$

Depth calculated for LLQ

$$S = 0.00014$$

$$LLQ = 2.525 * 10^{-4}\, {m^3}/{s}$$

$$z = 3$$

$$b = 0.5m$$

$$A = (b + z * y)y = (0.5m + 3 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 0.5m + 2 * y * sqrt(1 + 3^2)$$

$$2.525 * 10^{-4} = (0.5m + 3 * y)y * \left(\frac{0.5m + 3 * y}{0.5m + 2 * y * sqrt(1 + 3^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.0013\, m$$

Depth calculated for MQ

$$S = 0.00014$$

$$MQ = 0.01125\, {m^3}/{s}$$

$$z = 3$$

$$b = 0.5m$$

$$A = (b + 4 * y)y = (0.5m + 3 * y)y$$

$$P = b + 2 * y * sqrt(1 + z^2) = 0.5m + 2 * y * sqrt(1 + 3^2)$$

$$0.01125 = (0.5m + 3 * y)y * \left(\frac{0.5m + 3 * y}{0.5m + 2 * y * sqrt(1 + 3^2)}\right)^{2/3} * \frac{sqrt(0.00014)}{0.03} \rightarrow y = 0.051m$$

Missmyra Stream

Calculation of HHQ

$$N = 16.573\ km^2$$

$$S\ (total\ lake\ surface\ within\ the\ catchment) = 0.9584\ km^2$$

$$S_k\ (lake\ surface\ for\ the\ closest\ upstream\ lake\ within\ the\ catchment) = 0.4059\ km^2$$

$$P_k = \frac{(S + S_k)}{N} * 100 = \frac{(0.9584 + 0.4059)km^2}{16.573\ km^2} * 100 = 8.232\ \%$$

Mq from Figure 2.3 in the Swedish Road Authority is given to 6 l/(s*km^2)

$$MQ = Mq * N * 10^{-3} = 6 * 16.573 * 10^{-3}\ m^3/_s = 0.099438\ m^3/_s$$

Formula 12 from the Swedish Road Authority Document (Vägverket, 2008) is applied for small streams in southern Sweden with 10<N<75 km2 and P_k<45%.

Formula 12:

$$MHQ = MQ\left(1.3 + \frac{17.5}{N} + \frac{29}{P_k + 3.5}\right) = 0.099438\left(1.3 + \frac{17.5}{16.573} + \frac{29}{8.232 + 3.5}\right) = 0.4801\ m^3/_s$$

MHQ is then multiplied with the correction factor, found as 1.2 since it is on the border between 1.0 and 1.3, from Figure 2.2 in the Swedish Road Authority Document (Vägverket, 2008):

$$MHQ_{corrected} = 1.2 * 0.4801\, {}^{m^3}/_{s} = 0.5761\, {}^{m^3}/_{s}$$

Figure 2.5 in the Swedish Road Authority Document (Vägverket, 2008) is used to find the maximum discharge:

It is enough to calculate for 10 year flood since the safety is not as big concern in an agricultural landscape as it is in an urban area.

T=10 years:

$$\frac{HHQ_{10}}{MHQ_{corrected}} = 1.8 \rightarrow HHQ_{10} = 1.8 * MHQ_{corrected} = 1.8 * 0.5761\, {}^{m^3}/_{s} = 1.037\, {}^{m^3}/_{s}$$

Calculation of LLQ

Formula 212 in the Swedish Road Authority Document (Vägverket, 2008) gives:

Formula 212:

$$MLQ = MQ(0.036 + 0.0007 * N + 0.005 * P_k) = 0.099438(0.036 + 0.0007 * 16.573 + 0.005 * 8.232)\, {}^{m^3}/_{s} = 8.826 * 10^{-3}\, {}^{m^3}/_{s}$$

LLQ is approximately 0.5*MLQ for big areas giving:

$$LLQ = 0.5 * 8.826 * 10^{-3}\, {}^{m^3}/_{s} = 4.413 * 10^{-3}\, {}^{m^3}/_{s}$$

Byrum Stream

Calculation of HHQ

$$N = 2.3281 \text{ km}^2$$

$$S_1\ (lake\ surface\ of\ lake\ 1\ in\ the\ catchment) = 0{,}0076\ km^2$$

$$S_2\ (lake\ surface\ of\ lake\ 2\ in\ the\ catchment) = 0{,}0387\ km^2$$

$$S_3\ (lake\ surface\ of\ lake\ 3\ in\ the\ catchment) = 0{,}0272\ km^2$$

$$S\ (total\ lake\ surface\ within\ the\ catchment) = S_1 + S_2 + S_3 = 0.0735\ km^2$$

$$S_k\ (lake\ surface\ for\ the\ closest\ upstream\ lake\ within\ the\ catchment) = S_2 = 0.0387\ km^2$$

$$P_k = \frac{(S + S_k)}{N} * 100 = \frac{(0.0735 + 0.0387)km^2}{2.3281km^2} * 100 = 4.819\ \%$$

Mq from Figure 2.3 in the Swedish Road Authority Document (Vägverket, 2008) is given to 6 l/(s*km^2)

$$MQ = Mq * N * 10^{-3} = 6 * 2.3281 * 10^{-3}\ {m^3}/{s} = 0.01397\ {m^3}/{s}$$

MHQ/MQ =12 according to diagram 2.4 the Swedish Road Authority Document (Vägverket, 2008)

This gives:

MHQ = 12*MQ = 12*0.01397 m^3 = 0.1676 m^3

MHQ is then multiplied with the correction factor, found as 1.2 since it is on the border between 1.0 and 1.3, from Figure 2.2 in the Swedish Road Authority Document (Vägverket, 2008):

$$MHQ_{corrected} = 1.2 * 0.1676\ {m^3}/{s} = 0.2011\ {m^3}/{s}$$

Figure 2.5 in the Swedish Road Authority Document (Vägverket, 2008) is used to find the maximum discharge:

It is enough to calculate for 10 year flood since the safety is not as big concern in an agricultural landscape as it is in an urban area.

T=10 years:

$$\frac{HHQ_{10}}{MHQ_{corrected}} = 2 \rightarrow HHQ_{10} = 2 * MHQ_{corrected} = 2 * 0.2011\ {m^3}/{s} = 0.4022\ {m^3}/{s}$$

Calculation of LLQ

Formula 212 in the Swedish Road Authority Document (Vägverket, 2008) gives:

$$MLQ = MQ(0.036 + 0.0007 * N + 0.005 * P_k) = 0.01397(0.036 + 0.0007 * 2.3281 + 0.005 * 4.819)\ {m^3}/{s} = 8.622 * 10^{-4}\ {m^3}/{s}$$

LLQ is approximately 0.5*MLQ for big areas giving:

$$LLQ = 0.5 * 8.622 * 10^{-4}\, {m^3}/{s} = 4.311 * 10^{-4}\, {m^3}/{s}$$

Annex 2: Results from measurements

Table A2- 1 Measurements in Mulstad farm

	formula/info	Mulstad (pipe)	Upstream1	Upstream2	Upstream3	Upstream4	Upstream5	Upstream6	Upstream7	Upstream8	Pipe1	Pipe2	Upstream8
distance (m)	from point before	-	5 (from pipe Mulstad)	50	50	50	50	50	50	50	22 (from Upstream1)	45 (from Pipe1)	270 (from Pipe2)
diameter (cm)	pipe	40	-	-		-							
depth in pipe (cm)	pipe	5	-	-		-							
depth (cm) average		-	8	23	17	16	21	23	28	33			
width (cm)		-	80	105	135	165	190	170	180	180			
revolutions		75	27	14	13	11	11	7	5	3			
speed (m/s) n<0,76	v=0,2392n + 0,016 (m/s)	-	-	-	-	-	-	0,1834	0,1356	0,1118			
n>=0,76	v=0,2552n+0,004 (m/s)	1,918	0,693	0,3613	0,3321	0,2847	0,2847	-	-	-			
pH			7,23							7,33	7,8	7,43	7,33
T			7,8							6,3	9	7,7	6,3
αright(degrees)			45	25	30	20	30	20	30	30			
zright(1/tanα)			1	2,1	1,7	2,7	1,7	2,7	1,7	1,7			
αleft(degrees)			50	40	40	20	25	20	25	30			
zleft(1/tanα)			0,84	1,2	1,2	2,7	2,1	2,7	2,1	1,7			
zaverage			0,92	1,7	1,5	2,7	1,9	2,7	1,9	1,7			
S (Saverage= 0,000139)			0,00054	0,00018	0,00013	0,000097	0,000083	0,000043	0,000023	0,000016			
bottle name			MIP/MIN								MP1P/MP1N	MP2P/MP2N	MOP/MON

Table A2- 2 Measurements Byrum farm

	formula/info	ByrumInlet(ditch)	ByrumOutlet(ditch)
depth (cm) average		15	100
width (cm)		100	400
revolutions		64	1
speed (m/s) n<0,76	v=0,2392n + 0,016 (m/s)	-	0,0399
n>=0,76	v=0,2552n+0,004 (m/s)	1,6373	-
pH		6,9	7,27
T		8,8	8,1
bottle name		BIP/BIN	BOP/BON

Table A2- 3 Measurements Missmyra farm

	formula/info	Missmyra
depth (cm) average		100
width (cm)		400
revolutions		10
speed (m/s) n<0,76	v=0,2392n + 0,016 (m/s)	-
n>=0,76	v=0,2552n+0,004 (m/s)	0,2592
pH		7,4
T		11
bottle name		WOP/WON

Table A2- 4 Measurements in Såken inlet, Risten outlet and in Risten

	formula/info	SåkenInlet	RistenOutlet	InRisten
depth (cm) average		110	unestimated	unestimated
width (cm)		700	unestimated	unestimated
revolutions		5(in the right side)	unestimated	unestimated
speed (m/s) n<0,76	v=0,2392n + 0,016 (m/s)	0,1356	-	-
n>=0,76	v=0,2552n+0,004 (m/s)	-	-	-
pH		7,9	8	7,6
T		6,8	5,9	6,7
bottle name		SIP/SIN	ROP/RON	RP/RN

Annex 3: Data for comparison

Table A3- 1 Data from 1969 to 2009 for lake Risten, County board, 2013

Date	Depth(m)	Temp °C	pH	Alk/Acid meqv/l	NO3-N µg/l	PO4-P µg/l
31-aug-09	0,5	18,2	7,9	0,69		
31-aug-09	17,0	11,5				
15-aug-08	18,5	7,7				
15-aug-08	0,5	19,3	7,8	0,66		
05-dec-07	1	2	7,45	0,664		7
31-aug-07	0,5	17,0	7,8	0,65		
31-aug-07	23,5	6,9				
24-aug-06	0,5	21,8	7,9	0,66		
24-aug-06	18	8,1				
18-nov-05	1	7	7,44	0,67		
11-aug-05	16,5	8,5				
11-aug-05	0,5	18,8	7,8	0,63		
31-aug-04	12,0	13,2				
31-aug-04	0,5	18,2	7,6	0,65		
10-aug-04	0,5	19,8	8	0,64		2
13-aug-03	0,5	22,2	7,7	0,64		
13-aug-03	12,0	9,8				
08-aug-02	0,5	22,8	7,9	0,60		
08-aug-02	18,0	8,2				
16-jul-01	0,5	20,2	7,6	0,63		2
23-nov-00	0,5	8,2	7,25	0,582		
09-aug-00	13,0					
09-aug-00	0,5	18,4	7,5	0,64		
03-aug-99	12,5	10,2				
03-aug-99	0,5	22,2	7,9	0,64		
13-aug-98	0,5	18,5	7,7	0,63		
13-aug-98						
09-jul-98	0,5	19,8	7,9	0,62		3
13-aug-97	0,5	22,8	7,3	0,65		
13-aug-97	17	7,4				
07-aug-96	0,5	19,5	8,0	0,65		
07-aug-96	14	10,0				
14-nov-95	1	5,9	7,35	0,649		
10-aug-95	0,5	20,2	7,7	0,63		
10-aug-95	14	9,3				
30-aug-94	18	10,3				
30-aug-94	0,5	17,5	7,7	0,66		
19-jul-93						
19-jul-93	0,5		7,6	0,64		
13-aug-92	0,5	18	7,6	0,62		
13-aug-92	6	18				
29-jun-90	0,5	18,5	7,9	0,57		5
31-jan-90	2	2,2	7,28	0,592	184	
21-jul-83	0,5	18,0	7,5	0,56		9
26-jul-79	0,5	17,8	7,3	0,46		9
26-jul-74	0,5	18,2	7,6	0,51		9
13-aug-70	0,5					4
29-jul-69	0,5	20,1	7,8	0,49		