CHALMERS
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Environmental Impacts of Small Hydropower Plants

-A Case Study of Borås Energi och Miljö's Hydropower Plants

Master of Science Thesis in the Master Degree Programme, Industrial Ecology

MARIA STEINMETZ
NATHALIE SUNDQVIST

Department of Energy and Environment
Division of Environmental System Analysis
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Department of Energy and Environment
Division of Environmental System Analysis
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:

[The cover pictures show the four different hydropower plants owned by Borås Energi och Miljö. The image at the top left is Haby power station and the upper right picture shows Hulta power plant. The picture, which are at the bottom left shows Axelfors power plant and the picture on the bottom right shows the tube that is at Häggårda power plant. Copyright ©Borås Energi och Miljö.]

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Abstract

The use of hydropower in the society has a long history that started more than 2000 years ago. In Sweden, the first hydropower plants used for producing electricity were commissioned in the 1890s. The major expansion of hydroelectric power in Sweden took place in the 1940s-1970s. Today there are about 2000 hydropower plants in Sweden, accounting for in average 45% of the electricity production. Of these 2000 hydropower plants a large majority are so called small-scale hydropower plants.

The aim of this Master's thesis is to do an environmental review of the four hydropower plants owned by Borås Energi och Miljö. The four hydropower plants, Haby, Hulta, Häggårda and Axelfors, were all built and commissioned in the first part of the 1900s in a time when the requirements on the companies to also take the environmental impacts into consideration were small. The four plants are small-scale hydropower plants and located in two tributaries to Viskan, Slottsån and Häggån and in Ätran. In order to gain knowledge about the environmental impacts hydropower plants can result in, the project started with a literature study where scientific articles, reports and studies performed on hydropower plants were included. Also reports and previous studies performed about the four specific hydropower plants were looked at. The information from the literature study was used together with the information about the hydropower plants in the analysis to do an environmental review of the hydropower plants.

The analysis showed on how complex the impacts from hydropower on the environment are and that there are both direct and indirect impacts on the species living in the areas around the hydropower plants. The main impacts proved to come from the migration barriers that the hydropower plants constitutes, the changes in the water flow due to the regulation of the plants and especially the short-term regulation in Haby and Hulta, and the dry riverbeds that the diversion of the water has caused.

The literature study included also different measures that can be performed in order to mitigate or avoid the environmental impacts hydropower plants are resulting in. For the hydropower plants in this case, the focus should be on building fishways to that the species living in the stream can migrate as they could before the construction of the hydropower plants, start a minimum flow in the original riverbeds so that once existing aquatic life can be restored and start to regulate the water flow so that follows a more natural patter. Borås Energi och Miljö should also perform biotope adjustments to improve spawning sites for the fish.

The thing that mainly has hampered this environmental review was that information about the conditions at the sites before the construction were very limited due to the age of the plants. It has, however been possible to conclude that the four hydropower plants owned by Borås Energi och Miljö have effects on the environment. The impacts are possible to avoid or mitigate by different measures. The measures will result in costs but it is the only way to reduce the impacts the hydropower plants have today.

Keywords: Hydropower plant, environmental impacts, hydrological regime, migration barriers

Miljöpåverkan från Småskalig Vattenkraft
-En Fallstudie av Borås Energi och Miljö's Vattenkraftverk
Examensarbete inom Masterprogrammet Industrial Ecology
MARIA STEINMETZ & NATHALIE SUNDQVIST
Institutionen för Energi och Miljö
Avdelningen för Miljösystemanalys
Chalmers Tekniska Högskola

Sammanfattning

Vattenkraftens historia går långt bak i tiden och började redan för över 2000 år sedan. I Sverige började vattenkraften att användas för att producera elektricitet i slutet av 1800-talet. Den stora utbyggnaden av vattenkraften skedde mellan 1940-1970 och idag finns över 2000 vattenkraftverk i Sverige. Av de 2000 vattenkraftverken är en stor majoritet så kallade småskaliga vattenkraftverk. Tillsammans utgör idag den totala produktionen från vattenkraftverken 45% av elektricitetsproduktionen.

Syftet med examensarbetet var att undersöka vilken påverkan som de fyra vattenkraftverken som Borås Energi och Miljö äger har på miljön. De fyra vattenkraftverken, Haby, Hulta, Häggårda och Axelfors är småskaliga vattenkraftverk och byggdes i början av 1900-talet, under en tid då kraven på att undvika skador på miljön var små eller obefintliga. Tre av vattenkraftverken är belägna i biflöden till Viskan, Slottsån och Häggån. Det fjärde vattenkraftverket är beläget i Ätran. För att få kunskap om de olika effekterna som vattenkraftverk har på miljön startade projektet med en litteraturstudie där vetenskapliga artiklar och undersökningar och rapporter om vattenkraftverk studerades. I litteraturstudien inkluderades även rapporter och studier som behandlade specifikt de områden och miljön där de fyra vattenkraftverken ligger. Informationen från litteraturstudien användes i analysen för att kunna dra slutsatser om den miljöpåverkan som vattenkraftverken resulterar i.

Analysen visade hur komplex frågan om miljöpåverkan från vattenkraftverk är med direkt och indirekt påverkan på ekosystemen som de fyra vattenkraftverken ligger i. De faktorer som visade sig ha störst inverkan på miljön var de vandringshinder som vattenkraftverken utgör och som hindrar arterna i vattendragen från att röra på sig så som de en gång har kunnat, de ändringar i vattenflödet som regleringen har orsakat och främst då korttidsregleringen i Haby och Hulta samt de torrfåror som avledningen av vattenflödet från den ursprungliga vattenfåran har orsakat.

Litteraturstudien inkluderade också olika åtgärder som kan genomföras för att undvika eller minska den miljöpåverkan som vattenkraftverken resulterar i. För vattenkraftverken i det här fallet borde fokus ligga på att bygga fiskvägar så att de arter som lever i vattendragen kan vandra i vattendragen utan att stöta på konstgjorda hinder, minimiflöden skall släppas i torrfåror så att det liv som en gång fanns där kan komma tillbaka och regleringen av vattenflödena skall anpassas så att de mer följer de naturliga variationerna som finns. Biotopåtgärder bör också utföras så att lekområden för fiskar förbättras.

Det som främst har försvårat arbetet med att avgöra vattenkraftverkens påverkan på miljön är avsaknaden av information om hur förhållandena såg ut runt vattenkraftverken innan de byggdes. Det har dock varit möjligt att dra slutsatsen att de fyra vattenkraftverken har påverkan på miljön och på vad som kan göra för att minska denna påverkan. Åtgärderna kommer medföra kostnader men är det enda sättet att minska vattenkraftverkens påverkan. Se Appendix A för en mer utförlig och övergripande sammanfattning på svenska.

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Maria Steinmetz & Nathalie Sundqvist
Gothenburg, June 12, 2014.

Chapter 1

Introduction

This project aim to look at the environmental impacts related to the operation of Borås Energi och Miljö's four hydropower plants. What are the possible environmental impacts and which are the options available to mitigate the impacts or avoid them? The following chapter will give an introduction to the concept of hydropower, the history, the technology and the hydropower's situation in today's society. It should also give an introduction to the project itself including the purpose and the boundaries.

1.1 Hydropower

The use of hydropower has a long history, a history that goes far beyond the use of hydropower for electrification. The Greeks used the power from water for more than 2000 years ago for grinding wheat into flour. It has also been used for irrigation systems, watermills and sawmills. In 1870 the first hydropower plants used for electricity production was installed in Cragside, Rothbury, England. But the breakthrough did not come until 12 years later when the turbine was connected to the generator. The use of hydropower for making electricity proved to be much more stable than other ways of producing electricity at the time. This resulted in an increase of the installation of small- and middle-sized hydropower plants. By 2008 the installed capacity from hydropower in the world contributed with 16% of the total electricity production (Kumar et al., 2012).

The first hydropower plants in Sweden were built in the 1880s but it was between the 1940s-1970s the major expansion of the hydropower in Sweden occurred. Today the installed capacity from hydropower plants is about 16 200 MW spread over about 2000 hydropower plants. The 200 biggest plants, with an installed power above 10 MW, contribute with about 94% of the total production. The hydropower plants lying in the range 1.5 MW-10 MW contributes with 3.9 % of the total production. The hydropower plants with an installed power of less than 1.5 MW are the largest group of hydropower plants in Sweden. Around 1700 plants in Sweden have an installed power of less than 1.5 MW and together they produce about 2.6% of the total electricity production from hydropower (Statens Offentliga Utredningar, 2013).

The hydropower is today an important part of the electricity production in Sweden and not only as a producer of electricity but also as a possibility to use it as a regulating- and balancing power, by storing the water in reservoirs, the water can be saved and used for electricity production when there is demand for it. The production and the possibility to store water fluctuate due to the changes in the weather conditions. In the last 10 years the hydropower has produced on average 66 TWh, which is about 45% of the total production in Sweden (Statens Offentliga Utredningar, 2013).

There are three main categories in which the different types of hydropower plants can be divided into, run of river, storage hydropower and pumped storage. The run of river could have a smaller storage, which is big enough to store water for some hours or a day but the amount of electricity it produces depends generally on the flow of water available at the time. This result in that it is hard to control the amount of electricity produced and when it is produced, and it depends instead on the conditions in the water flow (Kumar et al., 2012). The flow depends on precipitation and runoff and has often daily, monthly and seasonal variations (International Energy Agency, 2011). Run of river plants have in general lower environmental impact than storage hydropower plants of similar size (Kumar et al., 2012).

Storage hydropower consists of a reservoir used for controlling the flow through the turbines. The reservoir will decrease the dependence on the natural water flow and level out the variability. The generating stations are situated at the dam toe or further down streams. The stations are linked with the reservoir through pipelines or tunnels (Kumar et al., 2012). Generally the dams used are artificial but when the conditions allows, natural existing lakes can be used as reservoirs (International Energy Agency, 2011).

A pumped storage hydropower plant on the other hand, is not a way of producing energy but a way to store the energy. When not so much electricity is needed the water is pumped up from a lower reservoir to a higher reservoir. At the time for an increased need of electricity the stored water can be used to produce electricity (Kumar et al., 2012).

Another kind of hydropower technology, which is rather new, is the water current turbines, also called hydrokinetic or in-stream turbines. This technology has received a growing interest in many parts of the world. These turbines can be used to produce electricity from free flowing water in a river or stream and it do not rely upon a head to produce electricity. No dams or major construction is therefore needed to extract the energy (Sørnes, 2010).

Another way to divide and classify different kinds of hydropower plants can be according to the size. However, there is no existing general standard on how to classify the hydropower plants after the size today (Kumar et al., 2012). Different ways are used to classify them and also the view on which size of the plant that should be seen as small differs. One way to classify them is to order them after the size of the head. For example could heads over 300 m be said to be high-heads, head between 30-300 m be medium-heads and heads below 30 m could be seen as low-head. But there is no general standard and what is seen as low or high differs between countries. Another way to structure the hydropower plants after size is to look at the installed capacity. Also here, the distinction in what should be considered as small or large varies between the countries and there is a wide range. In China, for example is hydropower with an installed capacity of below 50 MW considered as small-scale (International Energy Agency, 2011). In Europe on the other hand is the general definition for small hydropower, a plant with an installed effect of up to 10 MW (European Small Hydropower Association (ESHA), 2014). For Sweden the limit for large-scale hydropower is considered to be above 10 MW (Bergengren et al., 2013). However, there are few different perceptions about what should be considered as small-scale hydropower in Sweden and it is possible to find classifications in the literature where only hydropower plants with an installed capacity below 1.5 MW should be seen as small-scale.

Generally it can be said that hydropower consists of different basic components, see figure 1.1.

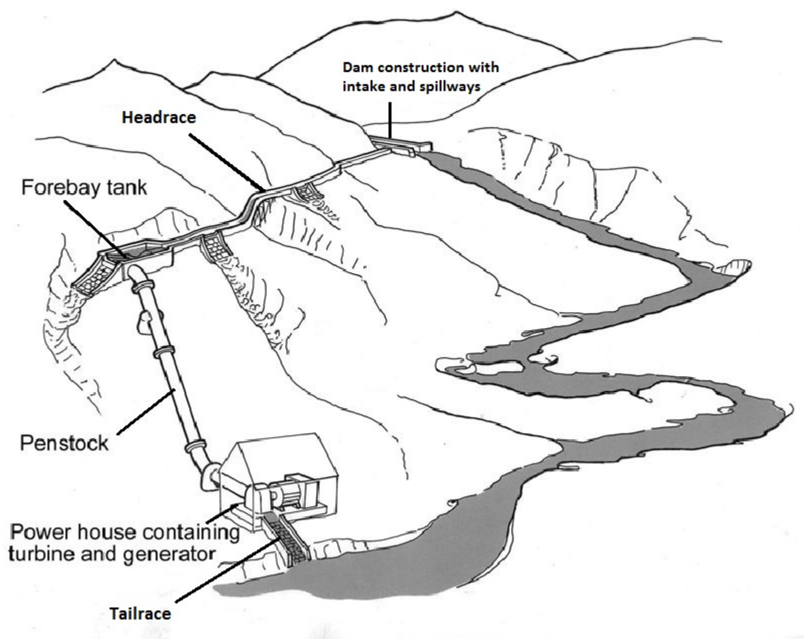

Figure 1.1: General components of a hydro power plant. The figure is based on the original picture from (Gatte and Kadhim, 2012)

This picture is mainly valid for storage hydro but may also be consistent with the run of river when disregarding the dam construction. For the storage hydro there first is a dam construction with intake and spillways. Before entering the intake there will be an intake screen. This intake screen has the task to clear away garbage such as branches that can cause problems in the turbine. The screen will also protect so that the fish does not come through and can be damaged by the turbine. The intake screen consists of a grid, the distance between each parallel element in the grid is called the grid width. Different sizes of the grid width affect what can be released through it. At many hydropower plants the intake screens are occasionally cleaned. This is done by a device similar to rakes. The rakes, which can be manually or mechanical, gathers what have been stuck on the screens for example levees, branches but also fish (Calles et al., 2013).

Further, now also applicable for run of rivers, the intake whit its intake screen, leads to a take-off channel that is called headrace, which directs all or a part of the water in the stream to the power plant. At the end of the headrace a settling tank is located, called the forebay tank. This tank helps to slow down the water and having particles to settle down, this to counteract that all particles go through the turbines where it can make damage. From the forebay tank the water continue in a closed pipe, commonly called a penstock. This pipe is leading the water in to the powerhouse where the turbine(s) and the generator are located. After the water has passed through the turbine it is returned to the river via a channel called tailrace. Worth mentioning, however, is that there are different variations of how a hydropower plant could be constructed and that the use of the different components may differ (Gatte and Kadhim, 2012; Packer, 2011). The magnitude of the environmental impacts is also depending on which components that is included and how the power plants are constructed. Another thing worth to mention, is that it does not normally flow so much water in the natural riverbed, which can be misleading in the picture. This is only valid when the spillways are open due to regulations.

To extract electricity from hydropower different kind of energy is used. First, there is the potential energy, this energy is available upstream the power plant due to the water mass and the head. This potential energy will then be converted to kinetic energy, which is the energy in the falling water. The pressure from the water makes the turbines to rotate and mechanical energy can be converted. The mechanical power can then be used to produce electricity in generators. The possible amount of power to produce is proportional to the head times the flow. It can in a more general formula be described as:

$$P = \eta * \rho * g * Q * H \ [W]$$

In the formula is P the mechanical power, η is the efficiency of the turbine, ρ [kg/m^3] is the density of the water, g [m/s^2] is the acceleration of the water due to the gravity, Q [m^3/s] is the flow of the water through the turbine and H [m] is the head (Paish, O. 2002).

Two different mechanisms can be used in the turbines and hence there are two different types, the reaction turbines (e.g. Francis and Kaplan) and the so-called impulse turbines (e.g. Pelton) (European Small Hydropower Association (ESHA), 2004b).

The most commonly used turbine is the Francis turbine, see figure 1.2. The reason to that is that it is suitable for a variety of head and for both large and small flows and that it also has a very good efficiency (International Energy Agency, 2011). However, the efficiency drops quickly if the turbine is not run on the water flow, or close to the water flow, it is constructed for. The Francis turbine is usually used for heads in the range from 25 m to 350 m. (European Small Hydropower Association (ESHA), 2004b). The water in the Francis turbines flows radially inwards into the runner but the outlet is axial (Paish, 2002).

Figure 1.2: Francis turbine (Sempler, 2009).

The Kaplan turbine is just like the Francis turbine a reaction turbine. The Kaplan turbines are suitable for conditions with low heads and large flows. The water flows in radially into the turbine but in the turbine the water is turned 90 degrees and is therefore flowing axially when it reaches the spinning impeller, see figure 1.3 (International Energy Agency, 2011).

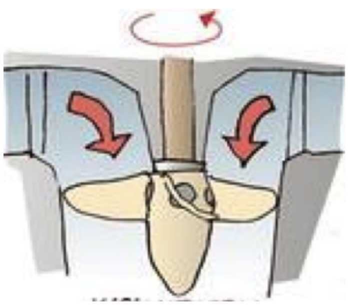

Figure 1.3: Kaplan turbine (Sempler, 2009).

The Pelton turbine on the other hand is an impulse turbine. The Pelton turbine is used for head that measures from 30 m up to 1000 m and for small flows. The turbine consists of one or more jets that strikes on a wheel that has several spoon-shaped buckets mounted, see figure 1.4 (European Small Hydropower Association (ESHA), 2004b).

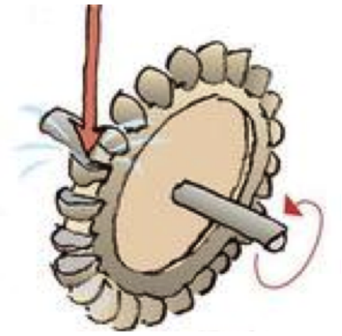

Figure 1.4: Pelton turbine (Sempler, 2009).

1.2 Directive/Regulations

This section is in the background to provide a good base about the laws and regulations that is associated with hydropower plants today. The section about Natura 2000 is included since an area downstream one of the hydropower plants in the case study is classified as a Natura 2000 area.

1.2.1 Water Framework Directive

The Water Framework Directive (WFD) started 2000 and is a directive formulated by the European Union to protect the waters based on the catchment areas independent on national or political boundaries. The waters should have a good ecological and chemical status. To classify the ecological status on the surface water, the water is divided into five different categories depending on the status of the water. The five different categories are high, good, moderate, poor and bad. To define the status on the water there are several different aspects that should be included to get a correct status of the water. The abundance of fish and aquatic fauna, availability of nutrients, salinity, temperature, pollutants, water flow, water depths, and structures of the riverbeds are aspects that should be included (European Union, 2010). According to the WFD the biological quality factors such as fish and aquatic fauna is the one with greatest weight, followed by physico-chemical factors and finally the hydromorphological quality elements (Sjölander et al., 2009).

The goal is that by year 2015 all the streams should have a good ecological status. If there is a risk that a stream will not reach the goal, actions should be implemented in order to achieve good ecological status (Länsstyrelsen Västra Götaland län, 2014). In the cases where the stream today is classified as bad, poor or moderate there is a possibility to prolong the timeframe to reach the goal or modify the goal that should be reached (Statens Offentliga Utredningar, 2013). In a report from Hav- och vattenmyndigheten from year 2012 they are concluding after having a meeting with a dialogue with relevant authorities, environmental organizations and hydropower companies, that water regulation and reservoirs are the main obstacles to reach the goal in the water framework directive (Havs- och vattenmyndigheten, 2012).

1.2.2 Water Activity Investigation

The Swedish Government decided in April 2012 to appoint a special commission with the mission to review the rules on water activities in the Environmental Code and the Law on special provisions for water operations. This becomes known as the Water Activity Investigation. The investigation suggests how to ensure that the facilities that are not permitted under the Environmental Code should be designed and operated in such a way that the Environmental Code are taken into account and that the requirements of EU laws with respect to water quality and the effect on animal and plant life will be met (Statens Offentliga Utredningar, 2013). Today only 2% of Swedish hydropower and dams are examined under the Environmental Code (Naturskyddsföreningen, 2013).

An interim report was published in 2013 where the investigators presented their standpoints regarding the analysis. The interim report comes with the proposals that hydropower plants constructed under older permits, with the support of older licenses and requirements than the Environmental Code should be reassessed so that they complies with the environmental requirements under the Environmental Code and the European Union law. An assessment would be carried out as if it were a brand new business or facility. This mean that the impact of these hydropower plants would be needed to be assessed and reported (Statens Offentliga Utredningar, 2013). New re-investigations of the hydropower plants are fundamental in the case that their condition must meet current environmental legislation and to Sweden as a country to live up to the requirements of the EU Water Directives (Naturskyddsföreningen, 2013).

The interim report has now been circulated for comments and opinions. A final report of the Water Activity Investigation shall be presented in the beginning of the summer, 2014 (Statens Offentliga Utredningar, 2013).

1.2.3 Natura 2000

Natura 2000 is a network in EU of protected areas in the environment. The purpose with Natura 2000 is to protect and preserve the biodiversity in the European countries within EU. The network was created to stop the extinction of animals and plants and to prevent their habitats from disappearing (Länsstyrelsen Västra Götalands län, n.d. b). Areas classified as Natura 2000 are sites with species or habitats that are especially worthy of protection in a European perspective (Naturvårdsverket, 2012). Where hydropower is present at Natura 2000 areas, it is especially important to control the hydropower plant's environmental impact, since this area is seen as particularly sensitive. It is also important to protect and prevent damage to the animals and plants that are considered to be extra sensitive.

Areas of Natura 2000 are designated based on two different EU directives, the Birds Directive and the Habitats Directive. Each Member State has, on the basis of the EU Birds and Habitats Directives, chosen which areas and species that they want to preserve and also determine how they should be managed. All species or protected areas need not to be unique in their country, but should be considered as threatened in a European perspective (Naturvårdsverket, 2012).

In connection with that an area is made to Natura 2000 a conservation plan for the area is performed. The conservation plan should include a description of the area and the natural values, possible impacts that can harm the environment in the area and what is required to maintain natural values. To prevent damage to Natura 2000 sites, permits are required for activities or measures that can significantly affect the environment in a Natura 2000 area (Länsstyrelsen Västra Götalands län, 2005a). The Environmental Protection Agency coordinates the work on Natura 2000 in Sweden. Länsstyrelserna performs large parts of the work, but key players are also forest agencies, local authorities, landowners and farmers (Länsstyrelsen Skåne län, n.d.).

1.3 Project

This project aims to look at the possible environmental impacts related to the construction and operation of the four hydropower plants owned by Borås Energi och Miljö. Hydropower is a very complex issue and its impacts on local landscapes and biodiversity is very hard to measure and to quantify and therefore hard to compare with other sources of impacts. Borås Energi och Miljö would therefore like to compile an environmental review of their hydropower stations and their surrounding environment to get a better understanding of it and also consider if there are improvements that can be made.

An environmental review will also be a good basis in order to meet any future requirements and laws on hydropower. As said earlier in the report, a water activity investigation is in focus right now. This may mean that hydropower plants built earlier than the Environmental Code may be re-examined. Many of today's hydropower plants were built before the Environmental Code was in force and therefore they have received their environmental permits based on other grounds. If the suggestions from the interim report goes through it may be the case that these hydropower plants also should be permitted according to the Environmental Code current today. This may mean that the impact of these hydropower plants may be needed to be reported and a lot of work has probably to be carried out for the hydropower plants' owners (Regeringskansliet, 2013; Svenskt Näringsliv, 2014).

This master's thesis and the result of the study will help Borås Energi och Miljö to get an overall picture of their hydropower plants, the possible environmental impacts that the hydropower plants have on the ecosystems surrounding them and what can be done to mitigate the environmental impacts. The master's thesis will also be helpful in the way that Borås Energi och Miljö later will be able to use this information for further evaluation work. By using for example an assessment model and thus weighting different impacts, they can be able to compare different impacts from different activity sources. By doing that they can compare their various fields of activity for example hydropower with district heating in an easier way.

1.4 Company

Borås Energi och Miljö is a company, which provide customized solutions in energy-, waste-, water and environmental areas within and around Borås municipality. The company is owned by Borås Stad and has 228 employees (Kretsloppsstaden, 2014). The yearly turnover for the company is about 950 million SEK (Borås Energi och Miljö, 2014a).

Borås Energi och Miljö's fields of activity are district heating and cooling, biogas, waste management, water and sanitation, energy and waste services. The company also produces electricity in their combined heat and power plant (CHP) and also in their hydropower stations (Borås Energi och Miljö, 2014a). Borås Energi och Miljö convert the energy from for example waste to become other energy sources as heating, cooling and biogas. They manage waste and wastewater treatment and they also provide drinking water to Borås.

Borås Energi och Miljö's ambition is to preserve and take care of all energy flows in Borås and convert them into utility. The company works to achieve the vision so that Borås will become a city free of fossil fuels. Borås is today an international role model in the work field of the cycle of the society (Kretsloppsstaden, 2014).

1.5 Purpose

The purpose of this thesis is to do an environmental review of the four hydropower plants, and some constructions belonging to the hydropower plants, owned by Borås Energi och Miljö. The report should include the environmental impacts the different plants may have on the surrounding ecosystem and also recommendations and different actions that can be taken to improve the situation and decrease the possible environmental impacts from the hydropower plants.

1.6 Problem Formulation

The project will include several different parts such as background information and information about earlier studies done in the field but there are some specific questions that should be answered during the progress of the work:

- Which are the environmental impacts from the hydropower plants owned by Borås Energi och Miljö?
- What can Borås Energi och Miljö do to mitigate the environmental impacts from hydropower on the surrounding ecosystem?
- How is Borås Energi och Miljö action processes against negative environmental impacts compared to some other operators at the market?

1.7 Boundaries

The project is a case study on the four hydropower plants owned by Borås Energi och Miljö and the environmental impacts described in text is therefore concerning the four specific hydropower plants. The project includes a literature study on the possible environmental impacts from hydropower, measures that can be taken to mitigate the impacts, information gathering about the four different hydropower plants and an analysis part where the information in the literature review is connected to the situation at the four plants. The study have not included any measurements or investigations performed at the sites.

The four hydropower plants are classified as small-scale hydropower plants and in general is therefore the information gained and presented here concerning small-scale hydropower plants. This is because the large amount of available information about hydropower plants, there was no time to look at all kinds of impacts from hydropower plants and it is neither relevant for this study. The four hydropower plants are approaching, or have even passed an age of 100 years. Due to that, no comparisons with the situation before the construction of the four hydropower plants have been included and the environmental impacts described is based on how the situation for the ecosystem are today.

No consideration has been taken on the remaining infrastructure such as roads and transmissions lines and the environmental impact related to that. Instead the focus has been on hydropower plants and the surrounding ecosystem and the environmental impacts connected to the plants. In similar way has the cumulative effects not been included, the focus should be on the four specific hydropower plants and what Borås Energi och Miljö can do to mitigate their environmental impact.

Chapter 2

Method

The master's thesis started with a literature study in order to gain the needed knowledge about the environmental impacts that can be connected with hydropower plants and especially small-scaled hydropower plants. To broaden the understanding about hydropower, information about how hydropower works and the history of hydropower was included in the literature study. Another important part of the literature study was to find information about the four different hydropower plants owned by Borås Energi och Miljö. This was done through e.g. earlier investigations. Information was gathered about how they are built and how they are operated. Except from only reading about the plants, a study visit at the four different hydropower plants also has been included. This was done in order to get a better view on how the hydropower plants looks, in what kind of environment they are situated and the size of the plants. The literature study was, also after the first weeks of the project, an important and ongoing part of project since new questions occurred as the work was progressing. The information from the literature study has been compiled in a literature review. The literature review has been divided into one part where the possible environmental impacts are described and the mechanisms behind them. Following the impact part is a section describing the possible measures that can be taken to mitigate or avoid damages on the ecosystem.

The case study about Borås Energi och Miljö's hydropower plants required a different approach than when performing the literature review. The literature review information was mainly gathered from scientific articles and reports about hydropower and its environmental impacts. The information about Borås Energi och Miljö's hydropower plants and the condition of the surrounding ecosystem have shown more diversity in form of the different sources to information that have been used. The information have had its origin in documents from Borås Energi och Miljö, notes from Borås Energi och Miljö about the renovations on the hydropower plants, water permits, different investigations of the ecosystem at the sites and by conversations with knowledgeable persons at Borås Energi och Miljö.

The gained information in the literature study has formed a base from which a model has been created. In the analysis, the model has been compared with the gathered information about the four hydropower plants so that an evaluation about the plants and their environmental impacts has been performed. Finally, the literature study have been used to write recommendations about what Borås Energi och Miljö can do to mitigate or avoid impacts on the surrounding ecosystems.

Except from looking at the four specific hydropower plants, a part has also been included in the project about what is done in other companies that seems to be at the forefront with their environmental work. Interviews with persons, familiar with the environmental work, have been performed to get information on how they have worked and thought when performing the environmental work. The questions asked to the companies have been develop through reading the information available about the companies and what the companies have performed in order to mitigate or avoid impacts on the environment together with a base in that the answers should get a view of why the company decided to do this kind of environmental work and what kind of result they have got.

Chapter 3

Literature Review

In the literature review the compiled information from the literature study is presented. The literature review is divided into two different main categories, impacts and mitigation actions. The chapter aims to give an insight, which the known environmental impacts connected to the operation of hydropower plants are, and especially those connected to small-scale hydropower plants. The chapter aims also to give an insight in what kind of measures that can be taken to avoid or mitigate the environmental impacts.

3.1 Impacts

The following section introduces possible impacts on the environment that are connected to hydropower plants. Both environmental impacts related to the construction of hydropower plants and impacts related to the operation of hydropower plants are included.

3.1.1 General Information

Hydropower plants are generally seen as green energy sources, which are carbon free and use inexhaustible resources to produce the energy. The prime driver is the force of gravity and the water used to drive this power is non-destructive (Abbasi and Abbasi, 2011). According to Yüksel (2010) hydropower do not pollute the air we breathe in the way that the energy source does not produce any air pollutants. Unlike thermal power plants for example, there are no gaseous of fly ash emissions emitted during the production. The fact that hydropower often replace fossil-fired generation, it can therefore also be said that it is reducing the problem with acid rain and smog (Abbasi and Abbasi, 2011; Yüksel, 2010).

Despite all these advantages hydropower plants have, there may also be negative impacts. Lately the impact on the ecological aspects from the power plants has received attention. In the report from World Commission on Dams (2000), it is stated that dams will have effects e.g. on the terrestrial ecosystem and biodiversity, the flow regime, migration of aquatic organisms, and can cause emissions of greenhouse gases. Bratrich et al. (2004) states that hydropower affects the flow regime, migration of organisms and transport of nutrients and sediments. Abbasi and Abbasi (2000) claim that hydropower plants causes major ecological impacts in all of the four different habitats, which are associated with the projects; the estuary into which the river flows, the downstream reaches of the dammed river, the reservoir catchment and the artificially created lake. So how right it is to say that hydropower is a green energy source or not has come up for discussion lately.

In the environmental barometer on small hydro power, by European Small Hydropower Association (ESHA) (2009), it can be read that 100% of questioned experts agreed upon that small hydropower plants has an impact on the environment. They all agreed that there is no difference in impacts depending on the size of the power plants.

In the report by Bakken et al. (2012) a study about 27 small-scale hydropower plants in Norway has been carried out. In this study an investigation about environmental impacts was done. Different impacts were assessed at the 27 different sites and the amount of cases of impact reported was noted. For example, the reduction in water flow was reported as an impact in 100% of the sites, fish fauna affected by the plant was reported in 78% of the sites and changed water quality was noticed at 11% of the sites (Bakken et al., 2012). Also in the report by European Small Hydropower Association (ESHA) (2009), some strongly identified impacts are mentioned in the environmental barometer on small hydro power, see figure 3.1. Experts have identified these impacts and the percentage value indicates how often the impacts have been mentioned (European Small Hydropower Association (ESHA), 2009).

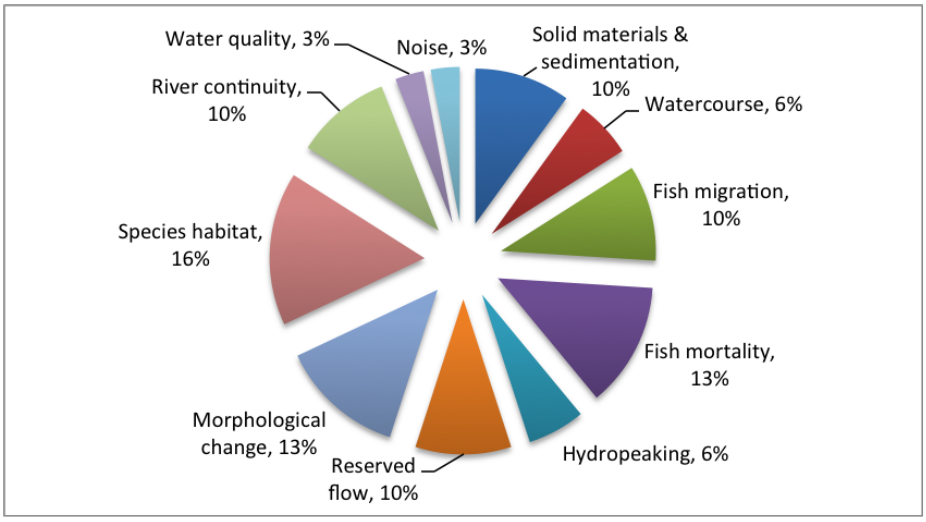

Figure 3.1: Strongly identified impacts from hydropower plants. (European Small Hydropower Association (ESHA), 2009)

From figure 3.1 above it can be seen that species habitat, fish mortality and morphological change are the most common impacts identified.

According to Bergkamp et al. (2000) it is possible to divide the impacts from hydropower plants into three different categories, first-, second-, and third-order impacts. This can further be divided into what happens downstream and upstream for the different levels. The first-order impacts located upstream are for example related to the change of the thermal regime, alteration of the water quality and accumulation of sediment in the reservoirs. Downstream the first-order impacts are related to changes in e.g. the water flow, morphology, water quality, water temperature and reduced sediment flow.

The second-order impacts are a result from the first-order impacts and concern the abiotic and biotic changes in the ecosystem structure together with the primary production, both upstream and downstream. Unlike the first-order impacts that occur as soon as a reservoir is commissioned, the impacts related to the second-order impacts are something that can take place over several years. The ecosystem that become affected downstream and upstream are similar to each other and concern for example the riparian vegetation, the growth of aquatic macrophytes and the plankton and periphyton in the stream (Bergkamp et al., 2000).

The third-order impacts are in turn a result of the first- and second-order impacts. These changes are on going over many years until a new ecological equilibrium may be reached. The third-order impacts are related to the effects on the invertebrates, mammals, fishes and birds in the ecosystem. Downstream it is also related to the marine and estuarine impacts (Bergkamp et al., 2000).

With the knowledge from this general information part about environmental impacts from hydropower plants, some impacts are further investigated in the report. These are; hydrological regimes, sedimentation, water quality, migration barrier, greenhouse gas emissions and biodiversity.

3.1.2 Hydrological Regimes

In the following section the impacts that hydropower plants have on the hydrological regime will be described. The first part gives an introduction to why the natural water flow is important for the ecosystem. The second part is more focused on the changes that hydropower plants result in. The section ends with some examples of how the hydrological regime can be classified.

3.1.2.1 Natural Water Flow

The flow of a stream varies naturally and is dependent on the climate and the geomorphology, which is the study of landforms and the processes that shape them. The naturally variability of flows is the most important characteristics in streams, this because it helps with structuring and maintain different functions of the natural waterways (Malm Renöfält and Ahonen, 2013). According to Bunn and Arthington (n.d.) many aquatic ecologists regards the flow regime to be the key driver of river ecosystems. The naturally variability of a flow create a dynamic environment for the surrounding, which creates conditions that favour high biodiversity. Natural patterns of longitudinal and lateral connectivity is said to be essential to the viability of populations of many riverine species. Aquatic species for example have evolved life-patterns based on the naturally seasonal flows. A natural flow variability also control nutrition and competitive relationships between species, which creates a stable ecosystem (Bunn and Arthington, n.d.; Malm Renöfält and Ahonen, 2013).

How the natural flow varies depends on both size of catchment areas and position in the landscape. To get an understanding of how natural variability of flow works, one could look at the amount of water (magnitude), duration of flow, how often a specific flow rate occur during a time span (frequency), for how long time the flow rate persist, when a flow rate happens (timing) and the rate of change. Due to regulations, one or more of these properties will be changed, which in turn affects the entire system (Malm Renöfält and Ahonen, 2013). Alterations of flow regimes is often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands (Bunn and Arthington, n.d.).

The natural variability of the flow can consist of different kinds of flow conditions. Some flow components are for example base flow, extremely low flows, pulses of high flows and larger floods. All of these components help to keep up with a good basis for good functioning waterways with associated ecosystems, one can say that different flows represent different services for ecosystems. Base flow helps to maintain adequate habitats among aquatic organisms and keep appropriate water quality. It contributes to a good situation for fish and allows them to look for food and to reach spawning grounds. The base flow also helps to provide a drinking water source for terrestrial animals. It also contribute to maintaining the water level in the shore land and ensure that the water content in the land closest to the stream, the shore soil, does not get too low during dry periods. Extremely low flows on the other hand helps prevent invasive species to establish. The flow also helps to concentrate some species to restricted areas for the benefit of predators but it can also create hiding places for some other species to help for not being reached by predators. The flow component regarding pulses of high flows helps to shape the structure of the riverbed and prevent the shore vegetation from growing down into the riverbed. The high flows also restore the water quality after periods of prolonged low flows and rinse off pollutions. It also controls the amount and size of the bottom substrate such as sand, gravel and stones. Larger floods are a component with a large effect of the shape of the riverbed and can also contribute to supply nutrients to the riparian zone. New habitats can be created and the floods can trigger changes in phases in different organisms' life cycle. The flood controls the vegetation of the riparian zone by drowning or pulling up certain vegetation. It also helps to provide the stream with organic material to the aquatic food webs and bring seeds into the stream to help the spreading. It is the naturally variability of floods and the related transfers of material that makes floodplains and rivers among the most fertile, productive and diverse ecosystems in the world (Jansson, 2002; Malm Renöfält and Ahonen, 2013; Bergkamp et al., 2000).

Malm Renöfält et al. (2010) refers to some flow characteristics that are fundamental to physical and biological processes in the river. Some of these characteristics were the magnitude, duration of flow, frequency, timing and the rate of change. Malm Renöfält et al. (2010) and Malm Renöfält and Ahonen (2013) discuss a series of changes that occur related to unnatural variations of these flow characteristic, see table 3.1.

Table 3.1: Hydrological regime characteristics

Characteristic	**Alteration**	**Ecosystem response**
Magnitude	Increased variation	Washout of organisms and organic matter. Can increase the risk of landslide.
	Stabilized flow	Can contribute to failed establishment of riparian species and invasion of exotic species. There will be a dominance of competitive species and loss of poor competitors.
Frequency	Increased variation	Will lead to a reduced habitat availability. Can also contribute to increased erosion that can lead to increased stress and loss of organisms.
	Decreased variation	There will be a dominance of competitive species and thus a loss of poor competitors. A decreased variation can also lead to decreased flushing of sediments.
Timing	Loss/change of seasonal flow variables	Disturbed life cycles that will lead to reduced growth rate and changed succession patterns. There will also be a reduced habitat availability.
Duration	Prolonged low flow	Can affect aquatic organisms and their physiological stress. There can also be an altered abundance and diversity.
	Prolonged inundation	Changes in the riparian community.
	Shortened low flows	Increases the availability of aquatic habitats.
	Shortened flood peaks	Encroachment of land organisms into the riverbed.
Rate of change	Rapid changes in river stages	Loss of riparian zone and its vegetation. Failed establishment of riparian organisms because of wash out and stranding of organisms.

Within these broad patterns of change due to unnatural variations of the flow characteristic, Bergkamp et al. (2000) states that there is a wide diversity of specific impacts. Impacts may vary between dams, catchments, ecosystems and also between species.

3.1.2.2 Hydropower Plants and the Hydrological Regime

Bergengren et al. (2013) states in their report that when constructing a dam or hydropower plant, changes in the hydrological regime will follow. IPCC suggest the same thing and claim in their report that changes in the hydrological regime is a significant impact from the hydropower plant. They argue that due to a hydropower plant there will be changes in water level, timing and temperature, which will affect the surrounding terrestrial and aquatic ecosystem (Edenhofer et al., 2012).

Many hydropower plants have a storage reservoir, which is created by damming a river. This creates a flood of the area upstream the power plant. By the creation of reservoirs by using dams it changes the naturally occurring water level variations and the land that have been above the water now turns under water, this cause impacts on the riparian zone. Conditions will be changed and organisms will be challenged (Hovsenius et al., 2002). The flooded area will impact people, animals and vegetation. In a regulated reservoir the water level fluctuations may not be synchronised with the natural regime. This contributes in the way that the riparian vegetation cover becomes extremely sparse and the riparian ecosystem gives the impression of a barren strip. The impacts of reservoirs are directly related to the topography, thus the gradient of the drawdown zone, which is the area alternately exposed to air and water due to the regulations of the water flow. In the case with steep gradient drawdown zones together with water fluctuations the zone often become characterised by barren strips. With flat gradients on the other hand, much wider areas can be affected, causing both a disappearance of species and the creation of new habitats for amphibians, birds and drawdown-area plants (Bergkamp et al., 2000).

When a dam is constructed, the water can be regulated, which in some cases can mean that at certain times no water will be released through the dam. This would then lead to that the area downstream the power plant would be largely dry. The dried flood bed will deteriorate the living environment for all the species living in and around the river. In the most extreme case, the whole riverbed will be dry downstream to the hydropower plant. This is devastating for any flora and fauna living in the water or in the riparian zone (Melin, 2010). Due to the dam and the reduced water flow, the spreading of seeds will be affected (Malm Renöfält and Ahonen, 2013). This will in turn have an effect of the fragmentation of the river vegetation (Melin, 2010). A reduced inundation of the riverbed downstream of dams may also reduce groundwater recharge in the riparian zone. This will result in a lowering of the groundwater table, with consequent impacts on riparian vegetation (Bergkamp et al., 2000).

Other problems with dry riverbeds are arising upstream and along the side of the plant. This because the situation when the water is led through a channel, tube or tunnel to reach a hydropower plant that is located some distance away from the dam or the water intake. Since most of the water is directed by the passage to the turbine, the water in the natural riverbed is reduced. If no water at all is let through the dam or through the spillways which are leading to the original riverbed, there will be a non-aquatic environment and significant changes in habitat and ecosystem (Bergengren et al., 2013). In some cases a minimum flow can be directed to this original waterway. This is done to get a more environmentally adapted flow and protect the old riverbed and its ecosystem and to maintain a good ecological status. The more water that goes through the old riverbed the better it is in an environmental perspective, this because it become more similar to the unregulated stream (Malm Renöfält and Nilsson, 2005). According to Malm Renöfält and Ahonen (2013) one single time of no water through the original riverbed can decrease the length of the food web to one third of its original length and the effect of this can last for about 20 years. If the minimum flow is very low the available proportion of the original habitats will decrease, this will hence complicate the spreading of organisms. Static minimum flows should although be avoided, the best way is if it reflects the naturally variability of the flow regime in current region. The Irish Department of Communications Energy and Natural Resources (2007) states that for low heads is the water diverted to the turbines large relative to total flow. This may reduce the residual flow in the natural channel. They claim that adverse effects to this can for example be disruptions of food webs downstream, stranding of fishes and drying out of egg masses.

When building a dam it will also affect the speed of the water. Earlier lotic water can be transformed into, almost lake-like lentic water upstream (Bergengren et al., 2013). High, fast changes of the flow rate can downstream result in damage to the vegetation, erosion and changed ice conditions, which in its way also lead to erosion and damage to the vegetation. Spawns of different fish species can be affected by fast flow changes in the way that they become stranded and the mortality will therefore increase (Malm Renöfält and Ahonen, 2013). A reduced flow rate on the other hand will also have impacts, in the winter lower flows increase the probability of anchor ice formation. This affect in the manner that anchor ice can isolate, strand and kill fish (Douglas, 2007). Sedimentation and transport of nutrients will also be affected by decrease of the flow rate. This will lead to that the bottom of the river and its biological significance will be changed. The ability to dilute contaminants will also be decreased because of a reduced water flow. A decreased flow rate can also have an impact on the surrounding environment. If the water stream will be slow, diffusion of small water droplets can decrease, this can affect the viability of the surrounding flora such as bryophytes and lichens (Hovsenius et al., 2002).

The temperature of the water will also be affected due to increased or decreased flow rate. The temperature is important for the flora but also for some fauna. Even though the temperature is in the range of the level of tolerance some organisms can be affected of both higher and lower temperatures. Temperature changes will for example impact on the fish spawning and the chances of survival for the spawn. Another example is that an increased water temperature in the spring has an impact on chironomids. Chironomids are mosquito-like insects that live in lakes and slower streams. Huge populations of these insects make them the most prolific food source for trout (Fly Fishing Shop, n.d.). The chironomids are influenced by the increased water temperature in the manner that their life cycles become to be brought forward and they will pupate earlier than usual. This will have an indirect effect on fishes, especially trout, because the chironomid will be lost as food for them (Hovsenius et al., 2002; Malm Renöfält and Ahonen, 2013).

The regulation of watercourses from hydropower plants alters the natural lifecycle of the floodplains located downstream from the plant. This can affect community structures and vegetation species, which in turn affect the avian fauna and mammalians. Frequent fluctuations in the water level downstream a hydropower plant might create problems for different mammals and can also affect birds as well (Edenhofer et al., 2012). Aquatic animals that lives in the streams are one of the organisms that will be mostly affected when the water stream become regulated (Malm Renöfält and Ahonen, 2013).

When using a run of river project, it change the river's flow pattern marginally, thus creating fewer impacts downstream from the plant (Edenhofer et al., 2012). But if there is a small hydropower plant that has small shallow reservoir or ponds they are likely to dry up quicker than deeper reservoirs used in large projects, and can therefore instead creating larger impacts (Abbasi and Abbasi, 2011).

When using a dam to regulate the water flow in hydropower plants the water flow is changed from a natural variation over the year to a water flow that is saved so that it can produce electricity when there is a need for it. This controlled water flow can show large variations from the natural flow. For example the large water flows during the spring in the north of Sweden, can be saved to be used when it gets colder outside and the need for electricity increases. This is because the demand is higher during this period. Too high flows and large and rapid flow changes during this period involves a fundamental stress on the ecosystem. In summers when the demand is lower the flow instead becomes low. Low flows during the productive summer period limit the available areas for benthic fauna and fish. When the regulation fluctuation follows the demand it has meant a reverse water regime in relation to natural conditions, which has caused major damage to biological life (Bergengren et al., 2013). Due to the climatic differences in Sweden are there also differences in the natural water flow of the year. In the north of Sweden large parts of the precipitation comes as snow during the winter. This snow melts then in the spring causing high spring floods. In the south parts of Sweden only 10-20 % of the precipitation comes as snow during the cold part of the year. This means that the water flow in the south part of Sweden has a much more even appearance than the water flow in streams located in the north of Sweden. Unregulated streams in the south of Sweden have normally the peak in the water flow during April. The flow is also usually high in December and January. The lowest flows are normally found in July and August (Naturvårdsverket, 2003). When comparing regulated and unregulated streams in the south of Sweden it has been shown that the range of variations in the water flow for the regulated streams is smaller. It has also been shown that for the regulated streams so are the changes in the size of water flow more frequent than for unregulated streams (Bergengren et al., 2013).

The hydropower can also be used to follow the variations in the demand during the night and day and produce more electricity at day time when more is needed (Svensk Energi, 2011). This short-term regulation causes decreased abundance and species richness in the stream and has a large impact on the benthos. For the fish in the stream the short-term regulation has both direct and indirect impacts. The large variations in the flow can lead to that it gets harder for the fishes to find food. It can also cause stranding at rapid reductions in the water flow or so can rapid increases of the water flow cause the fish fry and roe to be flushed away (Bergengren et al., 2013). Another consequence of regulation is when no water at all is let through the turbines or the spillways. That kind of regulation can cause times when the water downstream adopts lake-type conditions or gets drained. This will harm ecosystem and means that stream living fishes, e.g. the trout, will be exposed to an increased risk of predation from pikes. It can also lead to, as for the short-term regulation, that roe is drained or flushed away (Statens Offentliga Utredningar, 2013).

3.1.2.3 Classification

There exists ways to classify the hydrological regime in water streams with respect to e.g. the regulation amplitude and regulation degree. To classify the regulation amplitude, the prescribed regulation amplitude permitted by the Water Rights Court should be used. Depending on how large the regulation amplitude is, it can be divided into different groups and given a status (Naturvårdsverket, 2008). The different limits for the regulation amplitudes are shown in the table 3.2 below:

Table 3.2: The classification for the regulation amplitude (Naturvårdsverket, 2008).

Status	Class	Highest allowed regulation amplitude
High	1	No active regulation exists
Good	2	< 1 meter
Moderate	3	1-2.99 meter
Unsatisfactory	4	3-9.99 meter
Poor	5	≥ 10 meter

The regulation degree is given by dividing the sum of the total water volume upstream that can be stored with the annual average water flow.

$$Regulation\ degree\,(\%) = 100 * \left(\frac{Total\ water\ volume\ that\ can\ be\ stored}{Annual\ flow\ volume}\right)$$

The result from the regulation degree can be used to classify the flow regulation's impact on the stream together with the changed mean high water flow. For the classification the value indicating the worst situation should be used.

The following table 3.3, shows the classification for the flow regime's impact on the streams. It is although a very approximate measure of the impacts from the regulation in a stream (Naturvårdsverket, 2003).

Table 3.3: Classification for regulation degree (Naturvårdsverket, 2008).

Status	Class	Regulation degree
High	1	0
Good	2	>0-9.99
Moderate	3	10-19.99
Unsatisfactory	4	20-49.99
Poor	5	≥50

3.1.3 Sedimentation

The system of sediment transport consists of erosion, transports and sedimentation of particles (Bergengren et al., 2013). River currents transport particles in different sizes, from small, fine ones to coarser ones such as sand, rocks, and boulders. It is the speed and turbulence of currents that enable transport of the materials (Bergkamp et al., 2000). The carrying capacity of sediment of a river depends upon its hydrological characteristics such as water depth, velocity, slope, material available in the catchment and the nature of the sediments in the riverbed.

In areas dominated by rocky granite, sedimentation is generally not an issue. Rivers with large sediment loads are found mainly in arid and semi arid or mountainous regions with fine soil composition (Edenhofer et al., 2012). In the matter of small hydropower plants the upstream water in some times comes from a closely located lake. This provides a calm body of water all the way upstream. In this type of sequence it is normally less of a problem with sediment (European Small Hydropower Association (ESHA), 2004a).

When constructing a dam the slope and the water velocity become reduced first in the reservoir. That results in a decreased ability for the streams to carry sediment. An increased deposition of sediment because of the reduced capacity could cause raised levels in the river bed and in extension, increase the risk for flooding. The degree of sedimentation depends on external circumstances such as geomorphologic composition of the riverbed, soil composition and what kind of vegetation living in the catchment area (Edenhofer et al., 2012). An increased deposition can affect the possibilities for fish reproduction, this because migrating fish reproduction is dependent on gravel and stone bottoms (Kungliga ingenjörsvetenskapsakademien IVA, 2002).

Azarpour et al. (2012) claim on the same thing. They suggest that the natural carried sediment from the usual natural flow will be negatively affected. Just as Kumar et al. (2012) they say that the sediment that is naturally carried will be impeded by the dam impoundment resulting in accumulation of sediment. This will lead to the situation that the area just upstream of the impoundment would become shallow because of the increased deposition. Downstream of the dam on the other hand the turbidity of the water may be reduced, which indicates on the lack of sediments. This can however also be a problem because the sediment might also be a source of nutrients for the biota. Reduction in sediment deposition can lead to decrease in land fertility (Azarpour et al., 2012). According to the International Hydropower Association the impacts of a reduced sediment load downstream of a plant may arise depending on pre-existing sedimentation and erosion patterns, the riparian vegetation condition and the nature of the regulated flow release and the altered flooding regimes. When there are reduced sediment loads downstream of a power station combined with higher than natural base flows it may lead to erosion of the existing channel and destabilization of the riparian vegetation (International Hydropower Association, 2014a). According to Graf (2006) both general studies, site- specific investigations, and research based on different models have all came to the conclusion that channels downstream from dams are about to degrade through erosion related to the trapping of sediment in the reservoir behind the dam.

The reduction in sediment transport in rivers downstream of dams do not only has impacts on the channel and its floodplains it also alters habitat for fish and other groups of plants and animals. As a consequence of impoundment the turbidity may be reduced. Production of some organisms such as for example plankton is influenced by for instance the turbidity. Turbidity interferes with photosynthesis and algal development may be attenuated by the presence of suspended inorganic particles. Plankton development may therefore be enhanced because of a reduced turbidity and may even be stimulated to appear in new sections of rivers (Bergkamp et al., 2000).

3.1.4 Water Quality

The report by the International Energy Agency (2011) emphasizes that the impacts on the water quality is site-specific and depends on different conditions, such as the operation of the power plant and type of power plant. Except from the production of the electricity from small hydro plants no harmful discharges to the river are produced. The water have the same quality and quantity both before and after flowing through the turbines (European Small Hydropower Association (ESHA), 2000; International Hydropower Association, 2014b). It is although described in the report by Bergkamp et al. (2000) that the water quality may be affected around a hydropower plant. They states in opposition to ESHA (2000) that water discharged from a reservoir can be of a different composition to the water that is flowing into a reservoir. How the impacts appear depend on different factors, dam morphology and depth, the retention time of the water in the dam, the water quality in the tributaries, the kind of the soil and vegetation inundated and how fast the impoundment was going. How the plant is run can also affect the water quality, both in negative and positive ways (Edenhofer et al., 2012).

In the case where water quality issues arise, the problems can vary greatly and may include reduced oxygenation, stratification potential, temperature, nutrient capture, pollutant inflow, algal bloom potential, propensity for disease proliferation and the release of toxicants from inundated sediments (International Hydropower Association, 2014b).

Bergengren et al. (2013) states that for streams with reduced water flow, which often is the case in streams with installed hydropower plants, the sensitivity for contaminations increases, which can affect the water quality. Other reasons behind decreased water quality could also be changes in the sedimentation and retention time and inundation of land areas. Another issue causing poor water quality could according to Abbasi and Abbasi (2011) be that wastes from running hydropower plants for example using biocides and anti fouling preparations for pipe cleaning and other maintenance work can pollute the water. Due to the fact that oil based systems are used in hydropower plant for regulations of turbines and intake- and spillway gates, oil spill can also be a waste component affecting the water quality. Oil spill can provide environmental damage caused by pollution or toxic effects. The extent of damage depends on the type of oil, the size of the spill, duration time, the sensitivity of the area, season and external factors. Many hydraulic systems, where moving parts are lubricated by oil, have a small continuous leak during normal operation, which means that a certain amount of lubricating oils can disappear into the water (Åstrand, 2008).

Due to the fact that hydropower plants uses water regulations, removal of organic material from the riparian zone will increase when the water volume become changed. For areas where there is good potential for sedimentation this material will sink. Oxygen is required for decomposition of this material, in calm water there can therefore be a risk for lack of oxygen. Further, the released organic material will also gain the production of algae, which in turn also can increase the lack of oxygen (Kungliga ingenjörsvetenskapsakademien IVA, 2002). Some blue-green algae can in addition to oxygen depletion also cause an increased concentration of iron and manganese in the bottom layer of a reservoir. In stratified reservoirs this can lead to an increased amount of oxygen and pH in the upper layers, which will affect the water quality (Bergkamp et al., 2000).

Regulations of large areas of land may also contribute to the accumulation and release of nutrients originated from the flooded biomass from for example the riparian zone. This can in its turn lead to the undesired effect of eutrophication (von Sperling, 2012). Although nutrient levels generally decrease over time as the organic matter decreases, some reservoirs require a period of more than 20 years to become stable. Regarding eutrophication, Bergkamp et al. (2000) suggest that it may occur as a consequence of large influxes of organic materials and nutrients. But they also state that in most cases it is an anthropogenic consequence of for example using fertilizers, rather than a direct consequence of the presence of a reservoir.

Another problem with using regulations is that the total water volume increases in the catchment area due to the storage of water in reservoirs. This can lead to changed transports out to the sea for different substances, for example different nutrients. Kungliga Ingenjörsvetenskapsakademien, IVA (2002) refers to studies that indicate that the transport of nitrogen out to the Baltic Sea is less from regulated streams than from those who are not regulated. Phosphorus is still under investigation but also seems to be less transported out from regulated streams. Another problem according to Kungliga Ingenjörsvetenskapsakademien, IVA (2002) is due to inundation of land and that it can lead to the release of mercury that has been accumulated in the terrestrial environment. Mercury is naturally present as a harmless inorganic form in many soils. When the water level varies, variations in oxygen conditions also vary, this can facilitate for bacteria to transform this inorganic mercury to methylmercury. Plankton and other organisms at the bottom of the aquatic food chain absorb methylmercury. Due to the fact that methylmercury is a strong bio accumulative contaminant it become increasingly concentrated in the bodies of the animals higher up in the food chain eating the contaminated prey (Kungliga ingenjörsvetenskapsakademien IVA, 2002; Bergkamp et al., 2000).

In a hydropower plant with large and deep dams there can be a deficit on dissolved oxygen. In plant with bottom intake this problem can create an adverse impacts on the habitats in the stream (International Energy Agency, 2011). In deep lakes that tend to stratify, colder deoxygenated water at depths in the lake has in some cases released metals from the sediments e.g. methylmercury. Deep intakes can in some cases result in deoxygenated and hydrogen sulphide rich releases out of the power station into the downstream river (International Hydropower Association, 2014b). But there can also be water quality problems for hallow lakes, poor water quality can under certain catchment conditions result from wind-induced sediment resuspension, eutrophication and algal blooms (International Hydropower Association, 2014b).

Another quality problem that can affect the water is the temperature. Temperature is an important regulator of many important physical, chemical and biological processes. As for example the temperature together with light conditions, seasonal availability of minerals and nutrient dynamics controls the primary productivity (Bergkamp et al., 2000). Temperature also plays an important role for the metabolism of organisms (Arthington et al., 2009). The water of a reservoir is usually cooler in the summer and warmer in the winter than it would be without a dam. This altered temperature also affects the river when the water flows downstream. Therefore the temperature affects the animal life present in both the reservoir and the river (von Sperling, 2012). The temperature can differ from ambient temperatures, it can also fluctuate over short time scales depending on operating patterns. The temperature can have a major influence on biological health and can also be instrumental in providing migration signals for some species (International Hydropower Association, 2014b). Water temperature changes have been identified as a cause of the reduction in native species of fish, particularly impacting spawning success negatively. Changes may also affect growth rates and length of the growing season for many species (Bergkamp et al., 2000).

Turbidity is another thing also affecting the water quality. Turbidity attributes to the visual property of water. Increase in turbidity normally accounts for an increase in the concentration of suspended solids in the water. This increase in suspended solid is due to the increase in sediment concentration of the water body (Dahal, 2013). Turbidity issues can arise in cases due to erosion of riverbanks, incoming sediments, and resuspension of bottom sediments in shallow lakes (International Hydropower Association, 2014b). An increase in the concentration of suspended solids leads to a change in the amount of light available for the biological life in the stream (Dahal, 2013). Gas supersaturating is another problem. Particularly high hydropower dams have in cases had problems with gas supersaturation resulting in fish deaths and damage to invertebrates (International Hydropower Association, 2014b; Douglas, 2007). However, small hydropower plants generally reduce the total gas pressure leaving the plant, instead of increasing it (Douglas, 2007).

Hydropower plants can also have a positive impact on the water quality. According to Ghosh and Prelas (2011) a run of river system do not change the water quality in terms of temperature, decreased food production, siltation, increased nitrogen and phosphorus levels and low oxygen levels. In the case of run of river plants and areas with poor water quality the hydropower plant even can help with increasing the oxygen level in the water levels and filter floating waste out of the river (Edenhofer et al., 2012). Another positive impact is that many modern small hydropower plants have trash rack-cleaning machines. This machine removes material from the water and by doing this avoiding it to enter the plant waterways and reducing hydraulic performance and damaging electromechanical equipment. By using these machines it keeps the rivers clean and material such as plastic bags, cans and bottles become removed, which they would not have been otherwise. Another thing to keep the water quality good is to use biodegradable oils, which become more common to do in small hydropower plants (European Small Hydropower Association (ESHA), 2000).

3.1.5 Migrations Barriers

According to the report by Havs-och vattenmyndigheten, one of the biggest environmental problems due to hydropower is the barrier effect (Bergengren et al., 2013). Hydropower dams impede the flows of rivers and thereby affect the habitat of various aquatic lives (Ghosh and Prelas, 2011). Fishes are the main species affected by the hinder that the hydropower conduct but also other organisms are affected (Bergengren et al., 2013). Ström (2012) sees the problem in the same way and he means that hydropower only has local effects. He indicates that one of the major problems is that aquatic organisms have a harder time to migrate between streams and to get to lakes and seas than it had been without hydropower plants.

Migratory fishes require different environments for their different phases of their life cycle. Different stages are reproduction, production of juveniles, growth and sexual maturation. These different stages take place in different environments for different fishes (Laarinier, 2001). Fishes that migrate can basically be divided into two different categories. Anadromous fishes grow up in the sea and migrate from the sea to fresh lakes to spawn, this is called upstream fish migration. Examples of anadromous fishes are salmon and sea trout. Catadromous fishes are ones that grow up in fresh lakes and migrate from the fresh water into the sea to spawn, this is a downstream fish migration. (Bergengren et al., 2013). An example of a catadromous fish is the European eel (Calles et al., 2012). A third category is potadromous fish, which are fishes whose migrations occur wholly within fresh water lakes and streams (Länsstyrelsen Västra Götaland län, 2005).

Hydropower plants and its associated dam buildings can affect the fishes in several ways. Both downstream and upstream fish migration become affected. Fish migration is affected by a single dam but multiple dams in the same stream can worsen this situation dramatically (Bergkamp et al., 2000). Dams can restrict and delay the fish migration, increase predation and subject fishes to direct damage and stress (Ghosh and Prelas, 2011). One of the major effects of the construction of a dam on fish populations is the decline of anadromous species. If there is no kind of fishway for upstream migrating fish, the fish will not be able to bypass the power plant at all. According to Calles et al. (2013) only 10% of the hydropower plants in Sweden have fishways for upstream migrating fish. Passage of fishes from upstream to downstream is another barrier problem. A major concern regarding the use of hydropower is the mortality of turbine-passed fishes (Ghosh and Prelas, 2011). If there is no other fishway to lead the fish past the power plant the only possible way to pass the plant is through the turbines or to be immovable and be trapped upstream (Calles et al., 2013). Fish that survive the stressful condition associated with turbine passage are often damaged and susceptible to predation and mortality due to their injuries (Irish Department of Communications Energy and Natural Resources, 2007). The number of fishes injured, stressed or killed by turbine passage varies with species, age of the fish, time of year, temperature of the water, turbine type and operations (Ghosh and Prelas, 2011). The size of the fishes is another subject the injury is related to. The longer the fish is the higher risk to get hurt of the turbine. One species, which are badly affected is the eel (Calles and Bergdahl, 2009).

Fish passing through turbines are subjected to various forms of stress that are likely to cause damage or mortality. Damage to fish associated with power plant passage is in no way only restricted to strike from stationary or moving parts of the turbine blades, there are also other causes of loss, which are just as important or even more critical (Irish Department of Communications Energy and Natural Resources, 2007). Calles et al. (2013) states that these other causes can include pressure variation, cavitation, shear, abrasion and turbulence. The extent to which these factors cause damage to the fish depends upon the design on e.g. the water intake, cleaning machines, head, type of turbine and several other factors (Calles et al., 2013).

According to European Small Hydropower Association (ESHA) (2004a) the injury and mortality of fish depends on turbine type. A Kaplan turbine is more fish friendly than a Francis turbine. This is due to the different construction of the turbines. Calles et al. (2013) also agree on this and states that no turbine type is safe but a Kaplan turbine gives less damage to the fish than any other turbine type. They claim that the survival follows the efficiency curve of a Kaplan turbine, the more efficiently run the larger amount of fish survival.

Bourgeois and Therrien (2000) writes in their report, Fish Passage at Small Hydro Sites, that the major area of concern for cause to mortality for Francis turbines is the runner entrance where the guide vanes, the turbine blades and the runner's peripheral speed may harm the fish. They state that higher mortality has been correlated with greater guide vane openings and higher peripheral runner speed. According to European Small Hydropower Association (ESHA) (2004a) the mortality will increase from 5 to 35% if the peripheral speed increases from 12 m/s to 30 m/s when using a Francis turbine. Just as for the Kaplan turbine the Francis turbine has lower fish mortality the higher the efficiency on the turbine is (European Small Hydropower Association (ESHA), 2004b). For Kaplan turbines, the major area of concern is the interaction between the blade tips and the discharge ring. There is no strong relationship between peripheral runner speed and fish mortality for the Kaplan turbines unlike the Francis turbines. Bourgeois & Therrien (2000) asserts that there is no correlation between plant head and fish mortality for none of the different type of turbines. It has although often been stated that the head has an influence on the mortality rate but this can be explained on the fact that Francis turbines, which has a higher mortality rate, often are used at higher heads than Kaplan (Bourgeois and Therrien, 2000).

As written earlier in this report, pressure variation is another problem for fishes passing turbines. The pressure increases just before the passage of the turbine blades, but then it decreases very rapidly after the blades. This reduction in pressure is very fast and can cause major damage as for example rupture of swim bladder (Calles et al., 2013). Bourgeois and Therrien (2000) assert that the risk of injuries caused by pressure variations is higher if the plant head is greater than 20 m. The risk is also higher when the fish is going in through a deep-water intake compared to a water intake at the surface (Bourgeois and Therrien, 2000; Calles et al., 2013). As a consequence of the pressure drop, a dissolved gas supersaturation in the water can appear. A dissolved gas super saturation occur downstream of the turbine and exist when the water gas content exceeds the amount that can be dissolved in water at respective pressure and temperature. Due to this condition fishes can suffer from a gas bubble disease. This disease arises because of the dissolved gas supersaturation leads to the formation of gas bubbles in fish's blood and tissue. The problem with this condition seams to increase for higher heads over 30 m (Calles et al., 2013). Another pressure related problem is cavitation. Cavitation is the formation of vapour cavities in a liquid. When the pressure of water is lower than the vapour pressure, vapour cavities arises (European Small Hydropower Association (ESHA), 2004b). The formed bubbles in the water can collapse or implode at slightly increased pressure, this creates strong shock waves, and these chock waves may damage nearby fish tissue or give bleedings in the eyes and gills (Bourgeois and Therrien, 2000). Calles et al. (2013) says that cavitation is a very local problem and fish has to be very close to the turbine blades to get hurt. They also state that the risk for cavitation is related to the difference in height between the turbine and the water level at the water outlet.

Shear stress can also harm fishes when passing turbines. Shear stress is when different parts of a fish body are subjected to different forces in parallel. Fishes can be affected by shear stress when two masses of water moving in different directions intersect, or where moving water slows near a solid structure(Calles et al., 2013). Damage can occur for example where rapidly flowing water passes near structures such as turbines, pipelines, and canals. According to Cada et al. (2007), field observations and laboratory studies suggest that fluid forces such as these can cause tearing or bruising of tissues and even decapitation of fish.

Fishes passing through turbines and tailraces is affected by turbulence. This can in turn affect the way the fish is moving and they lose the ability to operate optimally. As a result they become dazed. When the fish reach the downstream area the dazed and exhausted fishes become particularly vulnerable and therefore an easy target for attacks of predators. Another thing that can harm fish passing turbines is trough abrasion. When fishes migrate through narrow passages or goes through pipes or end up in strongly turbulent passages they can get serious abrasions (Calles et al., 2013).

Except all of these injuries caused by turbine-associated conditions, damage can also arise to downstream migrating fishes due to intake screens. By keeping the water pressure on the screen low, the risk of contact and getting stuck will be minimized. The damage to the fish depends on the angel of the screen, the width between the grids and the water velocity. If the sweeping velocity of the fish along the screen is low, the fish can become pushed against the screen instead of being able to orient themselves along the screen. A low pressure on the intake screen is synonymous with a low head loss, this is therefore something to strive for in both a power as for an environmental perspective. Calles et al. (2013) claim that mortality due to intake screens occur at water velocities above 0.5 m per second. As said before, the width between the grids also plays an important role for the grade of injury to the fish. Screens that had been evaluated with a good function and adapted to fishes had a grid width of 18 mm. In some cases, the grid width has been further reduced to prevent fish from getting through the screen. But if it is hard for the fishes to find an alternative way or that there is no alternative way for the fish to go the function of the adapted intake screen could be insignificant or even negative. Small individuals can pass the screen and become forced to go through the turbine. Large individuals on the other hand become trapped and killed directly on the grid. The angel of the screen is another important thing to consider in order to make the intake screen as fish friendly as possible. An angel less than 45 degrees relative to the ground means that the force parallel to the intake screen will be larger than the force acting perpendicular to it. For good functioning however, any angle should be less than 30 degrees since the force parallel to the screen then becomes twice as high as the force against it, which increases the likelihood that a body, which is close of the intake screen will be passed along with it instead of being trapped against it. In Calles et al. (2013) two different hydropower plants are described, Ätrafors in Ätran and Övre Finsjö in Emån. Both of the plants reduced the risk of entrapment on the intake screens by replacing old steep 20 mm grid width with low sloping (less than 45 degrees) 18 mm grid.

Another problem associated with the intake screens are the cleaning of it by the use of the rake-like tool. This tool is used to remove what have been stuck on the screens for example levees, branches but also fish. The rakes are although not very kind to the fish and the residues are after it has been gathered, transferred further on a moving belt to a container or just dumped onto the hard ground (Calles et al., 2013).

Calles et al. (2013) states that even though the rate of injury for the different kinds of causes which occurs when a fish pass a hydropower plant is not that high, the synergistic as well as the cumulative effects during the passage of several hydropower plants can although be very harmful. In the Swedish magazine, Forskning och Framsteg, it can be read that according to Fiskeriverket, adult eels have roughly 30% chance of surviving passage through a hydropower plant. In some streams they also must get past several power stations to reach the sea, the probability to arrive alive to the coast was therefore estimated to be four percent on average (Nyström, 2011). By using e.g. Monte Carlo simulations it is possible to calculate estimations of the eel losses when passing different hydropower plants in the south of Sweden. In the report by Leonardsson (2012), Monte Carlo simulations have been performed in two different cases, one assuming that the total capacity of the turbines flow capacity is used and one assuming that half of the turbines capacity is used. It should be noted that no concern has been taken to the size of the intake screens and that there exists some insecurities so the numbers should be seen rather as estimations than as exact calculations. The author concludes in a stream with e.g. four hydropower plants the mortality cannot exceed 20 % per plant if 40 % of the eels should reach the ocean, which is a European goal. Despite that, it seems like there are few hydropower plants that not are exceeding a mortality of 20 % (Leonardsson, 2012).

If a hydropower plant was built where there was no hinders for the fish before, the construction may block the migration of fishes. But if a hydropower plant was build in a place where there was for example a waterfall before which made up a hinder for the fishes itself, the hydropower plant makes no difference seen to the obstacles for the migration of fishes (Edenhofer et al., 2012).

3.1.6 Greenhouse Gas Emissions

One of the biggest challenges the society is facing today is the climate change. The green house gas (GHG) emissions coming from the production of energy are responsible for a great share of the increased levels of GHG emissions in the atmosphere. By using renewable energy systems there exists a possibility to reduce the GHG emissions from fossil fuel based technologies and to mitigate the climate change (Edenhofer et al., 2012). Also the European Union points out the importance of that the energy sector reduces the CO_2 emissions and that renewable energy sources are good for the environment (Europeiska kommissionen, 2014). Hydropower is a renewable energy source. But even if hydropower is a renewable energy source it is not an energy source without GHG emissions (Kumar et al., 2012).

All energy systems used in the society today contributes to the anthropogenic emissions of GHG emissions to some extent (Gagnon et al., 2002). In order to estimate the emissions, approaches such as life cycle assessment (LCA) can be applied. LCA is a method that looks into the environmental impacts and emissions from the life cycle of a product or project, from cradle to grave. Both bottom-up and top-down approaches can be used to assess the emissions per functional unit (Raadal et al., 2011). In the report from IPCC they mention three different phases for a hydropower plant where GHG emissions can occur, the construction, the operation and maintenance and the decommissioning of the plant. During the construction phase the emissions comes from the production and transport of the materials needed for the construction and from the work equipment. In the second phase, the operation and maintenance, the emissions can come from e.g. heating or cooling systems and transportation for maintenance work (Kumar et al., 2012).

One important source of GHG emissions that should not be neglected is emissions that can arise from land use change due to constructions of reservoirs and the changes of the terrestrial carbon cycle that comes with that. There is today no consensus on the emissions that can arise from the land-use change that follows the construction of hydropower plants and reservoirs (Kumar et al., 2012). The estimations and the views of the size of the GHG emissions can show large variations. According to European Small Hydropower Association (ESHA) (2000) the hydropower contributes with no CO_2 emissions at all. There exist also estimations that show quite high values for the GHG emissions per kWh and in the article by Turconi et al. (2013) they report emissions of the order of 340 g CO_2 equivalents/kWh for hydropower plants in Brazil. For run of river plants the estimations are lower (Turconi et al., 2013). Abbasi and Abbasi (2000) states that according to some authors there are some hydropower plants with reservoirs that could be as worse as fossil fuel based energy systems when looking at the size of the GHG emissions, which also Hertwich (2013) agrees with.

The problem with quantifying the GHG emissions from hydropower plants is that they are highly site-specific. Literature reviews done in the area points out the diversity in the results, both depending on which boundaries used and where the hydropower plants in the research are located.

Hertwich (2013) points out the importance with understanding how the dams change the carbon cycle due to increased sedimentation, decay in the water bodies and the reduced transport of sedimentation to the seas. When building dams and reservoirs, the following result is often inundation of areas that before were wetlands or land. This can cause the release of labile carbon the first 10-15 years after the construction. Another result of the construction can be change of river areas into reservoir areas. This can increase the fractions of emitted CH_4 compared to the emissions of CO_2 due to the increased formation of anoxic conditions at the bottom. The dams will also change the transportation of organic matter in the stream and with following increased sedimentation or decay. Less particulate organic carbon will follow the stream to the ocean and instead of reaching the deep of the oceans it will be released earlier in the stream. A net absorption of carbon can be formed by the increased water temperature that can exist in dams, the higher temperature creates good conditions for growth of biomass and therefore there can be a net absorption (Hertwich, 2013).

The variation on the emissions depends on the specific conditions at the site. The factors that determine the size of the emissions are e.g. reservoir size, topography, climate, materials used in the construction and type of ecosystem (Gagnon, 1997).

To calculate the emissions per energy unit the life length of the plant must be estimated. In the study by Gagnon (1997) the used life length is 100 years and the included gases were carbon dioxide (CO_2), methane (CH_4), nitrous dioxide (N_2O) and carbon tetrafluoride (CF_4). These emissions come mainly from different parts of the production and manufacturing of the plant but can also come from the areas that have been flooded due to the building of the reservoir. The flooded biomass will start to decay and this process will emit GHG. The amount emitted is due to different factors. The size of the reservoir is an important factor that affects the size of the emissions. The climate affects also the size of the emissions. A cold climate will slow down the decay of the biomass. Another factor is the amount of biomass flooded and depends on what type of ecosystem the plant is located in. However, it is important to remember that measurements on the emissions from the reservoirs only show the gross emissions and not the net emissions (Gagnon, 1997). The reservoirs part in the anthropogenic release of GHG emissions is debated. There are uncertainties in both the measurements of the gross emissions from reservoir and the net emissions (Tremblay et al., 2004).

In the report by Teodoru et al. (2012) they have quantified both the emissions from the landscape before the creation of a reservoir and the emissions after the creation of a reservoir during a seven years long period. The measurements showed that the landscape before the impoundment was more or less neutral. After the impoundment the measurements indicated that the reservoirs in the beginning were a large source of net emissions of CO_2. The net emissions decreased fast the following years but even when looking over a long period the results suggest that the CO_2 emissions from the flooded area exceed the CO_2 emissions if there had not been any reservoir. However, it is not known where the emissions come from. This is although very important to have knowledge about in order to decide if the emissions increase the total amount of CO_2 or not. If the emissions are a result of the degradation of the flooded soil the emissions are a consequence of the construction of the reservoir. But if the emissions are a result of biological and photochemical mineralisation of allochthonous sources, which are sources of carbon or nutrients that comes from outside of the aquatic system, such as plant and soil materials, this would have happened anyway further down in the stream and is not a consequence in the same way of the construction of the reservoir (Teodoru et al., 2012; Sitka National Historical Park (U.S. National Park Service), 2014). The authors emphasize that even when including the emissions following from the impoundment, hydropower plants has probably much less emissions over a life length than fossil fuel based technologies per unit energy produced. In the report by Teodoru et al. (2012) measurements have been done on a reservoir in a boreal landscape and the result will not be the same for reservoir for other types of landscape e.g. tropical and subtropical. The result will also differ depending on the management of the plant and type of landscape flooded. If the landscape flooded, before was a wetland or peat bog the emissions can be reduced. This makes it hard to translate the emissions from one reservoir to another (Teodoru et al., 2012).

Also in the report by Gagnon (1997) it is suggested that the GHG emissions will decrease with time. The numbers on the emissions are from plants with an age of 2-25 years. Even if no numbers are included from older plants, the opinion in the report is that emissions will decline with time and that after 50 years the emissions from the reservoir will have reached zero net emissions. According to Demarty et al. (2011) old reservoirs shows the same behaviour as lakes when looking at the GHG emissions. A similar result can be found in the study done by Tremblay et al. (2004) where they have measured the carbon fluxes in more than 280 sites in reservoirs, rivers and natural lakes in Canada. The measurements showed that ten years after the commissioning of the reservoirs, the conditions in the reservoirs was similar to the conditions in terms of water quality and gross emissions of GHG emissions in natural lakes. The flooding of terrestrial ecosystems alters the chemistry in the soil and release both labile carbon and nutrients into the water. This in turn leads to an increase of the bacterial activity and the primary production in the reservoir. This will enhance the overall production in the lake. After 10-15 years the reservoirs will have approached values that are similar to natural lakes. In boreal ecosystem, these changes occur in a time period of 5-10 years. Due to the flooding there will also be a decomposition of the carbon in the soil and the plants. This carbon will partly be turned into CO_2 and CH_4 (Tremblay et al., 2004).

For cold climate, the sizes of the emissions are according to Gagnon (1997) 15 g CO_2 - equivalent/kWh, including the emissions from the construction phase. For run of river plants without reservoirs the emissions are generally lower since they require less material per unit energy created and since it is the reservoir that contributes the most with emissions from decaying biomass, plants without reservoirs will emit less. For small hydropower it can be seen that large hydropower plants have better ratios reservoir area/ energy unit produced than what small hydropower plants have (Gagnon, 1997).

In the report by Turconi et al. (2013) they have included 12 case studies on the emissions from hydropower plants. The largest share of the emissions comes from the infrastructure. The amount of emissions differed depending on if the plant was built with a reservoir or not. For plants with the reservoir the amount of GHG emissions emitted lay in the range of 11-20 g CO_2 - equivalents/kWh. For the run of river plants the emissions was in the range of 2-5 g CO_2 - equivalents/kWh. Large variations in the size of emissions were possible to see, which can be due to different factors such as climate, size of reservoir, soil type and which kind of vegetation flooded. The amount of flooded biomass can vary with a factor of 5, from 100 ton/ha for boreal regions up 500 ton/ha in areas with tropical forests (Gagnon et al., 2002). All these factors influence the possible methane emissions from reservoirs due to anaerobic digestion. The emission factors can vary from 0.35 g CO_2 - equivalents/kWh for alpine regions up to 340 g CO_2 - equivalents/kWh in Brazil. Also NO_x and SO_2 from the case studies were reported. The NO_x emissions were 0.004-0.006 g NO_x/kWh and 0.004-0.03 g SO_2/ kWh. However, these emissions are mainly related to the construction and not the operation of the dam (Turconi et al., 2013).

Raadal et al. (2011) has compiled the result from 39 LCA studies on the GHG emissions from hydropower. They found that there were large variations in the emissions reported from the hydropower plants. The emissions started from 0.2 g CO_2 - equivalents/kWh. The highest number found was 152 g CO_2 - equivalents/kWh. The large range can mostly be explained by the variation of GHG emissions from the flooded areas. It is important to remember that the measured and reported emissions most often are the gross emissions. If the emissions from the decaying if biomass not is taken into account the emissions per kWh is reduced to 2.9 g CO_2 - equivalents. For run of river plants the emissions from possible flooded areas are not assessed. The emissions for this kind of plants are 4.9 g CO_2 - equivalents/kWh. When the emissions from the flooded area are not included for plants with reservoirs the range is narrowed to 0.2-11.2 g CO_2 - equivalents/kWh (Raadal et al., 2011).

The report by Bratrich et al (2004) includes values for hydropower schemes in temperate regions. The emissions from a hydropower plant during the life cycle lies around 3-4 g CO_2 - equivalents/kWh and 0.00001 g SO_x/kWh and 0.00001 g NO_x/kWh (Bratrich et al., 2004).

Kungliga Ingenjörsvetenskapsakademien, IVA has looked at LCA:s performed on hydropower plants in Sweden. According to them the hydropower plants in Sweden have the same performance seen too emissions to air and water as wind power. There will be more carbon dioxide emissions from regulated waters than waters without regulations. The water regulation contributes with 5 g CO_2/kWh. They emphasize however the uncertainty in this numbers. The rivers in the north of Sweden have emissions that vary from 0.7 g CO_2/kWh up to 13.2 g CO_2/kWh. The average number for the emissions was 2.4 g CO_2/ kWh (Hovsenius et al., 2002).

To get a fair comparison of different kinds of energy systems it is important that the assessed hydropower plant is used only for producing electricity and not has a diversity of uses. The water in a reservoir could, even if that may not be the case in Sweden, for example also be used for irrigation. If that is the case, the emissions should be allocated so that the energy systems get assessed on equal terms. According to Gagnon et al. (2002) this is often not done, which leads to an overestimation of the emissions from the hydropower. Another aspect they mention is the difference in energy systems that are intermittent or systems with low flexibility such as nuclear and run of river plants compared to hydropower plants with reservoirs that can produce energy when there is a specific need for it. This should in the best of worlds be included in the comparison of the emissions from the energy systems even if it is difficult to include. A way to include this for intermittent energy systems is to also include the backup system so the total energy systems work as a "stand-alone" system. If the backup system is not included it is important to point that out so that is known when assessing the emissions (Gagnon et al., 2002). Also in the report from IPCC they points out the importance of the allocation and that how the allocation is done can play a significant role in the outcome of the LCA (Kumar et al., 2012).

The part contributing with most uncertainties when estimating the size of the GHG emissions is the emissions from flooded areas. In boreal areas is the quantity of flooded biomass rather small, thus it is probable that the emissions will stay at about the same level. For tropical areas the emissions could be higher than reported numbers (Gagnon et al., 2002). The emissions from the plants reported by Gagnon et al. (2002) are from hydropower plants with modern technology, the size of the plants were not considered, the short-term performance of the plants were used and the conditions were generally typical for the conditions in North-America and Europe. For hydropower plants with reservoirs, the typical size of the emissions were 15 g CO_2 - equivalents/kWh and for run of river the plants the typical size was 2 g CO_2 - equivalents/kWh.

LCA is one tool to estimate the impact from the different energy systems. The disadvantage according to Gagnon et al. (2002) is that the outcome of the LCA is largely affected by up-stream choices for energy supplies. The report gives the example that, if aluminium is used, the size of the emissions will have large variations depending on what kind of energy is assumed to be used for the aluminium smelters, if it is energy from coal or from hydropower. To reduce these variations, another method, the energy payback ratio can be used. The energy ratio is the energy produced by the energy system during its life span divided with the energy needed to build, operate and maintain the energy system. The higher ratio the better energy payback. For hydropower plants with reservoirs the typical energy payback ratio is 205. For run of river plants the energy payback is as high as 267. The ratios are for plants with an expected life length of 100 years and for plants located in northeastern North America. To get a comparison is the expected energy payback ratio for coal plants in this report 5-7, nuclear 16 and for wind power 80 (Gagnon et al., 2002).

For the life cycle emissions from hydropower, Akella et al. (2009) have divided the hydropower plants into large and small hydropower plants. For large hydropower plants the CO_2 emissions/kWh are 3.6-11.6 g CO_2, for SO_2 0.009-0.024 g and for NO_x the emissions/ kWh is 0.003-0.006. The same numbers for small hydropower are 9 g CO_2, 0.03 g SO_2 and 0.07 g NO_x (Akella et al., 2009). For hydropower it is better with large dams compared to small dams from a GHG emissions point of view according to Miller et al. (2011). They also conclude in their report that the GHG emissions from small hydropower plants are very small and that the small hydropower plants has almost none impact on the climate change compared to some other energy systems (Miller et al., 2011).

Below the numbers from the different reports mentioned in the text are presented, see table 3.4. It is important to remember when looking at the numbers that they are not completely comparable since different approaches may have been used and the same things not are included. As mentioned before is the size of the emissions very site-specific and depends on factors such as management, construction, allocation and the ecosystem in the area. Some of the reports have looked at the emissions from hydropower plants situated in cold climate and some are from areas with temperate or tropical climates. There are also differences if there has been a division between hydropower plant with reservoirs and run of river plants since there is a difference in the construction and management between these two types that can influence the size of the emission. Another factor that can influence the numbers is if the reports have included small and large hydropower plants in the same number since the size of the plant also can affect the size of the emissions per kWh. It is also important to remember that most of the numbers presented represent the gross emissions from the plants. Therefore the numbers should be seen as an indication of the range of which the emissions can be in and not that some of the numbers are more correct than others. Most of the reports used as references in the text have looked at a number of LCA studies done on different hydropower plants and summarized the results in their texts.

Table 3.4: Summary of GHG-emissions from different LCA studies

Report	CO_2 equivalents [g/kWh]	SO_2/SO_x [g/kWh]	NO_x [g/kWh]	Note
(Kumar et al. 2012).	Reservoir: 4-14	-	-	Had also found values as high as 150 g CO_2 eq/kWh for reservoirs but the majority was between the mentioned.
	Run of river: 4-15			
(Gagnon 1997).	15	-	-	For cold climate. The values found for run of river was a bit lower
(Turconi et al. 2013).	Reservoir: 11-20	0.004-0-03	0.004-0.006	
	Run of river: 2-5			
(Raadal et al. 2011).	Reservoir: 0.2-152	-	-	When the emissions from the flooded area was not taken into account for plants with reservoirs the CO_2 values ranged between 0.2-11.2
	Run of river: 4.9			
(Bratrich et al. 2004).	3-4	0.00001	0.00001	The emissions are from hydropower plants in temperate regions.
(Hovsenius et al. 2002).	0.7-13.2	-	-	For conditions in the north of Sweden
(Gagnon et al. 2002).	Reservoirs: 15	-	-	From plants situated in north-eastern North America
	Run of river: 2			
(Akella et al.2009).	Large plants: 3.6-11.6	Large plants: 0.009-0.024	Large plants: 0.003-0.006	
	Small plants: 9	Small plants: 0.03	Small plants: 0.07	

To get a comparison of the size of the possible life cycle emissions from hydropower the life cycle emissions from other energy sources are showed in the table 3.5 below.

Table 3.5: Life cycle emissions from different energy sources (Akella et al., 2009)

Energy source	CO_2 [g/kWh]	SO_2 [g/kWh]	NO_x [g/kWh]
Coal (best practice).	955	11.8	4.3
Oil (best practice)	818	14.2	4.0
Natural gas	430	-	0.5
Wind	7-9	0.02-0-09	0.02-0.06
Solar photovoltaic	98-167	0.2-0.34	0.18-0.3
Energy crops	17-27	0.07-0.16	1.1-2.5

3.1.7 Biodiversity

The earlier sections in this impact chapter are describing the physical changes on the surrounding ecosystem that the installation and operation of a hydropower plant can result in. These changes will, in various degrees, affect the biodiversity. This section will therefore give an overview of how the hydropower plants are affecting the biodiversity and which the effects are.

3.1.7.1 Introduction to Biodiversity and Hydropower

To know how the biodiversity is affected by installation and operation of hydropower plants and the regulation of the water level following it, it is important to have an understanding for what biodiversity is. In the Convention on Biological Diversity from the United Nations, biodiversity is described as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD Secretariat, 2014). Biological diversity is more than just the sum of species numbers, it encompasses the variety, the variability and the uniqueness of genes and species and of the ecosystems in which they occur. Generally, biodiversity can be said to be built up of three different levels. To achieve a sustainable biodiversity there should be diversity on a genetic level within and between individual populations, diversity of species and in the interaction in between the species, and a diversity of ecosystems and habitats (Länsstyrelsen Kalmar län, 2014). The biggest threats today against the biodiversity from a global perspective are destruction of biotopes, over-exploitation and the introduction of alien species and genotypes. The preservation of different ecosystems is very important since the ecosystems provide us with services that we cannot live without. It is the ecosystems that give us pollination, regulation of the climate, recirculation of nutrients, oxygen, food and drinking water to just a few ecosystem services we will not survive without (Centrum för biologisk mångfald, 2010).

The knowledge about the impacts on the biodiversity is today rather limited. There has although been studies in the area, which have managed to point out which the main environmental impacts from a hydropower plant are. The main disturbances pointed out are habitat changes, geological and climate changes in the surrounding such as temperature changes, increased human use of the area and the last one, direct mortality. According to these disturbances the most serious causes from the installation from hydropower plants on the wildlife is permanent loss of habitat and special biotopes through inundation, fluctuating water levels, loss of flooding, introduction and dispersal of exotic species and also obstacles to fish migration. However, the impacts are very general and it is hard to put any numbers on the losses. The impacts on biodiversity are also site-specific and depend on the situation and ecosystem where the hydropower plant is situated (Edenhofer et al., 2012). The report from The Swedish Agency for Marine and Water Management by Bergengren et al. (2013) points also out that it is very complex to quantify and be precise about how the biodiversity is affected and especially when it comes to population of terrestrial animals living close to streams.

The ecosystem around a stream includes several different parts. It is made up of the head-waters and the associated catchment areas, riparian areas, groundwater associated to the area, wetlands, estuaries and the environment close to the shores, which are dependent of the fresh-water coming from stream. As for other ecosystems, this type of ecosystem provides us with important ecosystem services. This kind of ecosystem stands for things such as flood control, storm protection, wild life, fish and forest resources. A modified habitat caused by hydropower plant associated with a large dam often create environments that are more conducive to non-native and exotic plant, fish, insect and animal species. These resulting non-native species often out-compete the native species. This often lead to developing ecosystems that are un-stable, nurture disease vectors, and are no longer able to support the social- and the historical environmental components (Bergkamp et al., 2000).

It exists thus many important reasons for why we should preserve the biodiversity. There is ecological, material, economical, cultural, social and health reasons to why we should not de-stroy the ecosystems surrounding us. Except for all these reason there are also an ethical reason to why we should preserve the biodiversity. All species have the right to live and the humans living now have a responsibility to preserve the biodiversity (Centrum för biologisk mångfald, 2010).

According to Kungliga ingenjörsvetenskapsakademien IVA (2002) the hydropower rarely leads to total exclusion of species and extinguishment of environments in a larger perspective. De-spite this, the proportions between different organisms often become changed and some envi-ronmental habitats will be increased to the detriment of some other habitats. Therefore, one can say that hydropower is not influencing on a nationally level but however the local effects may be significant (Hovsenius et al., 2002). Jansson (2002) indicates on the same thing and states that hydropower has caused relatively few species to go extinct from an entire river system in the Northern Europe but at the scale of rivers however, regulation has reduced species richness. Bergengren et al. (2013) also states that it is known that species living in environments with flowing water are negatively affected due to installations of hydropower plants.

In the Environmental barometer on small hydropower from European Small Hydropower As-sociation (ESHA) (2009) experts in the subject were interviewed. According to most of the experts the most critical impacts of small hydropower is that on the aquatic species. They ar-gue that not only fishes are affected but also other species living in the rivers. The species are affected in the terms of migration, change in the conditions and quality of their habitats but also in terms of mortality. Consequences due to morphological changes of the river and losses in the characteristics of the composition of the water are that some species can be disappearing and other can be arriving (European Small Hydropower Association (ESHA), 2009).

The International Energy Agency (2011) describes rather briefly how the biodiversity is affected by hydropower plants. They agree with European Small Hydropower Association (ESHA) (2009) that the power plants complicate or impede the migration for the fishes and they also indicate that the turbines can cause damages on the fish. The International Energy Agency (2011) also states that the other species living in the ecosystem surrounding the plant can be affected even if the impacts not necessarily need to be adverse according to them.

3.1.7.2 The Riparian Zone

The riparian zone, which are the interface between land and a river or a stream, have an important role in many ways, it gives for example protection for the fishes and the zone and its vegetation supplies the water with dead organic matter. With high regulations of the stream the riparian zone can be destroyed. The riparian ecosystem will change when its adjoining aquatic environment changes. In streams where the water flow is undisturbed by humans, the water regularly is flooding the strand zone, for example at the spring flood. These floods are necessary to maintain a high biodiversity in the vegetation. When these floods cease, the species sensitive to competition get it harder to survive (Bergengren et al., 2013). Melin (2010) indicate that when a reservoir replaces a river environment it offers a new habitat with much lower biodiversity. Studies from Sweden and Canada has shown that the riparian zone surrounding a reservoir is decreased by 84% regarding degree of coverage and 34% regarding number of species, compared to a natural river or a natural lake (Melin, 2010). It has also been shown that the use of hydropower, together with other impacts, is behind the larger reduction of species richness in this kind of ecosystem compared to the species richness in marine and terrestrial ecosystems (Malm Renöfält et al., 2010).

Species that will be affected by the water regulations are different species of insects. They will during the autumn lay eggs, if this will happen in dams with high water level the eggs can become to be drained when the level decreases. In the spring with low water level the eggs will be exposed to drought and sunlight and thus find it difficult to survive (Hovsenius et al., 2002). Birds, whose main food is insects is then negatively affected because a reduced accessibility to food. There is impact also on other birds but the correlations there are not as clear for insects eating birds (Bergengren et al., 2013). According to Bergkamp et al. (2000), waterbirds are important components of the biodiversity of wetlands. They use natural and dammed open water wetlands for breeding, and during their nonbreeding seasons for feeding and for roosting. Due to regulation wetlands may be changed and the birds become affected.

The riparian vegetation along run of rivers impoundments often forms a narrow belt without zonation close to the high water level, and below this there are sparse occurrences of amphibious and aquatic species. In the report by Jansson (2002), the biological cost of hydropower, it is said that in free flowing rivers in northern Sweden there are about 90 vascular plant species per 200 m long stretch of river. Along run of river impoundments on the other side, about one fourth of the species have disappeared whereas one third of the species are lost from storage reservoirs compared to free flowing rivers. Another study from Gunnilboån in central Sweden indicates in the same direction by showing the effect of small hydropower on biodiversity. In the study the intensity of water flow variation was increased, making the stream frequently vary in width from 7 to 1-2 m. The result was that 62 of the 198 taxa found in the stream before the new operations were missing (Jansson, 2002). Kungliga ingenjörsvetenskapsakademien IVA (2002) states that the highest water level aquatic plants can manage is about 2-3 m, if the depth increases due to regulations the light needed in order to be able to live will become insufficient (Hovsenius et al., 2002). According to Jansson (2002) the effect of regulation on species richness of riparian plants remains about 70 years after onset of regulations and will probably stay permanent.

3.1.7.3 Aquatic Species

As understandable, fishes are one of the species that are most affected by hydropower plants. Dams are closing waterways, and this eliminates the possibility for upstream migration for organisms, especially for the fishes. Downstream migration can also be affected in the way that the only passage can be through the turbines (Hovsenius et al., 2002). Kumar et al. (2012) suggests that it is not only the possible fish barriers that can occur and affect the fishes negatively but also changed flow regimes, changes in water temperature and destroyed habitats are impacts that harms the populations (Edenhofer et al., 2012). Bergengren et al. (2013) also agree upon that one of the biggest problems with hydropower plants are that they work as barriers for fishes. According to changed water flow regimes, short-term regulations can affect fish populations indirectly when the access to food decreases as a consequence of the regulation. Sudden regulations of the water could also flush spawn and roe away (Bergengren et al., 2013). In Bergkamp et al. (2000) it is written about 66 different case studies that have been assessed with regard to the impacts of dams on fish biodiversity. They concluded that 27% of the cases had positive impacts (i.e. increase in species richness). and 73% of the cases had a negative impact (i.e. decrease in species richness). Of those who were negatively affected 53% were downstream of the dam, and had problem with the upward migration (Bergkamp et al., 2000).

The European eel (*Anguilla anguilla*) is one of the fish species that are very important to protect. The eel is according to the ArtDatabanken critically endangered (ArtDatabanken Swedish Species Information Centre, 2010). The European eel population has declined dramatically over the past decades. The eels have a remarkable life cycle whose details are largely unknown to us humans. However it can broadly be described that they starts their life as larvae in the Sargasso Sea and then crosses the North Atlantic until it reaches our latitude. When they have crossed the Atlantic sea, they have evolved into glass eels and then developed to pigmented juvenile eels. Some of the juvenile eels migrate up the rivers and lakes, others stay in coastal waters throughout their lives, while some periodically migrates between the sea and the freshwater during the entire growing period. After the growing period the juvenile eels become yellow eels, this phase will last approximately for 2-20 years. After these years in freshwater the eels become sexually mature and the eels become known as silver eels. Now they begin their migration back to the Sargasso Sea to spawn and then die. The migration barrier due to hydropower plant is a significant form of impact on the eel population and therefore also on the biodiversity (Nyström, 2011; Calles et al., 2012).

Kungliga Ingengörsvetenskapsakademien, IVA says that the regulation of the water level will have an impact on the benthos (Hovsenius et al., 2002). There exists a large diversity of species in the benthos and it is not unusual that the species have specific demands on the environment they live in, in form of e.g. temperature, the velocity of the water and water quality. When the environment is altered, it could lead to that the environments needed for the organisms living in the benthos are destroyed. It has been seen that streams with highly reduced water flow has a decreased biodiversity and also smaller amounts of the species living there. Heavily varying flows, in form of for example short-term regulation means that the organisms are forced to move to find the environmental conditions they need and also that there is a risk for that the organisms are flushed away when the flow changes (Bergengren et al., 2013). At strongly reduced water levels the cavity in sediment and aquatic bryophyte will decrease, which also will have an impact on larger animals in the way they cannot establish (Hovsenius et al., 2002).

Some other organisms that will be affected in the way the water flows, the temperature changes and the turbidity are changed, are plankton. Plankton are organisms that float freely in the water, and are therefore dependent on water currents to move. The plankton organisms include animals (zooplankton), plants (phytoplankton), algae, fungi (mykoplankton), bacteria (bacterioplankton) and viruses (virioplankton). Plankton forms the basic nutrition for organisms higher up the food web and are an important link in the cycling of nutrients (Nationalencyklopedin, n.d.). If the amount of plankton decreases, it will indirectly affect many organisms due to the fact that most marine food chains depend on the plankton's presence as a primary food source. If the amount on the other hand increases the large amount of plankton makes the water transmits light less and that photosynthesis and oxygenation decreases in the bottom layer of the lake (Encyclopedia Britannica, n.d.). The Kungliga ingenjörsvetenskapsakademien IVA (2002) says that there will be further indirect impacts on the plankton by changes of the riparian zone and the nutrition leakage accompanying.

Freshwater mussels are another organism that become threatened of hydropower plants ant its regulations. Some of the species live mainly in lakes and dams but all can be found in flowing water as well, such as the well-known freshwater pearl mussel. The freshwater pearl mussel (*Margaritifera margaritifera*) is an important species in the mussel family, this because it is a rare population and that the population still remains small. Because of this the freshwater pearl mussel is classed as vulnerable at the Red List of Threatened Species. According to the EU Habitats Directive, regarding the protection of habitats for plants and animals, the freshwater pearl mussels also are specially considered. The freshwater pearl mussel is dependent on trout (*Salmo trutta*) and salmon (*Salmo salar*), in the way they help for the mussel's reproduction and works as a host for the mussels larvae. If there are trout and freshwater pearl mussels available in the streams it indicates on an in general good water environment. In streams where these two species become viable the environment for other species also are assumed to be good (Bergengren, 2008; Svensk Energi, 2012). Large freshwater mussels are today used extensively as environmental indicators, this is thanks to the complex reproduction. This means that the mussels are relatively sensitive to the influence of their environment and therefore appreciative to use as indicators. One reason for this is also that the mussels have a relatively long lifetime. At inventories of the freshwater pearl mussel, one important part is to note the smallest mussel found. This is in order to detect recruitment and the population's viability. It is often generally said that individuals below 50 mm indicates that there has been recruitment during the past 10 years (Bergengren, 2008).

A study of Xiaocheng et al. (2008) suggests that the sites beneath the dam of a hydropower plant are the place that has the most different community structures. This was indicating that diverting the water current completely is harmful to the protection of macro invertebrate diversity of the river. Small insect nymphs and invertebrates, which cannot tolerate high velocities, are often under-represented in downstream reaches. Although run of river plants do not normally affect downstream habitat or terrestrial habitat (Ghosh and Prelas, 2011).

In some ways, hydropower plants can lead to an increased primary production. This can be the case for aquatic macrophytes. At the inlets to a reservoir, water depths can become reduced, and then rapid build up of deposits near river can encourage macrophyte growth. However, if there are large water fluctuations their ability to colonies these areas may be limited. The increased growth of macrophytes can be a positive impact as they create wetland-like conditions with good biodiversity values, but also support fisheries and assist in structuring habitats. However, there can also be a negative impact in the way an increased production can provide habitat for disease vectors such as bilharzia-carrying snails and mosquitoes (Bergkamp et al., 2000).

3.2 Mitigation Actions

The purpose of environmental mitigation requirements at hydroelectric projects is to avoid or minimize the adverse effects of development and operation. Hydropower mitigation usually involves costs, such as reduced profits to developers and reduced energy production. The implementation of the measures should be followed by a monitoring phase, in order to check the effectiveness on biological function. In the follow section some types of mitigation actions will be described.

3.2.1 Dam Removal

Dam removal is becoming a more frequently used management option all around the world. Although, the practice of using dam removal as an environmental restoration method in Sweden is rather new. Dam removal is taking into consideration for especially old dams in need of renovation or small dams that are no longer used or have lost most of their reservoir capacity. Another point of view is that dams and the reservoirs have many ecological effects, the disruption of the movement of different organisms is probably the most important reason for dam restoration. Thereby, dam removal makes it possible for fish migration and fish species to shift from lentic to lotic, which in turn have the ability to migrate and reproduce in free-flowing water (Lejon et al., 2009)

Under some circumstances it may be economically more beneficial for the dam owner to remove the dam than to keep it, even if it still produces revenue. From a study made in USA, 14 dam removals in Wisconsin showed that the estimated cost of repair was on average three times higher than that the cost of removal. Removal can also be economically preferable to renovation because of the environmental benefits gained from the restoration of turbulent stream reaches and thus fish migration routes. Another important aspect for removing a dam is the safety issue, especially in cases in which dams are in bad shape and hold large amounts of water (Lejon et al., 2009). In the report from World Commission on Dams (2000), incentives to removal of dams are mentioned and could e.g. that the dams no longer are have an useful purpose, too large impacts and too expensive to maintain the safety.

There are no general guidelines on how to accomplish dam removals, neither are there any long term studies to learn from. Nevertheless, the choice to remove the dams is becoming more common because the recreation of more natural aquatic habitats is achievable and also politically desirable (Lejon et al., 2009). Most of the rivers can although not be completely restored to the condition it was before the dam was built. But the removal can however often recreate conditions that move the river towards those historic conditions (American Rivers, 2014)

According the many facts that dams contribute with negative consequences on the ecosystem one would assume that the society would support a dam removal decision. However, this is often not the case. In the report of Lejon et al. (2009) another study also from Wisconsin in USA is mentioned. The study shows that in all the cases of the removal of 14 dams citizens originally opposed the removal when it was first discussed at stakeholder meetings. Due to lack of information and misconceptions about what will happen after a dam is removed people think that the removal of a dam will alter the scenery in a negative manner.

American Rivers (2014) state that dam removal can result in fundamental changes to the local environment. They claim that dam removal can have short-term impacts such as increased water turbidity, water quality impacts from sudden releases of water, changes in temperature and sediment build-up downstream from releasing large amounts of sediment from the reservoir. The long build-up of sediment can contain toxic substances and the resuspending of accumulated toxic-laden sediments in the process of dam removal has the potential to damage downstream water quality and threaten the health of fish and wildlife. However, American Rivers (2014) also state that these short-term impacts are greatly outweighed by the quick recovery of the system and the long-term benefits that result from the dam removal.

Lejon et al. (2009) agrees with American Rivers and writes about a study from Wisconsin, which showed that vegetation established quickly after a dam removal and that less than 1% of all sampled areas (five quadrates out of a total of 650 surveyed) was bare sediment even on sites restored as recently as a year previously. The production capacity was even measured to be higher in former reservoirs compared to reference sites. This was probably because of nutrient-rich sediments and good access to sunlight (Lejon et al., 2009).

In some cases rivers can be so heavily developed and dammed that the removal of one dam will be pointless or just return flows to a smaller part of the river. Although, American Rivers (2014) claim that dams that have been targeted for removal generally have been strategically located and therefore, this additional section of river is enough to sustain a crucial section of the river critical to fish and wildlife.

The fact when removing a dam is that the electricity production will be less or completely disappears. The difficult position is therefore to weight the economic interest against the environmental gains that can be made by removing a dam (Ingram, 2012).

3.2.2 Flow Regulations

In order to make the use of hydropower plants more compatible with the natural life of rivers, a minimum flow must be released so as to assure the preservation of the hydrological continuity of the river and the consequent conservation of natural habitat and ecological life (European Small Hydropower Association (ESHA), n.d.). Minimum flow release means that you allow some flow below a hydropower plant with the dual aim of maintaining current water ecological conditions and partly also for aesthetic or recreational purposes on a watercourse distance, which would mostly had remained drained otherwise (Erlandsson, 2008). According to Vovk-korže and Korže (n.d.) the concept of minimum flow release is that a threshold value should be kept above which the discharge has to be kept all time in order to ensure the survival of downstream ecosystem.

The Irish Department of Communications Energy and Natural Resources (2007) agrees that the minimum flow is important. They state that the minimum flow would be designed to ensure an adequate flow regime downstream of the power plant to accommodate upstream migration, spawning sites, safeguard juvenile salmonids, and invertebrate life and also maintain holding pools for adult fish. They claim that an amount of water also should be released even at low summer flows.

Proper dimensioning of the release of minimum flow is controversial because the problem that energy output will be lost. This factor often contributes to the fact that no action to use minimum flow is done. Another contributing factor to that minimum flow not is applied is that there is no uniform method for determining the amount of the released flow in Sweden and lack of knowledge counteracts the attempt of action (Erlandsson, 2008). The Irish Department of Communications Energy and Natural Resources (2007) state that the release of minimum flow largely depends on the type of the riverbed and varies greatly from site to site.

Even though there is no uniform method to determine how a minimum flow should be applied, there are several general assessment methods. The methods range from simple, desktop calculations to methodologies that may require considerable site-specific fieldwork (Oak Ridge National Laboratory et al., 2010). Nevertheless, it is still quite difficult to express biological aspects in a mathematical formula. The European Small Hydropower Association (ESHA) (n.d.) state that there is a common belief among ecologist associations that it almost is impossible to extrapolate a optimum minimum flow to a special area. They claim that the an site-specific approach is needed, together with field activities and modelling, intregrated vision of the ecosystem and collaboration of competences.

Compared to mitigation measures like for example fish ladders and fish friendly turbines, the initiating of flow releases are not contributing to large construction costs or any installation of hardware that is difficult to remove or alter. Environmental flow releases can rather be altered relatively easily to make experiments and test hypotheses and to optimize environmental benefits and power production (Oak Ridge National Laboratory et al., 2010).

To avoid draining out of the river bed by using minimum flows is essential for aquatic organisms, but it is also important to work towards a more dynamic regulation that follows the natural seasonal variations in order to protect the ecosystem. The level of the minimum flow should be set to reflect the variability in the flow regime in the current location. Completely static minimum flows should therefore be avoided (Malm Renöfält and Ahonen, 2013). According to the Swedish Society for Nature Conservation the release of the minimum flow should correspond to the normal low water flow, thus about 5-20% of the average water flow depending on location. The pursuit should be that the minimum water flow over time at least corresponds to the natural low water flow with natural dynamics for the season (Fiskeriverket and Naturvårdsverket, 2008).

3.2.3 Sedimentation Measures

The problem with sedimentation in the surroundings of the hydropower plant can be mitigated by for example the construction of small-scale weirs to trap the sands and the particles that later can be manually removed (International Energy Agency, 2006). A direct approach to reduce the accumulation of sediment is to mechanically remove the sediments by periodic dredging (Bergkamp et al., 2000). Another way to deal with the sediment problem could be to remove it through periodic flushing of the reservoir by releasing large volumes of water through outlets in the dam. In the case of run of rivers the sediment can be reduced by using flow diversion, which excludes the sediment (Melin, 2010).

3.2.4 Biotope Adjustments

Through the creation of greater environmental heterogeneity, by using such as habitat adjusting measures, the biological diversity of the benthic fauna will be strengthened (Hovsenius et al., 2002). Gravel and rock bottoms are for example very important for the reproduction of migrating fish. In order to improve the habitat in the rivers, restoration can be made through artificial alterations of the channel morphology involving elevations and indentations to create good places for the fish. Stone blocks and rocks among other things will be placed in the river and thus creating stream concentrations and barriers. New spawning sites can also be created for example by putting out gravel to give a natural impression (Erlandsson, 2008). To make these adjustments to be efficient, however, the water depth have to be greater than 2 m in order to prevent the area from drying out or to freeze at the bottom (Hovsenius et al., 2002). The adjusted areas should also not be so small that there becomes a risk for the fish or other organisms to fall prey to predators (Erlandsson, 2008).

Biotope adjustments are often accepted as successful substitutes for increased releases of water in Sweden. Biotope adjustments have for a long time been established in Sweden, but it has although been little requirement to evaluate the outcome of such undertakings in scientifically satisfactory ways, making it difficult to say what advantages and disadvantages it has (Svensson, 2000).

Costs for biotope adjustments vary considerably, according to Svensson (2000) total amounts expended, including planning and field-working, range between SEK 15 000 and 50 000 per kilometre of the river.

3.2.5 Fishways

The construction of a hydropower plant in a stream often results in that where it before was possible to migrate for the species in the stream, there is now a barrier that stops the species from migrating, both upstream and downstream. To facilitate for the migration of the species in the streams it is therefore desirable to construct fishways (Oak Ridge National Laboratory et al., 2010). The aim should always be to allow passage for all occurring species, not only fish, but also benthic invertebrates, mammals and amphibians and the fishways should enable migration both upstream and downstream (Länsstyrelsen Västra Götalands län, n.d. a).

To make fishways possible and efficient there are many factors that have to be taken in account. One of the big problems for passage through fishways is to direct the fish into them. A common cause of dysfunction of many fishways would be that a low flow of water would be directed to the fishway in relation to the total flow of the river. The flow of water to and from a fishway must therefore have sufficient water velocity to attract the fish. Otherwise the fish will not simply find the fishway or just ignoring it in the belief that it is a smaller tributary (Länsstyrelsen Västra Götalands län, 2005b). It is therefore important to know which period of the year the fish migration occurs in order to construct fishways that takes into account the water flow at that particular period of migration (Ström, 2012). According to Bourgeois and Therrien (2000) the volume of discharge through the fishway and the attraction flow should be about 1-5% of the mean stream flow during the migration period. According to the Irish Department of Communications Energy and Natural Resources (2007) tests have been done, which have shown that if the ratio between the outflow velocity from the fishway downstream and the velocity in the receiving pool should be at least 3:1 to make the fish attracted to the fishway. The water depth at the outflow downstream of the fishway should be adequate and there is a need of a pool with sufficient depth to allow the fishes to rest before entering or finishing the fishway.

Another important factor to make the fishway well functioning is the location of the fishway entrance. The entrance should be positioned as close as possible to the barrier. The entrance should also be constructed in the way that high flows and turbulence would be avoided, which would otherwise complicate the entrance for the fish (Bourgeois and Therrien, 2000). The slope of the fishway is another factor to be considered. According to the Environmental Protection Agency's recommendations, the slope of a pool-type fishway should not exceed 10% for salmonids. For other fish spices, the slope should ideally be less than 10%. A Denil fishway may have a slightly higher slope, up to 25% for salmonids and 10-15% for trout (Länsstyrelsen Västra Götalands län, 2005b).

The angle between the flow from the fishway downstream and the main flow is also important. It is best to have the attraction flow parallel to the main flow. If this angle increases the attraction to the fishway decreases. The best situation for the fish is when they do not have to turn back to find the entrance (Irish Department of Communications Energy and Natural Resources, 2007).

A lot of new different techniques are under development, which incorporate a more sophisticated technology. Technologies like this can for example be light- or sound-based guidance measures that are used to help fishes to pass obstacles with a minimal loss of flow for power generation (Sale et al., 1991).

There exist also possibilities to facilitate fish migration without constructing fishways. One solution can be to trap and transport the fishes. This type involves attracting and trapping the fish below a barrier and then physically transports them over the barrier. This solution although require much more work (NSW Department of Primary Industries, n.d.).

3.2.5.1 Examples of Fishways

According to Fiskeriverket and Naturvårdsverket (2008) there are four natural-like options to make migration possible. The four different options that can be taken to action is removal of the obstacles, upfilling of the watercourse downstream the migration barrier with for example natural stones so that the bottom of the watercourse become to be at the same level as the migration barrier. The migration barrier is eliminated by rising up the entire watercourse (Länsstyrelsen Västra Götalands län, 2005b). Next option can be to build a stream through the obstacle (Sjölander et al., 2009). The last nature-like fishway option is to construct a stream around the obstacle. When constructing this new way it is important that it is made in the way that the slope becomes small, this however often entails that its path becomes long (Länsstyrelsen Västra Götalands län, 2005b). According to Erlandsson (2008) fishways built in this way, are about 50-90 m long distributed over a vertical drop of three to 6 m. This means that the construction of a bypass channel assumes that the environment around the migration barrier is relatively flat and does not consist of, for example mountain. The benefit of the construction of bypass channels like this is that it fits all different kinds of fish species and is almost maintenance-free. The idea is that it completely will mimic a natural watercourse and even may contribute to that a new reproduction and growth local will be formed (Fiskeriverket and Naturvårdsverket, 2008; Länsstyrelsen Västra Götalands län, 2005b).

Fiskeriverket and Naturvårdsverket (2008) also states that there in addition to these natural-like fishways also are five technical solutions available. Common to these five different constructions is that usually only fish can pass through them. They are also often very selective, thus only certain species and sizes of fish can pass. These technical solutions are often used at power plants with high heads. The five different constructions are; construction of spillways or steps in the barrier that allows passage, pool-type fishway, vertical-slot fish passage, Denil fishway and finally, also eel and elver fishways can be constructed (Fiskeriverket and Naturvårdsverket, 2008).

The pool-type fishway is one of the most common types of fishways used in the society today. The construction is based on pools, which the fish has to jump between to move through the fishway. Drawback of this fishway is that it is primarily suited to salmonids because they have a better ability to jump. The fishway is also very sensitive to variations in water flow. Advantage of this type of fishway is however that it has relatively low construction costs and that it does not require as much maintenance work (Länsstyrelsen Västra Götalands län, 2005b).

The vertical-slot fishway is similar to a pool-type fishway except that each pool has a smaller slot in the wall. This helps fish to swim through the fishway without jumping (Pettersson, n.d.). The benefits of a vertical-slot fishway construction are that it works in all different kinds of water flows and that it also is suitable to many different fish species. The disadvantages are that it is expensive and complicated to build (Erlandsson, 2008).

The Denil fishway uses a series of symmetrical close-spaced baffles in a channel to redirect the flow of water. This creates turbulence in the water flow, which in turn reduces the water velocity (Länsstyrelsen Västra Götalands län, 2005b). This type of fishway is common at high heads and at areas where it is lack of space (Erlandsson, 2008). The benefits of a Denil fishway is that it can handle large gradients and that it is not as sensitive to variations in water flow. The drawbacks are that they require much inspection because branches easily get stuck between the baffles (Länsstyrelsen Västra Götalands län, 2005b).

For eels and elvers it is often very difficult to use traditional fishways due to the water velocity. Therefore it is a need of a special way for these young eels. These fishways are based on the ability of eel/elvers to climb and crawl when passing an obstacle, a wet and rough surface is therefore required for the construction of this way (Vovk-korže and Korže, n.d.). The eel and elver fishway is often constructed of plastic tubes with some kind of substrate inside, which make it possible for the eel to move forward (Länsstyrelsen Västra Götalands län, 2005b).

3.2.6 Fish Plantations

These obstacles hydropower plants pose to migrating fish has made it necessary to artificially manage the fertilization, hatching, growth and release of especially salmonid fish (Kungliga ingenjörsvetenskapsakademien IVA, 2002). To introduce planted fish to protect endangered species or reintroduce species that have disappeared may be of great benefit to the environment and the biodiversity (Jordbruksverket, 2014). Fish farming has long been used in Sweden and is important in order to maintain a certain stock of various species. The technology used today however, affects the ecology, behaviour and genetics in wild populations and need to be developed to become a more naturalistic fish farming (Erlandsson, 2008).

The disadvantage of farmed fish is that they differ from the wild in for example appearance and behaviour. Release of those fishes therefore represents a risk that infectious fish diseases are spread and that different species of fish will be spread in an undesirable way to environments where they do not belong (Jordbruksverket, 2014). The introduction of planted fish can bring the risk that the new species will predate or invade the ecological niches of native species, so reducing the biological diversity instead (Bergkamp et al., 2000).

As the fish grows up in safe catchment areas with a good supply of food, they are not fully adapted to life in a natural water stream and the survival thus become lower than for natural fishes once they are released into freedom (Erlandsson, 2008). In Forskning & Framsteg it can be read that Fiskeriverket has studied planted eels in Mälaren in Sweden. From this study it has been seen that when it was time to begin the migration, only a few of the eels found their way out of the lake. This has been proven to be a widespread problem among the imported stocks. One explanation for their lack of orientation may be that they were transported to the release sites rather than to swim there. Indeed, there are studies that show that eels are oriented by the magnetic fields in the earth's crust, and it is believed that they create a kind of internal map during their travels, which will help them to find back the way they came (Nyström, 2011).

Another problem with fish plantation is that the planted fish become merged with various communities from a river that developed over a very long time period, which means that you get a new tribe that will not be adapted to any part of the watercourse instead (Erlandsson, 2008).

3.2.7 Fish Friendly Turbines

Fish friendly turbine technology is an emerging technology that provides a safe approach for fish passing though the turbines by minimizing the risk of injury or even death (Edenhofer et al., 2012). The research, which is done on fish friendly turbines, mostly aims at reducing four different causes of harm. These causes are strike, shear forces, pressure and cavitation (Bourgeois and Therrien, 2000). Conventional hydropower turbines only focus on electrical power generation, the aim of the new fish friendly technology is to bring benefits for both power generation and the protection of fish species (Edenhofer et al., 2012).

Much of the ongoing research in the hydropower sector is concerned with the attainment of the ideal turbine. The U.S. Department of Energy initiated the Advanced Hydropower Turbine System (AHTS) Program for developing just as wanted a low impact, fish friendly turbine. A new turbine, the Alden turbine, which is designed by the Alden Research Laboratory among others, has today been developed under this AHTS program and is based on the shape of a pump impeller. This one will minimize the leading edge of the blade and maximize the size of flow passages (Ghosh and Prelas, 2011). The Alden Laboratory predicts that this fish friendly turbine will have a maximum efficiency of 90.5% with a survival rate for fish of between 94 and 100% (Edenhofer et al., 2012). As a result of this research work, the Alden turbine is now ready for installation and further testing at a hydroelectric plant will be carried out during the following years (HydroWorld, 2013).

Another principle that can be used to be friendlier to the fish is the Archimedes screw. The Archimedes screw is a slow speed rotor and thanks to their much slower rotations velocity the turbine become fish friendly (European Small Hydropower Association (ESHA), n.d.). The screw works in the way that it takes in large blocks of water that travel slowly down the machine before emerging at the end. The blocks of water bodies are large enough to hold large fish. The speed of the blades on the rotor is very low, and they tend to bring the fish aside rather than hurt them. There are neither any high-pressure regions impacting the fish in the water because of the low forces from the screw. The Environmental Agency in the UK have been involved in considerable testing of the impact on fish from the screw, and they have found that damage to fish is extremely low or non-existent (Hutton, 2012).

There is still much to be learned about the causes and extent of injuries in the turbine system as well as the significance of indirect mortality and the effects of turbine passage on fishes. However, improvements in turbine design and operation, as well as new fields, laboratory facilities and modelling techniques to assess turbine-passage survival, are contributing toward a better solution of the fish passage issue at hydropower plants.

Chapter 4

Case Study

Borås Energi och Miljö are the owners to four different hydropower plants, located in the municipality of Borås and in adjacent municipalities. This section will give information about the hydropower plant and the environment surrounding the hydropower plants. The figure 4.1 on the next side shows a schematic orientation map of Ätran and Viskan and gives an overview of where the hydropower plants are located and how many other plants that are located in the two streams. Since three of the plants are located in tributaries to Viskan, also those streams are included on the map.

Figure 4.1: Schematic orientation map. Översiktlig orienteringskarta ©Länsstyrelsen Hallands län (Länsstyrelsen Hallands län, n.d.).

4.1 Summary and History About the Hydropower Plants

The hydropower plants owned by Borås Energi och Miljö were all built in the beginning in the first part of the 20:th century. The conditions at the different sites were considered as favourable for the construction of hydropower plants since possible problem with cold weather and snow could be considered as small. All the four hydropower plants are situated in Götaland and SMHI describes the climate in Götaland as temperate/mesothermal climate in the coast regions and the other parts of Götaland as continental/microthermal climate (SMHI, 2009a). The continental/microthermal climate is about the same as the boreal climate and even if it is hard in this case to find an exact definition of which climate zone the four hydropower plants belong to, so according to what can be read at SMHI (2009a), the climate can be compared with a boreal climate.

The four hydropower plants are of similar size even if there are some differences in the construction. Due to the long time period since the hydropower plants were built, there have been changes at the sites and the following sections will describe the hydropower plants and which changes that have been performed at the hydropower plants. The sections will also give an introduction to the hydrology at the sites and how the lakes, used as reservoirs, are regulated.

4.1.1 Haby

1912 the decision was made by Borås city to start to construct a hydropower plant in Haby in Slottsån. The conditions at the place were considered to be favourable for the construction of a hydropower plant. Haby is located three kilometres south of Skene, in the municipality of Mark and at Haby is the catchment area 413 km^2. The average water flow at the plant is 7 m^3/s and the hydropower plant has a head of 27.8 m. Upstream of Haby are the lakes Öresjön and Tolken. Öresjön consists of Västra and Östra Öresjön. To ease the control of the flow through Haby and the electricity production, Borås Energi och Miljö were given permission to regulate the water level in the Öresjön and Tolken. By being given the permissions to regulate the lake Öresjön 2.8 m and Tolken 2.5 m, storage of 60 million m^3 was possible (Borås Energi och Miljö, n.d. b). There are no requirements on a minimum flow from the plant. Even though they have the possibility to regulate both of the lakes more than 2 m the usual variations in the water level lies in the range 1-1.5 m and can at occasions reach 2 m (Fredberg, n.d.).

The construction of the plant started in February 1913 and two years later in January it was possible to start up the plant. From the regulation dam in Öresjön, a 200 m long headrace was built to lead the water. After the headrace follows a 630 m long tube made out of steel and with a diameter of 4 m. The steel tube ends up with swelling tower and thereafter is there a 100 m long tube down to the turbines, see figure 4.2. The purpose of the swelling tower is to work as a safety valve and mitigate the possible changes in pressure due to the sudden changes of the water movement in the tube. In the hydropower plants there are two twin turbines, which are of Francis type and had at 1913 each a power of 2700 horsepower (1985 kW) (Borås Energi och Miljö, n.d. b).

Figure 4.2: Haby hydropower plant. Upper left: the swelling tower, upper right: headrace, bottom left: dam construction and bottom right: tube (Seger, F., 2014, Haby hydropower plant [photography]).

Since the constructions of Haby, modernization and refurbishment has been done. 1922 the plant became semi- automatic. The reason behind this was the new law that limited the working hours to eight hours a day. The change required that more personnel were hired ant to avoid that the stations were made semi-automatic so that constant supervision was not needed. To make Haby semi-automatic, the plant was equipped with voltage regulators and relay protection equipment. In Haby they had problem with cavitation on the turbines impeller blades. The impeller blades was therefore exchanged in 1928 and replaced with new impellers made of stainless steel, which also gave an increase of the power with 800 kW. 1953 new machinery was installed in Haby. The new turbines were installed at the same place as the earlier ones but the generators were built completely new. Eight years later Haby became controlled from Borås and since 2001 Haby are operated from the control room in the combined heat and power plant in Borås (Borås Energi och Miljö, n.d. b).

In 2003 there was a change of the 75 years old hydraulic equipment in Haby into new hydraulic equipment since there was a leakage of oil and impaired function of the axes in the hydraulic equipment. The reasons to why there was a change of the equipment were that there was looseness in the regulation axes together with leakage of oil. With the new hydraulic equipment it was possible to reduce the amount of hydraulic oil in the powerpack from 100 litres of oil to 15 litres of oil (Borås Energi och Miljö, 2003). The summer 2005 was maintenance work performed on the dam construction in Haby. As a precaution a lowering of the water level was done to avoid a situation where the water level approaches the upper limit in the water rights permit and a release of water through the spillways in the dam was needed. The repair on the dam included change of the bottom outlets and spillways fix the water leakage through the dam body and jointing on a part of the paving in the inlet channel (Borås Energi och Miljö, 2005b). Maintenance work was also performed on the dam construction in 2012 and 2013 (Borås Energi och Miljö, 2013a).

The following table 4.1 shows the compiled information about the hydrology in the area where Haby is located together with some other important information.

Table 4.1: Haby in numbers (Borås Energi och Miljö, n.d. b).

Haby	
Catchment area	413 km^2
Area consisting of lakes	10.2 % or 42.2 km^2
Tolken's and Öresjön's area	24.1 km^2
Average runoff	17 $l/s\ km^2$ or 0.017 $m^3/l\ km^2$
Average water flow	7 m^3/s
Head	27.8 meter
Turbine	Francis
Installed capacity	5.3 MW
Construction years	1913-1915

4.1.2 Hulta

The construction of Hulta hydropower plant started in March 1916 and was completed in the end of September 1917, see figure 4.3. Hulta is also located in Slottsån but a bit downstream Haby and the water arriving at Hulta has therefore passed Haby before. The plant has a head of 13 m and due to the lower head the structure of Hulta looks a bit different compared to Haby. Hulta has a regulation dam across Slottsån. Together with a deep outlet channel it was possible to avoid long water ways and tubes and utilize the whole head at the power station. In Hulta there are one twin turbines of Francis type (Borås Energi och Miljö, n.d. b).

Figure 4.3: Hulta hydropower plant. Upper left: hydropower station, bottom left: cleaning racks at the turbine intake and right: dam construction. (Steinmetz, M., 2014, Hulta hydropower plant [photography])

In 1928 the power station in Hulta was made fully automatic and was controlled from Haby. As for Haby, Hulta became operated from Borås in the 1961 and 2001, from the control room, in the combined heat and power plant in Borås. 1977 maintenance work was performed on the dam construction, some of the spillways and the tree in some details were changed and blasting was performed (Borås Energi och Miljö, n.d. b). 2009 another maintenance work was performed on the dam construction. The purpose with the repair was to prevent bursting of pipes, stop the water leakage through the dam body, change spillways, intake gaps, some details in the bottom outlets and folds, grouting of the paving in the spillways and blasting of the guardrails (Borås Energi och Miljö, 2009, n.d. b).

As mentioned, are Borås Energi och Miljö allowed to regulate the lakes Tolken and Öresjön. To get an overview of how the lakes are regulated, figures showing the water levels in the lakes for some of the most recent years are included. According to the ruling pronounced by the Water Rights Court, Borås Energi och Miljö are allowed to regulate Öresjön 2.8 m but the whole range is rarely utilized, which can be seen in figure 4.4. It is also consistent with the information from Fredberg (n.d.). For Tolken, it is in accordance with the Water Rights Court's ruling decided that Borås Energi och Miljö are allowed to regulate Tolken 2.5 m. Also here are they following the same pattern and are seldom utilizing the whole range, see figure 4.5.

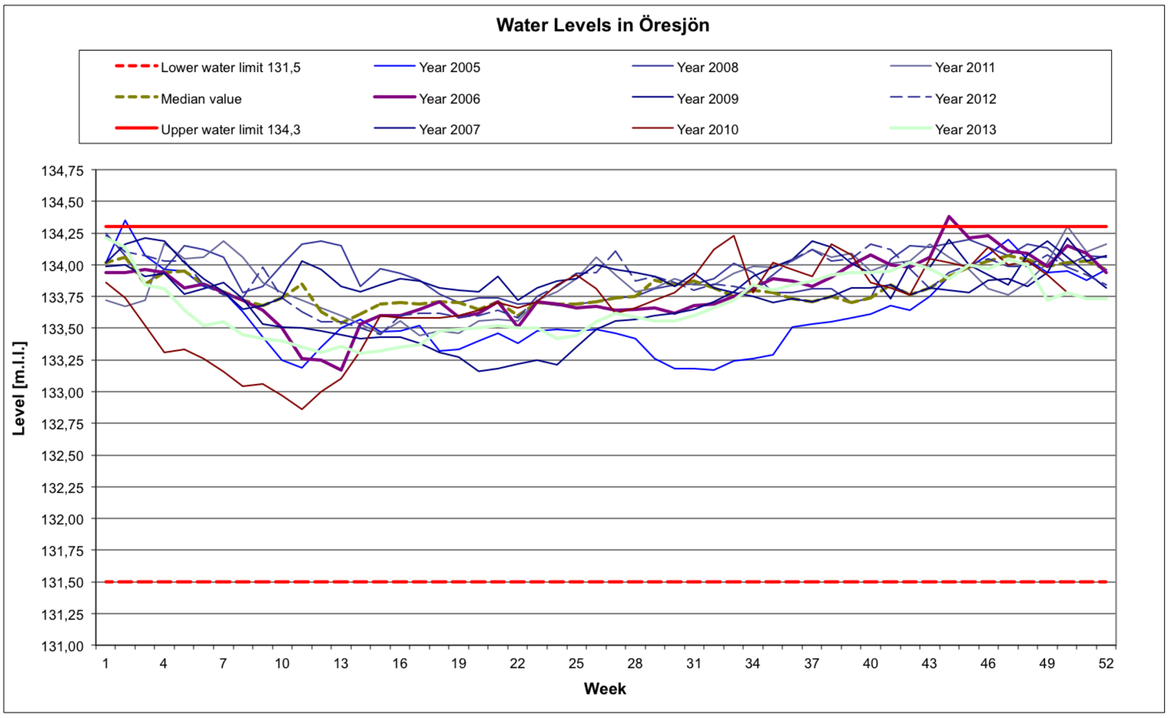

Figure 4.4: The water levels per week in Öresjön between 2008-2013. Height indicators refer to a local measure in meter based on a point in the area (Borås Energi och Miljö, 2013b).

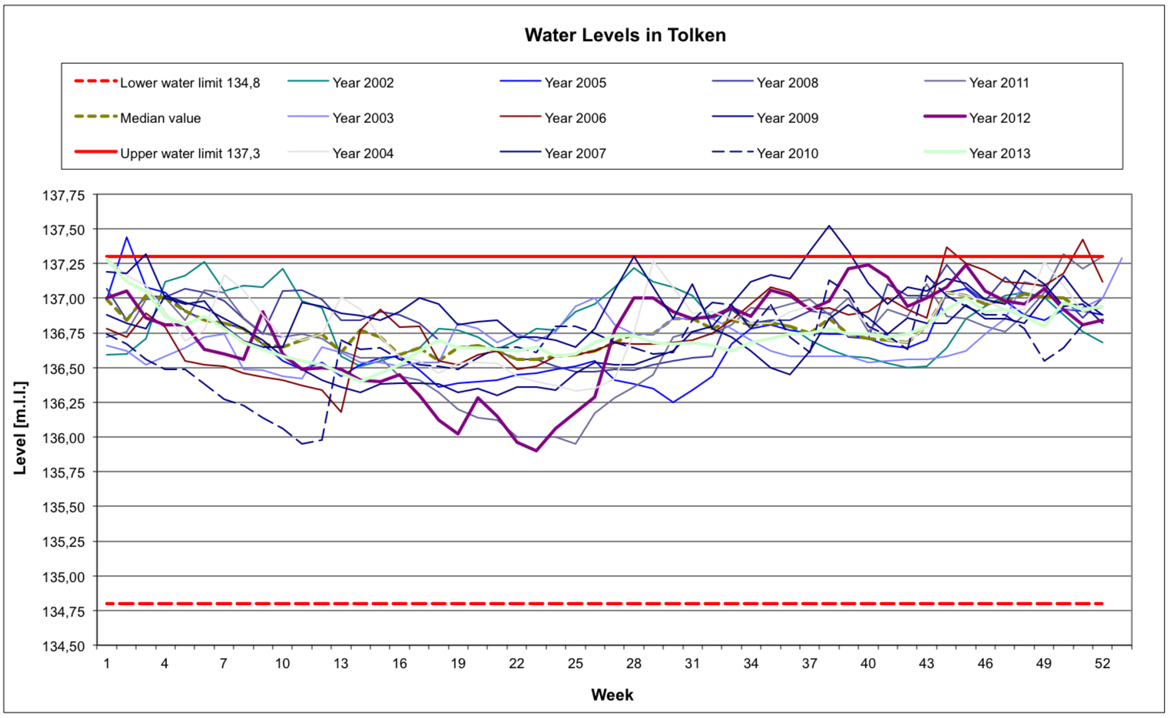

Figure 4.5: The water levels per week in Tolken between 2004-2013. Height indicators refer to a local measure in meter based on a point in the area (Borås Energi och Miljö, 2013b).

The table 4.2 below shows the compiled information about the hydrology for Hulta. Since Hulta is situated just a short bit downstream in the same stream as Haby are the hydrological conditions to be considered as similar as for Haby. The catchment area is thus of similar size and the average water flow can also be assumed to be of similar size as for Haby, which also can be seen in the table.

Table 4.2: Hulta in numbers (Borås Energi och Miljö, n.d. b).

Hulta	
Catchment area	413 km^2
Area consisting of lakes	10.2 % or 42.2 km^2
Tolken's and Öresjön's area	24.1 km^2
Average runoff	17 l/s km^2 or 0.017 m^3/l km^2
Average water flow	7 m^3/s
Head	13 meter
Turbine	Francis
Installed capacity	2.57 MW
Construction years	1916-1917

4.1.3 Hyltenäs

In the proposal to build the hydropower plant and regulation dam in Haby also the construction of a regulation dam in the Hyltenäsån was included, see figure 4.6 (Borås Energi och Miljö, n.d. e). Hyltenäsån is situated between Tolken and Öresjön (VISS Vatteninformationsystem Sverige, 2013c). This regulation dam should be used to control the water flow from Tolken so that the water level stays in between the established limits in accordance with the Water Rights Court's ruling (Borås Energi och Miljö, n.d. e).

Figure 4.6: Hyltenäs dam construction (Steinmetz, M., 2014, Hyltenäs regulation dam [photography])

4.1.4 Häggårda

Häggårda is over 100 years old and is the oldest of the four hydropower plants that is owned by Borås Energi och Miljö. The construction of the plant started in 1906 and the plant was completed in 1908 (Borås Energi och Miljö, n.d. f). Häggårda is located in Borås municipality in the stream Häggån, a tributary to Viskan and starts from the lake Frisjön, which are used to regulate the water. In accordance with the Water Rights Court's ruling the limit for the regulation in Frisjön is 1.9 m (Borås Energi och Miljö, n.d. f). This means that there exists a capacity to store 12 million m^3 of water in the lake. The head at Häggårda is 28.5 m (Borås Energi och Miljö, n.d. f). When the water reaches Häggårda it is lead first through a 150 m long headrace, see figure 4.7, and after that, a 110 m long tube before the water reaches the turbines (Borås Energi och Miljö, n.d. c).Originally, there were three turbines at the hydropower plant but due to low efficiency of the hydropower plant these were removed and also all the mechanical and electrical equipment was replaced by new equipment. In 1930 there was a new installed Francis turbine that was a twin turbine and had a maximum power of 2300 horsepower (1691 kW), which in 1956 also was supplemented with a smaller turbine. Like Haby and Hulta there was a transfer at the time from a control at the plant to a remote control and operations centre in a steam power plant. Today the plant is controlled from the control room in the combined heat and power plant in Borås (Borås Energi och Miljö, n.d. f).

Figure 4.7: Häggårda hydropower plant. Headrace leading to intake to tube. (Steinmetz,M., 2014, Häggårda hydropower plant [photography])

In accordance with the water rights permit it is decided that there always should be a flow of at least 1.5 m^3/ s with the exception that the water flow is allowed to decrease to 0.33 m^3/s five hours a day if the station is operated at usual the remaining time. The smaller one of the turbines is used for meeting the requirements on a minimum flow that always should be let through the plant, 1.5 m^3/s and is constructed especially for that when running at minimum power, let through this volume of water. The bigger turbine is used at flows above 1.5 m^3/s (Borås Energi och Miljö, n.d. c).

On the dam construction in Häggårda has different reparations been done recent years. 2011 was a retaining wall molded downstream the dam pillars. Damages on the left dam pillar were also fixed. In 2012 were joints on the stilling basin and the dam pillars done and in 2013 were repairs on the dam body performed (Borås Energi och Miljö, 2011). The same year, 2013, the control equipment on the generator G2 in Häggårda was changed (Borås Energi och Miljö, 2013a).

Borås Energi och Miljö regulates Frisjön in order to adapt the flow to the hydropower plant. As mentioned before the company has permission to regulate Frisjön 1.9 m. When looking at the different water levels in the lake each week since 2002 it is possible to see that they seldom regulate the water level to that extent, see figure 4.8. The upper and lower limits that the water levels should be between are also shown in the figure.

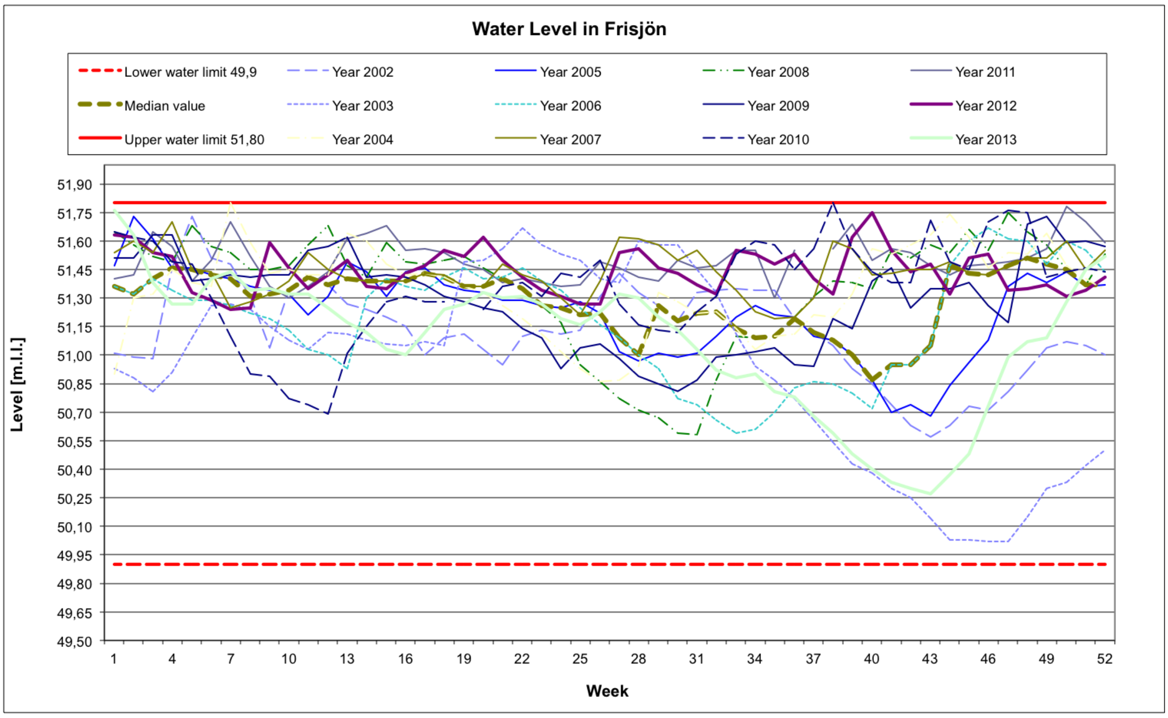

Figure 4.8: The water levels per week in Frisjön between 2004-2013. Height indicators refer to a local measure in meter based on a point in the area (Borås Energi och Miljö, 2013b).

The following table 4.3 compiles the information about the hydrology in the stream were Häggårda is located together with some other important information about the plant.

Table 4.3: Häggårda in numbers (Borås Energi och Miljö, n.d. c).

Häggårda	
Catchment area	150 km^2
Area consisting of lakes	7.2 % or 10.8 km^2
Frisjön's area	6.8 km^2
Average runoff	17 l/s km^2 or 0.017 m^3/l km^2
Average water flow	2.5 m^3/s
Head	28.5 meter
Turbine	Francis
Installed capacity	1.79 MW
Construction years	1906-1908

4.1.5 Axelfors

The construction of the hydropower plant in Axelfors started in 1935 and the plant was ready for commissioning in 1936 (Borås Energi och Miljö, n.d. a). There is a small regulation dam at the site but since the water there should be consumed in less than half an hour is the power station operated as a run of river hydropower plant. Axelfors is located in Ätran in Svenljunga municipality. The head is 11 m and in difference to the three other hydropower plants a Kaplan turbine is used in Axelfors to generate the power. The tube is 80 m long with a diameter of 4 m and the maximum flow into the turbine is 26 m^3/s, see figure 4.9 (Borås Energi och Miljö, 2014b, n.d. d). After the turbine there is a outlet channel, which is 110 m long (Borås Energi och Miljö, n.d. d).

Figure 4.9: Axelfors hydropower plant. Dam construction and tube. Spillways are closed and no water is passing by the turbine. (Seger, F., 2014, Axelfors hydropower plant [photography])

The plant in Axelfors was provided with a remote control system and was actually the first plant in Sweden with that kind of remote control system (Borås Energi och Miljö, n.d. a).

2005 was maintenance work performed on the 80 m long tube. Blasting and painting was done on the tube (Borås Energi och Miljö, 2005a). In 2010 was maintenance work performed on the dam in Axelfors. The maintenance work performed was mainly chiseling of the concrete to remove concrete damaged of corrosion and molding operations of all the spillway parts (Borås Energi och Miljö, 2010).

Table 4.4 is showing the compiled information about the hydrology where Axelfors is located together with some other information.

Table 4.4: Axelfors in numbers (Borås Energi och Miljö, n.d. a).

Axelfors	
Catchment area	1028 km^2
Area consisting of lakes	5.9 % or 60.6 km^2
Average runoff	12 l/s km^2 or 0.012 m^3/l km^2
Average water flow	12 m^3/s
Head	11 meter
Turbine	Kaplan
Installed capacity	2.57 MW
Construction years	1935-1936

4.2 Ecosystem in the area

The information below is about the ecosystems in the different areas where the hydropower plants are situated. The chapter will provide an overview of the existing information about the ecosystem, which investigations have been performed and on what is known about the impact from the hydropower plants today. Since Haby and Hulta are situated in the same stream the information about the ecosystem in Slottsån concerns both of them. Slottsån and Häggån are tributaries to Viskan and it is therefore important to also include information about the ecosystem in Viskan. Since the information possible to gain about the different ecosystems showed a big diversity the information is not uniform. What is known about one ecosystem is maybe not known about another ecosystem and vice versa.

4.2.1 Viskan

Viskan starts in the lake Tolken, which not should be confused with the lake Tolken in Slottsån's catchment area, in Västergötland and ends its journey in Klosterfjorden in Halland. The environment surrounding Viskan has a changing character as the rivers flows from Tolken until it reaches Klosterfjorden. The environment around the lower parts of Viskan consists mainly of agricultural landscape. The upper part of Viskan is surrounded of agricultural landscape together with forest. Viskan is from a fishing point of view regarded as national valuable water for fishing and historically has Viskan's catchment area been an important area for the eel to grow up in. The construction of the hydropower plants has complicated the migration for the eel and has made it hard for it to reach earlier growth areas. (Norconsult, 2011).

4.2.2 Slottsån

Slottsån is one of the bigger tributaries to Viskan (Norconsult, 2011). Before the migration obstacles were built in Slottsån it was possible for the salmon and trout to migrate the whole way up to Öresjön and Tolken and you could see both salmon and sea trout spawn in Öresjön (Länsstyrelsen Västra Götaland län, n.d. ; Wengström, 2011). Slottsån flows from the eastern part of Öresjön to Viskan and is about 4 km long. In the report from Länsstyrelsen, Haby and Hulta hydropower plants are classified as definitive migration obstacles for the fishes. Above Haby it is noted to exist a spawn area of 56 865 m^2 for the trout. Above Hulta there exist no possible spawn areas for the trout. Hulta is situated about 600 m above the outlet to Viskan. Haby is situated about 400 m downstream the outlet from the lake Öresjön. Today it is only possible for the salmon to spawn in the area in Slottsån closest to Viskan (Wengström, 2011).

In the eastern part of Öresjön there are today populations of perch (*Perca fluviatilis*), eel, bream (*Abramis brama*), rudd (*Scardinius erythrophthalmus*), pike (*Esox lucius*), vendace (*Coregonus Albula*), smelt (*Osmeridae*), tench (*Tinca tinca*), walleye (*Sander vitreus*, formerly *Stizostedion vitreum*), trout, bleak (*Alburnus alburnus*) , burbot (*Lota lota*) and roach (*Rutilus rutilus*). Slottsån is regarded as a stream with good potential for the salmon and sea trout reproduction. The fish population in Slottsån consists of fishes such as salmon, sea trout and trout living in lotic water. Occurrences of freshwater pearl mussels and eel have been found in Slottsån (Wengström, 2011). Earlier there have also been occurrences of crayfish in the stream (Wengström, 2011).

Öresjön and Tolken are considered as nationally valuable waters from a fishing point of view and regionally valuable waters from a natural value perspective. In Öresjön and Tolken there exists a stock of lake trout that is worthy of protection. Electro fishing has shown that there is a decrease in the trout population. Probable reasons to that are regulation of the water level, times with no water discharge and the existence of fish barriers. The best actions to improve the living conditions for the trout are to restore stream water habitats (Länsstyrelsen Västra Götaland län, n.d.)

According to the report by Wengström (2011), prioritized actions should be to create fish passages so it is possible for the fishes to pass by the hydropower plants in the stream. They are also suggesting where the construction of possible bypass channels should be situated for both Hulta and Haby. In Haby should there also be an establishment of a minimum discharge in the dry riverbed to benefit the species in the area (Wengström, 2011).

On behalf of Borås Energi och Miljö, Medins Biologi AB examined the benthic zone and its benthos at two sites in Slottsån in the autumn 2007. Maintenance work was supposed to be carried out at the dam at Hulta and a cofferdam would be built. The study aimed to describe the benthic zone before the procedure was carried out. The results from investigations on benthic zones have since the 1980's been used as bio indicators. Samples were taken at the dam of Hulta hydropower plant and also at Slottsberget (about 1.5 km upstream). Species richness was moderately high at the dam area, 25 taxa were found. The benthic zone was dominated by species that usually are found in still or quietly flowing water. No rare or endangered species were found at the place. However, there were several moderately sensitive species present. The caddisfly, *Lype phaeopa* that are sensitive to acidification were also found at the area. The presence of moderately sensitive species and the *Lype phaeopa* indicated that no acidification existed. At Slottsberget there were also a lot of species that were sensitive to acidification, which indicated also at this area that no acidification existed. From samples at Slottsberget 54 taxa were found, this is a very high diversity of species according to the report. There were also three rare species that were found, the caddisfly *Goera pilosa* and *Notidobia ciliaris* and the shell *Marstoniopsis scholtzi*. Overall, the benthic composition was indicating on nutrient rich conditions (Nilsson and Rådén, 2007).

In November 2011 another investigation was performed on the benthic zone. The investigation was performed on the behalf of Länsstyrelsen. A number of different places in Viskan were investigated and Slottsån was one of the places investigated. The purpose with this study was to see how the benthos was affected by the regulations at the selected locations. In Slottsån samples were taken at two locations, one close downstream the regulation dam for Haby and one a bit further downstream from the regulation dam. The distances were approximately 200 metres and 2 kilometres. The samples showed that the condition of the benthic zone in Slottsån could be assessed as good with respect to the hydromorphological impact. Even if the status was assessed to be good so is it probable that if there had not been any regulation in Slottsån so had the samples shown a higher species richness. The sample taken close to the regulation dam in Slottsån was taken where the original stream was flowing. It showed that high species richness could be found in the original stream. That suggests that there is probable no times when the original stream is totally drained. It was however possible to see that the samples taken further away from the regulation dam exhibited a higher species richness than the samples taken closer to the regulation dam (Ericsson et al., 2012).

The changes that can be seen in the species richness that can be derived to the regulations are that e.g. species that are favoured by the increased production of plankton in the regulation dam can be found in an increased number close to the floodgates since food availability for them has increased, so called filter feeders. Species that in other hand is affected negatively is for example stoneflies since the water often is changed from a streaming flow to a calmer flow. (Ericsson et al., 2012).

In the sample taken close to the regulation dam the type of species eating plankton mentioned earlier was possible to find, which can be regarded as natural because of the proximity to Öresjön. The benthic zone was assessed to have moderate species richness. The overall status was good but there exists some impact from the regulation (Ericsson et al., 2012). The sample taken in the location further down in the stream showed a similar result to the other sample even if it was possible to distinguish some differences. The location showed a higher species richness than the other one in Slottsån. Also here it was possible to find filter feeders but as for the sample taken at the location upstream it can be seen as natural due to the proximity to Öresjön (Ericsson et al., 2012).

Overall, all of the samples taken at the different locations in Viskan and its tributaries showed a good or high status. It can be understood in the text that it was a bit surprising for the authors of the report since Viskan and the other streams can be seen as heavily affected by regulation, something that is known to have adverse effects on the ecosystem. They are also discussing the reasons behind the result. One possible reason that they come up with is that even if the streams are regulated so are the regulation done in a way so that the changes in the flow happens slowly and that the differences in the regulated water flow compared to how the flow would be without the regulation is not that large as they could be. It is also worth to mention that the location furthest away from the regulation dam was specimens of stoneflies found. Stoneflies are very unusual in the southern part of Sweden. That the location provides a suitable environment for the stonefly to live in can be seen as an indicator of that the benthic zone holds high natural values (Ericsson et al., 2012).

Regarding the surrounding land area a geotechnical investigation was carried out at Slottsån for the area around Hulta hydropower plant. The study was made because the area just upstream the power station was planned to be dried up to enable the performance of maintenance work, and they therefore wanted to investigate if the surroundings could manage this. The results of this investigation were that due to Slottsån's relatively slow flow and the stability of the surrounding land no current erosion was available (SWECO Infrastructure, 2008).

From the same investigation as above it can also be read how the topography closest to the river looks. On the east side of Slottsån the ground is almost flat closest to the water. But on the south side on the other hand the hillside is steep (SWECO Infrastructure, 2008).

4.2.2.1 Potential to Reach Good Ecological Status

Due to the lack of continuity and the changes in the water flow has it been assessed that it is technically impossible to achieve the goal of good ecological status by year 2015 and the deadline has been postponed to year 2021. The criteria that define the status in the streams can be read about in chapter 1.2.1. Despite the prolonged time frame Slottsån has according to Länsstyrelsen in Västra Götaland still a risk that the ecological potential will not be reached by year 2021. Today the stream is classified as moderate. The water body has poor status due to the barriers in the stream. The fishes and other species living in the stream cannot migrate in a natural way and there exists two migration barriers in the water body that are anthropogenic (VISS Vatteninformationsystem Sverige, 2013d).

4.2.3 Hyltenäsån

Hyltenäsån is the stream that connects the two lakes, Öresjön and Tolken and as mentioned earlier has Borås Energi och Miljö a regulation dam in Hyltenäsån from where they control the water levels in Tolken (Borås Energi och Miljö, n.d. b; VISS Vatteninformationsystem Sverige, 2013c).

4.2.3.1 Potential to Reach Good Ecological Status

At Länsstyrelsens's homepage it can be read that there is a risk that a good ecological status will not be reached by year 2021 in Hyltenäsån. Today the ecological status in the stream is classified as moderate. Due to the conditions in the stream the deadline to reach good ecological status has been postponed until year 2021 since it has been assessed to being technically impossible to reach the goal by 2015. The reason to why that good ecological status not will be achieved is the changes in continuity in the stream. The species in the stream are hindered by barriers and migration species are also hindered by barriers downstream. The hydrological regime is also affected due to the water regulation in the dam (VISS Vatteninformationsystem Sverige, 2013c).

4.2.4 Häggån

Häggån is mainly a slow floating stream even though parts with more streaming water can be found. An estimation of freshwater pearl mussel population in Häggån was done in year 2003 and was assessed to consist of 10-100 individuals. No juvenile freshwater pearl mussels were found in the stream. Because of the existence of the freshwater pearl mussels, is the river considered to have a protection value. In the same report was also the result from an earlier inventory, from 1990 presented. The investigations done then estimated that population consisted of between 100-1000 individuals. It seems however like the population of freshwater pearl mussels in Lillån also are included in this inventory (Andersson, 2006). A more recent investigation on the occurrence of freshwater pearl mussel was done in 2013. In the investigation they looked for individuals of the freshwater pearl mussel in a test local located 400 m upstream where the watercourse gets divided into several branches. No individuals of the freshwater pearl mussel were found in this area, despite that approximately 3000 m^2 of what can be considered as good biotopes for the freshwater pearl mussel was searched. In total only three individuals of the freshwater pearl mussel were found in Häggån. The three individuals were found in a place close to Häggårda hydropower plant and thus not in the test local in Tattarströmmarna (Länsstyrelsen Västra Götalands län, 2014). Tattarströmmarna is a part of Häggån and can be found downstream the hydropower plant Häggårda. It is an approximately one-kilometre long distance of Häggån and is a Natura 2000 area (Naturvårdsverket, 2012). Tattarströmmarna is described by Naturvårdsverket as a watercourse that split into several channels that are surrounded by deciduous woodland and is regularly flooded. Tattarströmmarna is an unusual habitat and a home to threatened species such as the freshwater pearl mussel (Naturvårdsverket, 2013). Occasional freshwater pearl mussels can also be found in other parts of Häggån (Nilsson and Rådén, 2012). From the result of the investigation, the authors conclude that there is a risk that only single individuals are left in Häggån (Länsstyrelsen Västra Götalands län, 2014). The populations of trout have been estimated by performing electrofishing. The occurrence of trout in Häggån is assessed to be moderate and the fish is assessed to be negatively affected by the regulation of the hydropower plant in the stream (Andersson, 2006).

According to the report from Borås Kommun (2003) is there without doubt that the regulation of Häggån has had an adverse impact on the size of the trout population. The areas close to the hydropower plants and the dams, that before had the potential to be spawn- and growth areas have now disappeared. To improve the environment for the organisms in the stream the regulations should be adapted after conditions that are most suitable for the stream. Unnatural large fluctuations should be avoided and instead be adapted after the fluctuations in the prevailing water conditions (Borås Kommun, 2003).

In the conservation plan for the Natura 2000 area in Häggån there are two types of habitats/ species that must be retained in this area, the freshwater pearl mussel and the alluvial deciduous forests that occasionally are flooded. Both the freshwater pearl mussel and the alluvial deciduous forests are probably affected negatively by the regulation from the hydropower plant in Häggån. The regulation has probably decreased the area that is regularly flooded, resulting in that there is an increased risk for spreading of spruce in the area. For the freshwater pearl mussel means the regulation both indirect and direct adverse impacts. The freshwater pearl mussel is in the larval stage dependent on the trout stock for their survival since they live up to ten months as a parasite in the trout's gills. When the trout stock is affected by the regulation from the hydropower plant and the stock decreases it means that the possibilities for the glochidia to find a suitable trout gill to live in decreases and so are the possibilities for the freshwater pearl mussel to survive. It is also especially young individuals of trout that is suitable for the glochidia so a decreased reproduction of trout can also have adverse effects on freshwater pearl mussel population. The freshwater pearl mussel can also be affected directly by the regulation. Low water flows that may occur as a result of the regulation in Häggårda can directly damage the freshwater pearl mussel population (Länsstyrelsen Västra Götalands län, 2005a).

In June 2012 there was an examination performed in Tattarströmmarna as a follow up of the effects in the stream due to a disruption in March the same year. During the disruption it was for almost 24 hours no water flow from Frisjön. The stream was however, not totally empty on water since water comes from the tributary Sävbäcken. The follow up consisted of an examination of the benthic and the freshwater pearl mussel and electro fishing. The examination of the benthic showed that Tattarströmmarna has a valuable benthic and weak stock of trout and freshwater pearl mussel. The trout population was assessed to be adversely affected by the regulation in the stream but it was not possible to determine if it was due to the earlier mentioned disruption or the usual regulation in the stream since no earlier examinations have been done of the area (Nilsson and Rådén, 2012).

The marsh gentian (*Gentiana pneumonanthe*) grows in the riparian zone to lakes and rivers, on wet meadows and on moisture moors. It can be found in the Swedish red list and is classified as vulnerable. According to Kinnarumma Naturskyddsförening the marsh gentian can be found in three places within Borås municipality, and Frisjön is one of the places. To protect the marsh gentian Kinnarumma Naturskyddsförening has asked Borås Energi och Miljö to regulate the water levels in Frisjön so that the levels is kept on normal or low levels in July and only later let the levels rise in Frisjön so that the marsh gentian is protected (Kinnarumma Naturskyddsförening, 2013).

For Frisjön there also exists a wish to regulate the water levels so it will not affect the black-throated loon (*Gavia Arctica*) during the birds brooding, or the pike when it spawns (Borås Energi och Miljö, 2013b).

4.2.4.1 Potential to Reach Good Ecological Status

The last classification judges the ecological status in Häggån as moderate. Since Häggån is assessed to not have the possibility to reach a good ecological status by 2015 the time frame to reach good ecological status has been prolonged until 2021. However, even with the prolonged time frame, there is a risk that a good ecological status will not be reached by year 2021. The connectivity is judged as poor. There are migration barriers that ate definitive. The species in the stream cannot migrate in natural ways and there are barriers that stop the salmon and trout from reaching spawn areas in the water body of Häggån. The littoral zone is also affected and there is today a lack of natural environments for animals and plants. The hydrological regime is considered as good. Except for the hydropower plant in Häggårda there is also a plant downstream in Häggån that works as a barrier for the species that wants to migrate in the stream. The hydropower plant Kungsfors situated in Viskan is also a barrier for the species downstream in Viskan that wishes to reach upstream in Häggån. The water body is also regulated in a way so that the ecosystem is expected to be affected negatively (VISS Vatteninformationsystem Sverige, 2013b).

4.2.5 Ätran

According to Calles et al. (2012) Ätran has a history of being a productive stream and large populations of e.g. salmon and eel have lived in the stream. Ätran is classified as nationally particularly valuable. Today you can find valuable species such as sea trout (*Salmo trutta trutta*), river lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*), freshwater pearl mussel, eel and duck mussel (*Anodonta anatina*), swollen river mussel (*Unio tumidus*) and painter's mussel (*Unio pictorum*) (Calles and Bergdahl, 2009; Calles et al., 2012). These species together with the wild salmon stock that lives in Ätran is the reason behind why it is classified as particularly valuable. The benthic has high natural values and is also the only place in Scandinavia where the caddisfly, *Setodes punctatus* can be found (Calles et al., 2012). There exist eight hydropower plants in Ätran, from its start in a bog east of Ulricehamn to the outflow in Kattegat (Dahlin-Ros, 2008; Calles and Bergdahl, 2009). Due to the hydropower plants Ätran is considered as heavily fragmented (Calles and Bergdahl, 2009). In a study done by Calles et al. (2012) they have looked at the eels' migration in Ätran. The result shows that Ätran still produces a high number of silver eels each year and that the production of eel in Ätran has been underestimated. The authors focused however on the parts of Ätran downstream Axelfors and do not say that much of the situation in Axelfors (Calles et al., 2012).

The parts of Ätran between the hydropower plants Skåpanäs and Ätrafors is according to Vattenmyndigheten Västerhavet (2010) heavily modified in terms of hydrology, morphology and lack of continuity in the stream. This is mostly due to the hydropower plants in that part of Ätran. Axelfors is situated upstream of Skåpanäs together with Ljungafors hydropower plant. This part of Ätran is assessed to not be substantially physically affected despite the existence of the hydropower plants in this part of the stream and the regulation in Forsa at the outlet of Åsunden (Vattenmyndigheten Västerhavet, 2010).

4.2.5.1 Potential to Reach Good Ecological Status

The part of Ätran, which Axelfors hydropower plant is located in was in year 2013 classified as having moderate ecological status. As for the other streams the time frame for reaching good ecological status have been prolonged from 2015 to 2021 but there is still a risk that the goals will not be reached by 2021. The connectivity is judged as poor due to the migration barriers existing in the stream, the species in the stream are hindered to migrate in a natural way (VISS Vatteninformationsystem Sverige, 2013a).

4.3 Comparison and Compilation

As mentioned the knowledge differs about the hydropower plant and the ecosystem around them due to that the studies performed on the areas differs in type and number. To get an easy and short overview about the existing knowledge about the ecosystem where the hydropower plants are situated, a table is included with a short compilation of the information, see next page. Hyltenäsån and the dam in Hyltenäsån is not included in the table since most of the focus has been to find information about the streams that the hydropower plants are located in.

	Haby	**Hulta**	**Häggårda**	**Axelfors**
Stream	Slottsån, tributary to Viskan	Slottsån, tributary to Viskan	Häggårda, tributary to Viskan	Ätran
Nationally valuable water	Öresjön and Tolken are nationally valuable from a fishing point of view and regionally valuable from a natural value perspective		Tattarströmmarna, which is part the stream Häggån is a Natura 2000 area	Classified as particularly nationally valuable
Potential to reach good ecological status	Has a moderate status today with a risk of not reaching good ecological status by 2021		Has a moderate status today with a risk of not reaching good ecological status by 2021	Has a moderate status today with a risk of not reaching good ecological status by 2021
Knowledge about the regulation's effects	Known effects on the benthos		Known effects on the trout population	Said to not be substantially affected by the regulation
Known existing species in the stream *(The species mentioned are in no way trying to include all the species in the stream, but are species mentioned in the literature about the stream.)*	Eel, trout, freshwater pearl mussel, caddisfly, shell		Trout, freshwater pearl mussel	Trout, river lamprey, sea lamprey, freshwater pearl mussel, eel, caddis, salmon duck mussel, swollen river mussel and painter mussel (The species are however species that can be found in the whole stream and not specifically close to Axelfors.)
Other information	Electro fishing has shown a decrease in the trout population. It was before possible to find crayfish in the stream		Close to the Frisjön the marsh gentian can be found. There exist also wishes to regulate Frisjön during periods so not the pike or the black-throated loan are affected. Surrounding Tattarströmmarna is the alluvial deciduous forests that occasionally are flooded that should be retained Examinations have showed a that the stocks of the trout and freshwater pearl mussel are weak.	The benthos has high values.

Chapter 5

Analysis

In the analysis the information from the literature study is connected with the knowledge about the hydropower plants and the environment at the sites. This is done in order to estimate the impacts from the hydropower plants and which effects the impacts have on the environment surrounding the hydropower plants.

5.1 Hydrological Regime

The hydrology and the impacts from the water regulation differ between the four different hydropower plants. As mentioned in the literature review about the hydrological regime the natural flow is made up of several different factors, factors that will be changed when there is regulation in the stream. Things as the frequency and timing of different flows will be changed as well as the rate of change, changes that will affect the entire system. The following chapter will use the background from the literature together with the compiled information about the hydrological regime at the different hydropower plants to get an estimation about how large the effects are from the regulation of the water flow through the hydropower plants. Graphs for the four different hydropower plants are included in the following paragraphs. The graphs show the production of electricity on e.g. yearly or daily basis. They are used to get an overview of how the regulation is operated in the hydropower plants. What the figures shows are further discussed later in the text, see section 5.1.4, Compilation of hydrological review.

5.1.1 Haby & Hulta

Haby and Hulta use the same water for their electricity production. Two lakes are used for the water storage, Öresjön and Tolken. For Öresjön, the upper limit is approved by the Water Rights Court to be 134.3 meter local level (m.l.l.) and the lower limit is approved to be 131.5 m.l.l. That gives an allowed range of 2.8 m. According to the classification for the regulation amplitude this corresponds to class 3. The whole regulation amplitude is seldom utilized. In the case of Öresjön the utilized regulation lies more in the range of 1-1.5 m. The smaller range means however not a change in the classification but still lies in class 3. For Tolken the upper limit is 137.3 m and the lower limit 134.8 m. The water level can thus be regulated 2.1 m. Also the regulation for Tolken follows the same pattern as for Öresjön, and is not utilizing the whole range but lies in the same range as the used range for Öresjön 1-1.5 m. So also the regulation amplitude for Tolken can be placed in class 3 and could be considered to have a moderate impact on the water level.

When including the storage capacity for both Tolken and Öresjön, the total storage capacity for Haby and Hulta is 60 million m^3. The annual average water flow in Slottsån is 220 752 000 m^3.

$$Annual\ average\ water\ flow = 7\,m^3/s * 3600\,s/h * 8760\,h/year = 220\,752\,000\,m^3/year$$

$$Regulation\ degree = (60 * (10)^6\,m^3)/(220\,752\,000\,m^3) = 0.27 \rightarrow 27\,\%$$

The regulation degree is calculated to be 27%, which means that it is classified as unsatisfactory.

The graphs below show the regulation of the water through the hydropower plant for four months, se figure 5.1, 5.2, 5.3 and 5.4. The figures give an indication on how the regulation at the plants is managed. The first four figures show the regulation during four different months. The last figure, figure 5.5, shows how the electricity production varies over the year.

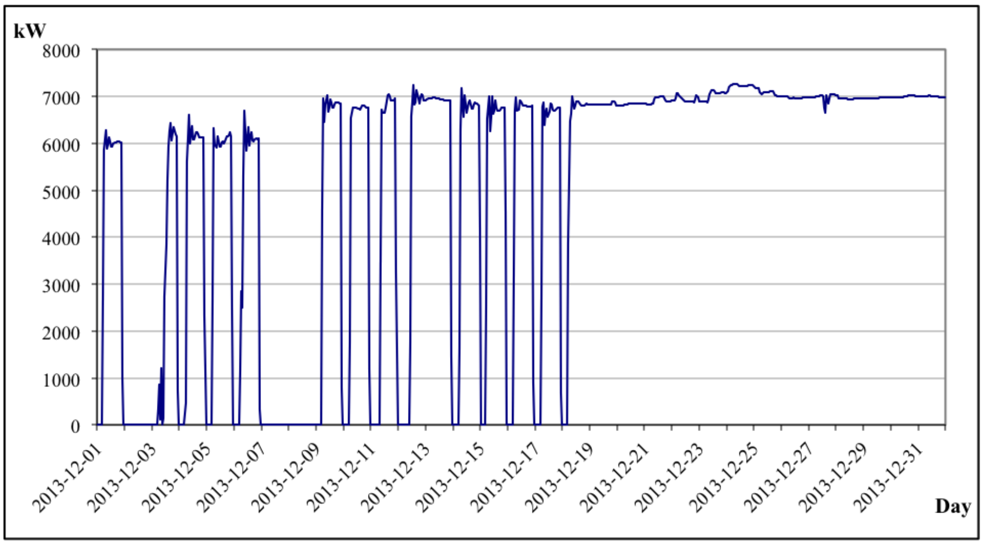

Figure 5.1: Electricity production in Haby and Hulta, December 2013 (Borås Energi och Miljö, n.d. g).

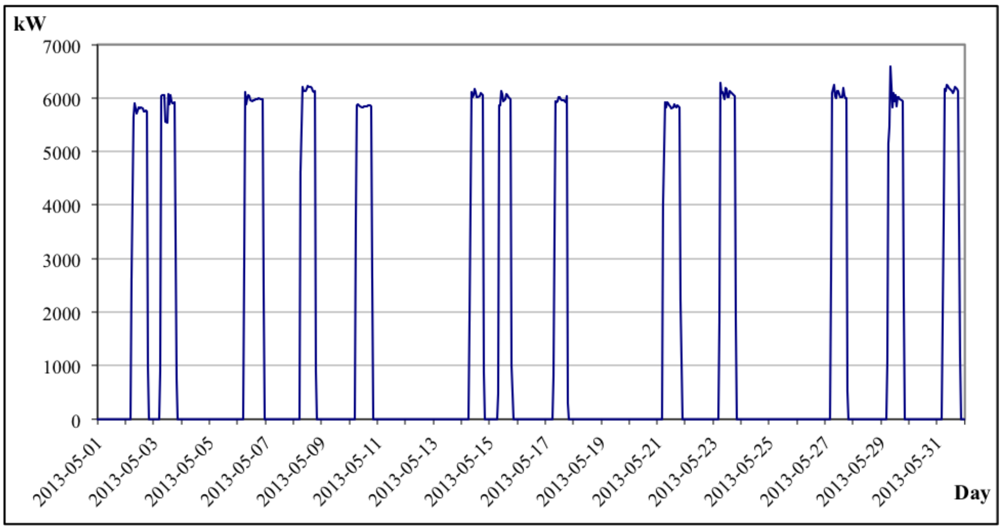

Figure 5.2: Electricity production in Haby and Hulta, May 2013 (Borås Energi och Miljö, n.d. g)

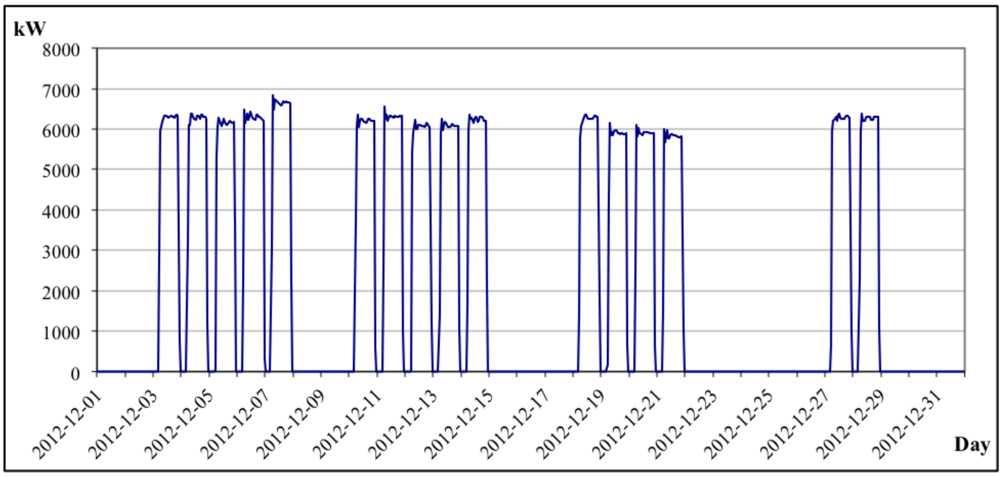

Figure 5.3: Electricity production in Haby and Hulta, December 2012 (Borås Energi och Miljö, n.d. g).

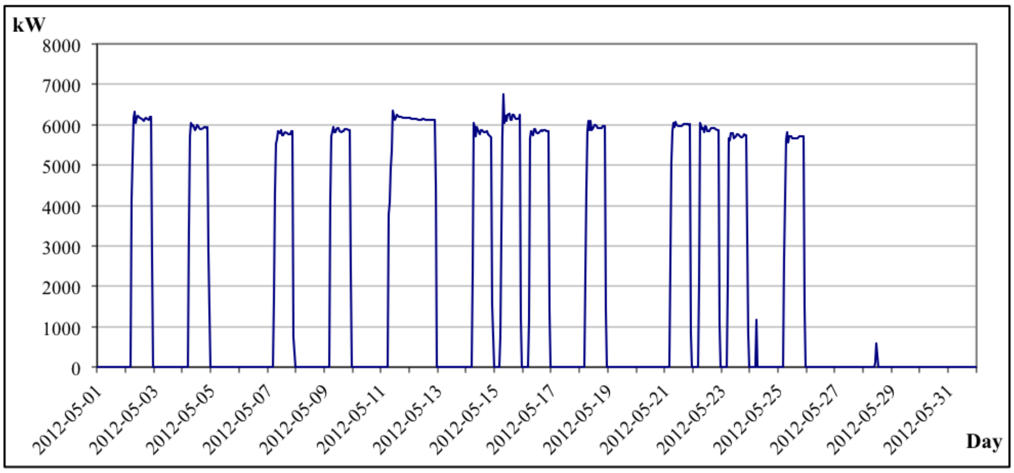

Figure 5.4: Electricity production in Haby and Hulta, May 2012 (Borås Energi och Miljö, n.d. g).

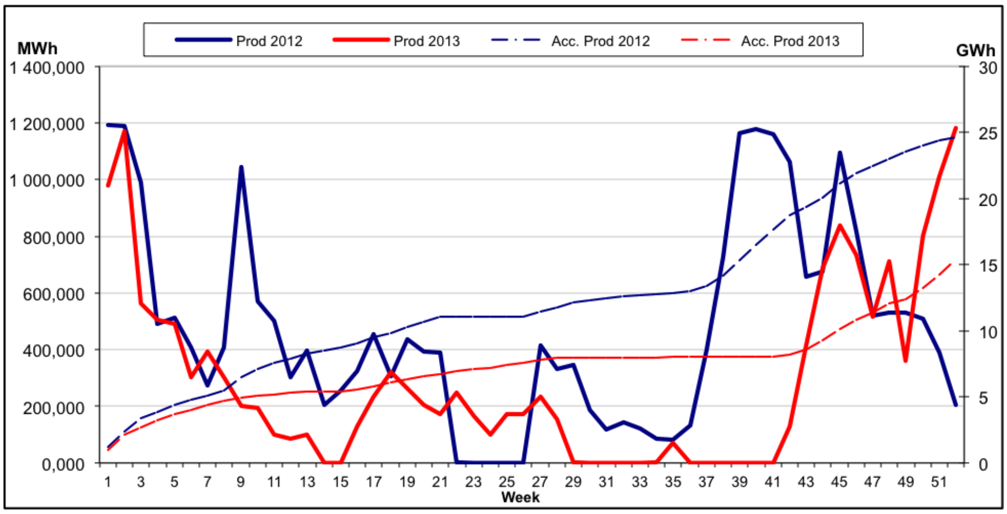

Figure 5.5: Electricity production in Haby and Hulta 2012 & 2013 (Borås Energi och Miljö, n.d. g).

5.1.2 Häggårda

The upper limit for the water regulation for Frisjön approved by the Water Rights Court is 51.8 m.l.l. and the corresponding lower limit is 49.9 m.l.l.. This gives a possibility to regulate the water level in Frisjön 1.9 m. If comparing this range with the classification found in Naturvårdsverket's statute for the regulation amplitude, the regulation range in Frisjön ends up in class 3 (1-2.99 m), which means that the regulation have a moderate impact on the water level (Naturvårdsverket, 2008). When looking at the weekly differences in the water level at Frisjön for the last twelve years it is possible to see that Borås Energi och Miljö usually not are using the whole range that they according to the Water rights Court have the right to use, which also can be seen in the figure 4.8 in the section 4.1.4. However, even if taking into consideration that they not usually are using the whole range they will end up in the same class.

The regulation degree can be used to estimate how large the negative effects in the stream are due to the regulation. In Frisjön Borås Energi och Miljö has the possibility to store 12 million m^3 of water. Häggån have an annual average water flow of 81 993 600 m^3.

$$Annual\ average\ water\ flow = 2.6m^3/s * 3600s/h * 8760h/year = 81993600m^3/year$$

$$Regulation\ degree = (12*(10)^6m^3)/(81993600m^3) = 0.146 \rightarrow 14.6\%$$

If the whole storage capacity is used, the result classifies the regulation degree in Häggån as moderate.

As for Haby and Hulta there are graphs showing the regulation for some months and how the production of electricity varies over the year, see figure 5.6, 5.7, 5.8 and 5.9. The first four figures show the regulation during four different months. The last figure, figure 5.10 shows how the electricity production varies over the year. It should be remembered however that for Häggårda the diagrams do not fully comply with the water flow that is let through since water at some times is let through the spillways. When the water through the turbines is less than the required minimum flow, it is compensated with an opening of the spillways so that required flow can be maintained.

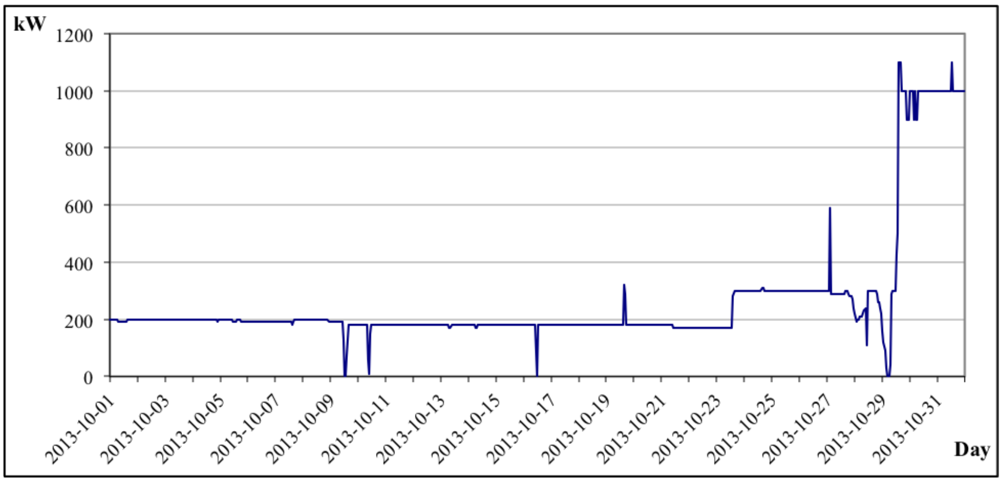

Figure 5.6: Electricity production in Häggårda, October 2013 (Borås Energi och Miljö, n.d. g).

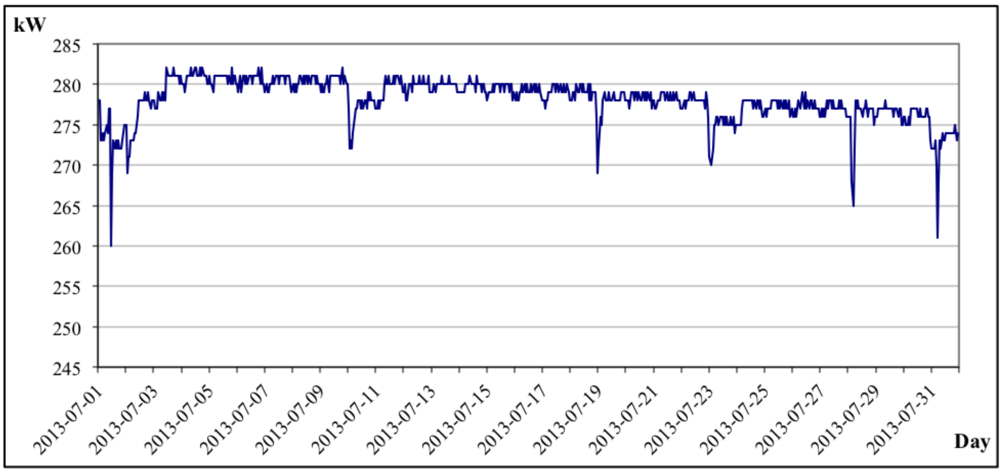

Figure 5.7: Electricity production in Häggårda, July 2013 (Borås Energi och Miljö, n.d. g).

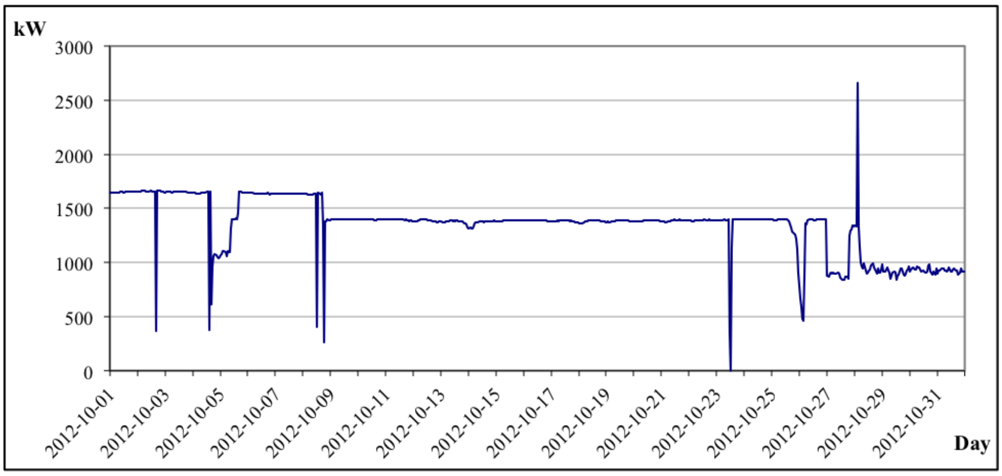

Figure 5.8: Electricity production in Häggårda, October 2012 (Borås Energi och Miljö, n.d. g).

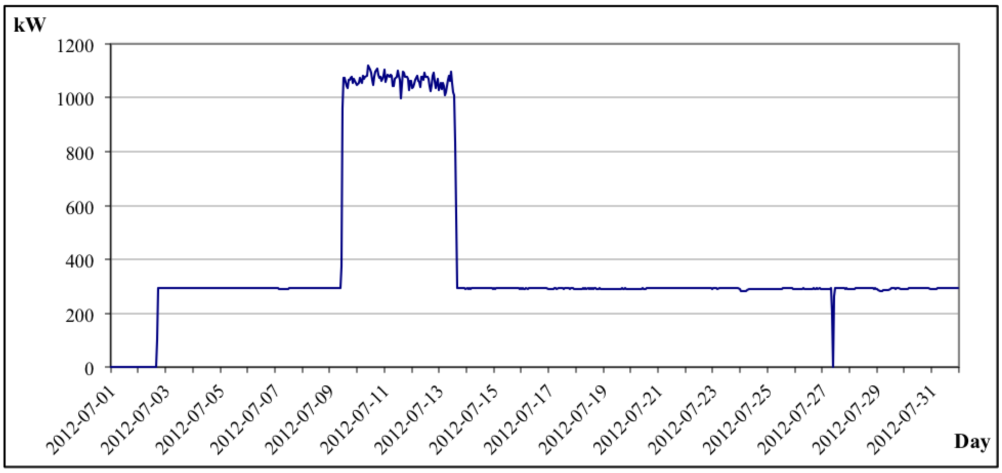

Figure 5.9: Electricity production in Häggårda, July 2012 (Borås Energi och Miljö, n.d. g).

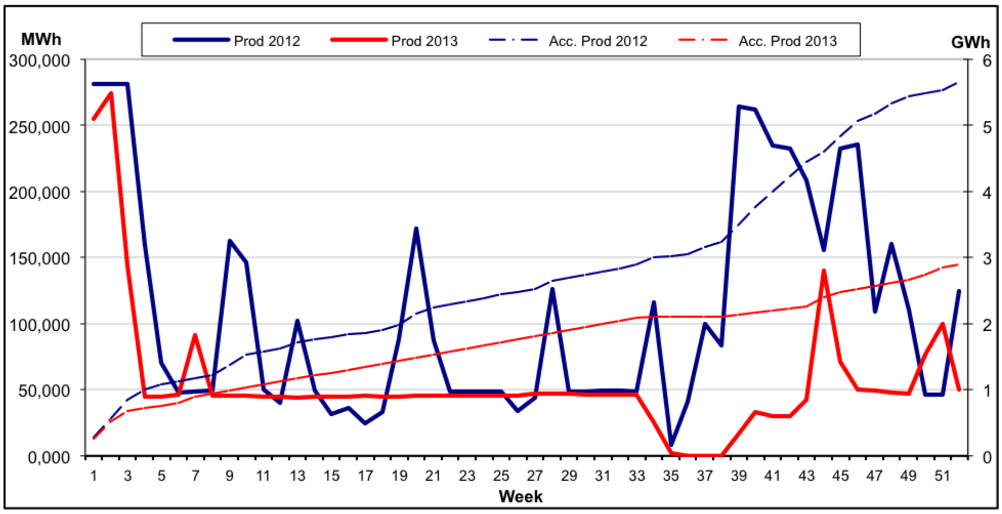

Figure 5.10: Electricity production in Häggårda 2012 & 2013 (Borås Energi och Miljö, n.d. g).

5.1.3 Axelfors

Axelfors is operated as a run of river plant. That means that Borås Energi och Miljö are utilizing the stream as it flows to produce electricity and that no regulation exists. Thus the regulation amplitude is zero or close to zero. In the classification for the regulation amplitude this corresponds to class 1 and the status is high. Since Axelfors has no storage capacity, no calculations about the regulation degree are needed as it is for Haby, Hulta and Häggårda. The regulation degree is classified as high. In the figures, 5.11, 5.12, 5.13 and 5.14 the regulation of the water through the hydropower plant for four months can be seen. The last graph, see figure 5.15, shows how the electricity production varies over the year.

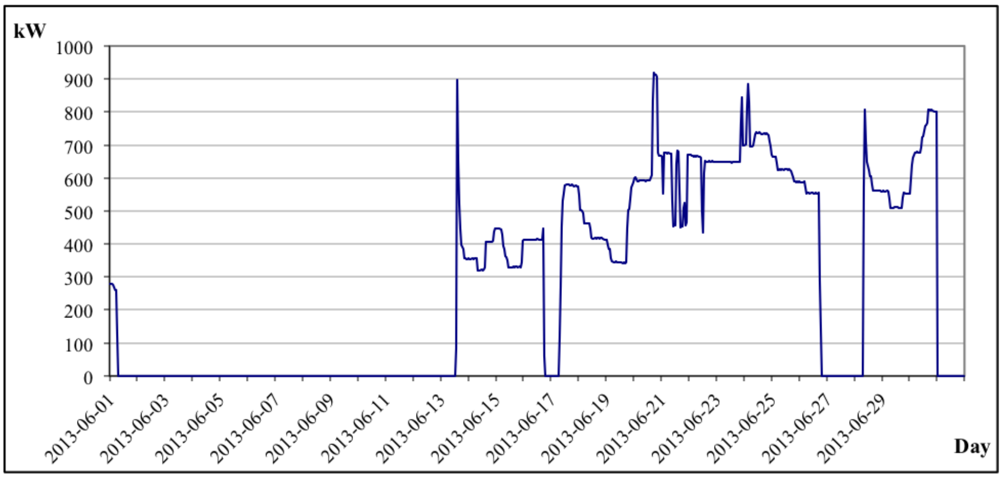

Figure 5.11: Electricity production in Axelfors, June 2013 (Borås Energi och Miljö, n.d. g).

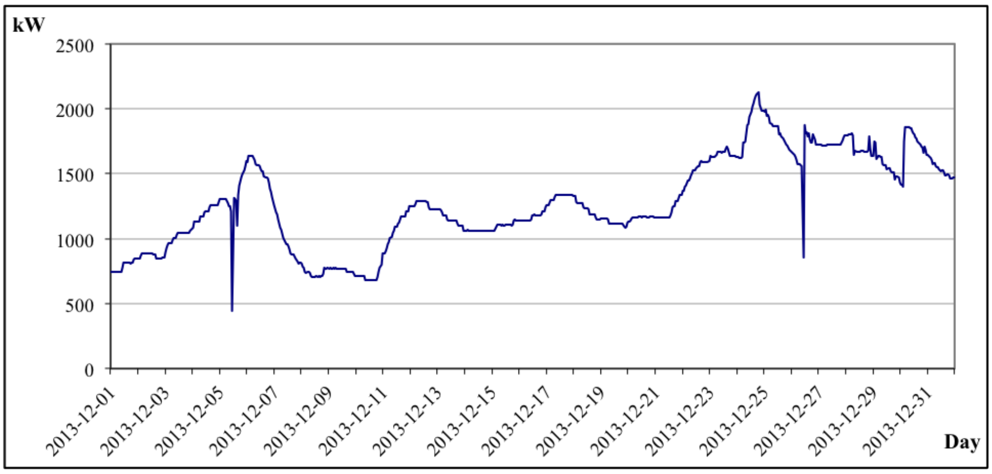

Figure 5.12: Electricity production in Axelfors, December 2013 (Borås Energi och Miljö, n.d. g).

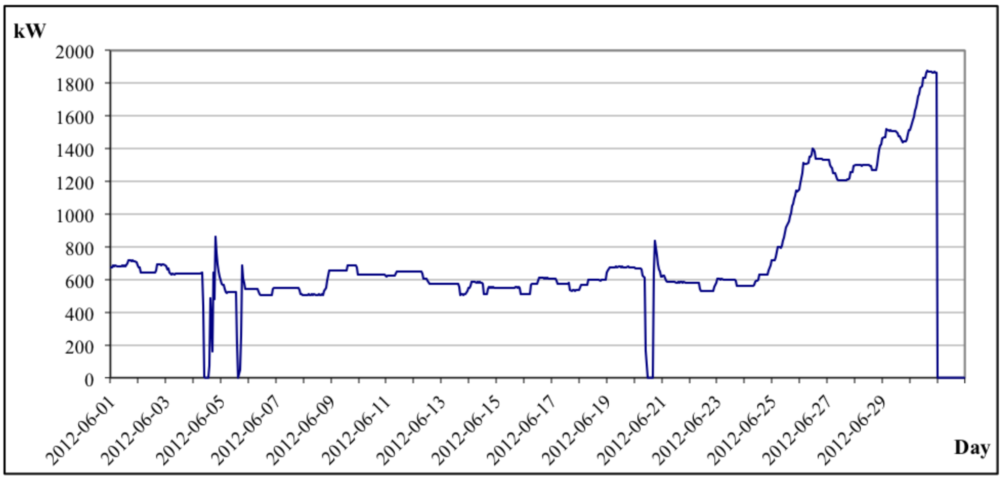

Figure 5.13: Electricity production in Axelfors, June 2012 (Borås Energi och Miljö, n.d. g).

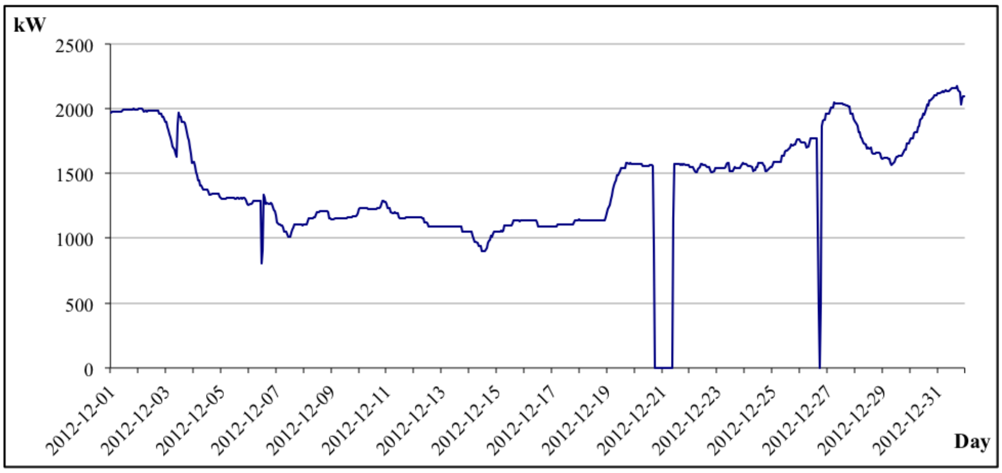

Figure 5.14: Electricity production in Axelfors, December 2012 (Borås Energi och Miljö, n.d. g).

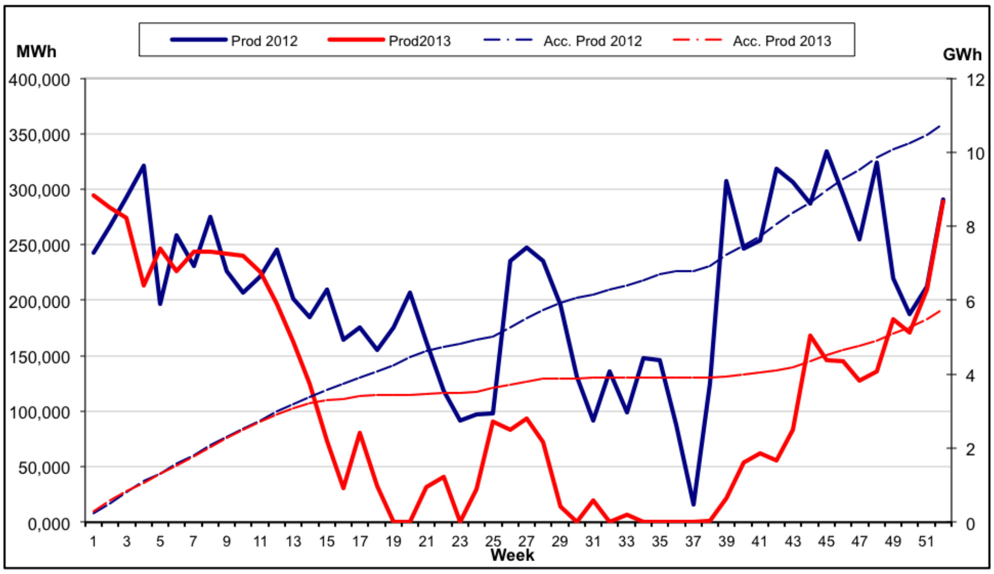

Figure 5.15: Electricity production in Axelfors 2012 & 2013 (Borås Energi och Miljö, n.d. g).

5.1.4 Compilation of Hydrological Review

Some conditions are equal or similar for all the four different hydropower plants. The hydrological regime is an important part of the ecosystem and alterations in the regime will thus have large effects on the surrounding environment. Since Axelfors is operated as run of river hydropower plant the alterations in the hydrological regime are somewhat smaller there than for the other three plants. The reason to that is that there are no regulations of the water but that the water is let through the turbine as it flows. There are thus no larger changes in frequency, timing and rate of change of the water compared to the natural situation.

In all the cases a dry part of the stream has been created as a result of the diversion of the water into the tubes. In Hulta there is no tube but there is still creation of a dry river bed. The dry river bed means that a non-aquatic environment has been created and that the ecosystem has been altered. A reduced flow or no flow at all will have effects on both the riparian species and the species in the stream. According to Borås Energi och Miljö it is seldom water in the dry riverbeds. The almost constant lack of water plants indicates that the once existing aquatic life is completely or partially destroyed. Visits at Axelfors, where the dry riverbed is located close and it is possible to see the dry riverbed in its full length, proves that it is not possible for e.g. fishes to live in the original riverbed anymore. Visits at the dry riverbed in Haby showed that, as Ericsson et al. (2012) states, that there is some water in the dry riverbed. The water can probably be derived from leakage in the adjacent channel. The water in the dry riverbed is however of such a small amount that it is not possible for any fishes to live there.

According to studies performed on Häggån, the stream is affected by the regulations. Spawn areas have been destroyed and the trout is one species that have been assessed to be affected negatively by the regulation.

Another important factor connected to the impacts on the environment and the hydrological regime is how the regulation is operated. Fast and short changes in the water flow, so called short-term regulation, will have adverse effects on the ecosystem, which also can be read in the literature review about the hydrological regime, se chapter 3.1.2. The regulations of the water level at Tolken, Frisjön and Öresjön are decided on a weekly basis. If no unforeseen events happen during the week, e.g. sudden increases in the water level in the lakes due to heavy rainfalls, no changes are done in the planned week regulation (A Rieck 2014, pers. comm., 24 February)[1] How the regulation of the water in the stream is operated can be seen by looking at the diagrams showing the production for the different months. It can be seen that it is Haby and Hulta that has the most significant short-term regulation. The plants in Haby and Hulta are often operated so that no electricity is produced during the night and then started up in the morning to produce electricity. This means that there are often times with no water coming at all through the hydropower plants and since there are no requirements on a minimum flow it means that no water at all is let through downstream. The short-term regulation can underlie adverse impacts at the ecosystem downstream and as can be read in the literature review there can be damages e.g. on the fish and the benthos living downstream. For the two other plants, Axelfors and Häggårda it is not possible to see the same short-term regulation as in Haby and Hulta. Axelfors has no regulation at all, the variations in the production is a result of the variations in the water flow. There are however times when there is no production, which also can be seen in e.g. the production for June 2013. However, at these times, the water is released through spillways. The reason behind the stops could e.g. be low water flows or revisions of the hydropower plants.

Another change following the commissioning of the hydropower plants are the damming of the river for the creation of a storage reservoir. Since Axelfors is a run of river hydropower plants no storage reservoir is created. For the three other plants, natural lakes are used for the storage of water. This means that no artificial reservoirs were created following the construction of the hydropower plants but that the natural existing lakes are used as reservoirs. Due to the lack of information about the state of the water levels in the lakes before the regulation it is hard to get an understanding for the size of the changes. It is however possible to assume that the changes were smaller than if a part of the stream would have been used for the creation of a storage reservoir. With a smaller part of land inundated it is also probable that there were fewer damages on e.g. the riparian zone.

It is possible to draw conclusions that due to the changes in the hydrological regime the flora

[1] Anna Rieck, Process Engineer Borås Energi och Miljö, conversation 24 February 2014

and fauna, both in the water and land living, are affected by regulation in the water stream and in the lakes. The hydrological regime and the alteration of the hydrological regime play an important role for the functions in the ecosystem, which also could be understood from the literature review where the hydrological regime and the changes in it is said to have an significant impact. The problem is to quantify the effects. Looking at the classifications has all the plants except Axelfors a moderate status for the regulation amplitude. For the regulation degree is Haby and Hulta classified as unsatisfactory and Häggårda as moderate. This does not say anything about the magnitude of the impacts on the ecosystem but only where on the scale the regulation of the plants is. Even if it does not say anything about the magnitude so gives it indications on that there are impacts. It is mentioned earlier in the text about the wishes to keep the water levels in Frisjön so it will not harm the pike, the black-throated loon and the marsh gentian. If that not is done, it is simple but obvious examples of impacts related to the regulation of the lake.

5.2 Sedimentation

In the literature review about sedimentation it is stated that the rate of sedimentation is due to several different factors. It can also be read that in the case of small hydropower plants with the water coming from a closely located lake, a calm body with water is provided. Generally with this type of hydropower plants the rate of sedimentation is low. Haby, Hulta and Häggårda are all small hydropower plants with the water coming from a closely located lake, which therefore could indicate on a low sedimentation rate. Also for Axelfors the conditions are indicating that the problem with sedimentation is small. When talking to Borås Energi och Miljö they state that they do not have any known problems with sedimentation. This together with the above mentioned reasons it is probable that the problems with sedimentation is not significant for the four hydropower plants.

5.3 Water Quality

The existing knowledge about the water quality in Häggån, Slottsån and Ätran is very limited which makes it hard to say anything about the water quality and if it depends on the hydropower plants or if it is derived from other disturbances. Literature findings indicate a strong site dependency for hydropower impacts on water quality. This makes it therefore hard to conclude anything about e.g. increased sensitivity due to reduced flow, turbidity and gas supersaturation in the stream. What can be said about the temperature is that the kind of changes in temperature related to the creation of reservoirs are not relevant here since Haby, Hulta and Häggårda are using naturally existing lakes as storage reservoirs. Axelfors has no storage of water at all and that kind of temperature changes are not relevant here either.

From the operation of a hydropower plants there are generally no direct emissions that are harmful but the hydropower plants can in other ways affect the water quality. The exception is the release of oil in the water and if different substances are used for the e.g. anti-fouling. In 2002 there was a release of oil in Haby due to a valve that was not sealed. There is no exact numbers on the amount of oil that reached the water but 75 litres was pumped out and not all of stayed in the sump or was wiped up but reached the water, exact quantities are not known. This caused an oil film on the water downstream the plant. The emergency services was called and placed out an oil boom and a company was hired for the oil decontamination (Borås Energi och Miljö, 2002). This shows that there exists a risk for oil spills that can have an adverse impact on the ecosystem.

As mentioned in the text about the hydropower plants there was a change of the hydraulic equipment in Haby, in 2003. When the hydraulic equipment was changed, a large amount of oil needed in the powerpack was reduced. This means that the amount of oil that will be in the power plant is significantly reduced. This means that if something goes wrong and the oil in the powerpack starts to leak, there is less oil that can reach and harm the surrounding environment.

From the inundation of land there can be a release of mercury that has been accumulated in the soil. Some of the mercury that can be find in the environment today in Sweden is result from use of alkyl mercury in the agriculture and the use of phenyl mercury in the pulp and paper industry (Kihlström, 2006). This started in the 1940's, which means that at the time for the commissioning of the four hydropower plants, there was no mercury accumulated in the soil that could be released. Since no measurements have been performed it is not known if this happened at the site here but since natural existing lakes has been used and the area of land inundated probably is limited, a possible estimation that the risk for a release of mercury is smaller than if large land areas had been inundated.

In the literature review different causes to eutrophication are mentioned. One possible cause is that the regulation leads to an increased level of nutrients in the water from the flooded biomass. Since natural existing lakes have been used and more than 20 years have passed, which is the approximate time limit for it to get stable, it is possible to assume that it is probably not a large problem here. It is also mentioned that in most cases the eutrophication is due to other anthropogenic causes and not due to the existence of hydropower plants.

Hydropower plants do not necessary need to have an adverse effect on the water quality but can actually improve the water quality. Run of river plants do not have many of the adverse effects on the water quality written about in the literature review. As known is Axelfors operated as a run of river plant and therefore can many of the impacts such as temperature, decreased food production, siltation, increased nitrogen and phosphorus levels and low oxygen levels be excluded in this case. For small hydropower plants, a category which all the four hydropower plants can be included in, the use of trash rack-cleaning machines hinders things such as plastic and bottles to be spread in the water system. This may not be a big problem in the streams in this case but it is one of the good effects on the water quality that hydropower plants can result in. For gas supersaturating it is also mentioned that in the case of small hydropower plants, the gas pressure often is decreased instead of increased, which means that gas supersaturation probably not is a problem here.

5.4 Migration Barriers

The problem with the hydropower plants and that it often constitutes a definite barrier for the species in the stream that migrates has briefly been discussed in the chapter about the impacts on the biodiversity. In this chapter the possible problems with the fish barriers in Axelfors Haby, Hulta and Häggårda will be more thoroughly discussed.

The fact that hydropower plants often stops the fishes and the other species in the stream from migrating is seen as one of the biggest problems with hydropower plants. As mentioned in the literature review some of the fish species are dependent of different environmental conditions during the different parts of the life cycle.

None of the hydropower plants owned by Borås Energi och Miljö has any fishways, nor are there any eel passages despite that it for Haby, Hulta and Häggårda are requirements on that mentioned in the water rights permit. The lack of connectivity constitutes a problem for all of the streams. The barriers that the hydropower plants form, is mentioned in the information from Vatteninformationssystem Sverige, as one of the main problems to reach good ecological status by 2021. The fishes are recognized as the main animal group affected by the existence of barriers in the stream but also other organisms living in the stream are affected. As can be read in the literature review about fish barriers examples of anadromous fishes are salmon and trout and an example of a catadromous fish is eel, examples of fishes that all can be found or has been found in the concerning streams. The hydropower plants in Haby and Hulta hinders today the trout from reaching 56 865 m^2 spawn area above Haby. It is therefore possible to draw the conclusion that the two hydropower plants together with the dam in Hyltenäsån hinders the salmon and trout from reaching Öresjön and Tolken and the trout form reaching its spawn area. Even for the eel, Hulta and Haby constitute a barrier and it is for example not unusual to see deed eel caught in the intake screen to Hulta (K-Å Mattson 2014, pers. comm., 3 March)[2]. Also for Axelfors and Häggårda the hydropower plants constitutes a barrier for the fishes.

[2]Kjell-Åke Mattson, Project Manager Borås Energi och Miljö, conversation 2 March 2014

A number of factors influence the risk for injuries when fish pass a hydropower plant. For fishes migrating upstream the journey ends when arriving to a hydropower plant if no fish passage exists. For the fishes migrating downstream it can be possible for the fish to pass. If the intake screen allows the fishes to pass the way through the turbine can cause death or damages due to e.g. pressure variation, cavitation, abrasion and turbulence, see chapter 3.1.5. The risk for damages due to pressure variation increases when the head is higher than 20 m. Häggårda and Hulta have both a head higher than 20 m, meaning that the risk for pressure variation there should be higher than in Axelfors and Hulta, which have lower heads. Due to its construction the Kaplan turbines are more fish friendly than Francis. This means that the fishes in Axelfors, which is the only one of the four plants that have a Kaplan turbine, has greater chance for the fish to survive the journey through the turbine or pass without injuries than the fishes in the other plants. The longer the fish is, the more exposed are they when passing the turbines. This means that especially the eel is exposed to the risks that come with the passage through the turbine. In the report by Leonardsson (2012) the risk for the eel to die is simulated for a number of hydropower plants including the four hydropower plants in this case. The result of the simulations is presented in table 5.1 below (Leonardsson, 2012).

Table 5.1: The losses of eel when passing the turbines at different flows (Leonardsson, 2012)

	At 50 % of the turbines maximum flow capacity	At 100 % of the turbines maximum flow capacity
Axelfors	67 %	79 %
Haby	46 %	90 %
Hulta	67 %	79 %
Häggårda	9 %	80 %

It should be remembered that these numbers only indicates how big the losses of eel are passing the turbines and not the total losses of eel passing the four hydropower plants since it could be possible for the eel to take other ways than through the turbines. In the literature review it is mentioned that adult eel has a chance of, in average, 30% to survive when passing a hydropower plant. This means that the chance of surviving is low for the eel when only passing one hydropower plant. In Slottsån, eels that are living upstream of Haby hydropower plant and want to migrate to the sea need to pass three hydropower plants and Värö Bruk which also is a migration barrier. If a chance of 30% for survival is estimated and 1000 eels will try to migrate to the sea, only 8 eels will reach the sea or in percent, only 0.8% will reach the sea.

$$1000\, eels * (0.3)^4 = 8\, eels$$

The eels living upstream of Häggårda need to pass one more hydropower plant than the eels living upstream of Haby. Of 1000 eels living upstream Häggårda trying to reach the sea, only

2 eels will reach the sea or 0.2 % of the eels will survive their migration to the sea.

$$1000\,eels * (0.3)^5 = 2\,eels$$

For the eel living upstream of Axelfors, the chance of reaching the sea is even smaller. The eel upstream Axelfors needs to pass seven hydropower plants. This results in that no eel, if there is as in this example 1000 eels trying to migrate, will reach the sea or that only 0.02 % of the eels living upstream of Axelfors will survive their migration to the sea.

$$1000\,eels * (0.3)^7 = 0.2\,eels$$

Even if other factors affect the eels' survival and the survival rate may differ between the different hydropower plants, give the calculations indications on how small the chances are for the eels to reach the sea when they need to pass several hydropower plants.

Borås Energi och Miljö are members of both Ålplan (eel plan) Ätran and Ålplan Viskan. The purpose with the eel plans is to plant out eel fry in the stream. The planting out of the eel fry works as a compensation for the missing eel passages. As mentioned in the text about the ecosystem, there are concerns on how well the eel plans works compared to if there had been well functioning eel fishways. It is therefore likely that the losses of eel are bigger than they would have been if there had been eel fishways at the hydropower plants instead. The authors in the report from Norconsult (2011) states even that the eel plan could have negative effects in the long term on the eel population due to insufficient knowledge about the eel collectors and the fact that the eels let out upstream have small chances of reaching the sea.

Some of the different causes behind injuries and death of the fishes are hard to prove, such as cavitation, abrasion, shear and turbulence, to the case for the four hydropower plants due to lack of information. However, these are common causes and there is nothing proving the opposite, thus it is possible to assume that the fishes are exposed to at least some of them. It is possible to conclude that all the four hydropower plants and the dam in Hyltenäsån are fish barriers and hinders the fish and other species to migrate in the stream. All of the streams where the hydropower plants are situated are classified, according to Länsstyrelsen, as having a moderate ecological status and with a risk of not reaching good ecological status by 2021. One of the reasons behind that is the existence of fish barriers in the streams. In the report by Wengström (2011) it is stated that the hydropower plants in Haby and Hulta works as definite migration barriers. With definite it means that the barrier most likely cannot be passed by fishes. For the dam in Hyltenäsån the migration barrier is partial, which means that the barrier at favorable conditions can be passed. The same information does not exist for Axelfors or Häggårda. However, by drawing parallels to the conditions in Haby and Hulta and combining that with the existing information, it is possible to do draw conclusions. For both Axelfors and Häggårda, there is a lack of fishways as for Haby and Hulta and the hydropower plants are constructed in similar ways. This means that both Häggårda and Axelfors constitutes at least partial migration barriers but probably are also they definite.

5.5 Greenhouse Gas Emissions

To get a correct estimation about the GHG emissions from the hydropower plants accurate and comprehensive studies would be needed. Numbers would have been needed about all the emissions from the whole life cycle, including construction, operation and maintenance etc. Measurements would also be needed on the differences in the GHG emissions from the land that may have been inundated following the commissioning of the hydropower plant. Even if those numbers not are available it is possible to use the knowledge from the studied literature to get an approximate estimation if the GHG emissions are of concern or not seen to the environmental impacts due to the use of the operation of the hydropower plants. The size of the emissions are highly site-specific and depends, as mentioned in the literature review, on factors such as climate, size of reservoir and the kind of vegetation flooded. It is therefore of importance to have an approximate idea about in which climate zone the hydropower plants are situated since the type of climate zone is one of the factors that can affect the size of the emissions. As can be read in chapter 4.1., can the climate where Haby, Hulta, Häggårda and Axelfors are situated, be seen as boreal climate and can be compared with the GHG emissions from hydropower plants located in boreal climate.

The size of the reservoir is an important factor when it comes to the estimation of the GHG emissions, one reason to that is that the size of the reservoir also determines the amount of land inundated. The biomass flooded will start to decay and produce GHG emissions. The numbers indicating on the largest emissions are from locations with tropical climates and these are thus not comparable with the size of the possible GHG emissions from plants located in other climates. With the exception of Axelfors that has no reservoir, natural existing lakes have been used as reservoirs. This means that it is possible to assume that very small areas were inundated at the time for the commissioning of the hydropower plants. One of the studies included in the literature review also points out that the quantity of the flooded biomass in boreal areas is rather small.

Some of the studies used in the literature review have also looked at the development of the inundated areas and the following GHG emissions. It seems like that the collective opinion was that the emissions will decline with the years and that reservoirs will after 10-15 years reach lake-like conditions and for boreal climates an even shorter time period is required. Another study estimates that after 50 years the emissions from the reservoirs will have reached zero net emissions.

The conditions at the locations for the three hydropower plants with the possibility to store water and the fact that natural existing lake have been used indicates that the possible GHG emissions was small already at the first years after the hydropower plants was built. Due to the age of the plants, which is considerably higher than 50 years, it can be assumed that the possible GHG emissions as declined and now reached zero net emissions. Looking back at the different stages of the life cycle that can produce GHG emissions, it is operation and maintenance that produces GHG emissions today. The overall conclusion is therefore that the operation of the four hydropower plants today produces very small amount of GHG emissions. From a life cycle perspective the GHG emissions probably lies in the range of 3-14 g CO_2/kWh. This is the size of the emissions that most of the studies performed on hydropower plants in similar conditions looked at in the literature study have shown. For Axelfors the numbers can be assumed to be a bit smaller than for the other plants due to its properties as a run of river plant. For most of the studies read in the literature review the expected life length, or the numbers of years they have allocated the emissions from the whole life cycle on, are 100 years. That makes the numbers suitable for a comparison with the conditions for the four hydropower plants in this case study since they are approaching or even have reached this life length. It could even indicate for an overestimating of the numbers since the plants can reach a life length that exceeds 100 years. The emissions today are connected to the emissions from the operation of the plant, e.g. renovations and maintenance.

Some of the LCA studies have also included NO_x and SO_2 emissions. The studies show that hydropower produces low emissions of these substances compared to many other energy sources. It should always be remembered, which also is emphasized in almost all the studies in the literature review, that the size of the emissions are highly site-specific. It is however, still possible to draw parallels to the situation in Axelfors, Haby, Hulta and Häggårda. There are some variations in the size of the emissions estimated for the NO_x and SO_2. None of the estimates indicates any high values and it is therefore possible to assume that the NO_x and SO_2 also for the four hydropower plants range in the lower part of scale. Thus the NO_x and SO_2 or the GHG emissions should not have a big environmental impact compared to many other energy sources. Also compared with other renewable energy sources such as wind power, the four hydropower plants should stand up well considering GHG, NO_x and SO_2 emissions.

5.6 Biodiversity

The changes in the environment that construction and operation of the hydropower plants results in will have effects on the environment. This section will use the compiled information from the literature review together with the known information about the ecosystem where the hydropower plants are situated, to get an estimation about the effects on the species living there due to the hydropower plants. In the literature review chapter it can be read that the impacts from hydropower plants can be divided into three different levels, see section 3.1.1. Since the information about the species living in the stream concern the species in the third level that it what mainly will be discussed here. This does not mean that there are no impacts at the other levels, especially since that the third-order impacts are a result of the two first ones, but that there is a lack of information. Due to variation in the information that is possible to gain about the biodiversity in the different streams, the information is not uniform and there are also differences on how much information that exists about the different streams.

5.6.1 Slottsån

Before the construction of the hydropower plants in Slottsån it was possible for the salmon and trout to migrate up to Öresjön according to Wengström (2011), which is something that is impossible today. The trout population has decreased, which can be seen as a possible result of the existence of the hydropower plants in the stream. Occurrences of eel and freshwater pearl mussel have been found in Slottsån. Investigations have also been performed on the species richness in the benthos at different locations in the stream. For the dam area in Hulta the species richness in 2007 was classified as moderately high. A later investigation was performed in 2011. The conclusion from that investigation was that even if the result indicated good conditions for the benthic zone with respect to hydro morphological impact the conditions would probably been even higher if there were no hydropower plants.

5.6.2 Häggån

According to the reports about Häggån, it is possible to conclude that the hydropower plant has had an adverse effect on the trout population in the stream. There have been several investigations performed to get an estimation of the size of the freshwater pearl mussel population. The problem with comparing them is that they have not the same boundaries and that not totally the same areas are included. However, looking at the studies, it is possible to see a reduction in the freshwater pearl mussel population. In an inventory from 1990, which probably also included the population in the tributary Lillån, the population was estimated to consist of 100-1000 individuals. An inventory performed 2003, estimated the population to consist of 10-100 individuals. The most recent inventory, performed in 2013, found only single individuals in

Häggån. The inventory from 2003 states also that no juvenile freshwater pearl mussels were possible to find.

Another species that can be affected by the hydropower plant is the marsh gentian. As can be read in the chapter about the different ecosystems, the regulation of Frisjön can cause that the flower is drained if the water level rises to high during some weeks in the summer. Also the black-throated loon and the pike living in Frisjön may be affected negatively of the hydropower plant.

5.6.3 Ätran

The information about the biodiversity in Axelfors is quite general and it is hard to find any specific information about the biodiversity around Axelfors. It can be read for example in the chapter about the information concerning the ecosystem around the hydropower plants that e.g. salmon and eel can be found in Ätran and that the benthic has high values. Since the information concerns mainly other parts of Ätran or the biodiversity in general it is hard to get an estimation of possible impacts on the biodiversity from the hydropower plant in Axelfors.

5.6.4 Compilation of Biodiversity Review

It is possible to conclude in some cases that the existence of the hydropower plants have had a negative effect on the biodiversity and species living in the ecosystem around the hydropower plants, which can be read earlier in the text, see section 3.1.7. In other cases it can be hard to decide if the changes in the biodiversity are coming from the hydropower plants in the different streams or if it is a result of other impacts and it is hard to put any numbers on the losses. One problem with deciding the impacts on the biodiversity is that it is still an area with limited knowledge and that the impacts on the biodiversity, as for many of the other impacts due to hydropower plants are very site-specific. In one of the studies, some fields, e.g. loss of habitat and special biotopes through inundation, fluctuating water levels, loss of flooding, introduction and dispersal of exotic species and also obstacles to fish migration, are pointed out as the most serious causes following the installation of hydropower plants. It can be stated that the hydropower plants are obstacles for fish migration and the problems with fish barriers is also pointed out in many of the studies included in the literature review about biodiversity. The problem with fish barriers due to the four hydropower plants in this case is further discussed in section 5.4 about Migration barriers. Since already existing natural lakes are used for the storage of water the size of land inundated was probably not as large as it would have been if reservoirs had been created instead. This means that loss of habitats probably also are smaller than if reservoirs would have been created where there before was a stream. But some land areas has most likely been inundated and caused loss of habitats.

One of the studies included in the literature review have compared the amount of species in the riparian zone for streams with run of river hydropower plants and streams with hydropower plants with regulation to streams without hydropower plants. The study shown a lower amount of species for the stream with a run of river plant compared to a stream without hydropower and even lower amounts for a stream with a hydropower plant with regulation. Transferring this information to the situation for Haby, Hulta, Häggårda and Axelfors would mean that for all the cases is the riparian zone affected but that the effects probably are larger for the three plants with regulation.

In one of the studies it can be read that the biodiversity in the benthos will be affected by the regulation of the water. For Slottsån, one of the investigations also concluded that the conditions for the benthos probably would have been better if there was no regulation. It can also be read that heavy regulation can force the organisms to move or flush them away. Haby and Hulta are more regulated than the two other plants in this case, which could indicate a possible larger impact on the organisms in the benthos there, than for the other plants.

The existence of trout and freshwater pearl mussel can be used as indicators for a general good environment in the stream. It is impossible to draw any exact conclusions about that no juvenile freshwater pearl mussels are found in Häggån and that the trout population in both Häggån and Slottsån are affected by the hydropower plants. But the fact that both the trout and freshwater pearl mussel are affected should at least not be seen as a good sign.

In the table 5.2 below is the information about the biodiversity compiled. Even if only the trout and freshwater pearl mussel is included in the table, it does not mean that they are the only species affected but that they are the species the commonly in focus in the information included in the literature study.

Table 5.2: Compiled information about the biodiversity.

	Slottsån	**Häggån**	**Ätran**
Trout	Affected by the hydropower plants	Affected by the hydropower plants	No information available
Freshwater pearl mussel	Occurrences of the freshwater pearl mussel have been found.	No juvenile freshwater pearl mussel found, can be a direct or indirect result of the hydropower plants.	The freshwater pearl mussel can be found in Ätran but there is no information about the conditions for the freshwater pearl mussel close to Axelfors.
Benthos	Investigations have shown that benthos probably is affected by the regulation		Valuable benthos
Riparian zone	According to studies included in the literature review, it is possible to assume that the riparian zone is affected	According to studies included in the literature review, it is possible to assume that the riparian zone is affected	According to studies included in the literature review, it is possible to assume that the riparian zone is affected, but that the effects are smaller than for Slottsån and Häggån

5.7 Compilation of the Analysis

In the following table, see next page, is the information from the analysis compiled to get an easy overview of the impacts that the hydropower plants are resulting.

	Haby	**Hulta**	**Häggårda**	**Axelfors**
Stream	Slottsån, tributary to Viskan	Slottsån, tributary to Viskan	Häggårda, tributary to Viskan	Ätran
Nationally valuable water	Öresjön and Tolken are nationally valuable from a fishing point of view and regionally valuable from a natural value perspective		Tattarströmmarna, which is part the stream Häggån is a Natura 2000 area	Classified as particularly nationally valuable
Potential to reach good ecological status	Has a moderate status today with a risk of not reaching good ecological status by 2021		Has a moderate status today with a risk of not reaching good ecological status by 2021	Has a moderate status today with a risk of not reaching good ecological status by 2021
Knowledge about the regulation's effects	Known effects on the benthos		Known effects on the trout population	Said to not be substantially affected by the regulation
Known existing species in the stream *(The species mentioned are in no way trying to include all the species in the stream, but are species mentioned in the literature about the stream.)*	Eel, trout, freshwater pearl mussel, caddisfly, shell		Trout, freshwater pearl mussel	Trout, river lamprey, sea lamprey, freshwater pearl mussel, eel, caddis, salmon duck mussel, swollen river mussel and painter mussel (The species are however species that can be found in the whole stream and not specifically close to Axelfors.)
Other information	Electro fishing has shown a decrease in the trout population. It was before possible to find crayfish in the stream		Close to Frisjön, the marsh gentian can be found. There exist wishes to regulate Frisjön during periods so not the pike or the black-throated loon are affected. Surrounding Tattarströmmarna is the alluvial deciduous forests that occasionally are flooded that should be retained Examinations have showed that the stocks of trout and freshwater pearl mussel are weak.	The benthos has high values.

Chapter 6

Comparisons

In the earlier chapter, several different environmental impacts that hydropower results in together with different suggestions on what can be done to mitigate the impacts have been mentioned. To widen the horizon from only looking at the hydropower plants owned by Borås Energi och Miljö and to get a comparison on what companies of a similar size actually has done in order to reduce their environmental impacts, two companies lying have been looked at. One person at each company with knowledge about the environmental work have been interviewed in order to get information about why the company chose to do this kind of environmental work and what kind of results the companies have seen.

A comparison with Nordisk elmix is also included to get an idea of how large the GHG emissions would be if the electricity produced would be replaced with electricity from Nordisk elmix.

6.1 Tranås Energi

Tranås Energi AB is an energy company located in Tranås, which distributes and sells electricity, fiber networks, district heating and energy services. It is a company with approximately 11 400 customers, with an electricity demand of 159 GWh/year. At Tranås Energi there are 40 employees and the company's annual turnover in 2013 was 194 million SEK (Tranås Energi, n.d. b).

The company wants to keep the services and products delivered to customers as renewable as possible. The electricity sold by Tranås Energi is 100% renewable. The electricity produced comes from two hydropower plants, and from their cogeneration plant (Tranås Energi, n.d. b).

Tranås Energi has two hydropower plants in operation, Forsnäs and Olstorp, but they also have four remaining installations that have no hydropower generation today. These are Tranås kvarn (Smedjeholmen), Åsvallehult, Vriggebo and Oppeby kvarn. Forsnäs consists of two aggregates, Forsnäs I from year 1920, which were complemented with Forsnäs II in year 1939. For a quick review over Forsnäs (I+II) and Olstorp see table 6.1 (Tranås Energi, 2012a,b)

Table 6.1: Short information about Forsnäs and Olstorp

	Forsnäs I	**Forsnäs II**	**Olstorp**
Location	Bulsjöån	Bulsjöån	Bulsjöån
Built	1920	1939	1928
Installed capacity	420 kW	240kW	320kW
Normal yearly production	1.2 GWh/year	600 MWh/year	0.8 GWh /year
Head	12 m	12 m	9 m
Turbine type	-	Francis	-
Water flow	8 m^3/s	8 m^3/s	4.5 m^3/s
Water level regulation	0.5 m (during 15/6-30/9 0.4 m)	0.5 m (during 15/6-30/9 0.4 m)	1.04 m (during 1/1 – 14/4 1.21 m)

As said before, there currently is no electricity production at Smedjeholmen, but then it previously was electricity production at the area there still is a migration barrier in terms of height differences and closed spillways. The same is also true for Åsvallehult (Tranås Energi, n.d. c). The dam at Oppeby kvarn also creates a migration barrier (VISS Vatteninformationsystem Sverige, n.d.).

Tranås Energi AB is investing in a green profile, which can reduce their environmental impact through fishways, water release bypassing the stations and cutting of grass and branches. All this will cost money, but Tranås Energi believes that customers are prepared to pay a little more for the environmental benefits (Johansson, 2011). Tranås Energi has started their environmental work to restore the nature as close to its original shape as possible. They want to maintain biodiversity with rich plant and animal life in the water bodies (Svensk Energi, 2012).

In table 6.2 below has Tranås Energi's environmental work at the different sites been summarized (Tranås Energi, n.d. a, 2012a; Tranås Kommun, 2012; Tranås Energi, n.d. c, 2012b).

Table 6.2: Tranås Energi’s environmental work

Site	Environmental work	Future work
Forsnäs	Tranås Energi themselves applied to raise the bypass release of water from 0.115 to 0.355 m^3/s.	Preliminary study to make a bypass channel
Olstorp	Construction of a stream around the obstacle in year 2008. Biotope adjustments in form of clearing the river and deployment of gravel and stones. In 2013 Tranås Energi themselves applied to raise the bypass release of water from 0.07 to 0.3 m^3/s.	
Tranås Kvarn (Smedjeholmen)	Construction of a Denil fishway with an integrated fish counter in 2006.	Restart of hydropower production is planned, with a new fish friendly technology
Åsvallehult	Construction of a stream around the obstacle in year 2006.	Thoughts of possibly restarting the hydropower production
Oppeby kvarn		
Vriggebo	The dam was removed in 2006	

Tranås Energy is the first energy company to voluntarily raise the judgment given for the minimum flow. By releasing less water, more energy could be produced in hydropower plant, but Tranås Energi chooses instead to increase the amount of bypass water and thus make environmental improvements (Energinyheter.se, 2014). The mitigation actions taken by Tranås Energi were made mainly because the company wanted to take responsibility for their environmental impacts (E Gahm 2014, pers. comm., interview 25 April)[3]. For full interview by Elina Gahm, Quality and Environment Coordinator at Tranås Energi see Appendix B. Elina Gahm says that what have influenced the company to work with the environment is both that they have had a feeling that requirements and legislation would become stricter and also that the company saw a profit in the long run to invest in the environment.

Even though the measures have cost a lot of money to Tranås Energi, the company have had very positive effects from other sources instead. Positive aspects from the environment have been received, trout and otters have for example been seen, which is a sign that the measures worked and that biodiversity has benefited. The company have also received many positive responses from customers, which in turn led to increased economic growth (E Gahm 2014, pers. comm., interview 25 April)[4].

[3]Elina Gahm, Quality and Environment Coordinator, Tranås Energi, Mail conversation 24 April 2014

[4]Elina Gahm, Quality and Environment Coordinator, Tranås Energi, Mail conversation 24 April 2014

In Olstorpsbäcken, which is a part of Bulsjöån, Östergötland's most numerous populations with freshwater pearl mussel can be found. The stock is although relatively small and any rejuvenation of mussels has not been detected in the past ten years. Inventories in the area have been conducted in the year 1985, 1999, 2006 and 2008. At the inventories 1985-2006 the mussels stock has shown a negative downward trend. However, thanks to the biotope adjustments and the construction of the stream around the obstacle at Olstorp so have the habitats of both the freshwater pearl mussel and the host organism for its larvae, the trout, improved significantly (Svensk Energi, 2012; Bergengren, 2008).

According to the construction of the Denil fishway at Tranås kvarn, one can also here notice a significant improvement. Due to the integrated fish counter there has been noted that the number of fish that passed the counter has increased every year since 2008. Both trout, perch and bream have been registered (Svensk Energi, 2012; Johansson, 2011).

According to Fiskejournalen, Tranås Energi goes first and shows the way. The chairman of Älvräddarna claims that by starting early all the costs and other things that are complained about when it comes to the water activity investigation can be eliminated (Fiskejournalen, 2014). As Tranås Energi already had a feeling that requirements and legislation would be stricter and due to the fact that the company already are prioritizing greening their facilities, Tranås Energi are not as much affected of the water activity investigation (E Gahm 2014, pers. comm., interview 25 April)[5].

The electricity produced by Tranås Energi is labelled with the independent environmental label, Bra Miljöval, which is issued by Naturskyddsföreningen (Tranås Energi, n.d. d). In the year 2012 Tranås Energi received, as the first energy company in Sweden, a diploma from Älvräddarna for their work on biodiversity and the greening of the hydropower plants (Tranås Energi, n.d. a).

Tranås Energi has further plans to make even more environmental mitigation measures. Plans exist to remove more obstacles to migration, to build more fishways and to reopen the hydropower production at one of their facilities with a new fish friendly screw technology (E Gahm 2014, pers. comm., interview 25 April)[6] .

[5]Elina Gahm, Quality and Environment Coordinator, Tranås Energi, Mail conversation 24 April 2014

[6]Elina Gahm, Quality and Environment Coordinator, Tranås Energi, Mail conversation 24 April 2014

6.2 Falkenberg Energi

Falkenberg Energi is an energy company located in Falkenberg. The company started in year 1995 and is owned by Falkenberg's municipality. Falkenberg Energi has been contracted by the municipality to develop, produce, distribute and trade in energy (Falkenberg Energi AB, 2013). The company is a sustainable energy company, who will be responsible for energy supply and to increase the proportion of renewable energy in the municipality of Falkenberg (Falkenberg Energi, 2014). The company have 33 employed persons and the yearly turnover year 2013 was 196 million SEK (Falkenberg Energi AB, 2013).

Falkenberg Energi is according to themselves characterized by sustainability thinking throughout the whole business and claim that they are a company with a clear environmental profile. Falkenberg Energi is only offering 100% renewable energy (Falkenberg Energi AB, 2013).

Falkenberg Energi has one power plant at Herting, which includes two different hydropower plants. In a side channel to Ätran the first hydropower plant (H1) was built in 1904. In 1944 a new channel was built closer to the river where the second hydropower plant (H2) was built. At this time, also a dam was built, which meant that Ätran's natural riverbed become dried (Falkenberg kommun, 2014). Since then, the water flow to the turbines have been regulated (NyTeknik, 2014).

For a quick review over Herting hydropower plant, see table, 6.3 (Fiskevårdsteknik AB, 2012; Falkenberg kommun, 2014).

Table 6.3: Short information about Herting power plant

	Herting
Location	Ätran
Built	1904 (H1) and 1944 (H2)
Effect	2,8 MW
Normal yearly production	15 GWh/year
Head	5 m

Falkenberg Energi has been working on measures to improve and reduce environmental impacts from the hydropower. For example, there have been, since historic times a fishway at Herting hydropower plant to help the fish to migrate past the power plant. The fishway is a Denil fishway and each year, thousands of fish are upstream migrating through this. Therefore it is possible for the fish to continue to upstream spawning areas. Also an eel and elver fishway for the upstream migrating eels have been built (J Melin 2014, pers. comm., interview 16 May)[7]. For full interview by Jens Melin, Environmental Manager at Falkenberg Energi see Appendix C. In the year 2006, a trap was constructed right next to the turbine intake at H1 (Falkenberg Energi, n.d. b). Around this time, initial attempts with trapping, marking and new release of downstream migrating fish was started. This to see how the fish was behaving in the water (Falkenberg Energi, n.d. a). During 2013 the process of removing the dam began (Falkenberg Energi AB, 2013). This was done to improve the problem with the downstream migration. The dam construction was removed and a fish safe, energy efficient intake screen was installed at H1 (Falkenberg kommun, 2014).

The action taken by removing the dam was due to the fact that the company received a requirement from Kammarkollegiet. They demanded that something had to be done to improve the downstream migration of the fish. Kammarkollegiet first suggested that Falkenberg Energi should build a culvert, but the company was uncertain about this solution and started instead an investigation in collaboration with the University of Karlstad. The study involved examining the fish in the stream and also to look at their migration pattern. Different alternative measures were examined to find out which solution would be best for the site. The conclusion from the investigation was to remove the dam (J Melin 2014, pers. comm., interview 16 May)[8].

The oldest part of Herting hydropower plant from 1904 (H1) is of cultural interest and will operate under the entire year. The new hydropower plant that opened in 1945 (H2) will on the other hand only be used during the winter when high flows occur (Falkenberg Energi AB, 2013). However, at least 11 m^3 of water should flow freely through the riverbed before the power plant may start to take water to the turbines. Therefore, no production at all is occurring in the power plant at certain times of the year (NyTeknik, 2014).

According to Falkenberg Energi themselves follow-ups and labeling of fish will be conducted during 2014 to verify the impact of the reconstruction. The company argues that by recreating the stream, the biodiversity that has been lost over decades will be restored (Falkenberg Energi AB, 2013).

Due to the fish counter, positive effects have already been seen. From this study it has been found that the number of fish has increased by a factor of four compared to before the dam was removed. The company has although noticed economical decreases following the dam removal. This due to the fact that their electricity production has gone down, the production at the power plant has decreased from 13 GWh to 8 GWh per year. However, the company expect to have a positive economic impact in the future. This will come from for example increased

[7]Jens Melin, Environmental Manager, Falkenberg Energi, Telephone conversation 16 May 2014
[8]Jens Melin, Environmental Manager, Falkenberg Energi, Telephone conversation 16 May 2014

fishing activities and tourism (J Melin 2014, pers. comm., interview 16 May)[9].

Anna Krantz, investigator at Älvräddarna claim that Falkenberg Energi probably is next up for Älvräddarnas' diploma thanks to their environmental work (Fiskejournalen, 2013).

6.3 Nordisk Elmix

From the analysis of the hydropower plants it has been concluded that the operation of the four hydropower plants have small carbon dioxide emissions. The emissions of carbon dioxide are one of the most important green house gases and already today can changes in the climate be seen (SMHI, 2012, 2009b). If Borås Energi och Miljö decides to stop the production of electricity at the four hydropower plants and replaces the production with electricity from Nordisk elmix, the emissions of green house gases would increase. 2012 consisted Nordisk elmix of 28.4 % electricity produced from renewable energy sources, 38.2 % of the electricity came from nuclear power and the rest, 33.4 % from fossil based energy sources. This results in that approximately 258 g CO_2 is emitted per produced kWh (Affärsverken, 2013). The production of electricity from the four hydropower plants varies from year to year so to get an estimation of the size of the possible emissions if the electricity from the hydropower plants is replaced with electricity from Nordisk elmix, the emissions are calculated for each year from 2000 to 2009. The average value from these years is also calculated, se table 6.4.

Table 6.4: Shows the approximate size of the CO_2-emissions that would have been released if the electricity produced from the hydropower plants with electricity from Nordisk elmix. Information about the produced electricity at the hydropower plants is from (Borås Energi och Miljö, 2013b).

Year	Produced electricity at the hydropower plants [MWh]	CO_2-emissions that would have been released with Nordisk elmix in tonnes
2002	29 800	7 400
2003	13 500	3 500
2004	36 800	9 500
2005	24 500	6 300
2006	32 300	8 300
2007	44 500	11 500
2008	44 700	11 500
2009	24 400	6 300
2010	33 000	8 500
2011	42 600	11 000

Looking at the average value for these years it can be seen that if Nordisk elmix would have been used instead, 8 420 tonnes of CO_2 had been released into the atmosphere. Since Borås Energi och Miljö works for a fossil free city this could be of importance.

[9]Jens Melin, Environmental Manager, Falkenberg Energi, Telephone conversation 16 May 2014

Chapter 7

Mitigation Actions and Recommendations

In the following chapter possible recommendations and actions will be discussed. The recommendations and actions will be based on the literature review about actions, the analysis and the comparisons made with other actors in the industry. These recommendations will be about actions that can be taken by Borås Energi och Miljö to make their hydropower plants more environmentally friendly. Some of the recommendations are connected with an estimated cost and to get some kind of reference in how expensive the costs are, the revenue for last five years for the hydropower plants are given in the table 7.1 below (A Rieck 2014, pers. comm., 5 May) [10]:

Table 7.1: Total revenue from the last five years for the four hydropower plants (A Rieck 2014, pers. comm., 5 May)

Year	Revenue in SEK
2009	7 446 000
2010	14 116 000
2011	11 606 000
2012	6 189 000
2013	-390 000
Average	7 793 400

7.1 Dam Removal

The first possible action mentioned in the literature review about actions is dam removal which, compared to the other actions can be described as a very radical action since the electricity production will cease completely. A removal of a dam can for example become relevant when the viability is low, when there is a safety issue connected to the dam, very significant environmental impacts and if there exists a high opportunity cost. In the case of Borås Energi och Miljö,

[10] Anna Rieck Process Engineer Borås Energi och Miljö, conversation 5 May 2014

they have in the recent years performed several renovations on the hydropower plants. For now, Borås Energi och Miljö have no planned renovations in the future but the hydropower plants are in good condition. This means that there is no economical incentive to remove the dams, which there could have been if the viability was very low and there would have been a great need of renovation and reparation. Nor do Borås Energi och Miljö have any opportunity cost connected to the existence of the dams. It should also be remembered that as concluded in the analysis so are the GHG emissions from the hydropower plants very small. That is something that can be seen as an important factor by Borås Energi och Miljö since one of their visions is that Borås should be a city free of fossil fuels and that it can be hard to replace the electricity from the hydropower plants with electricity from another energy source with equally small GHG emissions. The overall conclusion, with the current knowledge about the hydropower plants and the environmental impacts, is that a removal of the dams is not a recommendation.

7.2 Flow Regulations

An establishment of a minimum flow, also called environmental or ecological flow, can help to get the hydropower plants more compatible with the natural life of rivers. A minimum flow can refer to both the situation in Häggårda where there is constant flow of water trough the plants or the spillways of at least 1.5 m^3/s or when there is a water flow going on the side of the plant. Axelfors is operated as a run of river plant so there is a constant flow of water through the plant. For Häggårda there are requirements on a minimum flow so as for Axelfors there are no times when no water at all reached the stream downstream the plants. However, for both of the plants the water is let through the plants and not through the dry riverbed. For Haby and Hulta the situation differs compared to Axelfors and Häggårda. There are no requirements on a minimum flow for Haby and Hulta and following the regulation of the plants there are times when now water at all is reaching the stream downstream the plants. The problem with the minimum flow is that there exists no easy way to determine how large the minimum flow should be or how it should be operated. One recommendation on the size of the water flow is that is should correspond to 5-20% of the normal low water flow in the stream. It is also important that the flow not is static, it should follow the natural variations.

With a minimum flow in Haby and Hulta the situation with the short-term regulation should also be improved. Short-term regulation can have adverse effects on the ecosystem and should therefore be avoided. With a minimum flow the times when no water at all is let through could be avoided and reduce the damages. Overall, the recommendation is to look over the regulation of these plants since short-term regulation should be avoided. The damages connected to short-term regulation are described in the literature review can be adverse and investigations performed on the benthos in Slottsån have showed effects due to the regulation. It is hard to say how large the benefits for the ecosystem would be with a more environmentally friendly regulation without the fast changes and times without water but at least should some of the damages be avoided. Seen from an economical perspective, a change from short-term regulation to a regulation without that many changes in the water flow, will probably lead to a decrease in the earnings of the hydropower plants since the possibility to produce electricity when the price is as highest will decrease. Instead there will be improved conditions for the environment and the species living in the stream.

7.3 Sedimentation

Since the available information did not indicate any larger problems with sedimentation at the four sites there is no need at the moment to implement actions to improve the situation.

7.4 Biotope Adjustments

Another possible action is different kinds of biotope adjustments. Due to the regulation, spawn areas have been destroyed in Häggån, and Hyltenäsån is today more like a channel than a natural stream. By performing biotope adjustment it could be possible to restore the former spawn areas in Häggån or at least improve the current situation. For Hyltenäsån, biotope adjustments in form of placement of stones and spawning gravel, is recommended in the report from Wengström (2011). If biotope adjustments were done in Hyltenäsån, some of the earlier biotopes that existed in the stream could be restored, resulting in improved conditions for the trout. According to Wengström (2011), the stones that earlier lied in the stream, now are lying outside the stream, so in the case of a biotope adjustment, it would only be to put back the stones into the stream. About Axelfors in Ätran and the two plants in Slottsån, the same information about the need of biotope adjustments have not been found. But it is not improbable that also parts of Slottsån and Ätran are in the need of biotope adjustments due to cleaning for the development of hydropower plants or timber rafting that may have occurred. The cost for biotope adjustments range between 15 000 - 50 000 SEK/km (Svensson, 2000). If the inflation is taken into account this means that the cost varies between approximately 18 000 - 60 000 SEK/km (Statistiska centralbyrån, 2014). This means that for Hyltenäsån that is approximately 700 m long, the maximum cost would be 42 000 SEK and that is only if the whole distance of the stream is in the need of biotope adjustments and the "worst case" is assumed in form of the maximum cost. This means that cost for biotope adjustments in Hyltenäs are rather low compared to the revenue for the hydropower plants, apart from 2013, see table 7.1. For the other streams it is hard to estimate the cost since the extent of the requirements of biotope adjustments are not known.

7.5 Adapted Intake Screens

As can be read in the literature review the angel and the width of the intake screens is of importance for how large the risk is for damages to the fish in the stream. The ideal angel of the intake screens is 30 degrees. With an angel of 30 degrees or lower the risk that a fish will get stuck at the screen is smaller than with a higher angel since the force parallel to the screen becomes twice as high as the force against it. The grid width at the four sites is not exactly known but smallest grid width can be found in Häggårda, the grid width there is 2.5 centimetres, at the three other plants the grid width is larger than 2.5 centimetres (A Rieck 2014, pers. comm., 5 May)[11]. This means that none of the intake screens have the recommended grid width. The angel of the intake screens at the four hydropower plants is not known so it is hard to say if the angel is good or not. An intake screen with a grid width with a maximum of 20 millimetres and preferably 11 millimetres at Hulta and for Haby, a grid width of 11 millimetres is also recommended as an action in the report from Norconsult (2011). However, it should be remembered that without an alternative way for the species in the stream, the angel of and the grid width of the intake screens is of lesser importance. So even if it is a recommendation change the intake screens so that they follow the recommended measures, it should be done in connection to the construction of alternative ways for the species in the stream to pass the hydropower plants.

7.6 Fishways

Today all the four hydropower plants and the regulation dam in Hyltenäsån constitutes barriers for the migrating species in the stream. The migration barriers are even mentioned as one of the main problems to reach good ecological status by 2021. By the construction of fishways, the migration of the species in the stream could be facilitated and one of the biggest problems that the hydropower plants causes could be corrected or at least be of smaller magnitude. There are several different kinds of fishways. The aim of fishway is that should allow passage for all the migrating species and not only for fishes. The different kinds can be divided into natural-like fishways and fishway with technical solutions. The fishways with technical solutions has usually the disadvantage of only being suitable for fishes and not for other species. For example the pool-type fishway may not be recommended since it is primarily suited for salmonids. There have earlier been feasibility studies on if and possible fishways should be constructed at Haby and Hulta and the possible cost connected to the construction. Except from the cost for the construction of the fishway there will be an additional annual cost for the water that is spilled in the fishway and not goes through the hydropower plant to produce electricity. When constructing a fishway there is, as mentioned in the literature review, many aspects to take into

[11] Anna Rieck Process Engineer Borås Energi och Miljö, conversation 5 May 2014

consideration. It is therefore hard to give any exact recommendations about the construction of fishways. In the feasibility study from Fredberg (n.d.) the costs for both a technical fishway and the cost for a bypass channel at Haby and Hulta have been included. The costs are presented in the table 7.2 below and are in SEK:

Table 7.2: Estimations of the costs for the installation of fishways (Fredberg, n.d.)

Plant	Costs for bypass channel	Costs for technical fishway
Haby	2 500 000	2 000 000
Hulta	6 000 000	5 500 000

The costs for the construction of fishways are quite high, compared to the total annual revenue for all of the four hydropower plants it corresponds to approximately more than the revenue for an average year and the cost do not include the cost for fishways in Häggårda, Axelfors and Hyltenäs. But if the environment is important and the possibility for the species in the different stream to migrate as they could before, fishways are necessary. This is only one estimation of the cost and other estimations have not shown the same high numbers. The numbers are not showed here since they do no tell if all the costs are included and thus hard to compare with the costs stated above but the gist is that the number are only estimations and should only be seen as estimations.

When a fishway is installed, enough of water must be spilled in the fishway so that the fish is directed in to them. In the report from Versa (2009) a flow of 1 m^3/s is recommended if the salmons should have the possibility to migrate. If only the trout should have the possibility to migrate, which only 0.3 m^3/s required. At times with no migration the flow can be reduced to 0.1 m^3/s. In the feasibility study from Fredberg (n.d.), calculations have been included to estimate how large the production losses will be. To calculate the costs for the production losses the power the spilled water could have produced and the price for the electricity is needed.

The power is given by:

$$P = \eta * \rho * g * Q * H \; [W]$$

The density for water is approximately 1000 kg/m^3, the gravity is 9.82 m/s^2, Q is 0.1 m^3/s, 0.3 m^3/s or 1.0 m^3/s depending on which flow that is used and H is when including both Hulta and Haby 41 m. The same η as in the report from Fredberg (n.d.) is used here, the used efficiency there is approximately 0.8. This means that for the different flows are P:

$$P = 0.8 * 1000\,kg/m^3 * 9.82\,m/s^2 * 0.1\,m^3/s * 41\,m = 32.2\ kW$$

$$P = 0.8 * 1000\,kg/m^3 * 9.82\,m/s^2 * 0.3\,m^3/s * 41\,m = 96.6\ kW$$

$$P = 0.8 * 1000\,kg/m^3 * 9.82\,m/s^2 * 1\,m^3/s * 41\,m = 322\ kW$$

Depending on which size of the water flow that is spilled in the fishway and for how long time period the production losses vary. Two different combinations, the same as in report from Fredberg (n.d.), are used here. In the first combination, the largest water flow is spilled during six months of the year and the two other flows are spilled three months each. To get the production losses per each year, the power is multiplied with the total amount of hours per year.

$$Production\ losses = 32.2\,kW * (8760\,h)/4 = 71\ MWh$$

$$Production\ losses = 96.6\,kW * (8760\,h)/4 = 212\ MWh$$

$$Production\ losses = 322\,kW * (8760\,h)/2 = 1410\ MWh$$

This gives a total production loss of:

$$Total\ production\ losses = 71\,MWh + 212\,MWh + 1410\,MWh = 1693\ MWh$$

If the price for the produced electricity is 0.4 SEK/kWh the cost for the total production losses for one year is:

$$Costs\ due\ to\ production\ losses = 400\,SEK/(MWh) * 1693 = 677\,200\,SEK$$

With another combination the different flows, the costs due to production losses will be changed. If the flow with 1 m^3/s is spilled only four months instead of six months and the other water flows also are spilled four months each, the production losses will be:

$$Production\ losses = 32.2\,kW * (8760\,h)/3 = 94\ MWh$$

$$Production\ losses = 96.6\,kW * (8760\,h)/3 = 282\ MWh$$

$$Production\ losses = 322\,kW * (8760\,h)/3 = 940\ MWh$$

This gives a total production loss of:

$$Total\ production\ losses = 940\,MWh + 282\,MWh + 94\,MWh = 1316\ MWh$$

If the price for the produced electricity is 0.4 SEK/kWh the cost for the total production losses for one year is:

$$Costs\ due\ to\ production\ losses = 400\,SEK/(MWh) * 1316 = 526\,400\,SEK$$

As for the other costs, the costs due to the production losses only are rough estimations. In this case, factors such as the price for the electricity and the combinations of the amount and duration of the spilled water flow will affect the costs. Another important factor is that the spilled water not always will result in production losses since at times when there is no production it is possible that the water that now is spilled in the spillways can be lead through the fishways instead. Therefore the costs only should be seen as indications and should be weight to that the installation of fishways enables for the fishes to pass the hydropower plants. The costs for the production losses at Axelfors and Häggårda can be calculated in the same way. Since no information have been found on how large the water flow spilled in the possible fishway should be an estimation of 0.5 m^3/s. The reason to why that specific water flow is used is that, according to the report from Pöyry (2012), it is a water flow that represents an average of the water flow in a plurality of fishways in small-scale hydropower plants. For Häggårda an estimation of the costs due to the production losses are:

$$P = 0.8 * 1000\,kg/m^3 * 9.82\,m/s^2 * 0.5\,m^3/s * 28.5\,m = 112\ kW$$

$$Production\ losses = 112\,kW * 8760\,h = 981\ MWh$$

$$Costs\ due\ to\ production\ losses = 400\,SEK/(MWh) * 981 = 392\,400\,SEK$$

For Axelfors the estimation of the costs due to the production losses are:

$$P = 0.8 * 1000\,kg/m^3 * 9.82\,m/s^2 * 0.5\,m^3/s * 11\,m = 43\ kW$$

$$Production\ losses = 43\,kW * 8760\,h = 377\ MWh$$

$$Costs\ due\ to\ production\ losses = 400\,SEK/(MWh) * 377 = 150\,800\,SEK$$

An installation of a fishway can be seen as quite expensive action, both the construction of it and the following costs due to the production losses. But as mentioned earlier, the migration barriers in the streams are seen as one of the biggest problem to reach the goal of good ecological status by 2021. If taking the decision to construct fishways, it is important to construct it so it gets attractive for the fishes and is build in such a way so that many species is benefited from it. Enough of water should be spilled into it and the entrance should be as close as possible to the migration barrier, the fishway should also have characteristics as similar as to natural conditions for the best result.

According to the water rights permit, Borås Energi och Miljö has requirements on fishways for the eels at the plants. As mentioned, the substitution in form of eel plans may not show the same positive result as if there had been functioning fishways for the eels. To improve the situation in the streams for the eel, installation of fishways for eels would be recommended if not other fishways that also works for the eels is constructed. The eels that today wish to migrate are facing a very difficult situation and a lot of them never reach their destination or get killed along the way.

7.7 Fish Plantations

One of the drawbacks with fish plantation is that the planted fishes do not exhibit the same characteristics as the natural living fishes in the streams. This can lead to that planted fishes will have difficulties with e.g. food and finding their way when migrating. Another drawback is that the plantation of fishes can spread infectious diseases. There are also advantages with fish plantation, e.g. it can be advantageous when reintroducing extinct species, but the recommendation here will be that there are other actions that are of more importance than fish plantation.

7.8 Fish Friendly Turbines

There exists turbines that are more fish friendly than others but since there still is much to be learned about the turbines and how to make them more fish friendly, installation of more fish friendly turbines is therefore nothing that is recommended.

Chapter 8

Discussion

In the discussion the literature review, analysis and recommendations will be discussed. Also a section called environmental work will be discussed.

8.1 Literature Review

Borås Energi och Miljö's hydropower plants are approaching or have even reached the 100-year mark. As the baseline for comparison is set to be before the power plants were built and the fact that it is such a long time ago since the hydropower plants were built, it has complicated the investigation. It is almost impossible to know especially much about the conditions before the commissioning of the hydropower plants, which makes the comparisons about the environmental changes from the original situation hard. If for example data from investigations from the time before the hydropower plants were built existed, it would have been a different starting point for this investigation. It had in that case been easier to draw quantitative conclusions about the effects.

When searching for information to the literature review, one can see that there are many different views about how hydropower plants affect the environment or not. Some information suggests that the effect is small, while other information shows that the effects are large. However, there are clear evidences that the environment is affected. Another clear trend in the information found is that it says that the environmental impact is very site-specific. This makes it difficult to completely apply general information from the literature study on the specific sites where Borås Energi och Miljö's hydropower plants are located. Therefore, the information from Borås Energi och Miljö's hydropower plants and their surrounding areas, have been necessary in order to use and adapt the general information and thus on this basis to analyse the effects.

Another difficulty in this study was to gather the same kind of material about Borås Energi och Miljö's own hydropower plants and about the ecosystems that are in the areas the power plants are located. The information that was found was not uniform, the existing information about one hydropower plant and its area had for example information about some things while another power plant and its area had information about other things. There were also differences in how much information that existed about the different sites. This finding made it hard to analyse the different hydropower plants on the same basis and it also affected the conclusions that could be drawn about the different impacts from the different hydropower plants.

8.2 Analysis

The gained information in the literature review has formed a base from where a model has been created. In the analysis of the report, the model has been compared with the gathered information about the four specific hydropower plants so that an evaluation about the plants and their environmental impacts has been performed. Even though very little information from before the hydropower plants were built was available, environmental impacts have been detected. A difficulty in this study has although been to quantify the environmental impact. This is generally seen as a difficult task and often leads to that environmental impacts not are taken seriously because the understanding and the perception of how big the impact really are. As said before, one can on the basis of this study actually point out that there are environmental impacts from hydropower plants and thus put the emphasis on the importance and needs for mitigation actions to be taken.

In this study, no cumulative effects have been included. If one nevertheless, considers for example all hydropower plants located in a stream, the environmental impact would probably be much larger. Even when for example the regulation from one hydropower plant is not seen as a major threat to the environment, the regulation from two or more power plants can have a significant effect.

8.3 Environmental Work

In the comparison chapter of the report, it can be read about Tranås Energi and Falkenberg Energi, which are two companies that seem to be at the forefront with their environmental work. Both of the two companies have done much environmental work at their hydropower plants and both of them have also seen signs of positive improvement for the environment. The two companies are in about the same size as Borås Energi och Miljö and their hydropower plants are also in about the same sizes. This could be seen as a sign that it could also be successful for Borås Energi och Miljö to consider and take action to improve the environment. Tranås Energi and Falkenberg Energi's successes can show that it is possible to do something for the environment although the companies and the hydropower plants are not that large compared to some of the larger energy companies in Sweden.

Tranås Energi has made their actions without special requirements or laws, which is very unusual. More companies should take the initiative to do something about the environmental impact from the hydropower. However, according to the ongoing water activity investigation, it can come to be that many of Sweden's hydropower owners must meet certain environmental requirements to comply with the law. Thus, need to perform environmental mitigation actions.

Borås Energi och Miljö have performed a feasibility study on how to construct fishways at Haby and Hulta, which can be seen as a step in the right direction to decrease their environmental work. As mentioned earlier, Borås Energi och Miljö are not using the whole regulation amplitude they are allowed to in the lakes, which also can be seen as a measure to reduce the environmental impact from the regulation. Today, only a few of the hydropower plants in Sweden have functioning fishways and overall there are a lot of things that can be performed to decrease the impacts on the ecosystem from the hydropower plants. So, compared to many of the existing hydropower plants in Sweden, Borås Energi och Miljö seems to be on the same level when it comes to environmental work. But when comparing with the companies lying in the forefront, such as Tranås Energi and Falkenberg Energi, Borås Energi och Miljö needs to improve the situation in the streams before they can reach the same standard.

There are a lot of different opinions among the hydropower industry actors about the water activity investigation. The issue generally builds up two opposite sides. On one side the power companies stands, where it usually involves the economic interest and at the other side environmental organizations and agencies that work with the environment stands. The question about cost against environmental benefit is in focus, and is very complex due to the fact that quantification of environmental impacts is very hard. But, there is a fact that hydropower plants have impacts on the environment, and to do something about this involves a cost. It should however, also be remembered that there also could be other positive effects than the environmental. The environment coordinator Elina Gahm from Tranås Energi points for example out that they have had many positive responses from customers that have lead to economic benefits.

8.4 Recommendations

Some of the actions recommended in this study are quite expensive, but if the wish is to improve the situation in the streams for the species living in and around the stream and in extension reach good ecological status, actions need to be taken. As emphasized several times before in this report, Borås Energi och Miljö's hydropower plants are barriers and hinders not only the fishes but is also a hinder to reach good ecological status. To make it possible for the species in the streams, fishways are needed. The fishways should, ideally, be built so that it is adapted to all migrating species. To improve the situation further, the intake screens should be constructed so that the species do not get trapped and killed against or can make it through the grid. The recommendation is to start with the construction of fishways in Slottsån. By constructing fishways in Haby and Hulta the species will have the possibility to migrate all the way from Viskan and up to Öresjön, which was a possibility before the hydropower plants were built. In Ätran there are several other plants constituting a barrier and also in Häggån there are other plants. This means that the construction of fishways in Slottsån has the advantage that the responsibility and possibility to improve the situation in Slottsån only lies at Borås Energi och Miljö and no other company or person. In the other streams, cooperation with other plant owners can be needed to achieve the same result. Another reason to start with Haby and Hulta is that there is already some material and earlier investigations on how to construct fishways there.

Several of the recommended actions are connected in some way or depend on each other. For example it is important to change the regulation in Haby and Hulta so the kind of short-term regulation that exists today is avoided as far as possible. Another important thing is the investigation of a minimum flow and if there is a need of it in the dry riverbeds or if it should be somewhere else. If a minimum flow is implemented the effect from the regulation may be less severe compared to the situation today. The minimum flow can also go in the fishways. There are stated effects that probably are due to the regulation in Slottsån and Häggån and a change of the regulation and further studies on how to operate a minimum flow are of importance for the ecosystem either in a fishway when that is constructed or in other ways until there are fishways.

Of importance for ecosystem are also the recommended biotope adjustments. Biotope adjustments can have good effects on several of the species in the stream and should therefore be considered.

In some cases it may be seen as unnecessary to take environmental actions at one single hydropower plant in a river where there are several power plants, this because it might just benefit the environment at a certain distance and not the whole stream. But if one hydropower plant owner start taking action, it is easier to get the others to continue.

Chapter 9

Conclusions

To conclude, this study has given a generally knowledge about hydropower and its environmental impacts. By using this basis, conclusions about Borås Energi och Miljö's hydropower plants have been drawn.

The first conclusion drawn is that the hydropower plants owned by Borås Energi och Miljö are affecting the environment in a negative way. The major identified environmental impacts are:

- Migration barriers, the power plants are definitive migration barriers to fish.
- No minimum flow in the original riverbeds.
- Short-term regulation at Haby and Hulta, times during night when no water is released downstream.

The second conclusion that can be drawn from the study is that Borås Energi och Miljö actually can do something to reduce their environmental impact from the hydropower plants. The main things that Borås Energi och Miljö should address is:

- Build some kind of fishway, a bypass channels is recommended to benefit all organisms.
- Do some biotope adjustments to improve spawning sites for the fish and overall improve the environment for them.
- Start with minimum flow in the original riverbed.
- Have a regulation that will follow the naturally variable flow without any short-term regulations.

For some mitigation actions, more comprehensive investigations should be conducted for the measures to be site- specific adapted.

Chapter 10

Future Work

Before the work with the proposed measures can be taken into account, further work is needed. Thorough investigations is needed so that the fishways are constructed in a way so that as many species as possible can be benefited of them. It is also important to construct the fishways so that it is easy for species to find their way into them. Also for the biotope adjustments and minimum flow studies are needed so that the work gives the wished result.

Except for that can a lot be performed in order to gain more specific knowledge about the ecosystems where the hydropower plants are situated, how the situation are for the species living there and how the hydropower plants are affecting them. As emphasized earlier are the impacts from hydropower plants very site-specific and it is therefore important to do investigations on site to get an understanding for which measures that are needed and how they should be performed.

Bibliography

Abbasi, S., Abbasi, N., 2000. The likely adverse environmental impacts of renewable energy sources. Applied Energy 65 (1-4), 121–144.

Abbasi, T., Abbasi, S., 2011. Small hydro and the environmental implications of its extensive utilization. Renewable and Sustainable Energy Reviews 15 (4), 2134–2143, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S1364032110004193* [Accessed at: February 28, 2014].

Affärsverken, 2013. Elens ursprung.

Akella, A., Saini, R., Sharma, M., Feb. 2009. Social, economical and environmental impacts of renewable energy systems. Renewable Energy 34 (2), 390–396.

American Rivers, 2014. American Rivers | FAQs on Dams & Dam Removal | American Rivers. Available at: *http://www.americanrivers.org/initiatives/dams/faqs/* [Accessed: April 14, 2014].

Andersson, M., 2006. Flodpärlmussla i Västra Götalands län - Känd förekomst 2005. Tech. rep., Göteborg.

ArtDatabanken Swedish Species Information Centre, 2010. Artfakta - Sök arter. Available at: *http://www.artfakta.se/GetSpecies.aspx?SearchType=Advanced* [Accessed: March 25, 2014].

Arthington, A. H., Naiman, R. J. ., Mcclain, M. E., Nilsson, C., 2009. Preserving the biodiversity and ecological services of rivers : new challenges and research opportunities. Freshwater Biology.

Åstrand, S., 2008. Miljöeffekter av turbinoljeläckage från vattenkraftverk till älvar Environmental Effects of Turbine Oil Spills from Hydro Power Plants to Rivers. Ph.D. thesis.

Azarpour, A., Suhaimi, S., Zahedi, G., Bahadori, A., 2012. A Review on the Drawbacks of Renewable Energy as a Promising Energy Source of the Future. Arabian Journal for Science and Engineering 38 (2), 317–328, Available at: *http://link.springer.com/10.1007/s13369-012-0436-6* [Accessed: February 21, 2014].

Bakken, T. H., Sundt, H. k., Ruud, A., Harby, A., 2012. Development of small versus large hydropower in norway - comparison of environmental impacts. Energy Procedia 20 (1876), 185–199, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S1876610212007497* [Accessed: February 19, 2014].

Bergengren, J., 2008. Flodpärlmussla i Olstorpsbäcken- inventeringar 1999, 2006 & 2008. Tech. rep., Länsstyrelsen Östergötland.

Bergengren, J., Näslund, I., Kling, J., 2013. Vattenkraftens påverkan på akvatiska ekosystem. Havs-och vattenmyndigheten, Göteborg.

Bergkamp, G., Mccartney, M., Dugan, P., Mcneely, J., 2000. Dams , Ecosystem Functions and Environmental Restoration.

Borås Energi och Miljö, 2002. Rapport oljeutsläpp Haby.

Borås Energi och Miljö, 2003. PM3 Haby Ledskenestyrning.

Borås Energi och Miljö, 2005a. Blästring ståltub Axelfors 2005.

Borås Energi och Miljö, 2005b. Dammreparation Haby 2005.

Borås Energi och Miljö, 2009. Dagbok Hulta dammreparation 2009.

Borås Energi och Miljö, 2010. Dagbok Axelfors dammreparation 2010.

Borås Energi och Miljö, 2011. Dagbok Dammreparation Häggårda kraftstation 2010/2011.

Borås Energi och Miljö, 2013a. Dammreparationer 2012 och 2013.

Borås Energi och Miljö, 2013b. Produktionsuppföljning VKS 2013.

Borås Energi och Miljö, 2014a. Borås Energi och Miljö AB - Om Företaget. Available at: *http://www.borasenergimiljo.se/vanstermeny/omforetaget/borasenergiochmiljoab.4.6d83c434110a12a0dbc8000724.html* [Accessed: January 27, 2014].

Borås Energi och Miljö, 2014b. Våra vattenkraftstationer - Borås Energi och Miljö.

Borås Energi och Miljö, n.d. a. Axelfors kraftverk.

Borås Energi och Miljö, n.d. b. Haby och Hulta kraftverk.

Borås Energi och Miljö, n.d. c. Häggårda kraftverk.

Borås Energi och Miljö, n.d. d. Information om Axelfors vattendom.

Borås Energi och Miljö, n.d. e. Information om Haby Vattendom.

Borås Energi och Miljö, n.d. f. Information om Häggårda vattendom.

Borås Energi och Miljö, n.d. g. Information om Produktion.

Borås Kommun, 2003. Naturvärden i Häggåns vattensystem och förslag till bevarandeåtgärder. Tech. Rep. september, Borås.

Bourgeois, G., Therrien, J., 2000. Fish Passage at Small Hydro Sites. Tech. rep., Quebec, Canada.

Bratrich, C., Truffer, B., Jorde, K., Markard, J., Meier, W., Peter, A., Schneider, M., Wehrli, B., Dec. 2004. Green hydropower: a new assessment procedure for river management. River Research and Applications 20 (7), 865–882.

Bunn, S. E., Arthington, A. H., n.d. . Basic Principles and Ecological Consequences of Altered Hydrological Regimes on Aquatic Biodiversity. Environmental Management 30, 492–507.

Cada, G. F., Garrison, L. A., Fisher Jr, R. K., 2007. Determining the Effect of Shear Stress on Fish Mortality during Turbine Passage - HydroWorld.
Available at: *http://www.hydroworld.com/articles/hr/print/volume-26/issue-7/technical-articles/determining-the-effect-of-shear-stress-on-fish-mortality-during-turbine-passage.html* [Accessed: March 6, 2014].

Calles, O., Bergdahl, D., 2009. Ålens nedströmspassage av vattenkraftverk Ålens nedströmspassage av vattenkraftverk. Tech. rep.

Calles, O., Christiansson, J., Andersson, J., Sahlberg, T., Stein, F., Olsson, B.-M., Alenäs, I., Tielman, J., 2012. Ål i Ätran - en fallstudie för svensk ålförvaltning. Tech. rep., Karlstad.

Calles, O., Degerman, E., Wicktsröm, H. k., Christiansson, J., Gustafsson, S., Näslund, I., 2013. Anordningar för upp- och nedströmspassage av fisk vid vattenanläggningar. Havs-och vattenmyndigheten, Göteborg.

CBD Secretariat, 2014. Article 2. Use of Terms.

Centrum för biologisk mångfald, 2010. Biologisk mångfald. Tech. rep., Uppsala.

Dahal, S., 2013. Hydropower Reservoir and Sedimentation A Study of Nam Ngum Reservoir (May).

Dahlin-Ros, I., 2008. Äramossen: Här börjar Ätran.

Demarty, M., Bastien, J., Tremblay, a., Jan. 2011. Annual follow-up of gross diffusive carbon dioxide and methane emissions from a boreal reservoir and two nearby lakes in Québec, Canada. Biogeosciences 8 (1), 41–53.

Douglas, T., 2007. Green Hydro Power Understanding Impacts , Approvals , and Sustainability of Run-of-River Independent Power Projects in British Columbia. Tech. Rep. August.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Jul. 2012. Renewable energy sources and climate change mitigation: special report of the Intergovernmental Panel on Climate Change. Vol. 49. Intergovernmental Panel on Climate Change, New York.

Encyclopedia Britannica, n.d.. plankton (marine biology). Available at: *http://global.britannica.com/EBchecked/topic/463121/plankton* [Accessed: May 8, 2014].

Energinyheter.se, 2014. Ändrad vattendom vid Olstorps vattenkraftverk. Available at: *http://www.energinyheter.se/2014/02/ndrad-vattendom-vid-olstorps-vattenkraftverk* [Accessed: April 29, 2014].

Ericsson, U., Nilsson, C., Ljungman, M., 2012. Bottenfauna och vattenkraft - En undersökning av regleringseffekter påbottenfauna i Viskans avrinningsområde, 2012th Edition. Länsstyrelsen Västra Götaland, Vattenvårdsenheten.

Erlandsson, K., 2008. Användning av scenarier vid strategiska miljöbedömningar för anläggningsåtgärder inom vattenkraften. Ph.D. thesis, Sveriges Lantbruksuniversitet.

European Small Hydropower Association (ESHA), 2000. Hydropower Respects the Environment - A Clean and Indigenous Renewable Energy.

European Small Hydropower Association (ESHA), 2004a. Guide on How to Develop a Small Hydropower Plant.

European Small Hydropower Association (ESHA), 2004b. SmåVattenkraftverk- En Handbok.

European Small Hydropower Association (ESHA), 2009. Environmental Barometer on Small Hydro Power.

European Small Hydropower Association (ESHA), 2014. European Small Hydropower Association - ESHA: In Europe. Available at: *http://www.esha.be/about/about-small-hydropower/in-europe.html* [Accessed: February 26, 2014].

European Small Hydropower Association (ESHA), n.d.. Hydropower and environment technical and operational procedures to better integrate small hydropower plants in the environment.

European Union, 2010. Water Framework Directive.

Europeiska kommissionen, 2014. Klimatåtgärder - För en bättre värld med ett bättre klimat. Tech. rep., Luxemburg.

Falkenberg Energi, 2014. Välkommen till Falkenberg Energi! Available at: *http://www.falkenberg-energi.se/* [Accessed: May 16, 2014].

Falkenberg Energi, n.d. a. Vattenkraft. Available at: *http://www.falkenberg-energi.se/vattenkraft/vattenkraft* [Accessed: May 18, 2014].

Falkenberg Energi, n.d. b. Vattenkraft och nedströms vandrande fisk. Available at: *http://www.falkenberg-energi.se/vattenkraft/falla-for-nedvandrande-fisk* [Accessed: May 18, 2014].

Falkenberg Energi AB, 2013. Årsredovisning 2013. Tech. rep.

Falkenberg kommun, 2014. Hertingprojektet - Falkenbergs kommun. Available at: *http://www.falkenberg.se/1/bygga-bo–miljo/naturvard/naturvardsprojekt/herting projektet.html#.U3Yz5ig1pVh* [Accessed: May 16, 2014].

Fiskejournalen, 2013. Falkenberg Energi tar ansvar. Available at: *http://fiskejournalen.se/falkenberg-energi-tar-ansvar/* [Accessed: May 18, 2014].

Fiskejournalen, 2014. Frivillig omprövning av vattenkraft. Available at: *http://fiskejournalen.se/frivillig-omprovning-av-vattenkraft/* [Accessed: April 29, 2014].

Fiskeriverket, Naturvårdsverket, 2008. Ekologisk restaurering av vattendrag.

Fiskevårdsteknik AB, 2012. Återställn av vandringsväg.

Fly Fishing Shop, n.d. . Midges and Chironomids. Available at: *http://www.flyfishusa.com/flies/midges.htm* [Accessed: May 14, 2014].

Fredberg, U., n.d. . Förstudie angående möjlighet att anlägga fiskvägar vid Haby kraftverk och Hulta kraftverk.

Gagnon, L., 1997. Greenhouse gas emissions from hydropower The state of research in 1996 25 (I), 7–13.

Gagnon, L., Bélanger, C., Uchiyama, Y., Nov. 2002. Life-cycle assessment of electricity generation options: The status of research in year 2001. Energy Policy 30 (14), 1267–1278.

Gatte, M. T., Kadhim, R. A., Oct. 2012. Energy Conservation. InTech, Available at: *http://www.intechopen.com/books/energy-conservation/hydro-power http://www.intechopen.com/books/energy-conservation* [Accessed: May 9, 2014].

Ghosh, T. K., Prelas, M. a., 2011. Energy Resources and Systems. Vol. 2. Springer Netherlands, Dordrecht, Available at: *http://link.springer.com/10.1007/978-94-007-1402-1* [Accessed: January 31, 2014].

Graf, W. L., 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology 79 (3-4), 336–360, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S0169555X06002571* [Accessed: february 25, 2014].

Havs- och vattenmyndigheten, 2012. Dialog om vattenkraft och miljö - En redovisning av utfört regeringsuppdrag. Björn Risinger, Göteborg.

Hertwich, E. G., 2013. Addressing biogenic greenhouse gas emissions from hydropower in LCA. Environmental science & technology 47 (17), 9604–11, Available at: *http://www.ncbi.nlm.nih.gov/pubmed/23909506* [Accessed: March 28, 2014].

Hovsenius, G., Nilsson, C., Leijon, M., 2002. Vattenkraften i Sverige: En faktarapport inom IVA-projektet energiframsyn Sverige i Europa. Tech. rep., Eskilstuna.

Hutton, R., 2012. Damage to Fish By Hydro Turbines A New Fish Friendly Approach Using the Archimedes Screw Generator By.

HydroWorld, 2013. Update on status of technology research for the Alden fish-friendly hydro turbine. Available at: *http://www.hydroworld.com/articles/hr/print/volume-32/issue-2/articles/development-status-of-the-alden–fish-friendly–turbine.html* [Accessed: April 11, 2014].

Ingram, E. A., 2012. Exploring the Reasons behind Dam Removal. Available at: *http://www.renewableenergyworld.com/rea/news/article/2012/05/exploring-the-reasons-behind-dam-removal* [Accessed: May 9, 2014].

International Energy Agency, 2006. Iplementing agreements for hydropower technologies and programmes Annex VIII hydropower good practice : Environmental mitigation measures (May).

International Energy Agency, 2011. Technology Roadmap Hydropower. Tech. rep., Paris.

International Hydropower Association, 2014a. Hydropower Sustainability - Erosion & sedimentation. Available at: *http://www.hydrosustainability.org/About-Sustainability/Environment/Erosion—sedimentation.aspx#.UxCCFyh3-SR* [Accessed: February 28, 2014].

International Hydropower Association, 2014b. Hydropower Sustainability - Water Quality. Available at: *http://www.hydrosustainability.org/About-Sustainability/Environment/Water-Quality.aspx#.UxA5uyh3-SR* [Accessed: February 28, 2014].

Irish Department of Communications Energy and Natural Resources, 2007. Guidelines on the Planning, Design, Construction & Operation of Small-Scale Hydro-Electric Schemes and Fisheries. Tech. rep., Dublin.

Jansson, R., 2002. The biological cost of hydropower. Tech. rep., UmeåUniversity, Umeå, Sweden.

Johansson, M., 2011. Minnesanteckningar från regleringsmötet i Boxholm 2011-02-15.

Jordbruksverket, 2014. Utsättning av fisk. Available at: *http://www.jordbruksverket.se/amnesomraden/djur/olikaslagsdjur/fiskarochandravattenbruksdjur/utsattningavfisk.4.5586fdf512e8fc79a8480002288.html* [Accessed: April 22, 2014].

Kihlström, J.-E., 2006. Miljögifterna upptäcks - Från oförstånd till medvetenhet på tio år. Forskning & Framsteg (3).

Kinnarumma Naturskyddsförening, 2013. Klockgentiana och Frisjöns vattennivå.

Kretsloppsstaden, 2014. Kretsloppsstaden. Available at: *http://www.kretsloppsstaden.se/* [Accessed: january 5, 2014].

Kumar, A., Schei, A., Ahenkorah, A., Caceres Rodriguez, R., Devernay, J.-m., Freitas, M., Hall, D., Killingtveit, A., Liu, Z., 2012. Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Intergovernmental Panel on Climate Change, Cambridge.

Kungliga ingenjörsvetenskapsakademien IVA, 2002. Vattenkraften i Sverige - En Faktarapport inom IVA-Projektet Energiframsyn Sverige i Europa. Tech. rep.

Laarinier, M., 2001. Dams, Fish and Fisheries: Opportunities, Challenges and Conflict Resolution, Utgåva 419. Available at: *http://books.google.com/books?hl=sv&lr=&id=JpIO_ijVlWcC&pgis=1* [Accessed: March 5, 2014].

Länsstyrelsen Hallands län, n.d. . Översiktlig orienteringskarta.

Länsstyrelsen Kalmar län, 2014. Vad är biologisk mångfald?

Länsstyrelsen Skåne län, n.d. . Natura 2000 skyddar växter, djur och deras livsmiljöer i EU. Available at: *http://www.lansstyrelsen.se/skane/Sv/djur-och-natur/skyddad-natur/natura-2000/Pages/index.aspx* [Accessed: April 25, 2014].

Länsstyrelsen Västra Götaland län, 2005. Fungerar våra fiskvägar? Tech. rep., Vattenvårdsenheten, Vänersborg.

Länsstyrelsen Västra Götaland län, 2014. Vattenförvaltning.

Länsstyrelsen Västra Götaland län, n.d. . Lst Fiskevårdsplan.

Länsstyrelsen Västra Götalands län, 2005a. Bevarandeplan för Natura 2000-område - SE0530110. Tech. rep.

Länsstyrelsen Västra Götalands län, 2005b. Fungerar våra fiskvägar? Tech. rep., Vänersborg.

Länsstyrelsen Västra Götalands län, 2014. Flodpärlmusslans status i Västra Götaland - En inventering av nio av länets musselvattendrag 2013. Tech. rep.

Länsstyrelsen Västra Götalands län, n.d. a. Miljöanpassningsåtgärder vid dammar och vattenkraftverk.

Länsstyrelsen Västra Götalands län, n.d. b. Natura 2000.

Lejon, A., Malm Renöfält , B., Nilsson, C., 2009. Conflicts Associated with Dam Removal in Sweden.

Leonardsson, K., 2012. Modellverktyg för beräkning av ålförluster vid vattenkraftverk. Elforsk 12:36, Stockholm.

Malm Renöfält , B., Ahonen, J., 2013. Ekologiska flöden och ekologiskt anpassad vattenreglering. Tech. rep.

Malm Renöfält , B., Jansson, R., Nilsson, C., 2010. Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. Freshwater Biology 55 (1), 49–67, Available at: *http://doi.wiley.com/10.1111/j.1365-2427.2009.02241.x* [Accessed: January 27, 2014].

Malm Renöfält, B., Nilsson, C., 2005. Miljöanpassade flöden, Sammanställning av forskning och utveckling med avseende på flödesregimer. Tech. rep., Umeå University, Umeå, Sweden.

Melin, L., 2010. Potentially conflicting interests between Hydropower and the European Unions Water Framework Directive. Ph.D. thesis, Lund University.

Miller, V. B., Landis, A. E., Schaefer, L. a., Mar. 2011. A benchmark for life cycle air emissions and life cycle impact assessment of hydrokinetic energy extraction using life cycle assessment. Renewable Energy 36 (3), 1040–1046.

Nationalencyklopedin, n.d. . plankton. Available at: *http://www.ne.se/lang/plankton* [Accessed: May 14, 2014].

Naturskyddsföreningen, 2013. Utredning om vattenkraft hjälper Sverige att slippa hamna i EU-domstolen. Available at: *http://www.naturskyddsforeningen.se/nyheter/utredning-om-vattenkraft-hjalper-sverige-att-slippa-hamna-i-eu-domstolen* [Accessed: February 26, 2014].

Naturvårdsverket, 2003. Flöden i vattendrag - Bakgrundsrapport till Miljökvalitetsnormer för flöden/nivåer i rinnande vatten - redovisning av ett regeringsuppdrag (NV rapport 5292), nv rapport Edition. Naturvårdsverket, Stockholm.

Naturvårdsverket, 2008. Naturvårdsverkets författningssamling.

Naturvårdsverket, 2012. Natura 2000 - Naturvårdsverket.

Naturvårdsverket, 2013. Naturvårdsverket - områdesbeskrivning.

Nilsson, C., Rådén, R., 2012. Biologisk effektuppföljning i Tattarströmmarna , Häggån juni 2012 Undersökning av bottenfauna och flodpärlmussla samt.

Nilsson, P.-A., Rådén, R., 2007. Bottenfaunan vid två lokaler i Slottsån 2007. Tech. Rep. 556389, Medins Biologi AB, Mölnlycke.

Norconsult, 2011. Fiskevårdsplan för Viskan Från mynningen i havet upp till Kungsfors.

NSW Department of Primary Industries, n.d.. Fishways | NSW Department of Primary Industries. Available at: *http://www.dpi.nsw.gov.au/fisheries/habitat/rehabilitating/fishways#pool* [Accessed: April 24, 2014].

Nyström, J., 2011. De okända hoten mot ålen | Forskning & Framsteg | Populärvetenskapligt magasin. Available at: *http://fof.se/tidning/2011/10/de-okanda-hoten-mot-alen* [Accessed: March 25, 2014].

NyTeknik, 2014. Dammen revs för att rädda ålen. Available at: *http://www.nyteknik.se/nyheter/energi_miljo/vattenkraft/article3824656.ece* [Accessed: May 17, 2014].

Oak Ridge National Laboratory, the National Hydropower Association, the Hydropower Research Foundation, 2010. Environmental Mitigation Technology for Hydropower :. Tech. rep., Washington, DC.

Packer, N., 2011. Anatomy of a Small Scale Hydropower system (June).

Paish, O., 2002. Small hydro power: technology and current status. Renewable and Sustainable Energy Reviews 6 (6), 537–556, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S1364032102000060* [Accessed: March 18, 2014].

Pettersson, L., n.d.. Fiskvägar / Faunapassager.

Pöyry, 2012. Miljöförbättrande åtgärder vattenkraft, Delrapport 4: Småskalig vattenkraft, fiskvägar, miljöanpassade flöden, biotopvårdsåtgärder.

Raadal, H. L., Gagnon, L., Modahl, I. S., Hanssen, O. J. r., Sep. 2011. Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power. Renewable and Sustainable Energy Reviews 15 (7), 3417–3422.

Regeringskansliet, 2013. Ny tid ny prövning - förslag till ändrade vattenrättsliga regler. Available at: *http://www.regeringen.se/sb/d/16982/a/225262* [Accessed: February 26, 2014].

Sale, M. J., Cada, G. F., Chang, L. H., Christensen, S. W., Railsback, S. F., Francfort, J. E., Rinehart, B. N., Sommers, G. L., 1991. Environmental mitigation at hydroelectric projects Volume 1. Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage. Tech. Rep. December 1991.

Sempler, K., 2009. Vattenkraften värdefull vindkraftregulator - NyTeknik. Available at: *http://www.nyteknik.se/popular_teknik/teknikfragan/article261964.ece* [Accessed: May 15, 2014].

Sitka National Historical Park (U.S. National Park Service), 2014. Stream Ecology - Allochthonous Input. Available at: *http://www.nps.gov/sitk/naturescience/stream-ecology-allochthonous-input.htm* [Accessed: May 1, 2014].

Sjölander, E., Strömberg, M., Degerman, E., Göthe, L., Jougda, L., Schreiber, H., 2009. Åtgärdsplanering i reglerade vattendrag.

SMHI, 2009a. Jordens huvudklimattyper. Available at: *http://www.smhi.se/kunskapsbanken/klimat/jordens-huvudklimattyper-1.640* [Accessed: April 3, 2014].

SMHI, 2009b. Klimatförändringarna märks redan idag. Available at: *http://www.smhi.se/kunskapsbanken/klimat/klimatforandringarna-marks-redan-idag-1.1510* [Accessed: April 29, 2014].

SMHI, 2012. Växthuseffekten. Available at: *http://www.smhi.se/kunskapsbanken/vaxthuseffekten-1.3844* [Accessed: April 29, 2014].

Sørnes, K., 2010. Small-scale Water Current Turbines for River Applications (January).

Statens Offentliga Utredningar, 2013. Ny tid ny prövning. Stockholm.

Statistiska centralbyrån, 2014. Prisomräknaren - räkna på inflationen - Statistiska centralbyrån.

Ström, M., 2012. Småskalig vattenkraft: Dagsläge och framtidsplaner. Master thesis, Kungliga Tekniska Högskolan, Available at: *http://www.diva-portal.org/smash/record.jsf?pid=diva2:544010* [Accessed: February 7, 2014].

Svensk Energi, 2011. Korttidsreglering - Energilexikon.

Svensk Energi, 2012. Vattenkraft och Biologisk Mångfald - Goda exempel från elbranschen. Tech. rep.

Svenskt Näringsliv, 2014. Vattenkraften hotad av nya miljökrav. Available at: *http://www.svensktnaringsliv.se/fragor/miljoratt/vattenkraften-hotad-av-nya-miljokrav_210471.html* [Accessed: February 26, 2014].

Svensson, B. S., 2000. Hydropower and instream flow requirements for fish in Sweden. Fisheries Management and Ecology 7 (1-2), 145–155, Available at: *http://doi.wiley.com/10.1046/j.1365-2400.2000.00184.x* [Accessed: February 26, 2014].

SWECO Infrastructure, 2008. Hulta vattenkraftsanläggning Geoteknisk utredning. Tech. rep., Geoteknik, Göteborg.

Teodoru, C. R., Bastien, J., Bonneville, M.-C., del Giorgio, P. a., Demarty, M., Garneau, M., Hélie, J.-F., Pelletier, L., Prairie, Y. T., Roulet, N. T., Strachan, I. B., Tremblay, A., 2012. The net carbon footprint of a newly created boreal hydroelectric reservoir. Global Biogeochemical Cycles 26 (2), n/a–n/a.

Tranås Energi, 2012a. Tranås Energi - Vattenkraft. Available at: *http://www.limnologerna.org/VD2012/foredrag 2012/dag2 vattenkraft/MagnusLundberg.pdf* [Accessed: April 28, 2014].

Tranås Energi, 2012b. Tranås Energi AB Översikt. Available at: *http://www.vattenorganisationer.se/motalasodra/downloads/36/Tranas_energi.pdf* [Accessed: April 28, 2014].

Tranås Energi, n.d. a. Anpassad vattenkraft och naturvård. Available at: *http://www.tranasenergi.se/default.asp?initid=527&menutree=537&toplinkname=V%E5rtmilj%F6arbete&menuheading=V%E5rt milj%F6arbete&mainpage=templates/05.asp?sida=463* [Accessed: April 28, 2014].

Tranås Energi, n.d. b. Tranås Energi AB. Available at: *http://www.tranasenergi.se/default.asp?viewset=1&on=OmTranï£¡sEnergi&initid=347&heading=OmTranï£¡s Energi&mainpage=templates/05.asp?sida=265* [Accessed: April 28, 2014].

Tranås Energi, n.d. c. Våra anläggningar. Available at: *http://www.tranasenergi.se/default.asp?initid=527&menutree=537&toplinkname=V%E5rtmilj%F6arbete&menuheading=V%E5rt milj%F6arbete&mainpage=templates/05.asp?sida=463* [Accessed: April 28, 2014].

Tranås Energi, n.d. d. Vårt miljöarbete. Available at: *http://www.tranasenergi.se/default.asp?viewset=1&on=V%E5rtmilj%F6arbete&initid=527&he ading=V%E5rtmilj%F6arbete&mainpage=templates/08.asp?sida=456* [Accessed: April 28, 2014].

Tranås Kommun, 2012. Tranås Energi satsar på vattenkraft. Available at: *http://www.tranas.se/arkiv/nyhetsarkiv/tranasenergisatsarpavattenkraft.5.7ded76b9137e77 3257b80003.html* [Accessed: April 29, 2014].

Tremblay, a., Lambert, M., Gagnon, L., Mar. 2004. Do Hydroelectric Reservoirs Emit Greenhouse Gases? Environmental Management 33 (S1), 509–517.

Turconi, R., Boldrin, A., Astrup, T., Dec. 2013. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. Renewable and Sustainable Energy Reviews 28, 555–565.

Vattenmyndigheten Västerhavet, 2010. Åtgärdsprogram Västerhavets vattendistrikt 2009-2015.

Versa, R., 2009. Fiskvandring och biotopåtgärder.

VISS Vatteninformationsystem Sverige, 2013a. Vattendrag - Ätran: Svenljunga - sammaflöde med Assman. Available at: *http://www.viss.lansstyrelsen.se/Waters.aspx?waterEUID=SE6 37327-133786* [Accessed: February 28, 2014].

VISS Vatteninformationsystem Sverige, 2013b. Vattendrag - Häggån (från Frisjön till utlopp i Viskan). Available at: *http://www.viss.lansstyrelsen.se/Waters.aspx?waterEUID=SE6385 33-131840* [Accessed: February 27, 2014].

VISS Vatteninformationsystem Sverige, 2013c. Vattendrag - Hyltenäsån (mellan Öresjön och Tolken). Available at: *http://www.viss.lansstyrelsen.se/Waters.aspx?waterEUID=SE636906-130880&userProfileID=3* [Accessed: March 14, 2014].

VISS Vatteninformationsystem Sverige, 2013d. Vattendrag - Slottsån (från Ö Öresjön till utlopp i Viskan). Available at: *http://www.viss.lansstyrelsen.se/Waters.aspx?waterEUID=SE6 37559-130958* [Accessed: February 27, 2014].

VISS Vatteninformationsystem Sverige, n.d. . Vandringshinder - Oppeby Kvarn. Available at: *http://www.viss.lansstyrelsen.se/Measures/EditMeasure.aspx?measureEUID=VISSMEAS URE0107900* [Accessed: April 29, 2014].

von Sperling, E., 2012. Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects. Energy Procedia 18, 110–118, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S187661021200793X* [Accessed: April 29, 2014].

Vovk-korže, A., Korže, D., n.d. . Review of best practices / guidelines for compensation measures for hydropower About CH 2 OICE. Tech. rep.

Wengström, N., 2011. Biotopkartering av vattendrag i Slottsåns avrinningsområde 2003 Biologisk återställning i kalkade vatten. Tech. rep.

World Commission on Dams, 2000. Dams and Development - A new framework for decision-making. No. November. Earthscan Publications Ltd.

Xiaocheng, F., Tao, T., Wanxiang, J., Fengqing, L., Naicheng, W., Shuchan, Z., Qinghua, C., 2008. Impacts of small hydropower plants on macroinvertebrate communities. Acta Ecologica Sinica 28 (1), 45–52, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S1872203208600190* [Accessed: March 17, 2014].

Yüksel, I., 2010. Hydropower for sustainable water and energy development. Renewable and Sustainable Energy Reviews 14 (1), 462–469, Available at: *http://linkinghub.elsevier.com/retrieve/pii/S1364032109001592* [Accessed: May 7, 2014].

Appendices

Appendix A - Övergripande Sammanfattning

Nedan presenteras en längre sammanfattning av rapporten. Fokus ligger på de slutsatser som dragits i analysen och i rekommendationerna även om en kort del av litteraturstudien är inkluderad för förståelsens skull.

Bakgrund

Vattenkraftens historia går långt bak i tiden och började redan för över 2000 år sedan. I Sverige började vattenkraften att användas för att producera elektricitet i slutet av 1800-talet. Den stora utbyggnaden av vattenkraften skedde mellan 1940-1970 och idag finns över 2000 vattenkraftverk i Sverige. Av de 2000 vattenkraftverken är en stor majoritet så kallade småskaliga vattenkraftverk. Det finns idag ingen generell uppfattning om hur vattenkraftverken skall indelas och klassificeringen varierar mycket mellan olika länder. Även i Sverige varierar uppfattningen om hur vattenkraftverken skall indelas men det som verkar vara den mest rådande idag är att vattenkraftverk med installerad effekt över 10 MW skall klassificeras som storskaliga. Tillsammans utgör vattenkraften i Sverige idag den totala produktionen från vattenkraftverken 45 % av elektricitetsproduktionen.

Syfte och Metod

Syftet med examensarbetet var att undersöka vilken påverkan som de fyra vattenkraftverken som Borås Energi och Miljö äger har på miljön. De fyra vattenkraftverken, Haby, Hulta, Häggårda och Axelfors är småskaliga vattenkraftverk och byggdes i början av 1900-talet, under en tid då kraven på att undvika skador på miljön var små eller obefintliga. Under de två senaste åren har det varit en pågående utredning, vattenverksamhetsutredningen, om huruvida de vattenkraftverk som idag inte står under miljöbalken skall omprövas så att även de innefattas av de miljökrav som finns idag. Det betyder att det i framtiden kan komma ökande krav på att även äldre vattenkraftverk skall anpassas så att dess miljöpåverkan minskas. För att få kunskap om de olika effekterna som vattenkraftverk har på miljön startade projektet med en litteraturstudie där vetenskapliga artiklar och undersökningar och rapporter om vattenkraftverk studerades. I litteraturstudien inkluderades även rapporter och studier som behandlade specifikt de områden och miljön där de fyra vattenkraftverken ligger. Informationen från litteraturstudien användes i analysen för att kunna dra slutsatser om den miljöpåverkan som vattenkraftverken resulterar i. Litteraturstudien inkluderade också olika åtgärder som kan genomföras för att undvika eller minska den miljöpåverkan som vattenkraftverken resulterar i.

Litteraturstudie

Vattenkraften har länge ansetts som en miljövänlig energikälla med en mycket liten inverkan på miljön. Den miljöpåverkan som vattenkraften medför har dock fått allt mer uppmärksamhet och det är idag lätt att hitta information om de skador som vattenkraftverk faktiskt har på ekosystemen. Under konstruktionen och driften av vattenkraftverk är det ett antal faktorer i den omgivande miljön som påverkas och förändras. I ett orört vattendrag finns det flera naturliga variationer som är mycket viktiga för upprätthållandet av flera viktiga funktioner i ekosystemet. Till exempel så är basflödet viktigt för att upprätthålla lämpliga livsmiljöer för vattenlevande organismer och tillhandahålla vatten för de landlevande arterna. Höga flöden är viktiga för att rensa bort föroreningar och för att upprätthålla en bra vattenkvalitet. Löga flöden är viktiga för att förhindra att invasiva arter etablerar sig. När vattenflödet regleras till följd av ett vattenkraftverk i vattendraget innebär det att flera av de här viktiga funktionerna förhindras vilket kan få långtgående negativa följder på den omgivande miljön.

När ett vattenkraftverk och en damm byggs innebär det att vattnet går från att vara strömmande till mer lugnflytande. Vattenflödets hastighet ovan dammen reduceras vilket kan leda till sedimentation eftersom vattnets förmåga att bära sediment minskar, vilket innebär en ökad risk för sedimentation uppströms dammen. Det leder också till att vattnet nedströms innehåller mindre sediment eftersom sedimentet blivit kvar uppströms. Det kan orsaka erosion och också leda till att viktiga näringsämnen inte når arter som lever nedströms dammen.

Trots att det inte finns några större direkta utsläpp från vattenkraft som kan påverka vattenkvaliteten så innebär ändå konstruktionen och driften av vattenkraftverk att kvaliteten av vattnet kan påverkas. Då konstruktionen och driften av vattenkraftverk innebär att vattenflödet ändras kan det leda till att känsligheten för externa föroreningar ökar, det kan också orsaka temperaturförändringar, frisättning av ackumulerat kvicksilver i marken, och förändrad transport av olika ämnen, exempelvis kväve och fosfor.

Ett av de största problemen som vattenkraftverk medför är att de utgör vandringshinder för arterna som lever i vattendragen. Det medför att inte bara migrerande arter påverkas utan det har även negativa effekter på andra arter i ekosystemet. Ett exempel är flodpärlmusslan som under sitt larvstadie lever i gälarna på lax och öring. Både lax och öring är migrerande arter och när de hindras från att vandra i vattendragen påverkas även flodpärlmusslan. För arter som vandrar nedströms kan det finnas en chans att de kan ta sig igenom turbinen och på så sätt nå de nedströms liggande delarna även om det ofta medför skador eller till och med död. För arterna som vandrar uppströms innebär dock vattenkraftverken ett definitivt stopp.

Konstruktionen av vattenkraftverk med tillhörande reservoarer kan medföra utsläpp av växthusgaser. Den vegetation som översvämmas bryts ner och kan då skapa koldioxid och metan. Hur stora utsläppen av växthusgaserna blir beror på klimat och mängd vegetation. I tropiska klimat där stora mängder vegetation översvämmas samtidigt som det bildas anaeroba förhållanden påstår en del forskare att utsläppen av växthusgaser från vattenkraftverk kan vara av samma storlek som utsläppen av växthusgaser från kolkraftverk. Uppskattningarna på hur stora utsläppen är varierar dock mycket och för vattenkraftverk i boreala klimat uppvisar betydligt mindre utsläpp av växthusgaser.

När alla ovan beskrivna faktorer förändras innebär det att den biologiska mångfalden i ekosystem påverkas. Kunskapen om hur den biologiska mångfalden påverkas är idag begränsad men det går att se både direkt och indirekt påverkan. Det är också så att även om enbart en art påverkas direkt av vattenkraftverken innebär det i förlängningen att flera olika arter påverkas indirekt.

Analys

De båda vattenkraftverken Haby och Hulta är belägna i Slottsån som är ett biflöde till Viskan. För att kontrollera produktionen av elektricitet finns två uppströms belägna sjöar som används som reservoarer. För sjön Tolken är den tillåtna regleringsamplituden 2,5 m och för Öresjön är den tillåtna regleringsamplituden 2,8 m. Det är dock sällan den hela regleringsamplituden används utan regleringsspannet ligger på 1-1,5 m. I tabellerna nedan finns information om de båda vattenkraftverken samlade. Då de båda vattenkraftverken ligger i Slottsån med endast ett kort avstånd emellan är hydrologin för dem samma vilket också kan ses i tabellerna.

Table 1: Haby i siffror

Haby	
Avrinningsområde	413 km^2
Area som utgörs av sjöar	10.2 % or 42.2 km^2
Tolkens och Öresjöns area	24.1 km^2
Medelavrinning	17 l/s km^2 or 0.017 m^3/l km^2
Medelvattenflöde	7 m^3/s
Fallhöjd	27.8 meter
Turbin	Francis
Installerad effekt	5.3 MW
Byggår	1913-1915

Table 2: Hulta i siffror

Hulta	
Avrinningsområde	413 km^2
Area som utgörs av sjöar	10.2 % or 42.2 km^2
Tolkens och Öresjöns area	24.1 km^2
Medelavrinning	17 l/s km^2 or 0.017 m^3/l km^2
Medelvattenflöde	7 m^3/s
Fallhöjd	13 meter
Turbin	Francis
Installerad effekt	2.57 MW
Byggår	1916-1917

Genom att gå in på Vatteninformationssystem Sverige (VISS) är det möjligt att se vilken klassificering vattendragen i Sverige har. Det är en del av det vattendirektiv som finns i EU där målet är att vattendragen skall uppnå god ekologisk status och arbetet skall ske utifrån avrinningsområdena och inte utifrån nationella eller politiska gränser. Slottsån har idag en måttlig ekologisk status med en risk att god ekoligisk status inte kommer uppnås till år 2021. Det första målet var uppsatt till år 2015 men eftersom det anses tekniskt omöjligt att god ekologisk status kan uppnås till dess har målet blivit framflyttad till år 2021. Det som är det största hindret för att god ekologisk status skall kunna uppnås är att de vattenkraftverk, Haby och Hulta, som finns i Slottsån utgöt definitiva vandringshinder. De fiskar som innan konstruktionen av vattenkraftverken kunde vandra hela vägen från Viskan och upp till Öresjön når idag bara en liten bit in i Slottsån. En annan faktor som också har stor inverkan på miljön är hur regleringen av vattenflödet i Slottsån sköts. Genom att titta på hur produktionen av elektriciteten är det möjligt att se att produktionen i Haby och Hulta varierar mycket över korta tidsintervaller. Det produceras elektricitet på dagen när behovet är stort och på natten när efterfrågan är mindre, sker ingen produktion alls. Eftersom det inte finns några krav på ett minimiflöde innebär det stora variationer i vattenflödet. Ibland kommer inget vatten alls nedströms och ibland kommer det mycket. Regleringen av Haby och Hulta uppvisar ett tydligt exempel på korttidsreglering. Det är den sorts av reglering som har störst negativ effekt på omgivningen eftersom arterna som lever nedströms har svårt att anpassa sig till de stora förändringarna som sker i vattenflödet. Vid byggnationen av de båda vattenkraftverken skedde det även en avledning av vattenflödet från den ursprungliga vattenfåran vilket har orsakat torrfåror idag där inget vattenliv kan existera. I en del av litteraturen om Haby har det gått att läsa att tillflödet av vatten från biflöden i torrfåran är såpass stort att torrfåran enbart är helt torrlagd precis nedströms dammen. Efter ett besök vid torrfåran kan det dock konstateras att det finns ett visst tillflöde av vatten men att det absolut inte är av en sådan storlek att det möjliggör för något fiskliv i fåran.

Även för Häggån är klassificeringen idag satt till måttlig ekologisk status med en risk att god ekologisk status inte kommer att uppnås till år 2021 och även här är det de vandringshinder som finns i vattendraget som utgör det största problemet. Det är inte längre möjligt för arterna i vattendraget att vandra så som de en gång har kunnat. Regleringen för Häggårda skiljer sig en del från regleringen av Haby och Hulta. Produktionen ligger här på en betydligt jämnare nivå och de stora skillnaderna i vattenflödet går inte att se här. Då det även finns ett krav på ett minimiflöde innebär det att även när det inte produceras någon elektricitet så släpps det vatten vilket innebär att det inte uppstår situationer när inget vattenflöde alls når nedströms vattenkraftverket. Nedström Häggärda finns det idag ett Natura 2000-område vilket innebär att miljön där anses extra skyddsvärd. Det är främst två olika naturtyper/arter som skall skyddas, flodpärlmusslan och svämlövskogen. Trots detta är både svämlövskogen och flodpärlmusslan idag negativt påverkade av regleringen i Häggån. Även öringen anses vara negativt påverkad av regleringen. Även i Häggårda finns det en torrfåra som ett resultat av konstruktionen av vattenkraftverket där det forna vattenlivet idag är förstört. I tabellen nedan visas en kort sammanställning över bland annat hydrologi och lite andra siffror som rör Häggårda.

Table 3: Häggårda i siffror

Häggårda	
Avrinningsområde	150 km^2
Area som utgörs av sjöar	7.2 % or 10.8 km^2
Frisjöns area	6.8 km^2
Medelavrinning	17 l/s km^2 or 0.017 m^3/l km^2
Medelvattenflöde	2.5 m^3/s
Fallhöjd	28.5 meter
Turbin	Francis
Installerad effekt	1.79 MW
Byggår	1906-1908

Axelfors följer samma mönster som de tidigare vattenkraftverken när det gäller ekologisk status. Skillnaden här var att det inte gick att kolla på hela Ätran då det är ett såpass långt vattendrag och dessutom den nedströms liggande delen av vattendraget större påverkan från regleringen av de vattenkraftverk som ligger där än den övre halvan av Ätran. Trots det så uppvisar den delen av Ätran där Axelfors ligger måttlig ekologisk status med en risk att god ekologisk status kommer att uppnås till år 2021. Även här är det vandringshindrena som är det stora problemet. Ett tydligt exempel på hur svårt det är för den migrerande fisken är att kolla på överlevnadschansen för de ålar som lever uppströms Axelfors och skall vandra till havet. I genomsnitt har ålarna en chans på 30 % att klara sig levande förbi passagen av ett vattenkraftverk. Ålen som lever uppströms Axelfors behöver passera sju vattenkraftverk innan den når havet. Det innebär att endast 0.02 % av de ålar som påbörjar vandringen kommer nå havet. Även för ålen levande uppströms de andra vattenkraftverken ser situationen dyster ut även om de inte behöver passera riktigt lika många vattenkraftverk.

$$100\, \text{ålar} * (0.3)^7 = 0.002 \rightarrow 0.02\%$$

Axelfors skiljer sig från de andra vattenkraftverken då det är ett strömkraftverk och inte ett reglerkraftverk. Det innebär att vattenflödet inte regleras utan produktionen följer tillgången på vatten och det finns inte heller någon sjö här som regleras. Det betyder att den påverkan från regleringen som finns är mindre här än vad den är i de övriga tre vattenkraftverken. Även här har det dock skapats en torrfåra där det idag inte är möjligt för något vattenliv att existera. I tabellen nedan visas en kort sammanställning om Axelfors.

Table 4: Axelfors i siffror

Axelfors	
Avrinningsområde	1028 km^2
Area som utgörs av sjöar	5.9 % or 60.6 km^2
Medelavrinning	12 l/s km^2 or 0.012 m^3/l km^2
Medelvattenflöde	12 m^3/s
Fallhöjd	11 meter
Turbin	Kaplan
Installerad effekt	2.57 MW
Byggår	1935-1936

Genom att jämföra informationen från litteraturstudien med informationen om de fyra vattenkraftverken har det gått att konstatera att de fyra vattenkraftverken troligen inte har någon negativ påverkan på sedimentation och vattenkvalitet. Inte heller storleken på utsläppen av växthusgaser är något problem då de kan anses vara små vilket också stämmer överens med att det främst är i tropiska klimat problemet med stora utsläpp av växthusgaser uppstår. Genom att titta på livscykelanalyser gjorda på vattenkraftverk i boreala klimat, vilket på ett ungefär stämmer överens med området där vattenkraftverken ligger, uppskattas utsläppen ligga på 3-14 g CO_2-ekvivalenter/kWh. De utsläpp som finns idag kommer ifrån renoveringar och underhåll.

Rekommendationer

I litteraturstudien ingick också en del där olika åtgärder för att minska eller undvika miljöpåverkan från vattenkraftverk undersöktes. Efter att ha konstaterat vilken sorts miljöpåverkan de fyra olika vattenkraftverken har är det också möjligt att dra slutsatser över vad som behöver göras för att förbättra situationen. För att möjliggöra vandring i vattendragen behöver fiskvägar byggas. Det är viktigt att fiskvägarna konstrueras så att så många arter som möjligt kan dra nytta av dem. Många av de fiskvägar som finns idag är konstruerade så att endast några få arter klarar av att ta sig igenom dem. Det innebär att fiskvägen får begränsad nytta. Det är också viktigt att underlätta passagen förbi kraftverken för ålarna. De ålar som idag vandrar ut till havet har mycket liten chans att överleva den resan. Det är också så att de ålplaner som idag finns för Viskan och Ätrantroligen har en betydligt sämre effekt för ålarna överlevnadschans än om det hade funnits fungerande ålledare.

För att förbättra situationen för arterna i vattendraget bör biotopåtgärder utföras så att forna lekområden återställs. Detta för att förbättra reproduktionsmöjligheterna och för att minska risken för predation för en del arter.

Som nämnt har det skapats torrfåror vid alla de fyra olika vattenkraftverken. I dessa bör det släppas ett vattenflöde så att det vattenliv som en gång har existerat i dem kan komma tillbaka. Det bör också släppas någon sorts minimiflöde så att de tillfällen när det inte släpps något vatten alls genom vattenkraftstationerna upphör. Även regleringen bör ses över och speciellt då regleringen i Haby och Hulta så den korttidsregleringen som finns idag kan undvikas. Redan idag så används inte hela den regleringsamplitud i de tre sjöarna Öresjön, Tolken och Frisjön som Borås Energi och Miljö hat tillåtelse till enligt vattendomarna vilket är bra men även i fortsättningen bör regleringen skötas så att de önskemål som finns om att inte skada storlommen, gäddan och klockgentianan när de är som känsligast uppfylls.

Det är också viktigt att komma ihåg att flera av de nämnda rekommendationerna ovan hänger samma. Byggs det fiskvägar så behöver de släppas ett minimiflöde i dem vilket kan minska den påverkan som finns från regleringen. Det är också möjligt att fiskvägarna hamnar i anslutningen till torrfårorna vilket innebär att vattenlivet kan komma tillbaka till dem. Så även om det låter som många rekommendationer så hänger flera av dem ihop.

Appendix B - Interview with Tranås Energi

Interview with Elina Gahm, Quality and Environmental Coordinator at Tranås Energi. Mail contact 25/4.

In English:

1. What have you done to reduce the environmental impact at your hydro power plants? (as for example, built fishway.) *We have built two bypass fishways and a Denil fishway, removed a dam and raised the minimum flow*.
2. Why did you do these actions? What made you take the decision to make them? *Firstly, we wanted to take responsibility for our environmental impact, and secondly, we had a feeling that requirements and legislation would be tougher on this, and we saw a profit in the long run to invest in the environment. Then we had a good support from the Länsstyrelsen, the municipality and other expertise that could help us to get to it in the best way.*
3. Have you noticed any positive/negative differences in ecological and economic aspects? *We have seen trout and otters, which is a sign that the measures worked and that biodiversity has benefited. We have received many positive reactions from customers and the surroundings, which had led to increased economic growth.*
4. Given that you have built fishways and also raised the minimum flow, is this something that has reduced your production (given the less water through the turbines)? And has this been noticeably for your economic activity? *It is clear that these measures reduce production somewhat and that we not get the maximum economic efficiency in the same way, but we do not consider that it is constitutes a significant impact on our business. With the ecological values we win so we think it's worth it.*
5. What do you plan for the future? Do you have more plans for improvement? *We continue the greening of our facilities. Plans exist to remove more obstacles to migration and to build more fishways.*
6. I read that you have plans to use a new screw technology, is this something you still planning to get started? *It is true that we shall restore the hydro power of one of our facilities with a new fish friendly screw technology. We are currently applying for an environmental permit for this.*
7. How do you see the water activity investigation? *Since we already prioritize greening of our facilities, we are not so much affected. We think it's important that you take responsibility but then it is of course also true that not everyone has the same opportunities to implement these*

actions because they cost a lot of money.

Original Version in Swedish:

1. Vad har ni gjort för att minska miljöpåverkan vid era kraftverk (ex. byggt fiskväg)? *Vi har byggt två fiskomlöp och en fisktrappa, rivit ut en damm och höjt minimitappningen.*
2. Varför gjorde ni dessa åtgärder? Vad fick er att ta besluten att göra dem? *Dels ville vi ta ansvar för vår miljöpåverkan och dels hade vi på känn att krav och lagstiftning skulle bli hårdare på detta och vi såg en lönsamhet på sikt att investera i miljön. Sedan hade vi ett gott stöd av länsstyrelsen, kommunen och annan expertis som kunde hjälpa oss att få till det på bästa sätt.*
3. Har ni märkt någon positiv/negativ skillnad i ekologiska och ekonomiska aspekter? *Vi har sett öring och utter, vilket är ett tecken på att åtgärderna fungerat och att den biologiska mångfalden har gynnats. Vi har fått många positiva reaktioner från kunder och omgivning som lett till ökad ekonomiskt tillväxt.*
4. Med tanke på att ni byggt fiskvägar och även höjt minimitappningen, är detta något som minskat er produktion (med tanke på mindre vatten genom turbinerna)? Har detta då varit märkbart för er ekonomiska verksamhet? *Det är klart att dessa åtgärder minskar produktionen något och att vi inte får maximal ekonomisk lönsamhet på samma sätt, men vi anser inte att det utgör en märkbar påverkan på vår ekonomiska verksamhet. Med de ekologiska värden vi vinner så tycker vi att det är värt det.*
5. Hur tänker ni inför framtiden? Har ni fler planer på förbättringsarbete? *Vi fortsätter miljöanpassningen av våra anläggningar. Planer finns på att undanröja fler vandringshinder och bygga fler fiskvägar.*
6. Läste att ni har planer för att använda en ny skruvteknik, är detta något ni fortfarande planerar att sätta igång? *Det stämmer att vi ska återuppta vattenkraften i en av våra anläggningar med en ny fiskvänlig skruvteknik, glömde nämna det ;) Vi håller just nu på att ansöka om miljötillstånd för detta.*
7. hur ser ni på vattenverksamhetsutredningen? *Eftersom vi redan prioriterar miljöanpassning av våra anläggningar påverkas vi inte så mycket av vattenverksamhetsutredningen. Vi tycker det är viktig att man tar sitt ansvar men sedan är det naturligtvis också så att alla inte har samma förutsättningar för att genomföra dessa åtgärder då de kostar mycket pengar.*

Appendix C - Interview with Falkenberg Energi

Interview with Jens Melin, Environmental Manager at Falkenberg Energi. Telephone 16/5.

In English

1. What have you done to reduce the environmental impact at your hydropower plants (as for example, built fishway.)? *We have built a fishway for the upstream migratory salmon and also an eel and elver fishway for the upstream migrating eels. This has although not helped the downstream migration which has continued to be a problem. Recently, we have removed our dam construction and thus have been able to re-create free flowing streams and promote free migration in both directions. The hydropower plant closest to the removed dam will now only be run in the winter at high water flows.*
2. Why did you do these actions? What made you take the decision to make them? *What led us to our decision about removing the dam was that we got a requirement from Kammarkollegiet. They demanded that something had to be done to improve the downstream migration of fish. A proposal from Kammarkollegiet was to build a culvert, Falkenberg Energi was uncertain about this solution and chose to start an investigation in collaboration with the University of Karlstad. The study involved examining the fish in the stream and also to look at their migration pattern. Different alternative measures were examined to find out which solution would be best for the site. In the investigation, they concluded that the best solution was to remove the dam, simply to go "all in".*
3. Have you noticed any positive/negative differences in ecological and economic aspects? *Economically, we have noticed a difference because we have been producing less electricity. Our production at the plant has decreased from 13 GWh to 8 GWh per year. But we also expect to have a positive economic impact from for example increased fishing activities and tourism. However, it is too early to evaluate this effect. Ecologically speaking, we have already seen a positive difference. In collaboration with studies from the University of Karlstad, downstream migrating fish has been counted by being collected in a trap. This study has been going on for a few years so the study has also been going on before the dam was removed, which means that a difference can be seen when comparing before and after. The result we have been able to see is that the amount of salmon smolts have increased to twice as many as it was before. Since not all the fish go into the trap, but also goes in the stream on the side, the smolts have been radio labelled. After the fish have been labelled they have been placed back upstream and then we have been able to see how many that have been collected in the trap and how many that have been swimming in the side stream. The result we can see out of this is that the number of fish has increased by a factor of four compared to before the dam was removed.*

4. What do you plan for the future? Do you have more plans for improvement? *We feel that we have done what we can to improve the fish migration right now. What we can do more, and what we shall do, is to continue with the evaluation of our work.*
5. How do you see the water activity investigation? *As we already done the work that could come to be needed if hydropower plants should start to be re-investigated according to the water activity investigation, we do not see any problem with it. I myself am very indecisive in the question. While I think that the electricity we get from hydropower is very important for Sweden as a country, I also in the meantime think that we need to protect the environment.*

Original in Swedish

1. Vad har ni gjort för att minska miljöpåverkan vid era kraftverk (ex. byggt fiskväg)? *Vi har byggt en laxtrappa för uppvandrande lax och en krypränna för uppvandrande ål, detta har dock inte hjälpt för nedvandringen av fisk som har fortsatt att vara ett problem. Nyligen så har vi rivit fördämningen vid kraftverket och på så sätt kunnat återskapa forsen och främja fria vandringsvägar åt båda hållen. Det kraftverk som ligger närmst den rivna fördämningen kommer nu bara att köras vintertid vid höga vattenflöden.*
2. Varför gjorde ni dessa åtgärder? vad fick er att ta besluten att göra dem? *Det som fick företaget att ta beslut om att riva fördämningen var ett krav från Kammarkollegiet. De krävde att något var tvunget att göras för att förbättra nedvandringen av fisk. Ett förslag från Kammarkollegiet var att bygga en kulvert, Falkenberg Energi var dock osäkra på denna lösning och valde att starta en utredning i samarbete med Karlstads Universitet. Utredningen innebar att studera fisken i forsen och se på dess vandringsmönster. Olika åtgärdsalternativ utreddes för att ta reda på vilken lösning som skulle passa bäst. I utredningen kom de fram till att den bästa lösningen var att riva fördämningen, at helt enkelt gå "all in!".*
3. Har ni märkt någon positiv/negativ skillnad i ekologiska och ekonomiska aspekter? *Ekonomiskt sett har vi märkt skillnad i och med att vi har producerat mindre elektricitet. Vår produktion vid kraftverket har minskat från 13 GWh till 8 GWh per år. Men vi förväntar oss även att få en positiv ekonomisk effekt från bland annat ökat fiske och ökad turism. Det är dock allt för tidigt för att kunna utvärdera denna effekt. Ekologiskt sett har vi redan sett en positiv skillnad. I samarbete med studier från Karlstads Universitet så räknas den nedvandrande fisken som fångas i en utsatt fälla. Detta har pågått i några år så studien har även pågått innan fördämningen revs, vilket gör att man kan se en skillnad på före och efter. Resultatet man har kunnat se är att lax smolt har ökat till dubbelt så många. Då inte alla fiskar går i fällan utan också går i forsen vid sidan om har man radiomärkt smolt. Efter att de har märkts har man satt tillbaka dem uppströms och därefter kunnat se hur många som gått till fällan och hur många som gått i forsen. Resultatet utav detta är att man kan se att antalet fisk har ökat med en faktor fyra, jämfört med innan fördämningen revs.*
4. Hur tänker ni inför framtiden? Har ni fler planer på förbättringsarbete? *Fiskmässigt känner*

vi att vi är framme och det vi kan göra nu är att fortsätta med utvärderingar över vårt arbete.
5. Hur ser ni på vattenverksamhetsutredningen? *Då vi redan utfört arbetet som skulle kunna komma till att behövas om vattenkraften skall börja utredas så ser vi inga problem med det. Själv är jag väldigt kluven i frågan. Samtidigt som jag tycker att elektriciteten vi får från vattenkraften är mycket viktig för Sverige tycker jag också att vi behöver skydda miljön.*