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Visualizing water system services and assessing risks to drinking water sources

A case study of Mjörn and Sollebrunn-Gräfsnäs

Master's thesis in Master's Program Infrastructure and Environmental Engineering

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Abstract

Water is essential to sustain life and the protection of water sources is an increasingly important issue. However, implementing water protection measures can be difficult due to economic factors, time constraints or political motives. Recently, the ecosystem services framework has been modified to aid in the implementation of water protection measures, which are called water system services. This thesis is focused on investigating how the concept of water system services (WSS), i.e. services provided by water sources to society, can be included when performing a risk assessment for the protection of water sources. Visualizing the WSS in an effective and informative way is a key step to show what services and the importance of the services that the water sources can provide. The water sources that are investigated in this report are Lake Mjörn and Sollebrunn-Gräfsnäs aquifer. To start the investigation, a thorough literature review on the subject of water protection and visualization was performed. A previously made list of WSS was used to identify existing services for the water sources. Identified hazards were then connected to the existing services. The identified WSS and the connection to the hazards were visualized, and if there were hazards that were also a service these were visualized as well. To exemplify, a risk assessment was then performed for one hazard at each water source. The identified WSS was given scores based on decided parameters and the specific threats of the hazards. The key result of the study is a strategy for how to incorporate WSS into risk assessment for potential or existing drinking water sources. The visualizations presented are examples of how the relation between WSS and hazards can be illustrated for different stakeholders and recipients. In conclusion, including WSS in the risk assessment provides a bigger picture than just looking at the service of drinking water and the developed method can be used in the process of creating a water protection area.

Keywords: risk assessment, visualization, water protection, water system services.

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Sammanfattning

Vatten är en väsentlig del för liv och skydd av vattenkällor är ett uppkommande och viktigt problem. Trots detta kan det vara svårt att implementera skyddande åtgärder på grund av ekonomiska faktorer, brist i tid eller politiska motiv. En modifikation av ramverket kring ekosystemtjänster har nyligen skapats för att underlätta arbetet kring vattenskydd, vilket har benämnts som vattensystemtjänster (WSS). Denna uppsats har som fokus att undersöka hur konceptet kring vattensystemtjänster, dvs. tjänster som vattenkällor tillhandahåller samhället, kan inkluderas vid en riskbedömning för att skydda vattentäkter. Att visualisera vattensystemtjänster på ett effektivt och informativt sätt är ett viktig steg i att visa vilka tjänster och vikten av de tjänster som vattentäkterna kan tillhandahålla. Vattenresurserna som undersöks i denna rapporten är sjön Mjörn och akivfären Sollebrunn-Gräfsnäs. För att inleda undersökningen gjordes en grundlig litteraturgenomgång i ämnet vattenskydd och visualisering. En tidigare upprättad lista över vattensystemtjänster användes för att identifiera befintliga tjänster för vattentäkterna. Identifierade faror kopplades sedan till de befintliga tjänsterna. De identifierade vattensystemtjänsterna och kopplingen till farorna visualiserades, och om det fanns faror som också var en tjänst visualiserades även dessa. För att exemplifiera, utfördes en riskbedömning för en riskkälla vid varje vattentäkt. De identifierade vattensystemtjänsterna gavs poäng baserat på förbestämda paramterar och de specifika hoten för faran. Resultatet av studien är en strategi för hur vattensystemtjänster kan inkluderas i en riskbedömning för potentiella eller befintliga vattentäkter. Visualiseringarna som presenteras är exempel på hur relationen mellan vattensystemtjänster och faror kan illustreras för olika intressenter och mottagare. Sammanfattningsvis ger riskbedömningen av vattenförsörjningssystem en större helhetsbild än att bara titta på dricksvattenförsörjningen, och den utvecklade metoden kan användas i processen för att skapa ett vattenskyddsområde.

Nyckelord: riskbedömning, visualisering, vattenskydd, vattensystemtjänster.

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Alice Andreasson & Frida Cederqvist, Gothenburg, June 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CICES	Common International Classification of Ecosystem Service
DWD	Drinking Water Directive
EC	European Commission
EQSD	Environmental Quality Standard Directive
ES	Ecosystem Services
EU	European Union
MA	Millenium Ecosystem Assessment
PBL	Planning - and Building act (Swe. Plan- och bygglagen)
SEPA	Swedish Environmental Protection Agency (Swe. Naturvårdsverket)
SGU	The Geological Survey of Sweden (Swe. Sveriges Geologiska Undersökning)
SSNC	The Swedish Society for Nature Conservation (Swe. Naturskyddsföreningen)
SwAM	Swedish Agency for Marine and Water Management (Swe. Havs- och vattenmyndigheten)
UN	United Nations
WFD	Water Framework Directive
WHO	World Health Organization
WISS	Water Information System Sweden (Swe. Vatten Informations System Sverige)
WSP	Water Safety Plan
WSS	Water System Services

Glossary

Below is a glossary with words that have been used throughout this thesis listed in alphabetical order:

Aquifer	*"A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater"* (EC, 2000).
Catchment area	*"The area of ground within the water flows to a lake. The boundary is defined as the surface watershed and shoreline. The area of the catchment area for a lake is equal to the watershed for the outlet of the lake minus the lake area"* (SwAM, 2021).
Contamination	...*"the presence of a substance where it should not be or at concentrations above background"* (Chapman, 2007).
Ecosystem services	...*"the contributions that ecosystems make to human well-being"* (Haines-Young & Potschin, 2018).
Good water status	A measure of the chemical and the ecological status in Swedish water sources (Svenskt Vatten, 2021c).
Groundwater	...*"all water which is below the surface of the ground in the saturation zone and direct contact with the ground or subsoil"* (EC, 2000).
Groundwater source	Water within an aquifer (EC, 2000).

Hazard	A source or situation that can cause ... *"physical injury or damage to health, property or environment"* (International Electrotechnical Commission, 1995).
Hazardous event	The event which causes a release of hazardous substances. These substances can be toxic, persistent and liable to bio-accumulate, as well as substances which give rise to a similar level of concern (EC, 2000).
Hazard source	The activity or business that can cause a hazardous event (SwAM, 2021).
Pollution	When the contaminants reach a harmful level and can not be reversed. (Chapman, 2007).
Risk	The probability and consequence of a hazardous event occurring, together with the vulnerability of the water source.
Risk assessment	*"The process of identifying, analyzing and evaluating the risk"* (SwAM, 2021).
Surface water	Inland waters excluding groundwater (EC, 2000).
Watershed	The area of both water and ground which a surface divider defines the boundaries and within the runoff have the same outlet in a watercourse (SwAM, 2021).
Water protection area	An area within regulations are established to protect a water source (The Swedish Parliament, 1998b).
Water protection regulations	Regulations that manage identified risks in the water protection area, and are a complement to the environmental legislation (SwAM, 2021).
Water source	A water body used for extraction of water for drinking, heat recovery, irrigation or water plant (SwAM, 2021).
Water system services	... *"the aspects of drinking water sources utilized to produce human well-being"* (Gärtner et al., 2022).

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1 Introduction

In this chapter, the background to the thesis is presented. The aim and objectives as well as limitations are also defined.

1.1 Background

The supply of safe and accessible freshwater is essential to sustain life and improving the access to these water sources can be beneficial to human health (WHO, 2022). The global demand for freshwater has been increasing for the last decades with driving factors such as increasing population and changing consumption patterns (Mekonnen & Hoekstra, 2016). These freshwater sources are exposed to different risks, for example, discharged wastewater (Shuval, 2003). About 80% of the wastewater produced globally is released back to the environment without treatment and the released wastewater can contain millions of pathogens that can cause endemic diseases (Shuval, 2003; UN, n.d.). In 2017, almost ¾ of a billion people lacked access to basic water services (UN, 2019). Countries across the globe have started to realize the importance of adequate water resource management but implementation of these can be restrained due to human and financial resources (UN, 2019).

In Sweden, access to water resources is generally good, but one of the main problems is eutrophication (Svenskt Vatten, 2016, 2021c). Many of the water sources do not achieve good water status, which is a measure of the chemical and ecological status in Swedish water sources (Svenskt Vatten, 2021c). With climate changes, the drinking water sources in Sweden are predicted to become more polluted compared to the current situation and for some parts of Sweden, water scarcity will become a problem (Svenskt Vatten, 2021c). Protection of water at the source is therefore important since this can prevent further treatment at water treatment plants (Svenskt Vatten, 2021b). This can be done by establishing water protection areas, which is a complicated process with several steps that need to be carried out with a systematic approach (SwAM, 2021).

A water protection area is established to protect water sources used for drinking water, heat recovery or irrigation (SwAM, 2021). When developing a water protection area and the associated water protection regulations, a risk assessment from the drinking water producer is needed. The Drinking Water Directives require a risk-based strategy for water supply, and the Water Safety Plans recommended by the World Health Organization (WHO) include a risk assessment (EC, 2020; WHO, 2022). The basic idea with a risk assessment is to calculate every potential risk and if the risk is not acceptable, measures to reduce the risk can then be evaluated (WHO, 2022).

When conducting risk assessments for water sources, it is important to avoid overlooking the additional services that can be provided by the water sources beyond drinking water (Gärtner et al., 2022). These services could be pollination by spreading of seeds by water, recreational purposes, agricultural production and prevention of subsidence (Gärtner et al., 2022; WHO, 2023). However, these services are rarely accounted for in risk assessment (Postel & Thompson, 2005). Gärtner et al. (2022) created a list of these additional services, called Water System Services (WSS), and describes how they can be included in risk assessment. The concept of WSS is created by (Gärtner et al., 2022) and is the services the water provides for human well-being. The list is a modification of the one with Ecosystem Services (ES) based on the Common International Classification of Ecosystem Services (CICES) framework. The WSS list has only been used once in a risk assessment for a drinking water source in Sweden, and to see if the list applies to different drinking water sources, further evaluation is needed. Furthermore, to facilitate the communication of water system services and related risks, new approaches for visualizing them should be developed which can help drinking water producers in communication. Additional studies to further integrate WSS into risk assessments are also needed to provide useful tools that can be applied in the water sector. Therefore this study will investigate how WSS can be visualized and integrated into risk assessments.

1.2 Aim & Objectives

The overall aim of the project is to apply and evaluate the concept of WSS to demonstrate and visualize the link between hazards and the benefits to society provided by drinking water sources.

The specific objectives are:

- To apply and evaluate the concept of WSS (using an existing list of services) and identify hazards to two drinking water sources in Sweden, one surface water and one groundwater source.
- To develop a suitable approach for visualizing and highlighting the different WSS provided by a water source and how they are affected by or causing different hazards. The visualization should facilitate communication between stakeholders.
- For one hazard from each water source, develop a strategy for how to assess and quantify the risk to the drinking water service and other relevant WSS.

1.3 Limitations

Important limitations for the study are:

- The conditions are for Swedish water sources and the results are not necessarily applicable to water sources with different conditions.
- The evaluation of the WSS is limited to two water sources in Sweden.
- Only the hazards that are present within the watershed for the lake and the area of the aquifer are included in this study. The reason for this is to limit the work according to the time frame of the project and to have a clear boundary of which hazards to include. The lake and the aquifer are affected by the upstream rivers, but this is excluded in the report.
- Potential WSS and possible future hazards will be identified but only the ones existing today will be evaluated further.
- The risk due to a limited number of hazards is calculated for each water source. More hazards exist but a thorough risk assessment will only be developed for the chosen hazards.
- No recommendations of measures or water protection areas will be given. It will only be discussed how the risk assessment can be used to reduce the risk. The report focuses on developing a strategy and does not give final recommendations for the studied water sources.

2

Theoretical background

The Roman Empire viewed fresh water as an important resource that could benefit both individuals and the state if taken care of properly (Bannon, 2017). The earliest evidence of legislation on fresh water is from the *Twelve Tables*, which is a written legislation by the Roman Law dating back to 451–450 BC (Bannon, 2017; Encyclopaedia Britannica, 2018). With time, people started to recognize that some waters were contaminated, while some were not, leading to the realisation that you cannot judge a water source by just your senses (US EPA, 1999). In the 1800s scientists gained greater knowledge of drinking water contaminants. For example, Dr. John Snow proved in 1855 that cholera is a waterborne disease and in the late 1880s Louis Pasteur described how microbes could be transported through media like water.

When looking at Sweden, the earliest water-related legislation came in 1941 (Carlberg, 1975). The purpose of this legislation was to regulate the discharge of untreated wastewater into lakes and rivers. Towards the end of the 1960s, new legislation and technologies were developed to prevent further pollution of water sources (Liedberg & Olsson, 1975). The area of water protection is ever-changing as new ideas and perspectives are introduced. In the following sub-chapters, authorities, laws, regulations, guidelines and objectives that have been developed and are used today are presented. The process for water protection areas and risk assessment together with the concept of ES and WSS are also presented. Some background on communication and visualization are introduced as well.

2.1 Water protection laws, regulations, guidelines and goals

In this section directives created by the European Commission (EC) and guidelines regarding drinking water quality from the World Health Organization (WHO) are presented. Further national laws and regulations, and the Swedish environmental objectives are described.

2.1.1 Directives

According to Merriam-Webster (n.d.), a directive is *"...something that serves to direct, guide, and usually impel toward an action or goal"*. Within the European Union (EU), a directive is a goal that the countries must achieve, but how it is reached is up to the countries themselves (Directorate-General for Communication, n.d.).

The Water Framework Directives (WFD) are established to protect the quality and volume of the water bodies, both for human health and the environment (EC, 2000). It is the comprehensive law regarding water protection in Europe. It declares that member states should implement measures to protect surface water and groundwater sources and for them to achieve good water status. The Groundwater Directive (GWD) is a daughter directive, which supports the WFD (EC, 2023). The GWD contains a more detailed description of how to achieve good groundwater quality and provides criteria to prevent contaminated groundwater (EC, 2006). The Environmental Quality Standards Directive (EQSD) is also a complement to the WFD but is more directed towards surface water (EC, 2008).

The EU updated the Drinking Water Directives (DWD) where minimum requirements are established, and in 2023 these requirements should have been legislated on a national level (EC, 2020). The purpose of the DWD is to ensure adequate water quality, protect the health of consumers and increase the availability of the water. The supply of water should be developed on a risk-based strategy. Regarding the catchment areas, the DWD (EC, 2020) states that *"Member States shall ensure that risk assessment and risk management of the catchment areas for abstraction points of water intended for human consumption are carried out"* (p.18). Other directives regarding water are for example The Bathing Water Directive, Marine Strategy Framework Directive and Urban Wastewater Treatment Directive (EC, n.d.).

2.1.2 Guidelines for drinking-water quality

The WHO developed guidelines regarding drinking-water quality which gives recommendations to ensure safe drinking water (WHO, 2022). Some of the objectives of the guidelines by WHO (2022) are to:

- Provide a comprehensive preventive risk management framework for health protection, from catchment to consumer, that covers policy formulation and standard setting, risk-based management approaches and surveillance.
- Summarize the health implications associated with contaminants in drinking water and the role of risk assessment and risk management in disease prevention and control.
- Provide guidance on hazard identification and risk assessment.

The guidelines recommend developing a Water Safety Plan (WSP) which is used to protect the supply system of drinking water. Developing WSPs includes the use of a risk assessment and risk management approach. It should be carried out by a team led by the drinking water producer. WHO (2022) describes that one step in developing a WSP is to ... *"undertake a hazard assessment and risk characterization to identify and understand how hazards can enter into the water supply"*. Developing WSPs and using risk management is an effective way to ensure safe drinking water. WHO (2022) also describes that an important step in developing a WSP is communication between authorities, regulators and water suppliers.

2.1.3 National laws, regulations, guidelines and goals

Different agencies are working with protecting the water in Sweden. Laws and regulations are established regarding water sources which the agencies must adapt to. Figure 2.1 shows the identified legislators, authorities and organizations that work towards protecting water resources in Sweden.

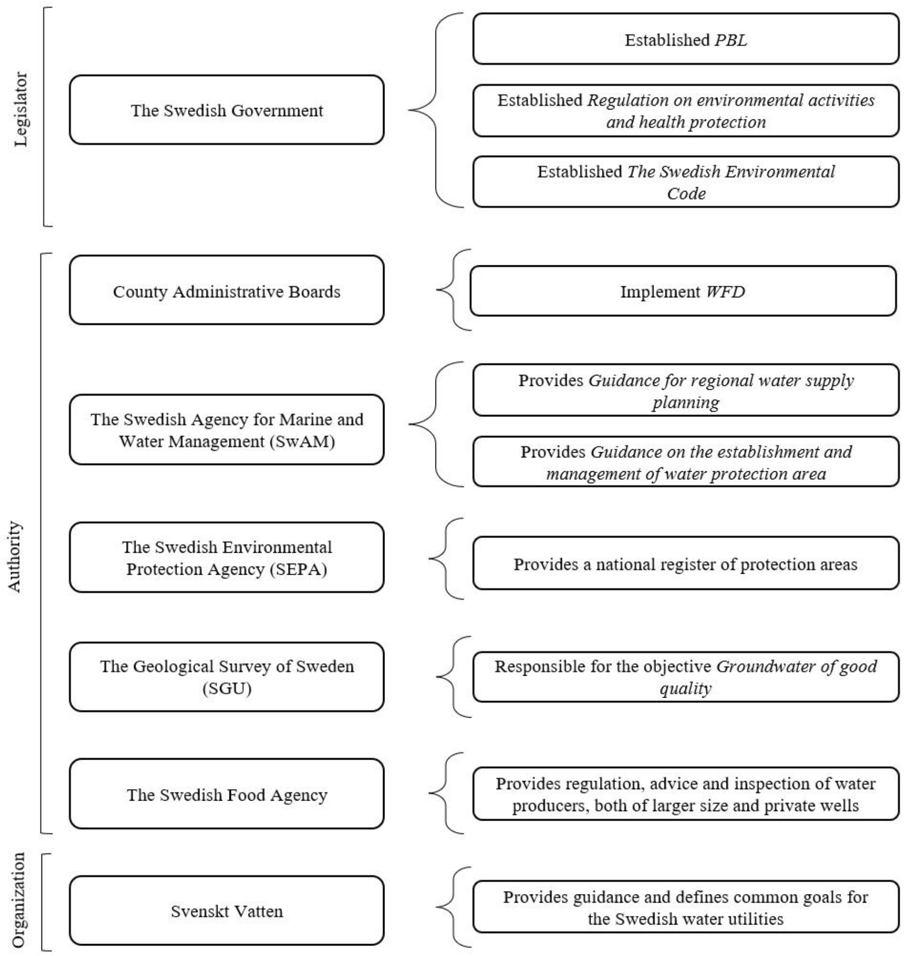


Figure 2.1: Legislator, authorities, organizations and their area of responsibility.

The *Planning- and building act (PBL)* is a law regulating building on the ground and in the vicinity of water (SwAM, 2021). It was first introduced by the Swedish Government in 2010 and has been updated several times since then, the latest update in March 2024 (Government Offices of Sweden, n.d.). The law is designed to protect the long-term supply of water and the building should not hinder future possibilities for water supply (The Swedish Parliament, 2010). The *Regulation on environmental activities and health protection* states that regulations protecting water sources can be established to protect human health, both for surface water sources and groundwater sources (The Swedish Parliament, 1998a). Water sources can also be protected through nature reserves, environmental protection areas and water protection areas for example according to *The Swedish Environmental Code*

(The Swedish Parliament, 1998b).

The Swedish Government has assigned five county administrative boards to be the water authority in each district (Water authorities, n.d.). The water authorities are working towards better water in Sweden and are at the same time responsible that the *WFD* is implemented.

The Swedish Agency for Marine and Water Management (SwAM) are working for the government to preserve water sources (SwAM, 2021). The goal of SwAM is to achieve sustainable use and restoration of water sources and fish resources (SwAM, n.d.-a). SwAM has developed guidance for regional water supply planning where key water sources should be identified (SwAM, 2020). By doing this, these important water sources can in the future be preserved and protected, for example through establishing a water protection area. The plan should include a description of the water use beyond drinking water for households, such as water for industries and agriculture, both for the situation today and in the future (SwAM, 2020). When developing a regional water supply plan, a risk assessment should be included as well as suggestions for appropriate measures. They have also developed guidelines regarding the establishment of water protection areas which are described in section 2.2 (SwAM, 2021)

The Swedish Environmental Protection Agency (SEPA) is working with the environment in Sweden and is a governmental authority (SEPA, n.d.-a). They provide guidance and information regarding the management of SEPAs properties, for example, water sources, sewage and water facilities. The SEPA is also responsible for ensuring that laws and guidelines regarding drinking water sources are followed (SEPA, 2023).

The Geological Survey of Sweden (SGU) is the government authority that has the responsibility to provide geological information (SGU, 2023). The authority also works with issues connected to groundwater and the information provided can be helpful when conducting an impact assessment and for the protection of groundwater sources (SGU, n.d.-b). SGU also carries out environmental monitoring of seepage sediment and groundwater (SGU, 2018). The monitoring is used to follow up environmental quality objectives and to reveal new environmental disturbances.

Another means to protect water sources is the Swedish environmental objectives. The purpose of the objectives is to provide guidance towards reaching the Agenda 2030 targets (The Swedish environmental objectives, n.d.-a). The objectives focus on the ecological parts and are within the areas of "*...waste, biodiversity, hazardous substances, sustainable urban development, air pollution and climate*" (para.1) (The Swedish environmental objectives, n.d.-b). Some of the goals connected to water are *Groundwater of good quality*, *Flourishing lakes and water courses*, and *No eutrophication* (The Swedish environmental objectives, n.d.-b). Even though some of the goals are not directly connected to drinking water, it is important to consider these as well since they are still connected to the water sources. The 16 different goals are divided between 8 national authorities that share the responsibility over them, for example, SGU is the responsible authority for the *Groundwater of good quality goals* (SGU, 2022).

The Swedish Food Agency (2024) works according to their website for *"safe food and drinking water, transparency in food handling and sustainable food consumption"*. They achieve this by doing controls, collaborating with authorities, and providing advice and rules. It includes working towards a secure supply of drinking water independent of the situation. They are providing regulations, advice and inspections regarding drinking water facilities of larger size as well as advice on how private wells should be managed (SwAM, n.d.-b).

Svenskt Vatten is a professional organization that works for the Swedish water and wastewater utilities (Svenskt Vatten, 2022; SwAM, n.d.-b). According to Svenskt Vatten (2022) they have goals for the Swedish water and wastewater utilities to reach in 2026. These goals are regarding the supply of water services and a sustainable community and environment.

2.2 Water protection areas

In The Swedish Environmental Code c. 7 21 § by The Swedish Parliament (1998b) a water protection area is described as:

“A land or water area may be declared a water protection area by the county administrative board or municipality to protect a ground- or surface water resource that is used or can be assumed to be used for water supply”.

Today the Swedish Agency for Marine and Water Management (SwAM) is the authority working with water protection areas (SEPA, n.d.-c). They have developed the document *Guidance on the establishment and management of water protection areas* (SwAM, 2021). It provides a structured approach for developing a water protection area. A water protection area is established to protect water sources used for drinking water, heat recovery or irrigation. When developing a water protection area and the associated water protection regulations a risk assessment is needed to help decide the boundary, possible zones within, and to motivate assigned regulations for the water protection area. The process of the establishment of the water protection area in chapter 3 in the document by SwAM (2021) is described below and summarized in Figure 2.2.

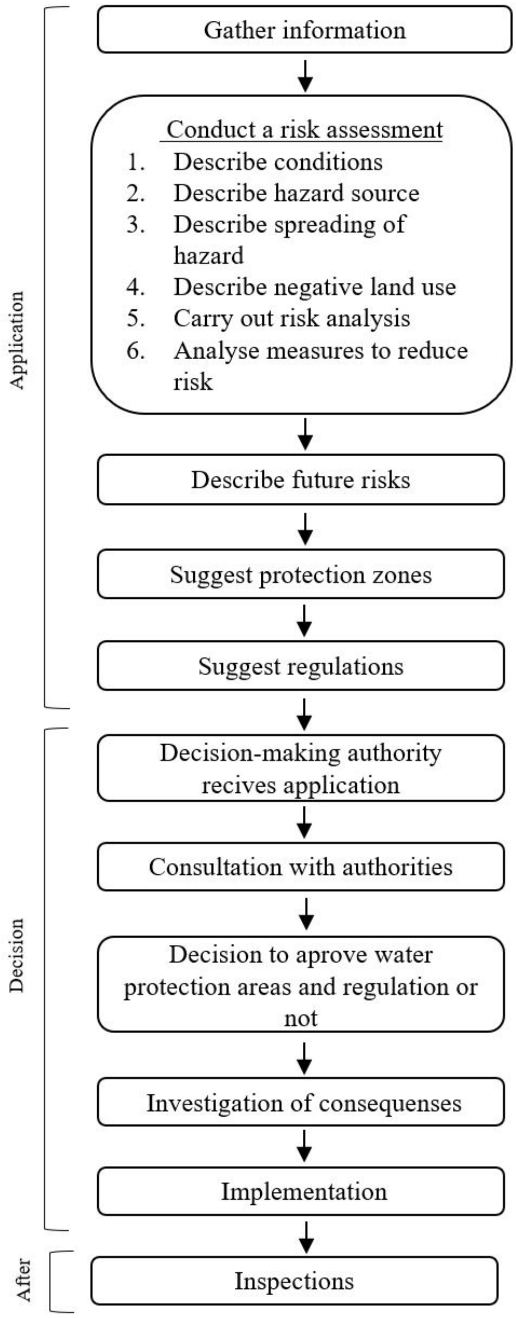


Figure 2.2: The process of establishing a water protection area.

2.2.1 Application

The process of establishing a water protection area starts with an application, often from a drinking water producer, which should include an assessment to support the decision (SwAM, 2021). The application needs to contain information about the applicant and the purpose of the water protection area. Information about the river basin including geology and topography among other things, and the water source should be described. The information in the descriptions depends on whether it is a surface water source or a groundwater source. A risk assessment should be carried out and included in the application, with the steps described below.

1. First, the conditions of the water source are described. Raw water analyses are carried out and compared with limit values. Also, long-time series detecting effects of diffuse sources, for example, agricultural land and air pollution that have a non-point source, are used (British Geological Survey, n.d.; SwAM, 2021).

2. Second, the source of the hazards which affect or can affect the drinking water source is identified (SwAM, 2021). From the analysis, current diffuse sources and direct sources can be found and described. Also, potential future hazards should be included.

3. Third, the spreading from the source of the hazard to the water source should be described. It should include the kind of hazard source and event, the place of the source, the size of the pollution, how the transportation occurs and the time to reach the extraction point. The vulnerability should be described and if climate change has an effect it should be included as well.

4. Fourth, land use which can have negative effects, like higher vulnerability or deterioration of natural protective barriers, should be described. For example, material extraction or soil stabilization could cause these effects.

5. Fifth, a risk analysis is carried out. The risk of the hazards depends on the likelihood and consequences of an event to occur and can be carried out in different ways. The risk can be described in a qualitative or quantitative way, the most suitable method should be used. Process-based modelling can be used to calculate the spreading of pollutants. With logical diagrams, chains of events can be described and the probability calculated. Risk ranking with matrices is a way to overarching analysis and in a simple way view the results. The calculated risk is then determined whether it is acceptable or not.

6. Sixth, when needed the risk is reduced or prevented through establishing measures in the sense of regulations, which can include prohibition and requirements. The regulations restrict land use and can be used to prevent risks from occurring. The results from the risk assessment could then be used as a base for deciding the boundary of the water protection area.

Climate changes and how they will affect drinking water should be described in the application and other risks that can appear in the future should be mentioned as well. Boundaries of the water protection area should then be suggested and it should be described if the area needs to be divided into different zones. A water source zone can be established around the abstraction point which could be fenced. The zones can be divided into primary, secondary and tertiary protection zones and should be established with regard to identifiable boundaries in the terrain. The reason behind the division of zones is to be able to adjust the restrictions depending on the risk and the need for protection (SEPA, 2011).

Suggested regulations should be motivated (SwAM, 2021). The motivation of the reviewing authority and the inspection authority should be included in the application, together with a list of property owners. Communication with the affected in the area is recommended to be done in an early stage and should be described in the application.

2.2.2 Decision

The decision-making authority receives the application and consultation with the authorities should be carried out (SwAM, 2021). The reviewing authority reviews permits from the regulations of the water protection area. Both the decision-making authority and the reviewing authority can either be the county administrative board or the municipality. The SGU is an expert authority providing information regarding groundwater and must be consulted before a decision about water protection areas is taken. When a decision is made, SwAM and SEPA among others should be informed.

The county administrative board or the municipality can decide to establish a water protection area and water protection regulations, but they can also repeal a water protection area. The regulations can include the prohibition of activities. Businesses can be regulated through the requirement of a specific permit or deceleration to conduct the activity. Regulations can also be established that are directed to the public, and general regulations are applied to the area.

The consequences need to be investigated before establishing the regulations. Also, there needs to be an assessment of interest between the protection of the water and the utilization of the property. Affected properties can be compensated. However, ensuring future drinking water supply is of great interest and to make a decision, a risk assessment can be helpful.

2.2.3 After the decision

After the water protection area is established the inspection authority (county administrative board or municipality) checks that the regulations are complied with by land users and others (SwAM, 2021). SwAM have the main responsibility for the protection area and SEPA, together with the water authorities, is for example responsible for developing a national register of protection areas.

2.3 Risk assessment

As mentioned in chapter 2.1 and 2.1.3, it is often recommended or compulsory to conduct a risk assessment when working with the protection of water. One of the definitions of risk is *"the likelihood of identified hazards causing harm in exposed* *populations in a specified time frame, including the magnitude of that harm and/or the consequences"* (p. 50) (WHO, 2022). Figure 2.3, based on reports by Rosén et al. (2007) and Odilon Mendel Kombo Mpindou et al. (2022), shows that a risk assessment consists of both risk analysis and risk evaluation. These are key steps in the risk management process when assessing water sources.

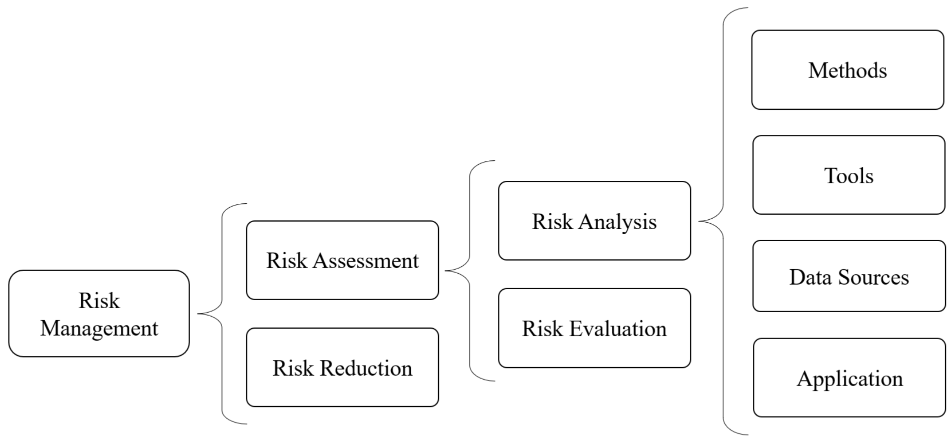


Figure 2.3: The risk management process for water sources.

The concept of risk management originates in gambling, where the probability of an outcome was analyzed (Przetacznik, 2022). The scientific approach to risk assessment and management is quite new and since the beginning, more sophisticated methods and techniques have been developed which are now used in most sectors (Aven, 2016). A risk assessment combines the likelihood and consequence of hazards to determine which hazards should be prioritised when evaluating risk-reducing measures (Queensland Health, 2021). The following questions from Kaplan and Garrick (1981) could be used to be able to determine the risk:

1. What can happen? (i.e., What can go wrong?)
2. How likely is it that that will happen?
3. If it does happen, what are the consequences?

The first part of a risk analysis is to evaluate the hazards present at the water source and the level of risk each hazard poses (Rosén et al., 2007). To identify hazards, the TECHNEAU-checklist created by Beuken et al. (2008), can be used which includes different categories of hazards. There are two different types of hazards depending on the source (National Geographic Society, 2023). A point source hazard is easy to identify and comes from one place. A diffuse source hazard is harder to identify as it can come from many places at the same time. To evaluate the risk of each hazard, it is important to look at the probability of the hazardous event occurring, the consequences of the hazardous event and the vulnerability of the water source.

One way of evaluating the vulnerability of a groundwater source is through the DRASTIC method (Rosén, 1994). DRASTIC stands for different parameters that are investigated, which are explained in the list below. Each parameter is given a weighting score based on how important it is to the pollution potential of the aquifer. When using the DRASTIC method it is assumed that ... *"the contaminant is introduced at the ground surface, the contaminant is flushed into the groundwater by precipitation, the contaminant has the mobility of water, and the area evaluated using DRASTIC is 40 acres or larger."* (Rosén, 1994). The different DRASTIC parameters are explained in the list below.

- **D**epth to groundwater
- **R**echarge
- **A**quifer media
- **S**oil media
- **T**opography
- **I**mpact of the vadose zone media
- **C**onductivity of the aquifer

To be able to conduct a risk analysis, important steps are to choose an appropriate method, which tool is going to be used, where the required data can be acquired along with how and where the results can be applied (Odilon Mendel Kombo Mpindou et al., 2022). Examples of methods that can be used for risk assessment are qualitative, quantitative and deterministic. For the tools, examples of what can be used are Hazard and Operability Analysis (HAZTOP), Event Tree Analysis (ETA), Quantitative Microbial Risk Assessment (QMRA), and Chemical Risk Assessment (CRA). Data sources could be event data, historical data and different databases. The results can then be applied to, for instance, drinking water treatment plants, risk monitoring and safety design.

2.4 Ecosystem services

When conducting a risk assessment, additional services beyond drinking water are often overlooked (Gärtner et al., 2022). Even if a water protection area is formed to benefit the provision of drinking water, other services such as swimming in the lake, agricultural watering or ground source heat pumps are favoured. Gärtner et al. (2022) states that *"Decisions based on conventional risk assessments neglect those important services which may justify additional protection measures"*(p.2). It is therefore important to understand what these services are and how they can be included in a risk assessment to not overlook any possibilities. To account for these additional services, the well-established ecosystem services framework can be used.

According to Haines-Young and Potschin (2018), the definition of ES is *"the contributions that ecosystems make to human well-being, defined in terms of 'what ecosystems do'"* (p. 7). ES can help produce goods, such as timber and pharmaceuticals (Daily, 1997). Apart from goods, the ecosystems can also provide different services, such as the examples in the list created by Daily (1997) below:

- Purification of air and water
- Mitigation of floods and droughts

- Pollination of crops and natural vegetation
- Protection from the sun's harmful ultraviolet rays
- Support of diverse human cultures
- Partial stabilization of climate

With the earth´s population growing, more and more people are moving to urban areas (Carpenter et al., 2006). When living in these urban areas people still consume ES, but not directly, causing a detachment from nature (Carpenter et al., 2006). A study conducted by Folke et al. (1997) showed that cities demand ecosystem support with an area 500-1000 times larger than the area of the city itself. It is therefore important to identify these ES and how they can be quantified and valued (Bolund & Hunhammar, 1999).

One of the ways in which this can be done is through the Millennium Ecosystem Assessment (MA) (Millennium Ecosystem Assessment, n.d.). The MA has the purpose of assessing how change in ES affects human well-being and what information is needed to conserve these ecosystems. CICES, which is based on previous classification systems such as MA, can help identify ES and how they are contributing to human well-being (Gärtner et al., 2022).

According to (Haines-Young & Potschin, 2018), ES can be divided into regulating, provisioning, and cultural ES (SEPA, 2024). Other classification systems, such as MA, include supporting ecosystems as well (Millennium Ecosystem Assessment, n.d.). Supporting ES are needed to make the other services work, eg photosynthesis (SEPA, 2024). Regulating services provide a healthy natural environment, eg water regulation. Provisioning ES supplies raw materials for production, eg drinking water. Cultural ES give improved quality of life, eg outdoor activities.

2.4.1 Water system services

Gärtner et al. (2022) defines WSS as *"...the aspects of drinking water sources utilized to produce human well-being"* (p. 5). Some of the WSS can be seen as ES as well, while some are additional ones only for WSS (Gärtner et al., 2022). This is also shown in Figure 2.4. When using CICES as a method to identify WSS, only a selection of the existing WSS is included (Gärtner et al., 2022). The reason behind this could be that some of the WSS can only be present in conditions apart from the ones for ES.

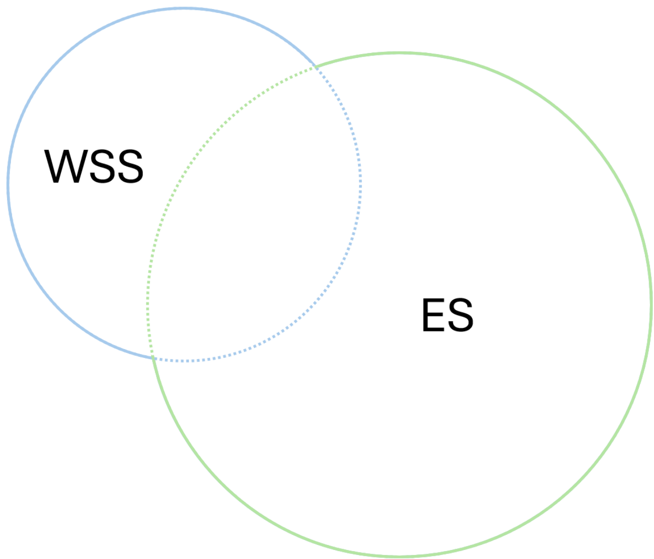


Figure 2.4: The relation between ES and WSS.

Gärtner et al. (2022) created a modified list of ES based on the CICES framework. The list is region-specific to Sweden. The list has the same structure as CICES, where the WSS are defined by using the categories water clause and use clause. This is to describe what the water is doing and how it contributes to or benefits human well-being. The list is also categorized by three services; Provisioning, Regulating and Cultural (Gärtner et al., 2022). Some of the service classes are merged due to similarities in abiotic and biotic classes in CICES (Gärtner et al., 2022).

2.5 Visualization & Communication

Since the beginning, humans have communicated through speech, but the first languages were not perfect, and communication via symbols was easier (Mather, 2022). Mather (2022) states that the earliest found cave painting using symbols is over 64,000 years old. The first attempt to create the modern alphabet was about 4,000 years ago (Wilson, 2021). When the alphabet was introduced, it became easier to send letters with information to each other and the very first letter is believed to have been sent in around 500 B.C. by the Persian Queen Atossa (Pen Heaven, n.d.). The telegraph was the first electronic communication system which used a system of dots and lines, created by Samuel F.B. Morse, to quickly send messages over long distances (McGillem, 2024).

2.5.1 Communication today

Nowadays, there is a strive to once again communicate through visualization (Lobel, n.d.). Bohlin and Bergman (2019) performed a survey sent out to 3,699 researchers and scientists in Sweden to see their views on communication and open research.

The results showed that most researchers and scientists want to communicate their work so that the "*...results should be utilised within society.*"(p.16), and over half of the participants want to spend more time communicating their research. The way researchers present their results can be difficult for the public to understand, which may be due to poor visualization (Lobel, n.d.).

It is therefore highly important that data and information are visualized in an efficient way so that it is easy to understand the message. Visual information can be processed 60,000 times faster than information through text or pure data (Lobel, n.d.). The key is to show the most important information, as too much information can lead to confusion (Interaction Design Foundation, n.d.). When information is visualized effectively, it can increase understanding between policymakers and non-experts (Appleton & Lovett, 2003). There are two ways that scientific research can be communicated, which is based on the recipient of the information (University Library Web Team, 2022). An exploratory visualization is aimed towards recipients who have great knowledge within the area and can analyze the information given. An explanatory visualization is more aimed towards the general public who does not have the same background knowledge. These two ways to communicate scientific research are both on different ends of a scale, a visualization can therefore be a combination of both. It is also important to consider how the recipient will approach the visualized information, which can be affected by previous expectations, beliefs and values (National Academies of Sciences Engineering and Medicine, 2017). It is therefore important to consider the background of the recipient and what kind of information they need (National Academies of Sciences Engineering and Medicine, 2017).

2.5.2 Visualization of ecosystem services

The most used form of visualization when working with ES is to use Geographic Information Systems (GIS) (Klein et al., 2015). Other examples of ways to visualize information are original or manipulated photographs and different simulators to show a virtual landscape (Karjalainen & Tyrväinen, 2002). It has been shown by Karjalainen and Tyrväinen (2002) that it is important that the visualization has realism to the site being visualized. Even though there are several ways to visualize the concept of ES, there has not been any method so far that has managed to efficiently integrate it into decision-making. Klein et al. (2015) performed an investigation to see the demand for ES information and how that can be achieved. The results from that investigation are summarized in Table 2.1. The investigation showed that for example when you want to use visualization for communication and decision support, texts and abstracts work the best, while for scenario development in public applications, a thematic 2D map is most suitable.

Table 2.1: Different types of ES visualization that are most effective for some purposes, based on information from Klein et al. (2015).

Purpose	Type of visualization
Analyzing and exploring ES-related information	3D landscape visualizations
Communication and discussion support	Texts and abstracts
Scenario development in public applications	Thematic 2D map
Estimations in group applications	Abstract 3D landscape visualizations
Analysis support	Charts and tables, combined with thematic 2D map representations

Boverket has developed a tool to identify ES in a project area of construction (Boverket, n.d.-b). It is used to analyze, visualize and communicate ES. Boverket has also developed icons to communicate the ES (Boverket, n.d.-a). NatureScot (2023) have visualized ES as icons representing each service, see Figure 2.5 and 2.6. The different categories of ES are divided by different colour scales with provisioning, regulating, cultural and supporting services. NatureScot (2023) created one for the services connected to land environments and one for the ones connected to sea environments.

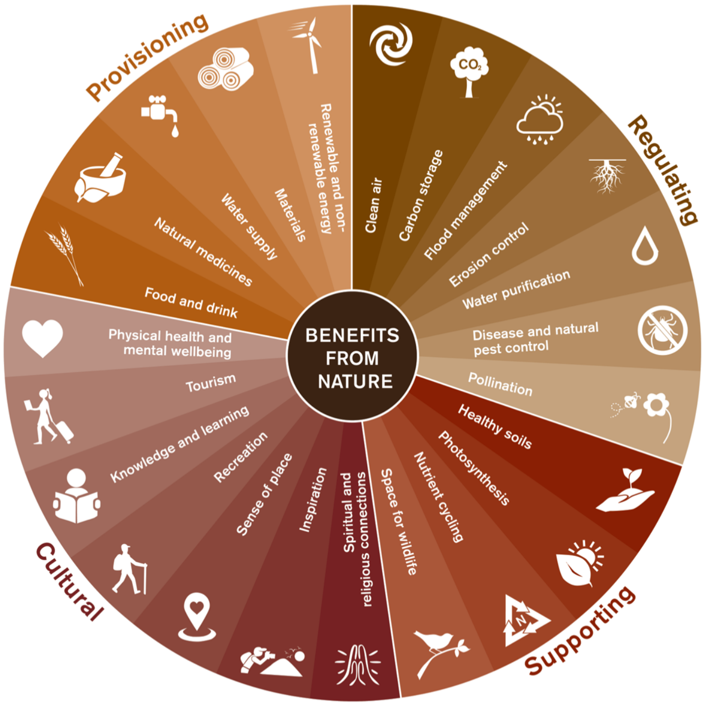


Figure 2.5: Land ES wheel created by NatureScot (2023).

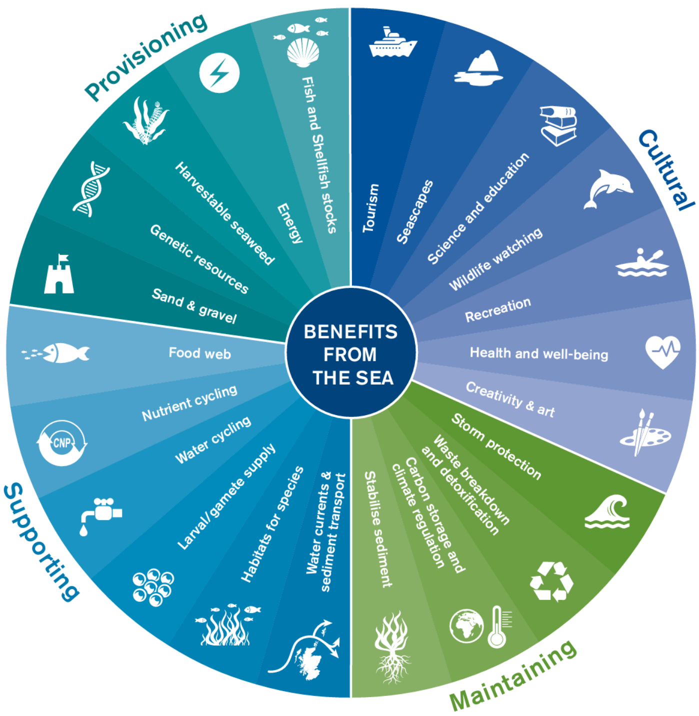


Figure 2.6: Sea ES wheel created by NatureScot (2023).

3
Case study description

The two case study sites used to test and evaluate WSS and the visualization of them are further described in this section. The reason behind choosing both Lake Mjörn and Sollebrunn-Gräfsnäs aquifer is to see how the concept of WSS can be applied to both a surface water and a groundwater source since these are the two types of drinking water sources in Sweden(Svenskt Vatten, 2021a). Mjörn has been identified as a key water resource for the region, both by the county administrative board and the Gothenburg Region, and is located near Gothenburg to easily be studied by the authors (Göteborgsregionen, 2020; Ruderfelt et al., 2021). Also, Sollebrunn-Gräfsnäs is a drinking water source located near Gothenburg (Tyréns, 2013) and has earlier been investigated by the authors, and can therefore with advantage be further studied.

3.1 Surface water source – Mjörn

The surface water source that will be investigated in this project is Lake Mjörn. It is located northeast of Gothenburg, in the municipality of Alingsås and Lerum, and has a total area of 55 km^2 (WISS, n.d.-a). The deepest part of the lake is 48 meters and holds about 855 million m^3 of water (SMHI & SwAM, n.d.). There are around 50 islands in the lake that have a diverse natural value (Bydén et al., 2001). The inlet to the lake is from two points, one from Mellbyån and one from Säveån. Säveån then continues towards Göta Älv and is thereby the outlet of the lake as well. There is no current water protection area for Mjörn, but the area contains nature reserves, bird protection areas and Natura 2000 areas, see Figure 3.1.

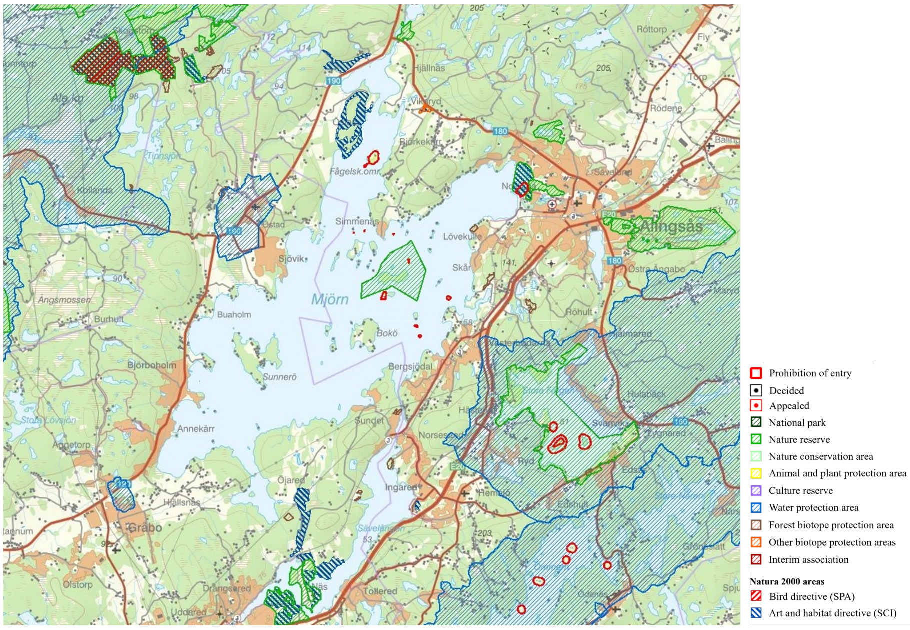


Figure 3.1: Different protection areas around Mjörn (SEPA, n.d.-b).

The lake has beaches, is wealthy of birds and fishes, and is surrounded by deciduous forest (Lerum Municipality, 2024). According to Water Information System Sweden (WISS), the lake is achieving a good chemical quality status (WISS, n.d.-a). However, the lake has previously had issues with algae blooming, and toxic substances from boats have been found in the lake (Lerum Municipality, 2023a, 2023c). Also, the outlet of the wastewater treatment plant in Sjövik is located in Mjörn (Lerum Municipality, 2023b).

3.2 Groundwater source – Sollebrunn-Gräfsnäs

The groundwater source that will be investigated in this project is the Sollebrunn-Gräfsnäs aquifer. It is located in the northern parts of Alingsås municipality and has an area of 9 km^2, see Figure 3.2 (WISS, n.d.-b). The outlet of the aquifer leads to Lake Anten, which eventually ends up in Mjörn. The aquifer is also connected to the Mellbyån and the Mörlandaån (WISS, n.d.-b).

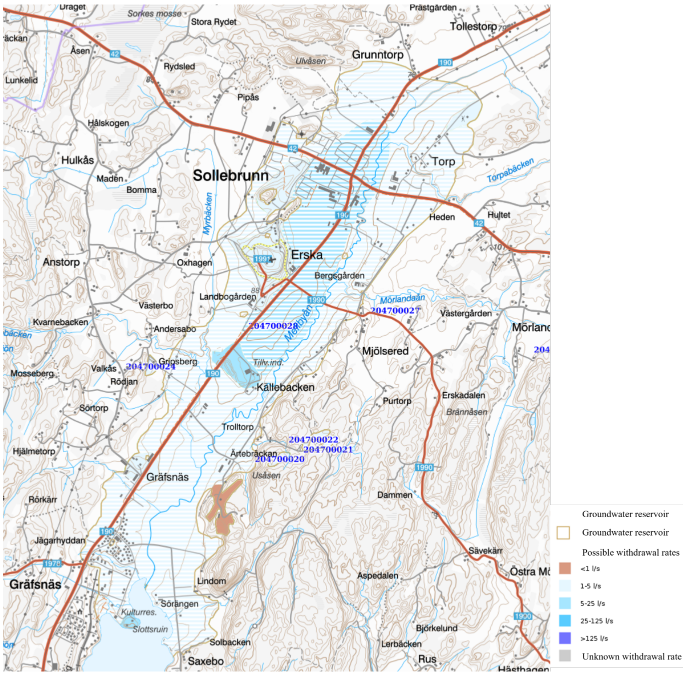


Figure 3.2: Groundwater aquifer of Sollebrunn-Gräfsnäs (SGU, n.d.-d).

Clay, sand and silt are the dominant soil types according to borehole data from SGU (n.d.-c). As can be seen in Figure 3.3, the top layer of the aquifer is mostly clay. Aquifers with a confining layer of clay have a lower vulnerability and a lower permeability, compared to an unconfined aquifer (SGU, n.d.-a). For some parts of the aquifer though, the glacial sediments are reaching the ground surface (Lång & Persson, 2011). Because of this, the aquifer can then be seen as both confined and unconfined.

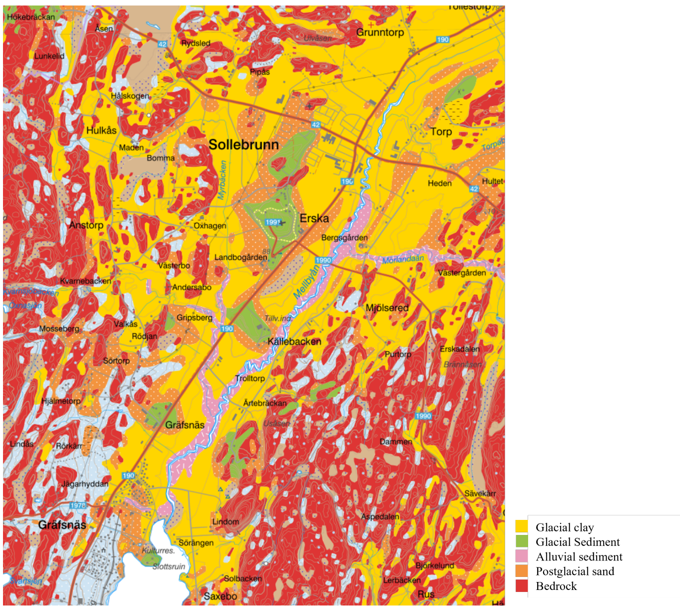


Figure 3.3: The different soil types for the Sollebrunn-Gräfsnäs aquifer (SGU, n.d.-e).

The aquifer consists of two different groundwater sources (Tyréns, 2013). There are currently four water protection areas for the aquifer, see Figure 3.4. Two of them are located in Sollebrunn and two are located in Gräfsnäs. There is also a cultural reserve in the area, protecting the Gräfsnäs castle ruins. The aquifer is at risk of not achieving good chemical water status by 2027, with the highest contributor to this being the infrastructure and transportation (WISS, n.d.-b).

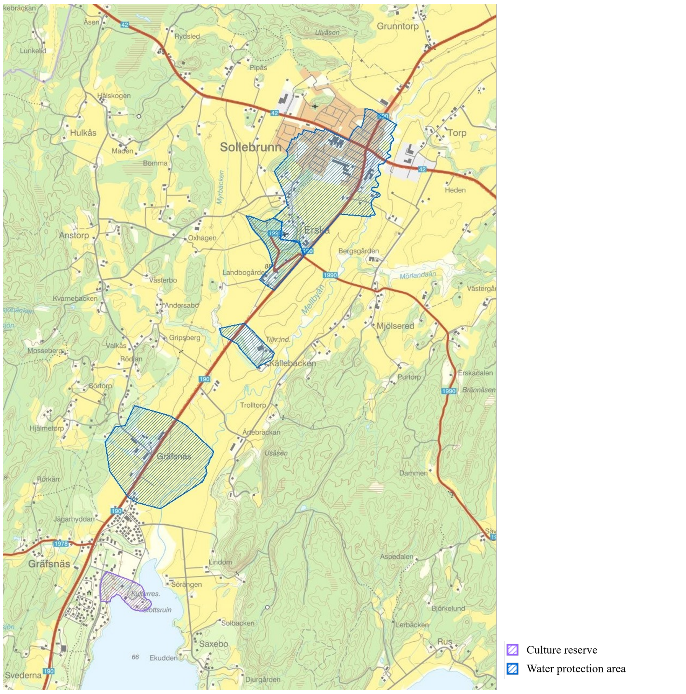


Figure 3.4: Water Protection areas around the Sollebrunn-Gräfsnäs aquifer (SEPA, n.d.-b).

4
Methods

The method is described below where the different parts were performed in parallel for both Mjörn and Sollebrunn-Gräfsnäs. The method was carried out according to the steps summarized in Figure 4.1 where it is shown how the steps are linked with each other. To begin with, a literature review regarding source water protection was performed, presented in Chapter 2. The literature review also included an investigation of the case study areas, presented in Chapter 3.

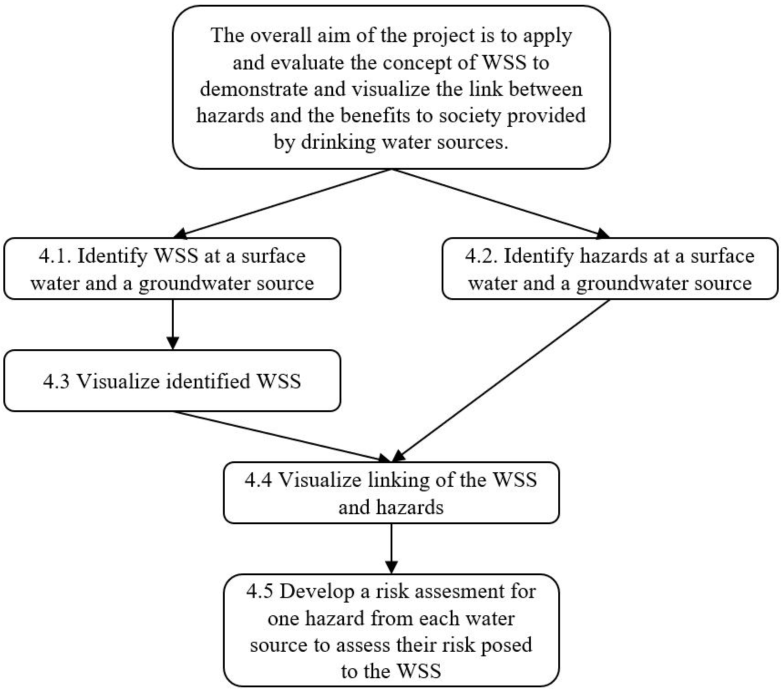


Figure 4.1: The different steps in the method to achieve the aim of the report.

4.1 Identification of WSS

The WSS for the two water sources were identified with the list provided by Gärtner et al. (2022). The list is divided into provisioning, regulating and cultural services. In each category, the WSS are divided into division, group and class. The list includes reference numbers to CICES where the origin of the WSS can be found and examples of WSS are provided. The list also has columns where it can be marked if the WSS is important for the case study area, what the specific WSS is, the reason why it may be excluded and the data source. If the WSS is not utilized today, but could potentially be in the future, it was marked in an additional column. If a WSS were found to fit into two different classes, they were marked in those classes.

The WSS at Mjörn was identified through research online, for example from reports and company websites. Every WSS in the list was reviewed, where some of the WSS had a clear source of evidence that they existed while others were assumed to exist. The existing WSS and their reference were noted in the list. Also, potential WSS, which can be used in the future, was marked and if the WSS was excluded it was explained why. If it was found that a WSS did not exist, the literature source behind it was included. The provisioning, regulating and cultural services were then summarized in tables, one for the existing WSS and one for the potential WSS. During a site visit, the previously identified WSS were confirmed to exist. The site visit was aimed at getting an understanding of the water source and its surrounding area.

The WSS at Sollebrunn-Gräfsnäs were identified with the list through literature research in the same way as for Mjörn, but for this groundwater source, some WSS was found using ArcMap with data from SLU. The existing list with WSS was evaluated during the work.

4.2 Identification of hazards

Hazards that have a potential risk for the WSS at the two water sources were identified. An area had to be determined to know which hazards to include. SMHI has a database of the watersheds in Sweden, and Figure 4.2 shows the watershed for the outlet of Mjörn. Since it is a larger area when including all water entering Mjörn from a long distance, limitations were necessary. The area east of Mjörn is protected by a water protection area, which means that it already has measures to prevent contamination, see Figure 3.1. The watershed of the lake was found in a tool created by WISS (n.d.-c), see Figure 4.3. The precipitation within this area flows directly to the lake. When hazards were identified in the study, both the land area and the lake itself were included with the later-described boundaries.

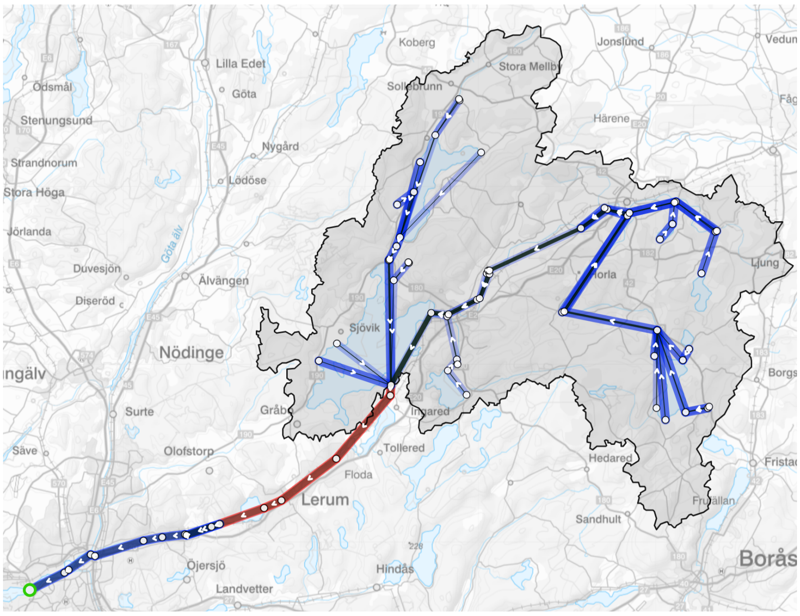


Figure 4.2: The flow of water 27th February in the watershed of Mjörn (SMHI, n.d.-a).

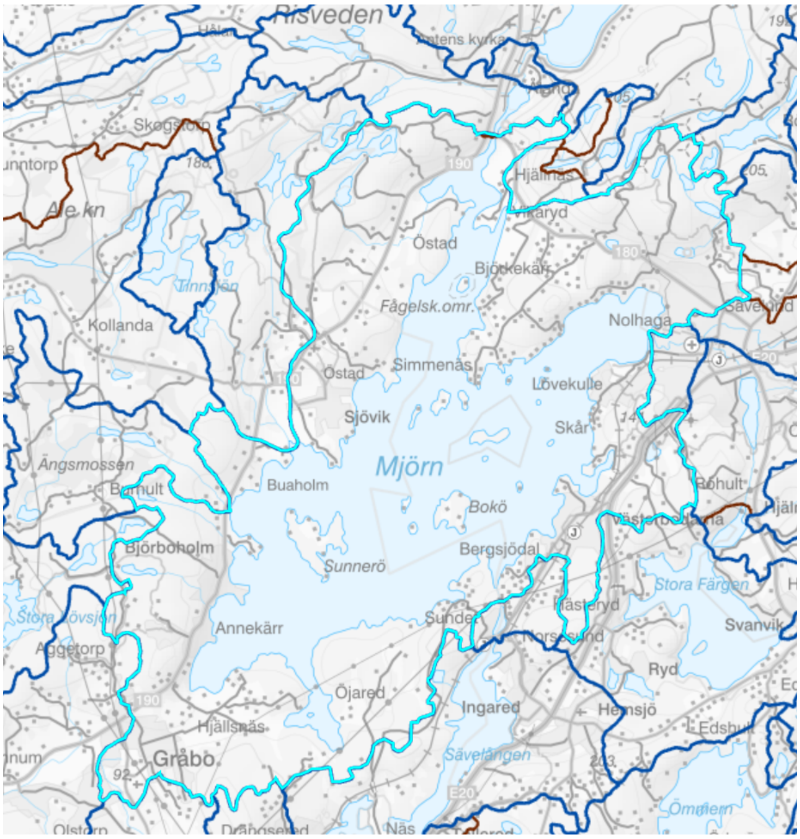


Figure 4.3: The catchment area of Mjörn marked in light blue (WISS, n.d.-c).

The TECHNEAU-checklist by Beuken et al. (2008) was used to identify hazards at Mjörn. The checklist consists of twelve different categories where the categories

1. Surface water catchment - 1.1. Catchment area and *12. Future hazards - 12.1. Source water* was used since these are the categories connected to surface water sources. The list has columns with hazardous events, types of hazardous events, types of hazards and potential consequences. The list also includes columns where it should be filled in if the hazard is present at the site, the specific hazard present at the site, the specific threat and data sources. To fill the checklist the EBH-map (County Administrative Board, n.d.) was used, where identified and potentially contaminated areas are marked. Google Maps and research online were then used to identify further existing hazards. The hazards in the watershed of Mjörn were also marked in Google Maps to later be localized when visiting the site. Through the site visit the previously identified hazards were localized and newly found hazards were added to the TECHNEAU-checklist. The TECHNEAU-checklist were essentially made regarding drinking water and supply systems but covered a lot of hazards that affect the different WSS (Beuken et al., 2008). When hazards were identified that did not fit into any of the TECHNEAU-checklist categories, they were added as a separate category to the bottom of the checklist. When this was completed, the hazards were summarized in two different tables. One for the hazards present at the site today and one for possible hazards in the future. Lastly, the identified hazards were marked on a map in ArcMap to see where the hazards are located.

The hazards at Sollebrunn-Gräfsnäs were previously identified by the authors and could therefore be used in this study. The hazards identified by Andreasson et al. (2022) were found through the EBH-map, research online and a site visit. Those hazards were added to the TECHNEAU-checklist where the used categories were *2. Groundwater catchment - 2.1. Catchment area* and *12. Future hazards - 12.1. Source water*, since these are the categories connected to groundwater sources. While looking at the TECHNEAU-checklist, new hazards were identified through research online and with Google Maps. They were thereby added to the list, with the location of the hazard noted as well which was used through a site visit. The limiting area where hazards were identified was the aquifer, see Figure 4.4. All hazards were summarized in two tables as for Mjörn. Their location was then marked in a map created in ArcMap.

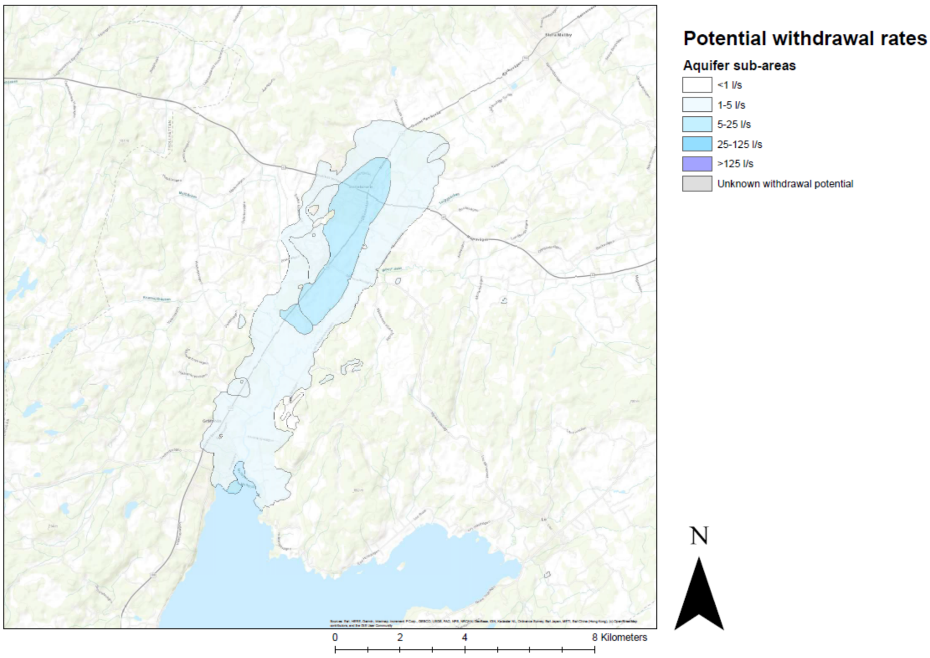
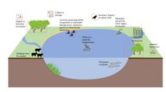
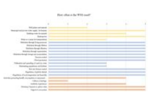


Figure 4.4: The outline of the aquifer for Sollebrunn-Gräfsnäs.

4.3 Visualization of WSS

With the study in Chapter 2 of how ES have been visualized previously, icons created by Boverket and SwAM were taken as inspiration for further visualization (Boverket, n.d.-a; SwAM, 2019). The visualization was meant to be done in a way that makes it easy to understand the meaning of the WSS and make it clear, both for the public and all involved in the process of protecting the water. Below in Table 4.1 is the work of how the different visualizations of the WSS at both water sources were developed. The WSS were visualized and grouped in their associated classes.

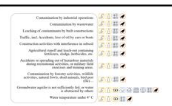
Table 4.1: The different visualization of WSS with descriptions and examples.

Visualization	Description	Example
Icons	Appropriate icons were made with PowerPoint to communicate the identified WSS in this study. The frame around the icons were coloured in the same way as Boverket colour the ES (Boverket, n.d.-a).	
Cross section	A cross section of the two water sources were made in PowerPoint and the icons of the WSS were placed in the cross section to communicate where the services exist.	
Map with pictures	Data from herkules.slu.se was used as background layer in ArcMap to make a map of the areas. Pictures of the WSS were then taken from the site visit and put into the map to provide an understanding of how the WSS can look like and where they are located.	
The importance of the WSS	The importance of the WSS were visualized with a bar chart with an estimation of how often the WSS are used.	

4.4 Visualization of links

Then the connection between hazards and WSS was studied. The hazards were grouped into hazardous events since the same type of hazard is affecting the same class of WSS. It was marked in a table if a connection existed and the connection was then visualized with graphs and icons according to the process in Table 4.2.

Table 4.2: The different visualization of connections with descriptions and examples.

Visualization	Description	Example
Table with connection	The connection were marked in a table made in Excel.	
WSS affected	The amount of WSS affected by each category of hazards were communicated with bar charts.	
WSS affected with icons	The amount of WSS affected by the hazards were also visualized with icons of each WSS.	
Bubbles	The number of hazards affecting each WSS were visualized with icons of the WSS in bubbles in order of magnitude by how much they are affected.	
Grouping	The WSS and hazards were grouped, and the connections were visualized in a picture.	
WSS and hazard	Some hazards are present since it is also a WSS. The connection of the hazard and the WSS were visualized with arrows.	

4.5 Risk assessment

After the visualization was completed, a risk assessment was performed on one identified hazard for each water source. This was done to analyse the concept of WSS further and evaluate how a risk assessment including WSS can be carried out. The hazards chosen to be evaluated in the risk assessment were a hazard that affects many WSS combined with if the hazard occurred close to the water source. The risks were quantified and evaluated thoroughly in a systematic way based on existing methods but adapted for this specific application. The risk posed by each hazards was calculated for each WSS and also combined for all WSS. The specific threats of the chosen hazards were decided to be evaluated separately since they cause different kinds of risks for the WSS. The parameters included in the risk assessment were the weighting of the WSS, the probability the hazardous event occur, the vulnerability of the water source and consequences that affect the capability of the service. The used method is shown in Figure 4.5.

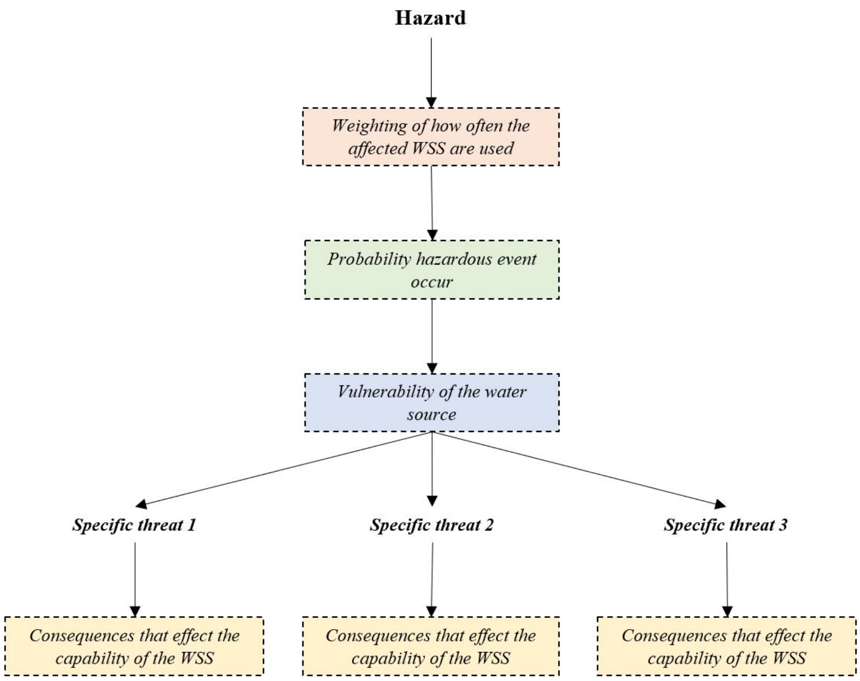


Figure 4.5: The method of the risk assessment.

The weighting of the WSS was included to show the importance of the WSS. Only the WSS assessed to be affected were evaluated. The weighting was based on how often the WSS is used and was given a number according to how many days of a year it was used. The values were given according to Figure 4.6. This kind of ranking was chosen so that the difference in values represents the difference in time as well.

Weighting of how often the affected WSS are used	
0.5/365.25	WSS used less than once a year
1/365.25	WSS used once a year
12/365.25	WSS used at least once a month
(365.25/7)/365.25	WSS used at least once a week
365.25/365.25	WSS used at least once a day

Figure 4.6: The criteria for the weighting.

The probability for the hazardous event to occur was estimated in a similar way as the weighting. A number was given to the hazard according to how many days in a year it happened. See Figure 4.7 for the division.

Probability hazardous event occur	
0.5/365.25	Event occurs less than every year
1/365.25	Event occurs once a year
12/365.25	Event occurs at least once a month
(365.25/7)/365.25	Event occurs at least once a week
365.25/365.25	Event occurs at least once a day

Figure 4.7: The criteria for the probability.

The vulnerability of the water source was evaluated according to the ability of the hazard to reach the water source. For the surface water source, the vulnerability was based on possible barriers and the distance to the water. For the groundwater source, the vulnerability was decided to be evaluated with DRASTIC. A high DRASTIC score was equal to a high score for vulnerability. See Figure 4.8 and Figure 4.9 for the criteria.

Vulnerability of the surface water source	
1	Water source have barriers which prevents hazard to reach the water
2	Hazard have low ability to reach the water
3	Hazard can reach the water
4	Hazardous event occurs close to water source with no barriers
5	Hazardous event occurs in the water

Figure 4.8: The criteria for the vulnerability of the surface water source.

Vulnerability of the groundwater source based on DRASTIC	
1	Very low DRASTIC score
2	Low DRASTIC score
3	Medium DRASTIC score
4	High DRASTIC score
5	Hazardous event occurs in the aquifer

Figure 4.9: The criteria for the vulnerability of the groundwater source.

The consequences for the capability of the WSS affected were assessed according to the specific threats of the hazard. A number was given according to how reduced their capacity or how unusable the WSS get. See Figure 4.10 for the division.

Consequences that effect the capability of the WSS	
1	Very low consequences, WSS almost not affected
2	Low consequences, WSS barley reduced
3	Medium consequences, WSS reduced
4	High consequences, WSS highly reduced
5	Very high consequences, WSS gets unusable

Figure 4.10: The criteria for the consequences.

The four parameters with the weighting, probability, vulnerability and consequence were then multiplied for each of the WSS according to Equation 4.1 to get the risk. The total risk for the specific threat was then calculated as the sum of the risk for each WSS according to Equation 4.2.

$$R_S = W \cdot P \cdot V \cdot C \tag{4.1}$$

$$R_{tot} = \sum R_S \tag{4.2}$$

where,

R_S - Risk for each WSS
R_{tot} - Risk total for the specific threat
W - Weight of how often the WSS is used
P - Probability that hazardous event occur
V - Vulnerability of the water source
C - Consequence

The level of risk for each WSS was divided into three intervals low, medium and high risk. The lowest and highest possible risk for the WSS was calculated according to Equation 4.3 and 4.4. R_L, which is the upper limit for a low risk, was calculated by putting all of the parameters at the second lowest level, see Equation 4.5. For example, the consequence was set to *Low consequences, service barely reduced.* R_H, which is the lower limit for high risk, was calculated by putting three of the four parameters at the highest level, while the last one on the second highest level, see Equation 4.6. For example, both consequence and vulnerability are set to highest together with probability, while the weighting of how often a WSS is used is set to *Service used at least once a week.*

$$R_{S,min} = W_{min} \cdot P_{min} \cdot V_{min} \cdot C_{min} \tag{4.3}$$

$$R_{S,max} = W_{max} \cdot P_{max} \cdot V_{max} \cdot C_{max} \tag{4.4}$$

$$R_L = W_{2min} \cdot P_{2min} \cdot V_{2min} \cdot C_{2min} \tag{4.5}$$

$$R_H = W_{2max} \cdot P_{max} \cdot V_{max} \cdot C_{max} \tag{4.6}$$

where,

$_{min}$ - Lowest score for the parameter
$_{max}$ - Highest score for the parameter
$_{2min}$ - Second lowest score for the parameter
$_{2max}$ - Second highest score for the parameter
R_L - The upper limit for a low risk
R_H - The lower limit for a high risk

Also, the ranking of risk was calculated for the specific threat. The lowest risk for the specific threat was taken as the lowest risk for one service. The highest risk for the specific threat was calculated by taking the highest risk for a WSS multiplied by the total number of classes of WSS at the water source, see Equation 4.7. The upper and lower limits were calculated in the same way, see Figure 4.11 how the interval was divided.

$$R_{tot,max} = R_{S,max} \cdot n \tag{4.7}$$

where,

n - Number of classes of WSS for the water source,
incl. the ones not affected by the specific hazard

	Low risk	Medium risk	High risk
Risk each WSS	$R_{S,min}$ to R_L	$> R_L$ to $< R_H$	R_H to $R_{S,max}$
Risk specific threat	$R_{S,min}$ to $R_L * n$	$> (R_L * n)$ to $< (R_H * n)$	$R_H * n$ to $R_{tot,max}$

Figure 4.11: The intervals to decide the level of risk.

5

Results

In this chapter are the results of the identifications, visualizations and risk assessment presented.

5.1 Identified WSS

Appendix A.1 shows the WSS list and which of the WSS are present at Lake Mjörn. It includes the reasoning behind why some services might have been excluded, as well as examples of specific services for Mjörn. Figure 5.1 and 5.2 contains a summary of the services that are present for Mjörn, while Figure 5.3 shows the potential services that do not exist at the site today but could in the future. In summary, 33 services are present today and 18 services have the potential to be used in the future. One WSS, *Phosphorus and nitrogen stored in the sediment of the lake*, were found to fit into two classes. Most of the regulating services depend on the chemical quality of the lake.

Table 5.1: Identified WSS for Mjörn.

Category	Division	Group	Class	Services in the case study
Provisioning Services	Biomass (aquatic)	Food	Wild plants or animals	1.) Pike-Perch, Perch, Pike, Roach, Burbot, Bronxe bream, Ide, Tench, Eel
				2.) Crawfish
	Water	Water for drinking	Municipal and private water supply, for humans	3.) Drinking water source
			Drinking water for animals	4.) Water source for wild animals and livestock
		Energy	Hydropower	5.) Solveden hydropower plant
		Water for transport	Water as a mean for transportation	6.) Transport of tourists with steamboat
				7.) Motor boats
				8.) Transport with kayak, canoe, boat
Regulating Services	Transformati-on of biochemical or physical inputs to ecosystems	Mediation of waste, toxic substances and nuisances	Through living processes	9.) Denitrification occuring in the lake
				10.) Puryfing water through water-living plants
			Through dilution	11.) Treated wastewater discharged from a wastewater treatment plant into a surface water body for effluent dilution
			Through filtration	12.) Water is purifying air through capturing the air pollutants
			Through sequestration	13.) Nutrient degradation
			Through storage or accumulation	14.) Phosphorus and nitrogen stored in the sediment of the lake
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Erosion control	15.) Water level in lakes can act as prevention of landslides
				16.) Reed and other vegetation exists in the sides of the lake
			Flood protection	17.) Mjörn can collect access rainwater and prevent flooding downstream
		Lifecycle maintenance, habitat and gene pool protection	Pollination and spreading of seeds by water	18.) Both non-aquatic and aquatic plants are present, highly likely that the seeds will be dispersed by the lake
			Maintaining populations and habitats	19.) Several species of fauna present in the lake

Table 5.2: Identified WSS for Mjörn.

Category	Division	Group	Class	Services in the case study
Regulating Services	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest and disease control	20.) UV-light from the sun on the water surface
		Atmospheric composition and conditions	Regulation of global climate	14.) Phosphorus and nitrogen stored in the sediment of the lake
				21.) Water has the ability to capture carbon
				22.) Relative high levels of oxygen in Mjörn --> low probality of methane produced
			Regulation of local temperature and humidity	23.) Lakes modifies the climate of the surrounding areas
Cultural Services	Direct, in-situ and outdoor interactions that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Activities promoting health, recuperation or enjoyment through active, immersive, passive or observational interactions	24.) 3 island building a nature reserve with high nature value and rich bird life
				25.) Fishing
				26.) Beach where you can swim, boating, hiking, views over the lake
		Intellectual and representative interactions with natural environment	Culture or heritage	27.) The outlet Säveån has been used to transport logs
				28.) Steam powered boats have been used on the lake
				29.) Settlements from the late stoneage has been found around the lake
			Aesthetic experiences	30.) Pretty views over the lake and surrounding nature areas
	Indirect, remote, often indoor interactions …	Other biotic or abiotic characteristics that have a non-use value	Existence, bequest or option value	31.) Nolhagviken is a place where birds enjoys living. Area around Nolhagaviken is a natura2000 area, with protected species.
				32.) Several islands and areas around the lake have some sort of protection area. Some of the islands even have an access ban becuase of this.
	Support to …			33.) Landscapes that have important natural value.

Table 5.3: Potential WSS for Mjörn.

Category	Division	Group	Class	Services in the case study
Provisioning Services	Biomass (aquatic)	Food	Cultivated plants or animals	a.) Fish can be cultivated for food
		Material	Fibres and other materials from cultivated plants or animals	b.) Reed used to cultivate
			Fibres and other materials from wild plants or animals	c.) Wild reed
				d.) Jewlery with fish scales
		Energy	Cultivated plants or animals as an energy source	e.) Cultivate reed for biogas
			Wild plants or animals as an energy source	f.) Wild reed for biogas
		Genetic material	Genetic material from all organisms	g.) Cultivated trout
	Water	Water for drinking	Reserve water source	h.) Reserve water source
		Water for non-drinking purpose	Irrigation	i.) Irrigation of agriculture
			Cooling	j.) Water used as cooling in industries
			Water used as a material, e.g. process water	k.) Could be used in idustrial processes
		Energy	Storage of heat and coolness	l.) Lake cooling
				m.) Lake heating
Regulating Services	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Drought attenuation	n.) Vegetaion could be used to redecude the impact of extreme events
			Fire protection	n.) Mjörn could act as a barrier against fires and water can be used to fight fires
		Maintaining water conditions	Maintaining water conditions	o.) Living processes maintaining the already acceptable water quality
Cultural Services	Direct, in-situ and outdoor interactions...	Intellectual and representative interactions with natural environment	Scientific investigation, creation of traditional ecological knowledge, education, training	p.) Studies of water chemistry, biology and environmental toxins
				q.) Mjörnbygdens Naturcentrum next to the lake where the purpose is to get more educated about the nature

In Appendix A.2 the complete table with the existing and non-present WSS for Sollebrunn-Gräfsnäs are shown. It also includes the reasoning behind why some services might have been excluded from the analysis as well as examples of included services specific for the site. Table 5.4 shows which of the services are present at the site today, in total 10 WSS. Table 5.5 shows 7 WSS which are not existing for Sollebrunn-Gräfsnäs today but could be in the future.

Table 5.4: Identified WSS for Sollebrunn-Gräfsnäs.

Category	Division	Group	Class	Services in the case study
Provisioning Services	Water	Water for drinking	Municipal and private water supply, for humans	1.) Groundwater withdrawals
			Reserve water source	2.) Gräfsnäs is reserve water source for Sollebrunn
		Energy	Groundwater and surface water as an energy source	3.) Energy wells
Regulating Services	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Flood protection	4.) Aquifer can collect infiltrated rainwater
			Prevention of subsidence	5.) Houses on top of the clay layer
		Maintainging water conditions	Controlling the chemical quality of freshwater	6.) GW body feeds Anten with water
	Support to...		Contribution to hydrological cycle	7.) Contribution to hydrological cycle
			Contribution to biodiversity	8.) Species depending on habitats maintained by groundwater discharge
Cultural Services	Indirect, remote, often indoor interactions...	Other biotic or abiotic characteristics that have a non-use value	Existence, bequest or option value	9.) Existence
				10.) Option value

Table 5.5: Potential services for Sollebrunn-Gräfsnäs.

Category	Division	Group	Class	Services in the case study
Provisioning Services	Water	Water for non-drinking purpose	Irrigation	a.) Irrigation of agriculture
			Cooling	b.) Water used as cooling in industries
			Water used as a material, e.g. process water	c.) Could be used in industrial processes
		Energy	Geothermal energy	d.) Geothermal energy can be used in the future
			Storage of heat and coolness	e.) Storage of heat and coolness can be used in the future
Regulating Services	Regulation of physical, chemical...	Atmospheric composition and conditions	Regulation of global climate	f.) Groundwater as a carbon sink
Cultural Services	Direct, in-situ and outdoor interactions ...	Intellectual and representative interactions with natural environment	Scientific investigation, creation of traditional ecological knowledge, education, training	g.) Can have observartion wells in the future

5.2 Identified hazards

The identified hazards present today are marked in a map of the area, see Figure 5.1. It can be seen that most of the hazards are located in the urbanized areas. In Appendix A.3, the TECHNEAU-checklist with hazards at Mjörn is presented. In Table 5.6 and 5.7 are the existing hazards summarized and in Table 5.8 are the future hazards presented. The future hazards are mostly from diffuse sources. 23 hazards exist today and 20 hazards have a possibility to occur in the future.

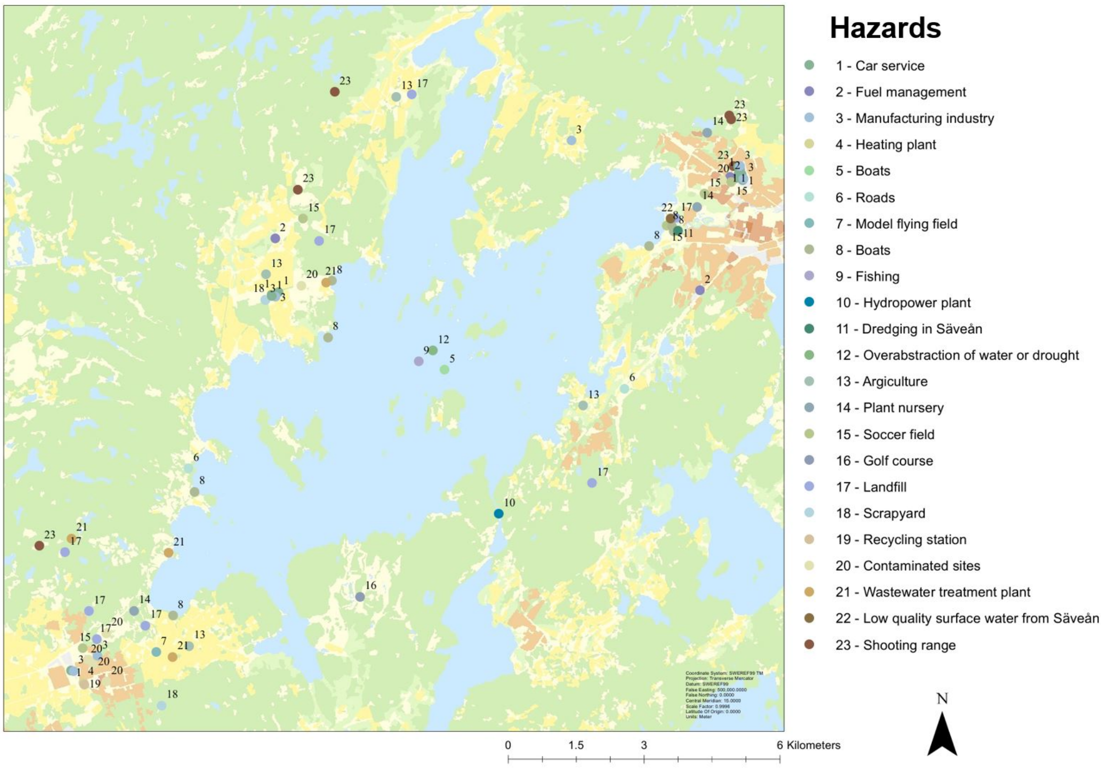


Figure 5.1: Map of the identified hazards for Mjörn.

Table 5.6: The identified hazards for Mjörn.

TECHNEAU Ref.		Hazardous Event	Hazards Mjörn
1.1 Contamination of catchment zone	1.1.1	Industrial discharge of chemicals	1.) Car service
			2.) Fuel management
			3.) Manufacturing industry
			4.) Heating plant
	1.1.4	Traffic accidents with ships, trains, vehicles and planes	5.) Boats
			6.) Roads
			7.) Model flying field
	1.1.7	Emissions and leakage, oil spills (MTBE) by shipping or traffic	5.) Boats
			6.) Roads
	1.1.8	Harbour activities	8.) Harbours
	1.1.10	Intensive fishery, fish farming, massive fish death	9.) Fishing
			10.) Hydropower plant
	1.1.13	Erosion of sediments by dredging or shipping	8.) Harbours
			11.) Dredging in Säveån

Table 5.7: The identified hazards for Mjörn, continued.

TECHNEAU Ref.		Hazardous Event	Hazards Mjörn
1.1 Contamination of catchment zone	1.1.17	Drought, blockage of water upstream or abstraction	12.) Overabsraction of water or drought
	1.1.20	Runoff from agriculture and urban green areas containing fertilizers, sludge, herbicides, etc	13.) Agriculture
			14.) Plant nursery
			15.) Soccer field
			16.) Golf course
	1.1.21	Continuous leakage from landfills, contaminated soils or waste dumps	17.) Landfill
			18.) Scrapyard
			19.) Recycling station
			20.) Contaminated sites
	1.1.22	Discharge of treated wastewater	21.) Wastewater treatment plant
	1.1.23	Contaminated storm water	22.) Low quality surface water from Säveån
Other			23.) Shooting range

Table 5.8: The identified possible future hazards for Mjörn.

TECHNEAU Ref.		Hazardous event possible in the future	Hazards Mjörn
1.1 Contamination of catchment zone	1.1.3	Emissions during accidents (fire or explosions) e.g. industrial accidents or forest	Possible (Heavy duty construction vehicles)
			Possible (Fire or explosion)
	1.1.10	Fish farming	Possible
	1.1.15	Toxic chemicals from air deposits or air pollution	Possible
	1.1.16	Nuclear power accident	Possible
	1.1.24	Deliberate contamination by sabotage or terrorist action	Possible
1.1 Contamination of reservoir	1.1.25	Birds dropping or animals allowed to cross a protection zone	Possible
	1.1.26	Algae blooms (mostly during summer month's)	Possible
12.1 Sabotage or terrorist attack	12.1.1	Intentional chemical contamination	Possible
	12.1.2	Intentional microbial contamination	Possible
	12.1.3	Non accessible information. To prevent sabotage and terrorist attacks information regarding source water, treatment and distribution are classified …	Possible (Classified information can lead to accidental contamination)
12.1 Conflicts	12.1.4	Military conflicts	Possible
	12.1.5	Political conflicts	Possible
	12.1.6	Competing land use	Possible
12.1 New chemicals and changed chemical pathways	12.1.7	Discharge of new chemicals to source waters due to e.g. accidents or continuous	Possible
	12.1.8	Discharge of chemicals due to new applications	Possible
12.1 Emergin pathoge ns	12.1.9	Presence of emerging pathogens able to overcome existing barriers	Possible
12.1 Climate changes	12.1.10	New precipitation and evaporation patterns	Possible
	12.1.11	The climate changes' effects on water quality (changed surface runoff and material transport effecting water quality)	Possible
Other		Pest and diseases, invasive species	Possible

The existing hazards in Sollebrunn-Gräfsnäs are marked in a map in Figure 5.2. In Appendix A.4 is the full table with hazards presented. In Table 5.9 the existing hazards are summarized, in total there are 19 hazards. In Table 5.10 is 16 possible future hazards presented. The possible future hazards are mostly from diffuse sources.

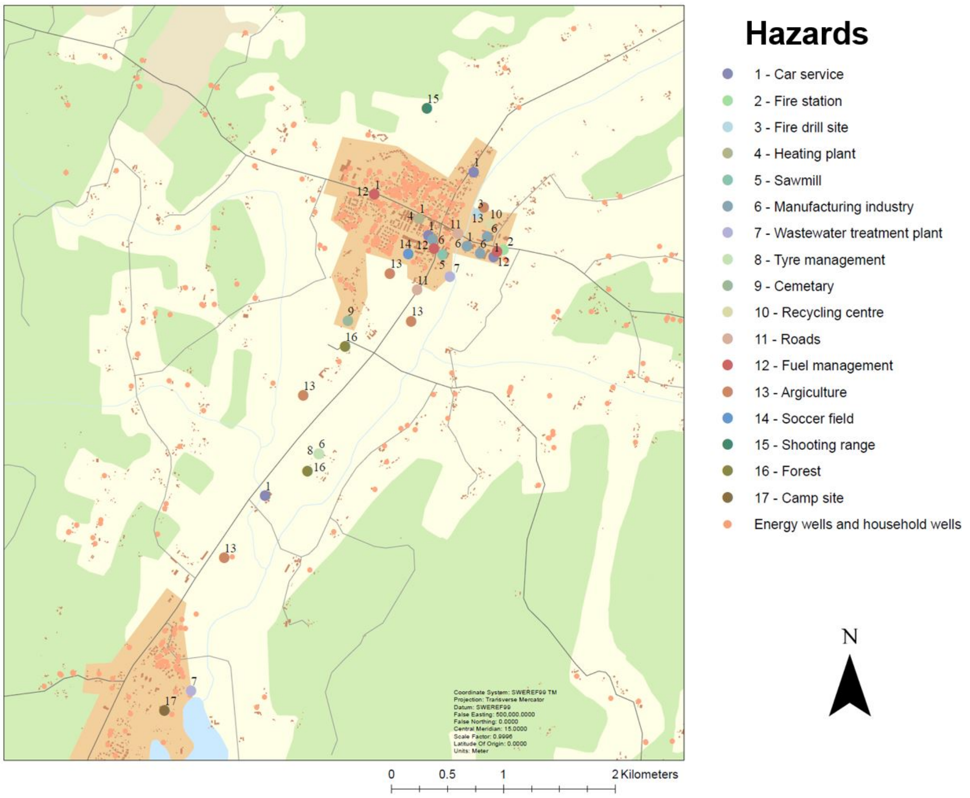


Figure 5.2: Map of the identified hazards for Sollebrunn-Gräfsnäs.

Table 5.9: The identified hazards for Sollebrunn-Gräfsnäs.

TECHNEAU Ref		Hazardous Event	Hazards Sollebrun-Gräfsnäs
2.1 Contamination of aquifers	2.1.1	Contamination by industrial operations (including continuous discharge as well as installations, construction work and other)	1.) Car service
			2.) Fire station
			3.) Fire drill site
			4.) Heating plant
			5.) Sawmill
			6.) Manufacturing industry
	2.1.2	Contamination by wastewater	7.) Wastewater treatment plant
	2.1.3	Leaching of contaminants by built constructions	8.) Tyre management
			9.) Cemetary
			10.) Recycling station
	2.1.4	Traffic, incl. accidents (railway tracks, airfields, roads, parking areas, petrol filling stations, air accidents), loss of oil by cars or boats	11.) Roads
			12.) Fuel management
	2.1.7	Agricultural runoff and leach-out containing fertilizers, sludge, herbicides, etc.	13.) Agriculture
			14.) Soccer field
	2.1.10	Accidents or spreading out of hazardous materials during recreational activities, or military field exercises and training areas.	15.) Shooting range
	2.1.11	Contamination by forestry activities, wild life activities, natural fowls, dead animals, bird pest (flu)…	16.) Forest
			17.) Camp site
		Groundwater aquifer is not sufficiently fed or water is abstracted by others	18.) Household wells in the catchment area
2.1 Reduced biologic al…	2.1.14	Water temperature under 4°C	19.) Energy wells

Table 5.10: The identified possible future hazards for Sollebrunn-Gräfsnäs.

TECHNEAU Ref.		Hazardous event possible in the future	Hazards Sollebrunn-Gräfsnäs
2.1 Contamination of aquifers	2.1.5	Construction activities with interference in subsoil	Possible
	2.1.11	Groundwater aquifer is not sufficiently fed or water is abstracted by others	Possible
	2.1.15	Radioactivity fall-out	Possible
	2.1.16	Terrorist and vandalism action	Possible
12.1 Sabotage or terrorist attack	12.1.1	Intentional chemical contamination	Possible
	12.1.2	Intentional microbial contamination	Possible
	12.1.3	Non accessible information. To prevent sabotage and terrorist attacks information regarding source water, treatment and distribution are classified …	Possible (Classified information can lead to accidental contamination)
12.1 Conflicts	12.1.4	Military conflicts	Possible
	12.1.5	Political conflicts	Possible
	12.1.6	Competing land use	Possible
12.1 New chemicals and changed chemical pathways	12.1.7	Discharge of new chemicals to source waters due to e.g. accidents or continuous	Possible
	12.1.8	Discharge of chemicals due to new applications	Possible
12.1 Emergin pathoge ns	12.1.9	Presence of emerging pathogens able to overcome existing barriers	Possible
12.1 Climate changes	12.1.10	New precipitation and evaporation patterns	Possible
	12.1.11	The climate changes' effects on water quality (changed surface runoff and material transport effecting water quality)	Possible
Other		Pest and diseases, invasive species	Possible

5.3 Visualized WSS

In this section are the visualizations of the WSS presented. The following visualizations are of the identified WSS for both Mjörn and Sollebrunn-Gräfsnäs that exist today. In Figure 5.3 are icons connected to Mjörn, and in Figure 5.4 are icons connected to Sollebrunn-Gräfsnäs presented. The icons illustrate the different WSS for the water sources. The icons are coloured in the same way as Boverket (n.d.-a), where yellow represents Provisioning services, blue represents Regulating services, and orange represents Cultural services.

Figure 5.3: Icons - The created WSS icons for Mjörn. Some icons were collected from Flaticon.com. For filtration and contribution to the hydrological cycle is made by kornkon, the icon for regulation of global climate is made by iconjam, and the icon for contribution to biodiversity is made by tifaeksa.

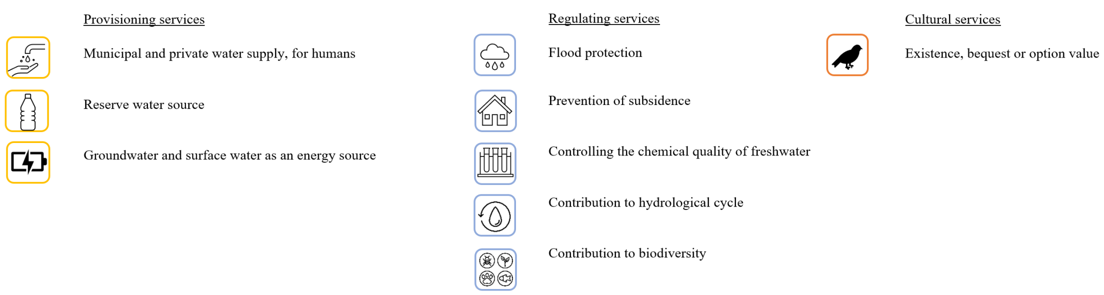


Figure 5.4: Icons - The created WSS icons for Sollebrunn-Gräfsnäs. Some icons were collected from Flaticon.com. The icon for contribution to the hydrological cycle is made by kornkon, and the icon for contribution to biodiversity is made by tifaeksa.

Figure 5.5 and Figure 5.6 are illustrations of what the different WSS can look like at Lake Mjörn. For example, the WSS drinking water for animals is illustrated by some cows at the edge of the lake, and wild plants and animals are illustrated by fishes in the lake. The reason for dividing the WSS for Mjörn into two figures is that some of the services will always be present at surface water sources and are not site-specific.

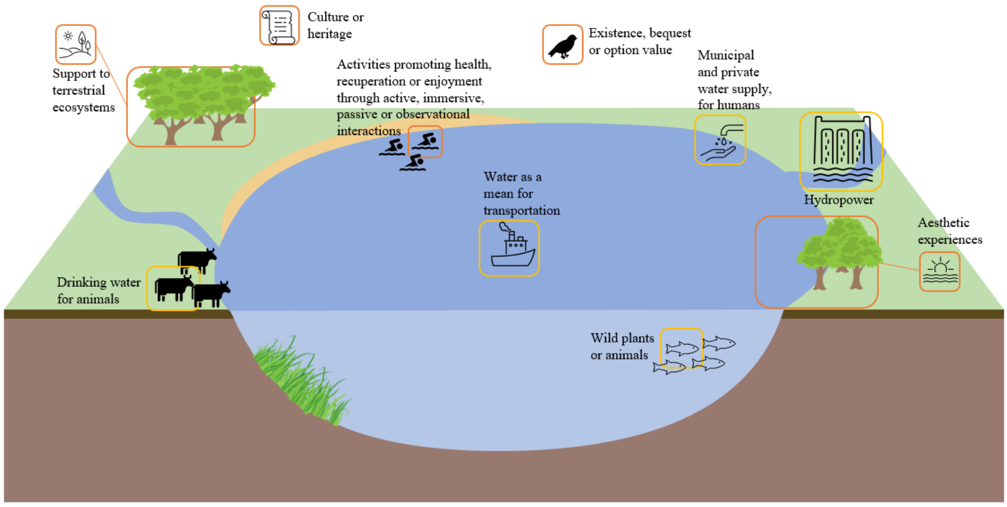


Figure 5.5: Cross section - Visualization of the site-specific WSS for Mjörn. The grass is made by ylivdesign, and the trees are made by Vectors Market, both from Flaticon.com.

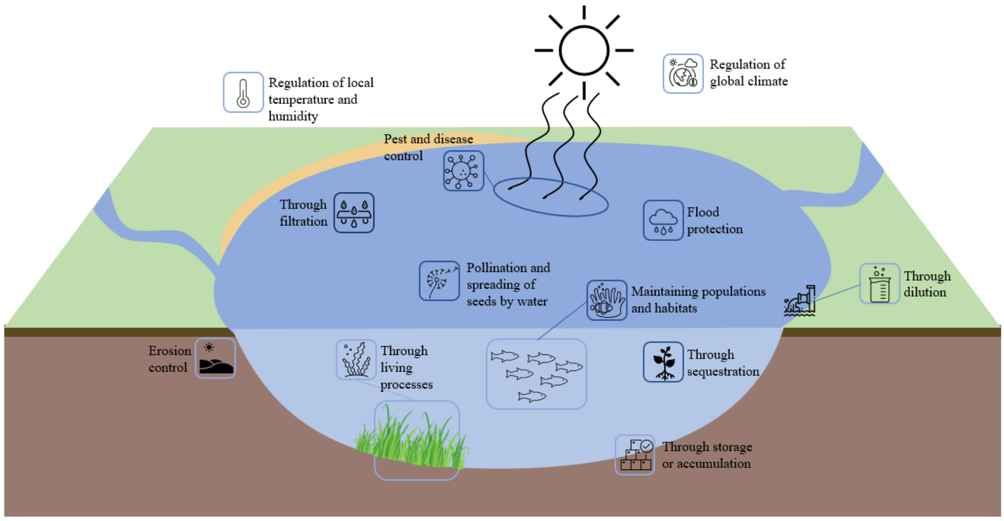


Figure 5.6: Cross section - Visualization of the WSS for Mjörn that always exists for a surface water source. The grass is made by ylivdesign, from Flaticon.com.

Figure 5.7 illustrates what the WSS might look like at Sollebrunn-Gräfsnäs. For example, the outlet of the aquifer can act as a contribution to biodiversity since certain species of plants and animals live in these types of environments.

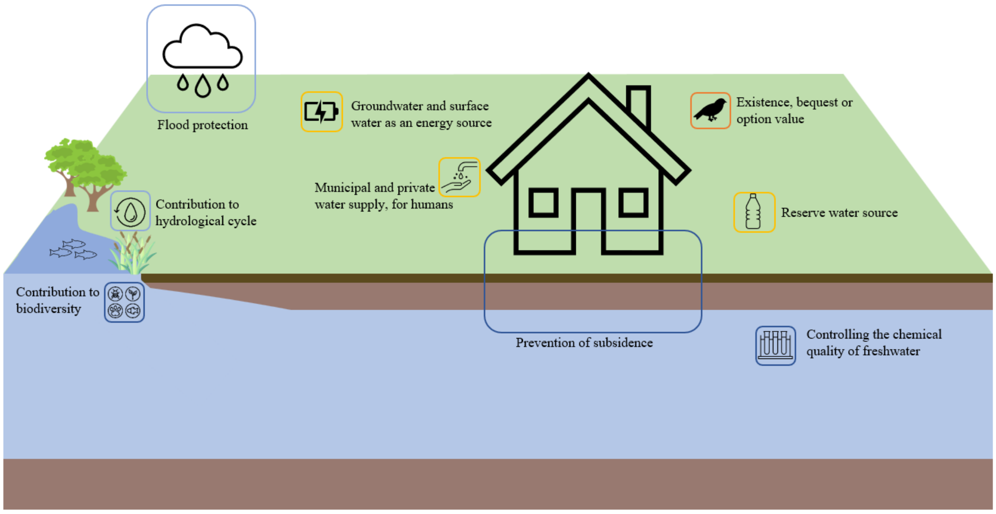


Figure 5.7: Cross section - Visualization of the WSS for Sollebrunn-Gräfsnäs. The trees are made by Vecotrs Market, and the reed is made by freepik, both from Flaticon.com.

During the site visit to both Mjörn and Sollebrunn-Gräfsnäs, photos were taken of the identified WSS. Figure 5.8 and Figure 5.9 are maps where locations of the WSS are pictured.

Figure 5.8: Map with pictures - The different WSS for Mjörn.

Figure 5.9: Map with pictures - The different WSS for Sollebrunn-Gräfsnäs.

To be able to compare the different WSS in a fair and equal way, the WSS was given a score based on how often each WSS is used. The scale ranges from *used less than once a year* to *always*. Figure 5.10 shows how often the WSS for Mjörn is used, and Figure 5.11 shows the same but for Sollebrunn-Gräfsnäs. For Mjörn, most of the regulating services are always used, which can be explained by that most of these services happen without the interaction of humans. For the provisioning services, *Municipal and private water supply, for humans* and *Hydropower* are the most used WSS. Nolhagaviken, islands and the surrounding landscapes are the most used cultural services. When looking at Sollebrunn-Gräfsnäs, all WSS except two are always used. The WSS *Flood protection* and *Contribution to hydrological cycle* are used *at least once a week*.

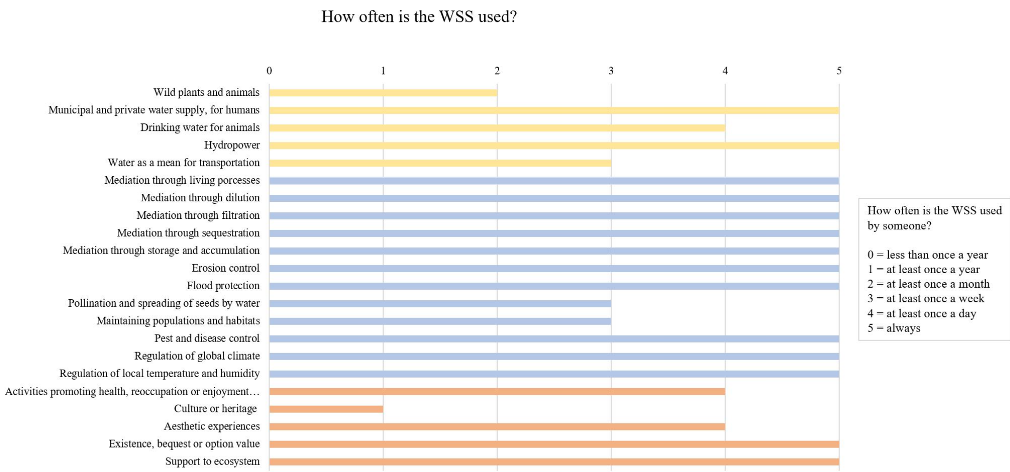


Figure 5.10: The importance of the WSS - Graph showing how often a specific WSS is used for Mjörn.

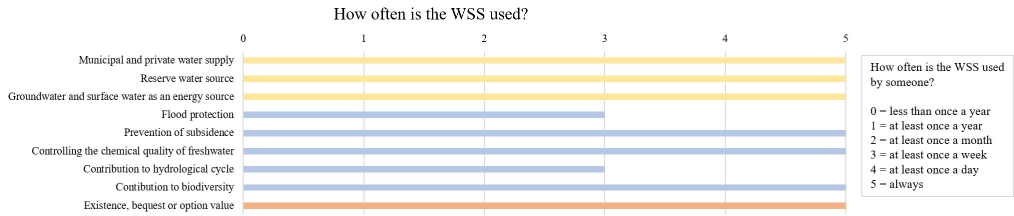


Figure 5.11: The importance of the WSS - Graph showing how often a specific WSSis used for Sollebrunn-Gräfsnäs.

5.4 Visualized links

Below are the visualizations of the linking between WSS and hazards presented. First, the connection of WSS and the hazardous events are visualized in Figure 5.11 and Figure 5.12.

Table 5.11: Table with connection - The linkage between the identified services and which hazardous event it can be affected by for Mjörn.

	Hazardous Event / WSS	1.1.1 Industrial discharge of chemicals	1.1.4 Traffic accidents with ships, trains, vehicles and planes	1.1.7 Emissions and leakage, oil spills (MTBE) by shipping or traffic	1.1.8 Harbour activities	1.1.10 Intensive fishery, fish farming, massive fish death	1.1.13 Erosion of sediments by dredging or shipping	1.1.17 Drought, blockage of water upstream or abstraction	1.1.20 Runoff from agriculture and urban green areas containing fertilizers, sludge, herbicides, etc	1.1.21 Continuous leakage from landfills, contaminated soils or waste dumps	1.1.22 Discharge of treated wastewater	1.23 Contaminated storm water	Shooting range
Provisioning Services	Wild plants or animals	X	X	X	X	X	X	X	X	X	X	X	X
	Municipal and private water supply, for humans	X	X	X	X		X	X	X	X	X	X	X
	Drinking water for animals	X	X	X	X		X	X	X	X	X	X	X
	Hydropower							X					
	Water as a mean for transportation							X					
Regulating Services	Mediation through living processes	X	X	X	X		X	X	X	X	X	X	X
	Mediation through dilution							X					
	Mediation through filtration	X	X	X	X		X	X	X	X	X	X	X
	Mediation through sequestration	X	X	X	X		X	X	X	X	X	X	X
	Mediation through storage or accumulation			X			X	X					
	Erosion control (Water and vegetation)	X	X	X	X		X	X	X	X	X	X	X
	Flood protection							X					
	Pollintation and spreading of seeds by water							X					
	Maintaining populations and habitats	X	X	X	X	X	X	X	X	X	X	X	X
	Pest and disease control							X					
	Regulation of global climate	X	X	X	X		X	X	X	X	X	X	X
	Regulation of local temperature and humidity							X					
Cultural Servies	Activities (Islands, fishing and beaches)	X	X	X	X	X	X	X	X	X	X	X	X
	Culture or heritage							X					
	Aesthetic experiences							X					
	Existence, bequest or option value	X	X	X	X	X	X	X	X	X	X	X	X
	Landscapes that have important natural value							X					

Table 5.12: Table with connection - The linkage between the identified WSS and which hazardous event it can be affected by for Sollebrunn-Gräfsnäs

	Hazardous Event / WSS	2.1.1 Contamination by industrial operations	2.1.2 Contamination by wastewater	2.1.3 Leaching of contaminants by built constructions	2.1.4 Traffic, incl. accidents, loss of oil by cars or boats	2.1.7 Agricultural runoff and leach-out containing fertilizers, sludge, herbicides, etc.	2.1.10 Accidents or spreading out of hazardous materials during recreational activities, or military field exercises and training areas.	2.1.11 Contamination by forestry activities, wild life activities, natural fowls, dead animals, bird pest (flu)…	2.1.13 Groundwater aquifer is not sufficiently fed or water is abstracted by others	2.1.14 Water temperature under 4°C
Provisioning Services	Municipal and private water supply, for humans	x	x	x	x	x	x	x	x	x
	Reserve water source	x	x	x	x	x	x	x	x	x
	Groundwater and surface water as an energy source								x	x
Regulating Services	Flood protection								x	
	Prevention of subsidence								x	
	Controlling the chemical quality of freshwater								x	
	Contribution to hydrological cycle								x	
	Contribution to biodiversity	x	x	x	x	x	x	x	x	x
Cultural Services	Existence, bequest or option value	x	x	x	x	x	x	x	x	x

In Figure 5.12 and Figure 5.13 the number of services that are affected by each hazardous event is visualized. The risk of drought in Mjörn and that the groundwater source is not sufficiently fed at Sollebrunn-Gräfsnäs are affecting all their services. Each hazard at Mjörn and Sollebrunn-Gräfsnäs is affecting at least 4 services.

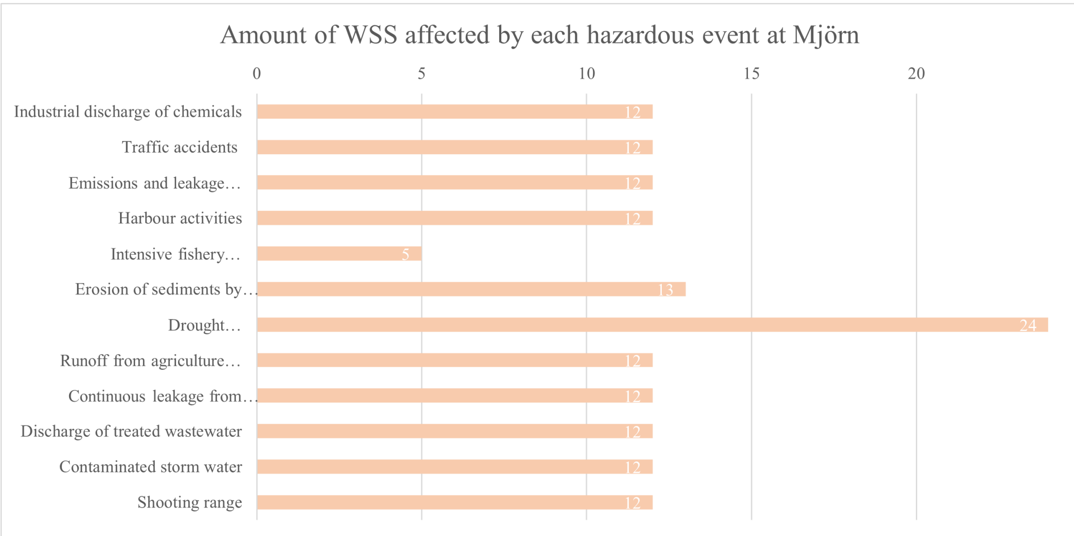


Figure 5.12: WSS affected - Graph showing the number of WSS that are affected by each hazardous event for Mjörn.

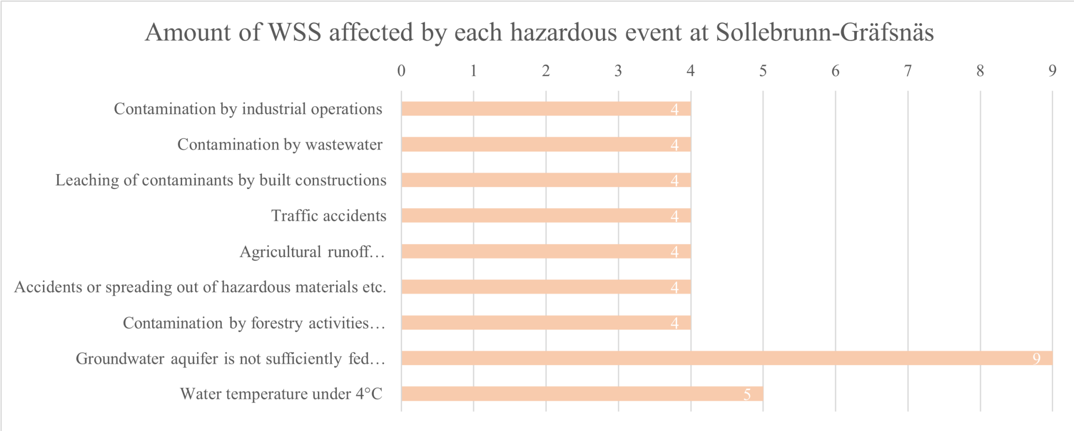


Figure 5.13: WSS affected - Graph showing the number of services that are affected by each hazardous event for Sollebrunn-Gräfsnäs.

In Figure 5.14 and Figure 5.15, the number of services affected by each hazardous event is visualized again, but each affected WSS is communicated with the associated icon.

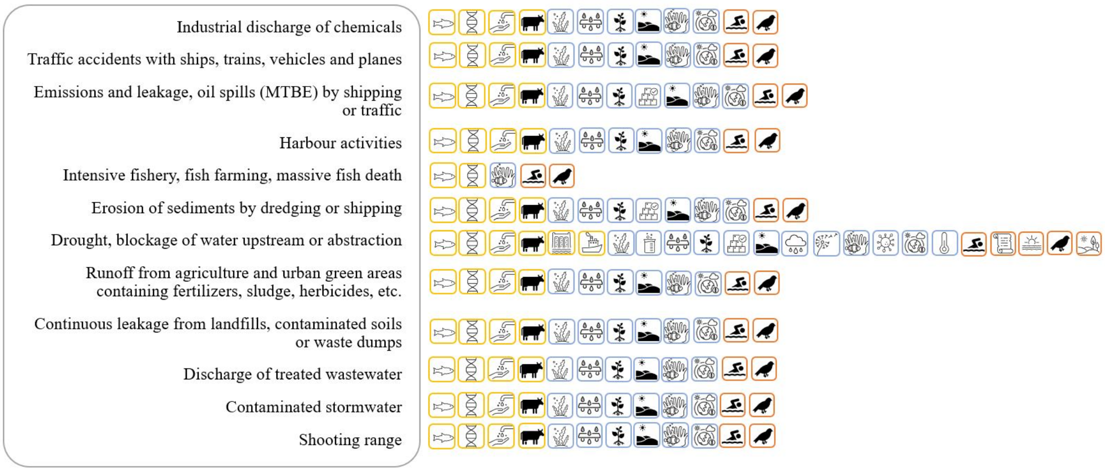


Figure 5.14: WSS affected with icons - The number of services affected by each source of risk for Mjörn.

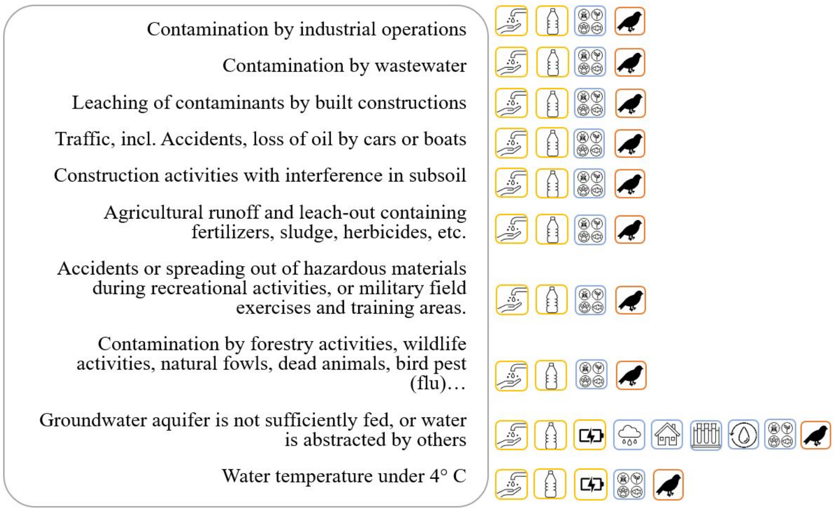


Figure 5.15: WSS affected with icons - The number of services affected by each source of risk for Sollebrunn-Gräfsnäs.

As well as each hazardous event affecting different services, each WSS is affected by different hazardous events. This is visualized with the created icons representing the WSS put in bubbles that have a different size depending on the amount of hazards that are affecting the WSS, see Figure 5.16 and Figure 5.17. For example, the WSS wild animals and plants are affected by more hazardous events than the WSS storage and accumulation for Mjörn. For Sollebrunn-Gräfsnäs, the WSS municipal and private water supply is affected by more hazardous events than prevention of subsidence.

Figure 5.16: Bubbles - The identified WSS for Mjörn scaled to the number of risks that can affect that WSS.

Figure 5.17: Bubbles - The identified WSS for Sollebrunn-Gräfsnäs scaled to the number of risks that can affect that WSS.

Grouping and connection of hazards and WSS are shown below in Figure 5.18 and 5.19. The WSS are grouped according to whether the WSS includes animals, water quality, storage or water quantity. Sollebrunn-Gräfsnäs also has one category including energy. The water quality includes services which both need good quality or give good water quality. The water quantity is services which need water quantity. The hazards are grouped according to whether they affect fishes, water quantity, water quality or sediment. The hazardous events that have potential chemical consequences are a risk for the same services, while hazardous events that threaten the presence of water are a risk for all services.

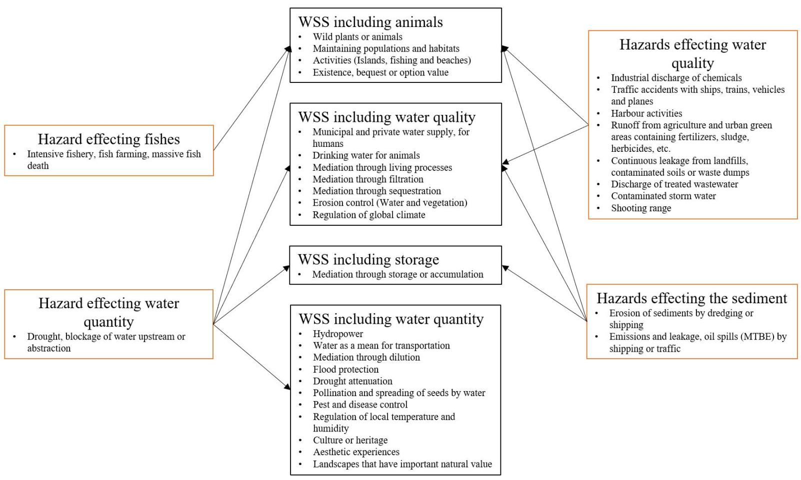


Figure 5.18: Grouping and connection of WSS and hazards for Mjörn.

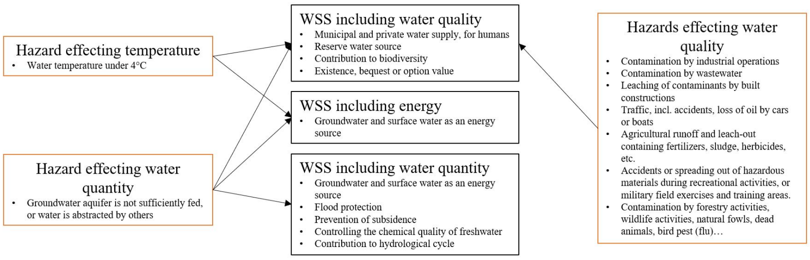


Figure 5.19: Grouping and connection of WSS and hazards for Sollebrunn-Gräfsnäs.

Some of the identified hazards are also a service at the same time. At Mjörn, transportation with boats in the lake is for example both a hazard and a service, which is visualized in Figure 5.20. The wastewater treatment plant in Figure A.1, hydropower plant in Figure A.2, disposal of stormwater in Figure A.3, water extraction in Figure A.4, and fishing in Figure A.5, are seen as both hazards and services as well.

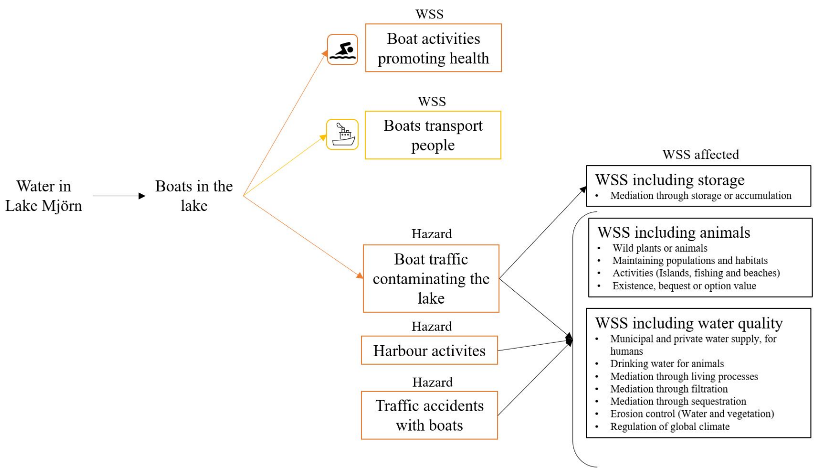


Figure 5.20: Transportation with boats is both a hazard and a service.

For Sollebrunn-Gräfsnäs, the hazard of energy wells is also a service, see Figure 5.21. The hazard of household wells can also be seen as both a hazard and a service, and is visualized in Figure A.6.

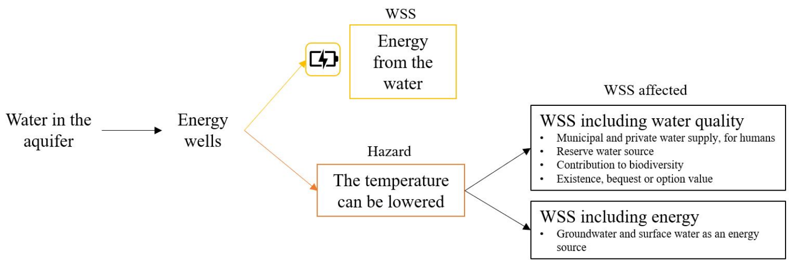


Figure 5.21: Energy wells are both a service and a hazard.

5.5 Risk assessment

The chosen risks to evaluate are boat traffic for Mjörn and energy wells for Sollebrunn-Gräfsnäs.

5.5.1 Boat traffic at Mjörn

Boat traffic is the chosen hazard for the risk assessment. It is a hazard that is also a service and affects more than half of the services at Mjörn. Boats are often present in lakes and the method to assess the risk can therefore be used in other cases. Emissions from the boat traffic is a hazardous event that occurs right in the lake, there is no transport of the contamination to the water.

16 percent of the Swedish household have a recreational boat and it is assumed to exist 864 200 seaworthy recreational boats in Sweden (Lagerqvist, Markus, 2021). Each boat is used on average 20 days per year. It is assumed to be a lot of boat traffic in Mjörn since the lake has some different harbours. One is in Hjällnäs which has 169 boat places (Hjällsnäs båt & bryggförening, n.d.). Different steamboat docks are also placed in Mjörn (Mjörns Ångbåstförening, n.d.). From the site visit were private docks in the lake and boats in gardens identified which are assumed to be used in the lake in the summer. Also, a motor boat club of the lake with 700 members exists (Mjörns motorbåtsällskap, n.d.). Their boat places are located in Säveån, at the inlet to Mjörn.

Boat traffic is a diffuse source and the contamination happens all the time when the boats are driving. Boat bottom paint contains microplastics and the emissions of microplastics from it are estimated to be around 30 to 308 tons per year in Sweden (Brännström et al., 2023). Boats release chemicals from the boat bottom paint but also air emissions and wastewater dumping to the water (WWF, n.d.). Boat bottom paint is not necessary to be used in lakes, it is the barnacles in the seas that the boats need protection from when using paint. Oil released from boats is a threat to birds and other animals. Two-stoke engines release up to 30 percent of the fuel unburnt into the water (Swedish Transport Agency, 2023b). For example, are 300 litres of unburned fuel released to the water when driving a 70-hp two-stroke engine with full power for 25 hours (Båtmiljö.se, 2023). It is assumed that 170,000 of these old-engine boats exist in Sweden. Two-stoke engines are recommended to be changed and the fuel to be greener according to the Swedish Transport Agency Swedish Transport Agency (2023a). Small boat harbours and docks are destroying the environment on the bottom of the lakes (SwAM, n.d.-c). Also when the boats drive in the lake turbidity of the sediment occurs and noise from the boats affects the animals in the lake.

These specific threats of the boat traffic are important to consider when developing and making a risk assessment. The chosen specific threats are leaking oil, turbidity and destroying the bottom, and noise from the boats. The risk for the services affected by the hazard is evaluated according to Table A.16 and A.17 in Appendix

A.7. Also, the weighting, probability, vulnerability and consequences for the specific threat are presented there. It is the services including animals, water quality and storage that are affected by the chosen hazard. A summary of the calculated risks is presented in Table 5.13. The calculated interval of low, medium and high risk are shown in Table 5.14. Most of the services and specific threats pose a medium risk. The risk is lowest for the service *Wild plants or animals* for all the specific threats, which is 0.09 and 0.12. The largest risk for leaking oil is 2.86 for *Maintaining populations and habitats* , *Existence, bequest or option value*, *Municipal and private water supply, for humans* and *Drinking water for animals*. For turbidity and destroying the bottom, it is the score 3.57 for *Maintaining populations and habitats*, *Activities (Islands, fishing and beaches)*, *Mediation through living processes* and *Mediation through storage or accumulation* that poses the highest risk. For noise from the boats, it is 3.57 for *Maintaining populations and habitats* that have the highest risk. The highest risk for the specific threats is a score of 26 for turbidity and destroying the bottom.

WSS / Specific threat	Wild plants or animals	Maintaining populations and habitats	Activities (Islands, fishing and beaches)	Existence, bequest or option value	Municipal and private water supply, for humans	Drinking water for animals	Mediation through living processes	Mediation through filtration	Mediation through sequestration	Erosion control (Water and vegetation)	Regulation of global climate	Mediation through storage or accumulation	Total
Leaking oil	0.09	2.86	2.14	2.86	2.86	2.86	2.14	2.14	2.14	2.14	2.14	0.71	25
Turbidity and destroying the bottom	0.12	3.57	3.57	0.71	2.14	2.14	3.57	0.71	0.71	2.14	2.86	3.57	26
Noise from the boats	0.12	3.57	2.14	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	12

Table 5.13: The resulting risk scores for each service and the specific threats, for Mjörn.

	Low risk	Medium risk	High risk
Risk each WSS	0 - 0.00003	>0.00003 -<3.57	3.57 - 25
Risk specific threat	0 - 0.00066	>0.00066 -<78.54	78.54 - 550

Table 5.14: Interval for low, medium and high risk.

Figure 5.22 show the risk for each WSS and specific threat. It can be seen that each specific threat often poses a similar score of risk to most of the services.

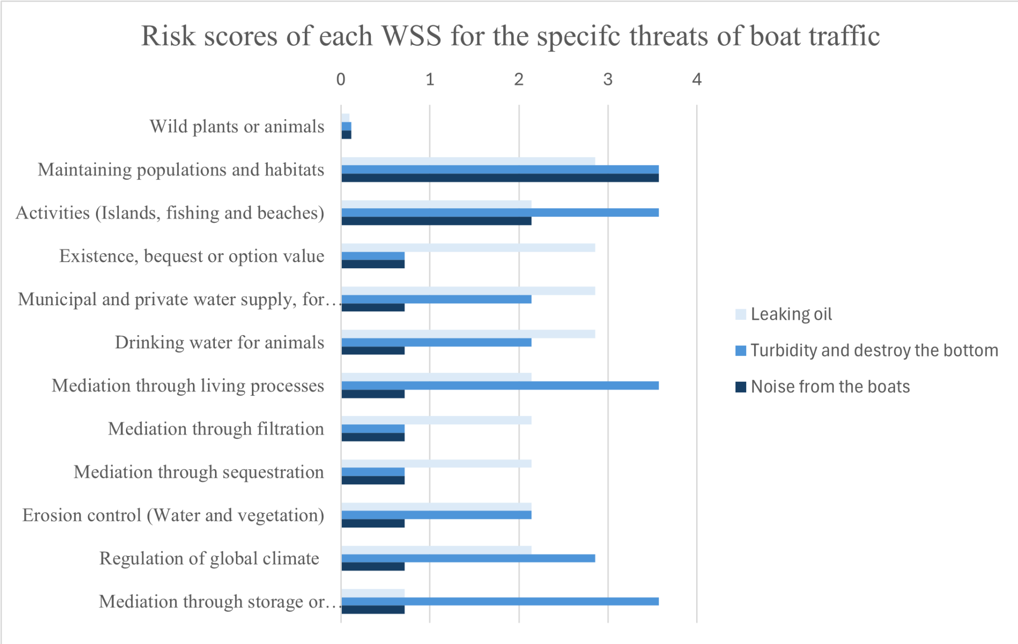


Figure 5.22: Risk scores of each WSS for the specific threats of boat traffic

5.5.2 Energy wells at Sollebrunn-Gräfsnäs

After analyzing the results of the visualizations for Sollebrunn-Gräfsnäs the chosen hazard to be evaluated is the energy wells. Looking at Figure 5.13, the hazardous event that is connected to energy wells is *water temperature below 4°*, which is affecting the second most services. This hazard can be considered as a WSS as well, which is interesting to investigate. Energy wells were not investigated in the previous report by Andreasson et al. (2022), which is another reason energy wells are chosen.

The identified energy wells are shown in Figure 5.23. An energy well can supply a home with heat or cooling by transporting heat to or from the ground (Office of Energy Efficiency & Renewable Energy, 2017). This kind of heating system does not need fossil fuels to operate and does therefore produce substantially less greenhouse gases compared to other heating systems that use fossil fuels (W. Lund & Petruzzello, 2024). Since the energy wells can extract heat from the surrounding ground, it could lead to a decrease in groundwater temperature. When the surrounding ground reaches temperatures below 4°C, there is an elevated risk that the groundwater freezes, leading to more difficulties in extracting the groundwater (National Snow and Ice Data Center, n.d.). A decrease in groundwater temperature can also lead to increased pH, increased survival time of pathogens, and reduced chemical oxidation and reduction (Health Canada, 2009). A decrease in temperature can thereby lead to the specific threats of aquifer freezing and a decrease in chemical water quality. These specific threats can complicate the treatment of the groundwater, and it is therefore important to investigate the risk of these energy wells to see if measures are needed to prevent a decrease in groundwater temperature. It is also important to make sure that the wells are constructed in a proper way to prevent them from malfunctioning which can lead to uncontrolled discharge of the geothermal fluids causing chemical contamination (Aksoy et al., 2009). The construction of the wells is seen as a possible future hazard in this report since it will only occur when building the wells and not while it is in operation. Due to this, only the risk of a decrease in temperature is evaluated for the wells and if new wells were to be built in the future this hazard would need to be taken into account.

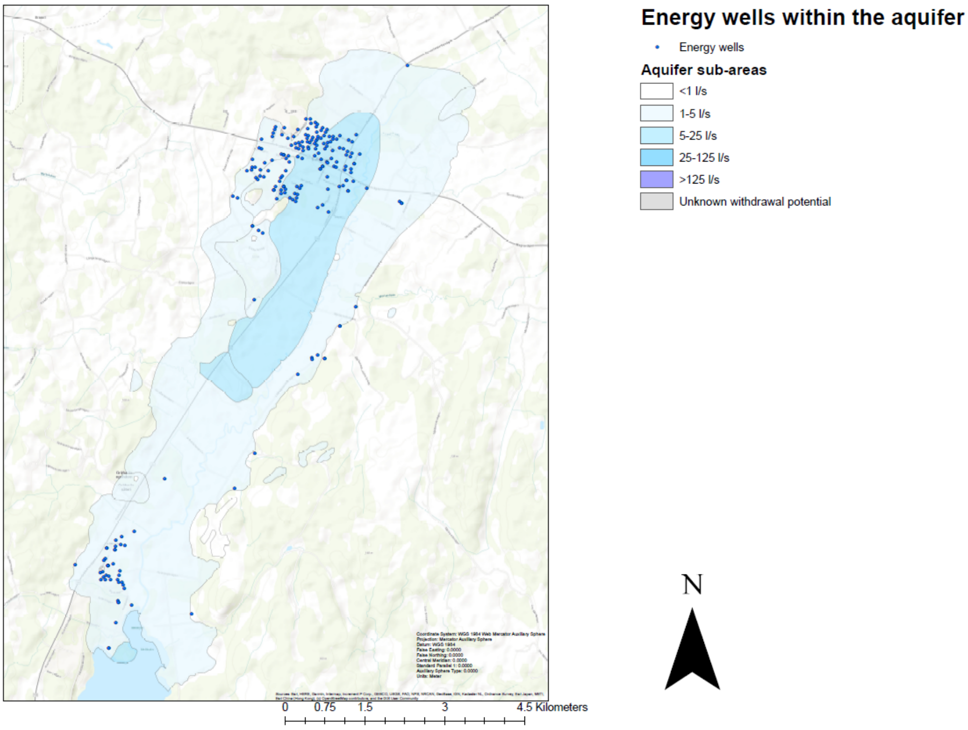


Figure 5.23: The identified energy wells for the Sollebrunn-Gräfsnäs aquifer.

In total there are 214 energy wells in the area of the aquifer, see Figure 5.23. As can be seen on the map, the energy wells are more concentrated in Sollebrunn and Gräfsnäs, with 159 and 41 wells respectively. It is assumed that all the energy wells are used at the same time, to get the worst-case scenario for the aquifer.

The aquifer can be affected by changes in temperature from the energy wells in up to 20 meters from the well (SGU, 2024). It is a gradient change, with the largest change, 5-10°C, closest to the well, decreasing to about 1 °C at 20 meters from the well. The average temperature of the aquifer can be represented by the average air temperature (SGU, 2024). SMHI has data on the air temperature from previous decades, where the closest observation station to Sollebrunn-Gräfsnäs is Gendalen (SMHI, n.d.-b). Data on the average daily temperature from the past 10 years was obtained to get an overview of the variation of temperature throughout the year. This parameter will be used to assess the probability that the hazardous event will occur.

With the data from the last 10 years, there is a 32% chance that the energy wells will affect the aquifer. This is based on when the air temperature is 4°C or lower and therefore it is a risk that the whole 20-meter radius from the energy well is 4°C or lower. This leads to an affected area of about 0.3 km^2, which is approximately 3% of the total aquifer area. Since the area affected by the decrease in aquifer temperature is only 3% of the total area, the consequence of the aquifer freezing is low when it comes to most of the services.

A summary of the results from the risk assessment of the specific threats for the WSS at Sollebrunn-Gräfsnäs is shown in 5.15. The larger table with the different risk scores is shown in Table A.18 in Appendix A.7, where the weighting, probability hazardous events occur, the vulnerability of the aquifer and the consequences of the hazard have on the affected services are presented. The scoring interval for assessing the hazard is shown in Figure 5.16. According to the scoring interval, most of the specific threats for Sollebrunn-Gräfsnäs pose a medium risk for the connected WSS. The specific threat of aquifer freezing has the highest total risk of 8.57. The WSS that is most affected by this specific threat and thereby contributes the most to this score is *Groundwater and surface water as an energy source*, with a score of 3.57 for the risk. The lowest score, and thereby the least affected for the aquifer freezing is the *Existence, bequest or option value* WSS, with a risk score of 0.71. For the *Decrease in chemical water quality*, the WSS of *Contribution to biodiversity* is affected the most, with a risk score of 2.86. The least affected WSS for this specific threat is *Groundwater and surface water as an energy source* and *Existence, bequest or option value*, where both have a risk score of 0.71.

Table 5.15: The resulting risk scores for each WSS and the specific threats, for Sollebrunn-Gräfsnäs.

WSS / Specific threat	Municipal and private water supply, for humans	Reserve water source	Groundwater and surface water as an energy source	Contribution to biodiversity	Existence, bequest or option value	Total
Aquifer freezes	1.43	1.43	3.57	1.43	0.71	8.57
Decrease in chemical water quality	1.43	1.43	0.71	2.86	0.71	7.14

Table 5.16: Risk scores of each WSS for the specific threats of energy wells

	Low risk	Medium risk	High risk
Risk each WSS	0 - 0.00003	>0.000030 - <3.57	3.57 - 25
Risk specific threat	0 - 0.00027	>0.00028 - <32.12	32.13 - 225

Figure 5.24 shows a comparison between the risk for each WSS and specific threat. As can be seen, the hazard poses the same risk for *Municipal and private water supply, for humans*, *Reserve water source*, and *Existence, bequest or option value.* For the WSS *Groundwater as an energy source* and *Contribution to biodiversity* the risk is a little different depending on the specific threat. For using the groundwater as an energy source, the specific threat of the aquifer freezing has the highest risk,

compared to the contribution to biodiversity where the decrease in chemical water quality has the highest risk.

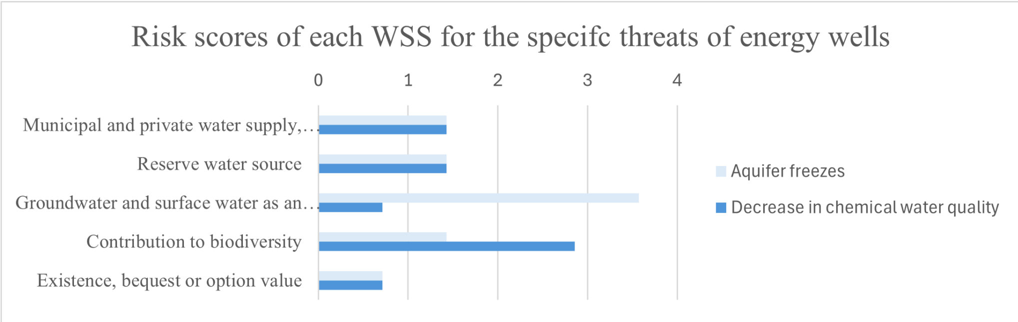


Figure 5.24: Risk scores of each WSS for the specific threats of energy wells.

6
Discussion

In this chapter is the identification of WSS and hazards, visualizations, and risk assessment and risk reduction discussed. Also WSS in relation to water protection and outlooks of the study are discussed.

6.1 Water system services

The identified WSS today are 22 classes at Mjörn and 9 classes at Sollebrunn-Gräfsnäs. The potential utilized services in the future are 15 classes at Mjörn and 7 classes at Sollebrunn-Gräfsnäs. The classes are used in the study to group the services and better get an overview and be able to use the study in future work. It is still important to highlight the service in the case study to be able to do a risk assessment for example. Fewer services are identified at the groundwater source, which is expected because the source is not used to the same extent since it is located below the ground surface. The potential services are important to mention since they have a high probability of being used in the future, and may thus also motivate protective measures. They are, however, not investigated further in this study but could be involved in the visualization and assessment in the future.

One way to get a better understanding of how important the WSS are to the people living in and visiting the area is to talk to them. This is to see how often they use the WSS and how often they think about them. Making assumptions about situations that have not been experienced can lead to unrealistic results. Another way to better understand the WSS is to take samples of the surface water and the sediment. For example, can it be discovered if phosphorus and nitrogen are stored in the sediment and to which extent the service mediation through storage or accumulation may be used.

6.1.1 Applicability of the WSS-list

The list used for the identification of WSS contains services for both surface water and groundwater sources. Some of the WSS can only exist in one of the source types. For example, the services *Geothermal energy* and *Prevention of subsidence* can not exist in a surface water source. The following services can not be provided by a groundwater source: *Hydropower*, *Water as a mean for transportation*, *Pollination and spreading of seeds by water*, *Maintaining populations and habitats*, and *Pest and* *disease control*. This could be looked into further, to see if it is beneficial to have one list specific for surface water sources, and one for the groundwater sources, in a similar way as the TECHNEAU-checklist is divided for different water sources. One finding during the process was that most of the services for the groundwater source depend on whether there is a spring or not. Mostly a spring contributes to cultural services like *Aesthetic experiences*. A suggestion is then to make two lists for the groundwater sources as well, where one is adapted to if a spring is present.

Some of the WSS, mainly for regulating services, are occurring anywhere where water is present. For example, *Pollination and spreading of seeds by water* for surface water sources and *Prevention of subsidence* for groundwater sources, can exist as long as there is water present. These services could be put in a separate list or be summarised somewhere in the larger table, to make the identification of WSS easier. Even though they will always exist, they are still important to evaluate since they can be present at different scales and different levels of risk can affect them.

When it was evaluated which WSS to include or not, it became clear that some of the services were not as obvious as others. The WSS list could be evaluated further with clearer definitions and examples since some confusion may occur otherwise. For cultural services, it was found that two classes are colliding. The class of *Activities promoting health, recuperation or enjoyment through active, immersive, passive or observational interactions* and *Aesthetic experiences* are both dealing with visual observations. No other WSS has been identified to be named twice, even if some events or occurrences can provide two different WSS. One suggestion is therefore to either remove the *Aesthetic experiences* and then include it in *Activities promoting health*, or to keep the *Aesthetic experiences* and remove the observational part of *Activities promoting health*. Doing this would reduce confusion since both of them are including the same WSS.

The WSS list is developed according to human well-being. Some of the WSS in the list may be beneficial for other living species, like drinking water for animals. It can be suggested to develop the list to not only provide services for humans but also include other services like food for animals. These services are probably a service for humans in the end but are maybe excluded because of the indirect service for human well-being. In all the three categories of WSS is the last division *Support to terrestrial ecosystems*. This could be the support that the lake gives to plants and animals on land that are not directly connected to the water source. It could also be that the lake, in combination with the surrounding trees, creates an aesthetic environment to be in. These indirect services that may not be a benefit for human well-being at first sight, are important to consider. The water source can maybe be assessed as more important if looking at more aspects than just the well-being of humans.

6.2 Hazards

The identified hazards for Mjörn are 23 and the possible future hazards are 20. For Sollebrunn-Gräfsnäs, the identified hazards are 19 and the possible future hazards are 16. These hazards are grouped according to hazardous events as those hazards are affecting services in the same way. For this report, it was chosen not to include possible future hazards when conducting the risk assessment. Many of the possible future hazards are either diffuse sources, accidents, depending on climate changes or are partly due to sources further away from the area beyond the possibility of control. These hazards are more complicated to predict and assess. It is, however, still important to highlight these hazards and to be aware that they could occur in the future.

When identifying hazards, the area to study had to be defined. For Mjörn it is the watershed for the lake which includes the runoff that flows directly into the lake. For Sollebrunn-Gräfsnäs the studied area is the aquifer. Hazards that do not occur directly in these areas or are transported by the stormwater further away are thereby excluded from the study. Due to this, some of the hazards that might affect the water sources are not included. Also, the main focus of the study was to evaluate the concept of the WSS and develop a method to include WSS when assessing the risks, and not to do a complete risk assessment for all existing hazards. A smaller area of investigation is therefore more reasonable to use since the purpose of the study will be fulfilled anyway. For Mjörn for example, the area upstream of the inlet Säveån could have been included to identify more hazards that can affect the lake. If this had been done, calculations on travel time and if the hazard could be captured before reaching the lake would have been necessary. The exclusion of these hazards does not impair the study since a methodology is to be developed and tested, and not a final assessment of the actual situation in the water sources.

The TECHNEAU-checklist is only developed for hazards towards drinking water sources and the supply system. Most of the hazards identified did fit into the checklist, even though it was not only for the drinking water service. Some of the hazards though, did not fit into any of the categories and had to be put in a *Other* category. For further study on this subject, a more comprehensive hazard-checklist should be developed to also include hazards that are affecting other WSS than the drinking water.

6.3 Visualization

The visualization of the services is done in four different ways. Icons of the services give a good clarification to the text and can provide a better understanding of the services than just a text, see Figure 5.3 and Figure 5.4. The combination of icons and the cross-section put it in the right context, see Figure 5.5 and Figure 5.7. Some WSS always exist at the surface water source as visualized for Mjörn, see Figure 5.6.

These WSS are used in different extents but are always present. They are important to highlight but are not unique. A list with the WSS can work fine for people in the field, while a visualization with a cross-section and icons can be good for people not in the field, who need to understand the importance of a water protection area and their restrictions. Visualizations can make it clear what the WSS means and it can provide the information fast.

The map with pictures in Figure 5.8 and 5.9 mainly shows that the WSS exist everywhere, but WSS are also difficult to show in photos since some WSS are invisible or hard to capture with a camera. It is mainly a problem for a groundwater source and means that this kind of visualization is better for surface water sources. A photo of a WSS can make you realise that the WSS exist and you may recognize the place of the photo.

The graph of how often the WSS are used in Figure 5.10 and 5.11 is a way to show their importance. All of them are used at some level, otherwise, they are just potential services, but it is difficult to know how often a service is used. Assumptions are made and it is not taken into account that the WSS can be used by a lot of people at the same time, only that someone uses the WSS in the defined time frame. When weighing the different services based on how often they are used by someone, both residents of the area and visitors were accounted for. For the regulating services, for example, mostly the residents within the catchment area can use the services, while for the provisioning and cultural people from outside the area can benefit from them. More people are thereby considered to actively choose to use the provisioning and cultural services, but the regulating services happen without human interaction.

The visualization of the connection between WSS and hazards is made in six different ways. The table with how they are linked in Figure 5.11 and 5.12 can work fine for people in the field and it can be seen which kind of hazardous events are connected with classes of services. The amount of WSS affected by hazardous events in Figure 5.12 and 5.13 can be an important visualization when communicating in a simple and fast way that the hazards have effects on the WSS. The icons of the WSS in Figure 5.14 and 5.15 can be used when it makes sense to show which kind of WSS are affected. The bubbles with the amount of hazard affecting each WSS in Figure 5.16 and 5.17 can be good to use when the importance of minimizing the risk of the hazards should be communicated to the public.

The grouping of hazards and WSS in Figure 5.18 and 5.19 can provide an overview of how everything affects each other. This can be used when evaluating measures to easier see how a restriction may provide positive effects for different WSS. The hazard of the water quantity is always affecting all of the WSS. The visualization of the hazards that also are a service in Figure 5.20 and 5.21 can be good to use when evaluating measures to be aware of the service that may be reduced when reducing the risk of the hazard. This visualization can be useful when it needs to be explained how a specific hazard affects services and how it also provides services. It is important to think of what wants to be said with the visualization and for whom.

The visualizations in the report could be developed to be more advanced than the current state. How the information has been visualized here is only a suggestion, and there are probably more ways that the same information could be shown. For example, the icons created using Microsoft PowerPoint icons could be developed further. The icons could be created from scratch to better fit the WSS it represents. Another suggestion is to further develop how some hazards are services as well, to make it easier for the general public to understand how they are interrelated.

It is important to consider who the information is intended for to be able to adapt the visualization based on this. As mentioned in chapter 2.5, there are two ways that information can be visualized. The visualizations presented in this report are both exploratory and explanatory. Figure 5.11 and Figure 5.12 are examples of more exploratory that stakeholders dealing with the development of a water protection area can use. Figure 5.5, Figure 5.6, and Figure 5.7 are more explanatory visualizations and are for the general public to easily understand where WSS are present in everyday life.

6.4 Risk assessment & Risk reduction

For this report, only one of the hazardous events connected to each hazard was studied. When investigating boat traffic, accidents with boats were excluded, and for energy wells, interference with subsoil was excluded. The reason behind this was that the different hazardous events connected to these hazards have different risks and specific threats to the water sources. This would be important to include if a complete risk assessment is performed, to get a better view of all the events that a certain hazard contributes to.

The method for calculating the risk is to multiply the four parameters. If the weighting of the WSS, the probability and the vulnerability are all at the highest, but the consequence is the lowest score, the hazard is a medium risk. Even though the consequence is low, there is still a very high chance that the event will occur and that it will reach the water in a short time. At the same time, if the consequence is low, and the hazard reaches the water the service will probably not be affected. Changing the interval if the hazards are a low, medium or high risk for this issue will lead to problems for the other services that should be at a medium risk level. When analysing the results and deciding which hazard to put a measure on, it can thereby be important to look into the scoring of the parameters i.e. a kind of sensitivity analysis.

The intervals of the hazard posing a low, medium or high risk are not divided into three equal parts. The risk would be low for all WSS if having three equal-sized categories. Since the parameters are chosen to not be split into equal categories, and there is a proportional gap between *at least once a day* and *once a week*, the risk intervals cannot be equal. The chosen parameters of the weighting of the WSS and the probability that the hazardous event will occur are according to how many days a year it is used and are calculated in scale with an addition of 0.25 to make up for the extra day in a leap year.

The results from the risk assessment can be used in two different ways. One way is to compare the results from each specific threat for the water source and see which of them have the largest risk score. The specific threats for a hazardous event can have very different impacts on the connected WSS. Boat traffic in Mjörn, for example, has the specific threats of *Leaking oil*, *Turbidity and destroy the bottom*, and *Noise from the boats*. If these three specific threats had not been investigated on their own, it would be harder to find proper measures since it would not be known which of them contributes the most to the risk. This method of reading the results is beneficial if you want to look at measures for the hazard that is affecting the most WSS.

The other way that the results can be used is if you want to look at a specific WSS and see which of the hazards are affecting it the most. For example, if it is decided that the WSS *Wild plants and animals* should be protected, then there are risk scores for each specific threat connected to this WSS. So the results can either be used to see which specific threat to find measures for or to find measures for a specific WSS deemed to protect. This can help find the most effective measures and that the right resources are implemented so that the water sources can achieve good quality status.

An addition that could be made to the results of the risk assessment is to add a column next to the total scores of the specific threats. This column could include the number of WSS that are affected by a hazard with a high risk. This would make it easier to distinguish between two specific threats with, for example, an overall medium score but with a different number of WSS that pose a high risk.

When evaluating which measure to implement, it is important to also consider that some hazards are acting as a service as well. If measures are implemented for a hazardous event, and the service of that event is disregarded or forgotten, then there is a risk that the WSS will be reduced as well. Looking at the hazard of treated wastewater entering the lake. If this hazard would be reduced, then there is an issue with where the treated wastewater should go instead. Also, if there were a restriction for no boats in the lake, then fewer people would enjoy it and use that service of the lake. It is therefore important to consider if the hazard is a service at the same time, and to include that measures to reduce the risk can entail reduction of a WSS as well.

The concept of using WSS when assessing risks to a drinking water source provides a bigger picture than just including the risk for the drinking water service. It is advantageous to include everything affected from a hazard to be able to not overlook services negatively affected by measures or choose measures with positive effects on more services. A few hazards are also a service, which makes this way of evaluation important to not forget the positive effects of these hazards.

Typically, risk assessments are performed to only consider the risks for the drinking water. The results from this study show that all hazards are affecting the WSS *Municipal and private water supply for humans*, except the hazard of intensive fishery. It can then be discussed if it makes sense to include other services if the risk of the hazards will be assessed anyway. The different hazards and their specific threats do not pose the highest risks to the drinking water, except for one specific threat that is shared with three others as the highest. This means that the risk primarily needs to be reduced due to other services, but could be further motivated to be reduced by the risk posed to the drinking water. When looking at the total risk of a specific threat it includes the risk from other services than drinking water. This kind of risk assessment and method to decide which risks to reduce will therefore look different than if it only includes the WSS *Municipal and private water supply for humans*.

6.5 WSS related to water protection

The visualization of WSS can be useful to show the benefits that drinking water sources give to society above drinking water. The result can be used in the future when establishing a water protection area or developing a WSP for example so that these WSS and the benefits they provide are protected. This can be used by drinking water producers to communicate to the public or authorities for example. The importance of the services can be hard to communicate, but visualization can provide more understanding than just a text. It is beneficial to show the stakeholders the importance of the WSS to be able to gain an understanding of what positive aspects water protection can give.

The concept of the WSS was evaluated, and it can be seen that it can be included in a risk assessment which needs to be carried out by drinking water producers when developing a water protection area and WSPs for example. The results of the risk assessment are an important step in finding ways to assess risks regarding WSS in the future. The developed method includes a detailed level of looking at the specific threats and each WSS to find where the risk should be reduced.

The purpose of a water protection area is mainly to protect the water to be used for drinking water, but to have a bigger perspective and not harm other services when trying to protect one WSS will add value to the water protection area. Finding more reasons to protect the water can be valuable when reasoning with affected people of the protection area. Since for example, the WFD considers the protection of the water quality and volume of water bodies for human health and the environment, the water sources should not only be considered to be protected regarding drinking water but also for other purposes. This way of including WSS is also a way to contribute to different objectives, for example, the Swedish environmental objective *No eutrophication*. The responsibility that different authorities have can be included when developing a water protection area that includes consideration of WSS, like the county administrative boards which are responsible for implementing the WFD, and the goal for SwAM which is to achieve sustainable use and restoration of water sources and fish resources. A water protection area that has been designed with a bigger perspective can therefore favor other important interests and give the possibility to motivate measures.

6.6 Outlook from the study

The study has been evaluating the concept of WSS and how it can be included in drinking water sources. Further, the visualization should be tested on different stakeholders, and the visualizations can then be adjusted if needed. The visualizations in this report are examples of how it can be done, and there are probably other ways that the same information can be visualized depending on the purpose. The visualizations can therefore be further explored and developed.

For the study, only the existing WSS and hazards were evaluated. To also include the potential WSS and possible future hazards can give a picture of what future scenarios look like. This will provide information so that precautions can be implemented beforehand so that the risk of the hazard is reduced.

The method for risk assessment is developed to be used for other water sources and other hazards than evaluated in this study. Therefore it should be tried on other water sources. It should also be evaluated how this method works when assessing the risks of all identified hazards for a water source, and if changes to the method are needed in that case.

To take this study further, measures to reduce the risks should be evaluated as well as a way to include the WSS of certain hazards when evaluating these measures. The risk reduction of the different measures should also be estimated.

7
Conclusion

The study aimed to evaluate the concept of WSS and how to visualize them. It was done by identifying WSS and hazards at two water sources, visualizing the WSS and their linkage to hazards, and assessing risks to the drinking water sources. The identification was successfully carried out for both Lake Mjörn and the aquifer at Sollebrunn-Gräfsnäs. The list of WSS was successfully applied but possibilities of improving the list have been identified.

The WSS were successfully visualized with GIS images with photos of the sites, created symbols, and cross sections. The connections between hazards and WSS were illustrated through different tables, graphs and figures. The visualizations were created to find different ways to communicate the concept of WSS to stakeholders.

As an example and to test the suggested approach a risk assessment was made for one hazard for each water source. The boat traffic and the energy wells were assessed, and their specific threats were evaluated. Boat traffic seems to affect the services of *Maintaining populations and habitats*, *Activities (Islands, fishing and beaches)*, *Mediation through living processes* and *Mediation through storage or accumulation* for Lake Mjörn. Energy wells seem to affect the service of *Groundwater and surface water as an energy source* for the aquifer Sollebrunn-Gräfsnäs. Since the specific threats are quite different and affect different services it made sense to separate them in the assessment. The way of doing this makes it possible to reduce the risk more specific to the threat. It was observed that the risk was medium for all of the specific threats.

The concept of using WSS when assessing risks to a drinking water source provides a bigger picture than just including the risks for the drinking water service. It is advantageous to include everything affected from a hazard to be able to not overlook services negatively affected by measures or choose measures with positive effects on several services. A few hazards are also a service, which makes this type of evaluation important to not forget the positive effects on these hazards.

The result of this project can be used when developing water protection areas or other kinds of water protection. It is beneficial to have this holistic perspective to not overlook important services and interactions with hazards. The report gives suggestions on how a risk assessment with WSS can be carried out, but the inclusion of WSS in the risk assessment should be evaluated further and tested on more sources. The visualizations are beneficial to different stakeholders and they give an idea of how the WSS and connections can be communicated but they could be more advanced. It is recommended to try the visualizations on stakeholders to improve them further.

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A
Appendix

A.1 Identified WSS for Mjörn

Table A.1: Provisioning services for Mjörn.

Division	Group	Class	Important for case study?	Potential service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Biomass (aquatic)	Food	Cultivated plants or animals	✗	✓	a.) Fish can be cultivated for food	Not used today	Food and Agricultural Organization: 7. Fish cultivation in natural lakes and reservoirs
		Wild plants or animals	✓	-	1.) Pike-Perch, Perch, Pike, Roach, Burbot, Bronxe bream, Ide, Tench, Eel 2.) Crawfish		iFiske.se: Mjörns FVOF Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter
	Material	Fibres and other materials from cultivated plants or animals	✗	✓	b.) Reeds used to cultivate	Not used today	Odla.nu: Sätta vass
		Fibres and other materials from wild plants or animals	✗	✓	c.) Reeds used to cultivate d.) Jewellery with fish scales	Not used today	svenska.yle.fi: Vass från Skärgårdshavet skulle kunna bli utmärkt växtunderlag i stället för torv-företagare är redo: "Vi behöver nu vass i stora mängder" hemslojd.se: Fina Fisken
	Energy	Cultivated plants or animals as an energy source	✗	✓	e.) Reed can be used for biogas	Not used today	slu.se: Vass - Framtidens nyttogröda!
		Wild plants or animals as an energy source	✗	✓	f.) Reed can be used for biogas	Other energy sources around Mjörn	Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter slu.se: Vass - Framtidens nyttogröda!
	Genetic Material	Genetic material from all organisms			g.) Cultivated trout	Has been used previously	Aqua reports 2012:11: Genetisk kartläggning av öring i Mjörn

Table A.2: Provisioning services for Mjörn continued.

Division	Group	Class	Important for case study?	Potential service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Water	Water for drinking	Municipal and private water supply, for humans	✔	-	3.) Drinking water source	Not a drinking water source today	Ruderfelt, Svedlindh, Gidlund: Regional vattenförsörjningsplan för dricksvatten i Västra Götaland Göteborgsregionen: Vattenförsörjningsplan för Göteborgsregionen
		Drinking water for animals	✔	-	4.) Water source for wild animals and livestock		Hitta.se: Björkekärrs Lantbruk AB
		Reserve water source	✘	✔	h.) Reserve water source	Not listed as a reserve water source	
	Water for non-drinking purpose	Irrigation	✘	✔	i.) Irrigation of argiculture	No information if used today for irrigation	
		Cooling	✘	✔	j.) Water used as cooling in industries	No information if any industry uses the water today.	
		Water used as a material, e.g. process water	✘	✔	k.) Could be used in idustrial processes	No information if any industry uses the water today.	
	Energy	Hydropower	✔	-	5.) Solveden hydropower plant		Alingsås Energi: Vår produktion Lerum Energi: Därför ska du välja el fran Lerum Energi
		Geothermal energy	✘	✘		Surface water source, geothermal energy is takan from the ground	SGU: Bergvärme
		Groundwater and surface water as an energy source	✘	✘		Not used today	
		Storage of heat and coolness	✘	✔	l.) Lake cooling m.) Lake heating	Not used today	Bygg.se: Sjövärme - Viktigt att tänka på Energiföretagen: Fjärrkyla
	Water for transport	Water as a mean for transportation	✔	-	6.) Transport of tourists with steamboat 7.) Motor boats 8.) Transport with kayak, canoe, boat		Mjörn steamboat association Mjörns motorboat association vastsverige.com: Republiken Risön
Support to terrestrial ecosystems							

Table A.3: Regulating services for Mjörn.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxic substances and nuisances	Through living processes	✔	-	9.) Denitrification occuring in the lake 10.) Puryfing water through water-living plants		ScienceDirect: Nitrogen Removal
		Through dilution	✔	-	11.) Treated wastewater discharged from a wastewater treatment plant into a surface water body for an effluent dilution. The outlet of Sjövik treatment plant is in Mjörn.		Lerums Kommun: Kommunalt avlopp
		Through filtration	✔	-	12.) Water is purifying air through capturing the air pollutants		A sustainable water vortex-based air purification for indoor air quality Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter
		Through sequestration	✔	-	13.) Nutrient degradation		nature.com: Imbalance of global nutrient cycles exacerbated by the greater retention of phosphorus over nitrogen in lakes
		Through storage or accumulation	✔	-	14.) Phosphorus and nitrogen stored in the sediment of the lake		Länsstyrelsen Västra Göraland: Mjörn 2000 - en limnologisk studie
		Through visual cover	✖	✖		The lake Mjörn is a natural lake and is not man-made	
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Erosion control	✔	-	15.) Water level in lakes can act as prevention of landslides 16.) Reed and other vegetation exists in the sides of the lake		Impact of Water Level Fluctuations on Landslide Deformation at Longyangxia Reservoir, Qinghai Province, China Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter
		Flood protection		-	17.) Mjörn can collect access rainwater and prevent flooding downstream		waterlinepreservation.com: How do lakes prevent flooding? Solitude Lake Management: What does it mean when your lake or pond floods?

Table A.4: Regulating services for Mjörn continued.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Prevention of subsidence	✗	✗		Not for surface water	
		Drought attenuation	✗	✓	n.) Vegetaion could be used to redecude the impact of extreme events		Jessica C. A. Baker - Planting trees to combat drought Royal Netherlands Institue for Sea Research - River plants counter both flooding and drought to protect biodiversity
		Fire protection	✗	✓	o.) Mjörn could act as a barrier against fires and water can be used to fight fires	Mjörn not used to take water from when fighting fires today. Rivers have more potential to provide a barrier against fire. More important if want to protect a specific nature reserve with the water.	
	Lifecycle maintenance, habitat and gene pool protection	Pollination and spreading of seeds by water	✓	-	18.) Both non-aquatic and aquatic plants are present, highly likely that the seeds will be dispersed by the lake		Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter
		Maintaining populations and habitats	✓	-	19.) Several species of fauna present in the lake		Länsstyrelsen Västra Göraland: Mjörn 2000 - en limnologisk studie
	Pest and disease control	Pest and disease control	✓	-	20.) UV-light from the sun on the water surface		Ultraviolet A ligth effectively reduces bacteria and viruses including coronavirus A review on pesticides degradation by using ultraviolet light treatment in aricultural commodities
	Maintaining water conditions	Controlling the chemical quality of freshwater	✗	✓	p.) Living processes maintaining the already acceptable water quality	MAR is not applicable for a surface water body Fish in the lake have been proven to contain both PFOS and mercury	Göta älvs vattenvårdsförbund: Anten och Mjörn 2018 - En undersökning av vattenkemi, biologi och miljögifter
	Atmospheric composition and conditions	Regulation of global climate	✓	-	14.) Phosphorus and nitrogen stored in the sediment of the lake 21.) Water has the ability to capture carbon 22.) If high level of oxygen in Mjörn --> reduced risk of methane produced		Länsstyrelsen Västra Göraland: Mjörn 2000 - en limnologisk studie Yale School of the Environment: Expolring the Depths of Water's Role in Climate Change Linköping University: Jordens sjöar släpper ut mindre metan än man tidigare trott
		Regulation of local temperature and humidity	✓	-	23.) Lakes modifies the climate of the surrounding areas		Springer Link: Lakes, effects on climate
Support to terrestrial ecosystems							

Table A.5: Cultural services for Mjörn.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Direct, in-situ and outdoor interactions that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Activities promoting health, recuperation or enjoyment through active, immersive, passive or observational interactions	✔	-	24.) 3 island building a nature reserve with high nature value and rich bird life. 25.) Fishing 26.) Beach where you can swim, boating, hiiking, views over the lake, biking		Länsstyrelsen Västra Götaland: Risön iFiske.se: Mjörn Naturskyddsföreningen: Yttrande över planprogrammet Mjörnstranden Swedenbybike.com: Sverigeleden
	Intellectual and representative interactions with natural environment	Scientific investigation, creation of traditional ecological knowledge, education, training	✘	✔	q.) Studies of water chemistry, biology and environmental toxins r.) Mjörnbygdens Naturcentrum next to the lake where the purpose is to ge more educated about the nature		Länsstyrelsen Västra Göraland: Mjörn 2000 - en limnologisk studie Mjörnbygdens naturcentrum
		Culture or heritage	✔	-	27.) The outlet Säveån has been used to transport logs 28.) Steam powered boats have been used on the lake 29.) Settlements from the late stoneage has been found around the lake		Säveåns Landskap - En natur- och kulturmiljöstudie
		Aesthetic experiences	✔	-	30.) Pretty views over the lake and surrounding nature areas		Naturskyddsföreningen: Yttrande över planprogrammet Mjörnstranden
Indirect, remote, often indoor interactions that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Religious, sacred or symbolic meaning	✘	✘		No evidence on that the lake is sacred or have a symbolic meaning	
		Entertainment or representation	✘	✘		Mjörn is not used as a landmark or other amusement activities	
	Other biotic or abiotic characteristics that have a non-use value	Existence, bequest or option value	✔	-	31.) Nolhagviken is a place where birds enjoys living. Area around Nolhagaviken is a natura2000 area, with protected species. 32.) Several islands and areas around the lake have some sort of protection area. Some of the islands even have an access ban becuase of this.		Länsstyrelsen Västra Götaland: Nolhagaviken Naturskyddsföreningen: Yttrande över planprogrammet Mjörnstranden SEPA: Skyddad Natur
Support to terrestrial ecosystems				-	33.) Landscapes that have important natural value.		Länsstyrelsen Västra Götaland: Mjörn 2000 - en limnologisk studie

A.2 Identified WSS for Sollebrunn-Gräfsnäs

Table A.6: Provisioning services for Sollebrunn-Gräfsnäs.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Biomass (aquatic)	Food	Cultivated plants or animals	✗	✗		Nor for a groundwater source	
		Wild plants or animals	✗	✗		Not for a groundwater source	
	Material	Fibres and other materials from cultivated plants or animals	✗	✗		Not for a groundwater source	
		Fibres and other materials from wild plants or animals	✗	✗		Not for a groundwater source	
	Energy	Cultivated plants or animals as an energy source	✗	✗		Not for a groundwater source	
		Wild plants or animals as an energy source	✗	✗		Not for a groundwater source	
	Genetic Material	Genetic material from all organisms	✗	✗		Not for a groundwater source	
Water	Water for drinking	Municipal and private water supply, for humans	✓	-	1.) Groundwater withdrawals: Sollebrunn: 495 m3/d & Gräfsnäs: 90 m3/d		Tyréns: Vattenförsörjningsplan Alingsås Kommun
		Drinking water for animals	✗	✗		Not for a groundwater source	
		Reserve water source		-	2.) Reserv water soruce for Sollebrunn		Tyréns: Vattenförsörjningsplan Alingsås Kommun

Table A.7: Provisioning services for Sollebrunn-Gräfsnäs continued.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Water	Water for non-drinking purpose	Irrigation	✘	✔	a.) Can be used in the future.	No infortmation that its used today.	SGU Kartvisare: Well data
		Cooling	✘	✔	b.) Can be used in the future.	No industry in proximity which uses groundwater	herkules.slu.se: Property map Built-up areas
		Water used as a material, e.g. process water	✘	✔	c.) Can be used in the future.	No industry in proximity which uses groundwater	herkules.slu.se: Property map Built-up areas
	Energy	Hydropower	✘	✘		Not for a groundwater source	
		Geothermal energy	✘	✔	d.) Geothermal energy can be used in the future.	No indication for geothermal energy (drillings not deep enough)	British geological survey: Groundwater and energy
		Groundwater and surface water as an energy source	✔	-	3.) Energy wells		SGU Kartvisaren: Well data - Energy wells
		Storage of heat and coolness	✘	✔	e.) Storage of heat and coolness can be used in the future.	No information that its used today.	SGU Kartvisaren: Well data
	Water for transport	Water as a mean for transportation	✘	✘		Not for a groundwater sources	
Support to terrestrial ecosystems							

Table A.8: Regulating services for Sollebrunn-Gräfsnäs.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxic substances and nuisances	Through living processes	✗	✗		Not for a groundwater source	
		Through dilution	✗	✗		Not for a groundwater source	
		Through filtration	✗	✗		Not for a groundwater source	
		Through sequestration	✗	✗		Not for a groundwater source	
		Through storage or accumulation	✗	✗		Not for a groundwater source	
		Through visual cover	✗	✗		Not for a groundwater source	
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Erosion control	✗	✗		Not for a groundwater source	
		Flood protection	✓	-	4.) Aquifer can collect infiltrated rainwater		California department of water resources: Going with the flow - How aquifer recharge reduces flood risk
		Prevention of subsidence	✓	-	5.) Houses on top of the clay layer	-	herkules.slu.se: Property map Built-up areas
		Drought attenuation	✗	✗	-	Not for a groundwater source	
		Fire protection			-	Not for a groundwater source	

Table A.9: Regulating services for Sollebrunn-Gräfsnäs continued.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and spreading of seeds by water	✗	✗	-	Not for a groundwater source	
		Maintaining populations and habitats	✗	✗	-	Not for a groundwater source	
	Pest and disease control	Pest and disease control	✗	✗	-	Not for a groundwater source	
	Maintaining water conditions	Controlling the chemical quality of freshwater	✓	-	6.) GW-body feeds Anten	-	VISS: Sollebrunn-Gräfsnäs
	Atmospheric composition and conditions	Regulation of global climate	✗	✗	-	Not for a groundwater source	
		Regulation of local temperature and humidity	✗	✗	-	No springs regulating local temperature and humidity	SGU Kartvisaren: Källor
Support to terrestrial ecosystems			✓	-	7.) Contribution to hydrological cycle		Groundwater Ecosystem Services: Redefining and Operationalizing the Concept Groundwater ecosystem services: a review
				-	8.) Species depending on habitats maintained by groundwater discharge		

Table A.10: Cultural services for Sollebrunn-Gräfsnäs.

Division	Group	Class	Important for case study?	Potentiell service in the future?	Services in the case study	Reason for exclusion if applicable	Data Source
Direct, in-situ and outdoor interactions that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Activities promoting health, recuperation or enjoyment through active, immersive, passive or observational interactions	✖	✖	-	No spring where you can enjoy the water.	
	Intellectual and representative interactions with natural environment	Scientific investigation, creation of traditional ecological knowledge, education, training	✖	✔	f.) Can have observartion wells in the future.	No indication for observation wells.	
		Culture or heritage	✖	✖	-	There are cultural sites in the area but they are not related to the GW-source.	
		Aesthetic experiences	✖	✖	-	No springs in the area	
Indirect, remote, often indoor interactions that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Religious, sacred or symbolic meaning	✖	✖	-	No indication that springs are sacred	
		Entertainment or representation	✖	✖	-	No indication that springs are used for entertainment or representation	
	Other biotic or abiotic characteristics that have a non-use value	Existence, bequest or option value	✔	-	9.) Existence 10.) Option value	-	
Support to terrestrial ecosystems					-	-	-

A.3 Identified hazards for Mjörn

Table A.11: Identified hazards for Mjörn with examples.

TECHNEAU - database				Case study site			
Hazard	**Reference**	**Hazardous Event**	**Potential Consequences**	**Present in case study site?**	**Hazards**	**Specific threat**	**Data Source for Determination**
Contamination of catchment zone	1.1.1	Industrial discharge of chemicals	Contaminated water (chemicals)	✔	1.) Car Service (13) 2.) Fuel management (3) 3.) Manufacturing industry (7) 4.) Heating plant	1.,2.,3.) Oil leaking from car service, fuel management, and heating plant 1.,2.,3.,4.) Handling of petroleum products 1., 2.) Runoff from vehicle wash with degreaser 3.) Leakage of halogenated solvents	EBH Map of confirmed or potential contaminated areas Google Maps data
Contamination of catchment zone	1.1.2	Industrial discharge of bilogical matter	Contaminated water (pathogens)	✖			
Contamination of catchment zone	1.1.3	Emissions during accidents (fire or explosions) e.g. industrial accidents or forest fire	Contaminated water (chemicals)	✔	• Heavy duty construction vehicles • Fire or explosions	• Accidents with leakege from a contaminated site or construction vehicles • Chemicals from firefighting equipment and the bruning material	Google Maps data
Contamination of catchment zone	1.1.4	Traffic accidents with ships, trains, vehicles and planes	Contaminated water (chemicals)	✔	5.) Boats 6.) Roads (2) 7.) Model flying field	5., 6., 7.) Leaking fuel products 5., 6.) Fragments of metals and other chemicals	Data from Mjörns motorboat society Google Maps data The swedish model flying association
Contamination of catchment zone	1.1.5	Toxic chemicals from air deposits or air pollution	Contaminated water (chemicals)	✔	Possible		
Contamination of catchment zone	1.1.6	Nuclear power accident	Contaminated water (radionucleids)	✔	Possible		
Contamination of catchment zone	1.1.7	Emissions and leakage, oil spills (MTBE) by shipping or traffic	Contaminated water (radionucleids)	✔	5.) Boats 6.) Roads (2)	5.) Oil released 5.) Turbidity of the sediment and noise from the boats 6.) Metals, organic pollutants and microplastics	WWF - Shipping and cruise tourism SwAM - Recreational craft Traffic-related microplastic particles, metals, and organic pollutants in an
Contamination of catchment zone	1.1.8	Harbour activities	Contaminated water (chemicals, pathogens)	✔	8.) Harbours (7)	8.) Habitat disruption 8.) Boat paint and chemicals released into water	Google Maps data Mjörn motorboat society
Contamination of catchment zone	1.1.9	Latrine deposits from boats, etc.	Contaminated water (chemicals, pathogens). Nutrient load in water	✖			
Contamination of catchment zone	1.1.10	Intensive fishery, fish farming, massive fish death	Contaminated water (pathogens, chemicals)	✔	9.) Fishing 10.) Hydropower plant Fish farming	9.) Depletion of fish stock in lake 10.) Prevention upstream/downstream mating areas • Waste from fish feed and faces • Chemicals and pesticides from disease controll • Loss of beneficial ecosystem functions	Data from iFiske Google Maps data EBH Map of confirmed or potential contaminated areas sustainweb.org - Environmental impacts Commercial Fish Farming
Contamination of catchment zone	1.1.11	Disrupted inflow such as failure of dams and extreme runoff	Contaminated water (chemicals) Insufficient raw water	✖			
Contamination of catchment zone	1.1.12	Sewer overflows due to rainfalls or failures	Contaminated water (chemicals) Insufficient raw water	✖			Alingsås Municipality - Råd och anvisningar till Allmänna Bestämmelser för Vatten och Avlopp
Contamination of catchment zone	1.1.13	Erosion of sediments by dredging or shipping	Contaminated water (sediment, chemicals, pathogens)		11.) Dredging in Säveån 8.) Harbours (5)	11., 8.) Liberation of stored contaminants in sediments 11., 8.) Habitat degradation	Alingsås Municipality - Muddring i Säveån National Ocean Service - What is dredging? A review of impacts of marine dredging activities on marine mammals

Table A.12: Identified hazards for Mjörn with examples, continued.

TECHNEAU - database				Case study site			
Hazard	**Reference**	**Hazardous Event**	**Potential Consequences**	**Present in case study site?**	**Hazards**	**Specific threat**	**Data Source for Determination**
Contamination of catchment zone	1.1.14	Erosion into catchment with release of soil, sand or contaminants	Contaminated water (chemicals)	✘			
Contamination of catchment zone	1.1.15	Earthquake, landslides	Contaminated water (pathogens, chemicals). Insufficient raw water	✘			
Contamination of catchment zone	1.1.16	Salt intrusions from the sea	Contaminated water (salinity in elevated levels)	✘			
Contamination of catchment zone	1.1.17	Drought, blockage of water upstream or abstraction	Insufficient raw water	✔	12.) Overabsraction of water or drought	12.) Water shortage	Google Maps data WHO - Drought
Contamination of catchment zone	1.1.18	Climate or cooling water from power plants	Warm raw water to treatment	✘			
Contamination of catchment zone	1.1.19	Disposal of manure	Contaminated water (pathogens, nutrient load, pharmaceuticals)	✘			
Contamination of catchment zone	1.1.20	Runoff from agriculture and urban green areas containing fertilizers, sludge, herbicides, etc	Contaminated water (pathogens, chemicals, nutrient load)	✔	13.) Agriculture (4) 14.) Plant nursery (3) 15.) Soccer field (5) 16.) Golf course (1)	13., 14., 15., 16.) Nutrients reaching the water 13., 14.) Pesticides	
Contamination of catchment zone	1.1.21	Continuous leakage from landfills, contaminated soils or waste dumps	Contaminated water (chemicals)	✔	17.) Landfill (8) 18.) Scrapyard (2) 19.) Recycling station (1) 20.) Contaminated sites (6)	17., 18.) Degrading toxic waste 17., 18., 19., 20) Leaching metals 17., 18., 19., 20) Nutrients and chemicals from waste 20.) Ex. PERC, Acetal, Propylene Glycol Ethers from old dry celaning	EBH Map of confirmed or potenital contaminated areas Google Maps data
Contamination of catchment zone	1.1.22	Discharge of treated wastewater	Contaminated water (pathogens, chemicals, nutrient load)	✔	21.) Wastewater treatment plant (4)	21.) Nutrients, pathogens and cheimcals from treatment reaching the lake	Lerum Municipality - Kommunalt avlopp
Contamination of catchment zone	1.1.23	Contaminated storm water	Contaminated water (pathogens, chemicals, nutrient load)	✔	22.) Low quality surface water from Säveån	22.) Microplastics from road surface reaching the lake 22.) Nutrients and pathogens from green areas	VISS - Säveån mynningen i Mjörn till Alingsås Centrum
Contamination of catchment zone	1.1.24	Deliberate contamination by sabotage or terrorist action	Contaminated water (pathogens, chemicals, radionucleids). Insufficient raw water	✔	Possible	• Chemicals, pathogens, and other harmful substances • Microbial contamination that causes illness	
Contamination of reservoir	1.1.25	Birds dropping or animals allowed to cross a protection zone	Contaminated water (pathogens)	✔	Possible		
Contamination of reservoir	1.1.26	Algae blooms (mostly during summer month's)	Contaminated water (algae, chemicals, nutrient load)	✔	Possible		
Sabotage or terrorist attack	12.1.1	Intentional chemical contamination	Contaminated water. No/insufficient water supply. Public concern, bad image.	✔	Possible		
Sabotage or terrorist attack	12.1.2	Intentional microbial contamination	Contaminated water. No/insufficient water supply. Public concern, bad image.		Possible		
Sabotage or terrorist attack	12.1.3	Non accessible information. To prevent sabotage and terrorist attacks information regarding source water, treatment and distribution are classified. Due to this all necessary information might not be available to…	If the personal operating the system does not have all necessary information, actions might be taken that introduce…		Future drinking water source, information is/will be classified, risk of unintentional contamination		

Table A.13: Identified hazards for Mjörn with examples, continued.

TECHNEAU - database				Case study site			
Hazard	Reference	Hazardous Event	Potential Consequences	Present in case study site?	Hazards	Specific threat	Data Source for Determination
Conflicts	12.1.4	Military conflicts	Contaminated water. Technical damage	✔	Possible		
Conflicts	12.1.5	Political conflicts	Political actions leading to water shortage	✔	Possible		
Conflicts	12.1.6	Competing land use	Contaminated water. No/insufficient water	✔	Possible		
New chemicals and changed chemical pathways	12.1.7	Discharge of new chemicals to source waters due to e.g. accidents or continuous leakage	Contaminated water. No/insufficient water supply. Remediation of supply system	✔	Possible		
New chemicals and changed chemical pathways	12.1.8	Discharge of chemicals due to new applications	Because known chemicals are put into new pathways they may cause contaminated water, no/insufficient water supply…	✔	Possible		
Emergin pathogens	12.1.9	Presence of emerging pathogens able to overcome existing barriers	Insufficient water quality. Increased number of waterborne infections. Remediation of supply system.	✔	Possible		
Climate changes	12.1.10	New precipitation and evaporation patterns	No/insufficient water supply	✔	Possible		
Climate changes	12.1.11	The climate changes' effects on water quality (changed surface runoff and material transport effecting water quality)	No/insufficient water supply. Contaminated water (including higher temperature of supplied water)	✔	Possible		
Other					23.) Shooting range (6)	23.) Metals from bullets 23.) Gunpowder	EBH Map of confirmed or possible contaminated areas
Other		Pest and diseases, invasive species			Possible	• Lower degree of biodiversity • Low freshwater quality	

A.4 Identified hazards for Sollebrunn-Gräfsnäs

Table A.14: Identified hazards for Sollebrunn-Gräfsnäs with examples.

TECHNEAU - database				Case study site			
Hazard	**Reference**	**Hazardous Event**	**Potential Consequences**	**Present in case study site?**	**Hazards**	**Specific threat**	**Data Source for Determination**
Contamination of aquifers	2.1.1	Contamination by **industrial operations** (including continuous discharge as well as installations, construction work and other)	Contaminated water (pathogens, chemicals, radionucleids)	✔	1.) Car service (7) 2.) Fire station (1) 3.) Fire drill site (1) 4.) Heating plant (1) 5.) Sawmill (1) 6.) Manufacturing industry (5)	1.) Oil leaking from car workshop and runoff from vehicle wash with degreaser 2., 3.) Highly fluorinated chemicals from fire drill site 4.) Heating of petroleum products leading to acidification 5., 6.) Chlorophenol from dipping the wood 6.) Halogenated solvents from manufacturing industri 6.) Contamination when perfoming surface treatment of metalls 5.) Inorganic and organic substances and various metals are released when perfomning surface treatment of wood	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn"
Contamination of aquifers	2.1.2	Contamination by **waste water** (e.g. by WWTP, sewers, latrines, sewage collection pipes passed through catchment area, etc.)	Contaminated water (pathogens, chemicals). Nutrient load in water.	✔	7.) Wastewater treatment plant (2)	7.) Pathogens from households and chemicals from industries	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn"
Contamination of aquifers	2.1.3	Leaching of contaminants by **built constructions** (e.g. landfills using waste or contaminated ground, dumpsites, traffic facilities, installations for handling, storage and deposition of waste materials or excavation	Contaminated water (chemicals)	✔	8.) Tyre management (1) 9.) Cemetary (1) 10.) Recycling station (1)	8.) Toxic substances in case of a fire of tires 9.) If a person carrying a dangerous disease is buried, pathogens can be spread 10.) Fire in the recycling centre can lead to environmental	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn"
Contamination of aquifers	2.1.4	**Traffic, incl. accidents** (railway tracks, airfields, roads, parking areas, petrol filling stations, air accidents), loss of oil by cars or boats	Contaminated water (chemicals)	✔	11.) Road 190 & 42 (2) 12.) Fuel management (3)	11.) Metals, PAH and microplastics from wearing 11., 12.) Oil leaking from roads and petrol filling station contionus and accidently	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn"
Contamination of aquifers	2.1.5	**Construction activities** with interference in **subsoil** (e.g. waterway construction, installations for handling or storage of hazardous substances, facilities for construction workers; etc.) (incl. accidents)	Contaminated water (chemicals). Insufficient raw water	✔	Possible		
Contamination of aquifers	2.1.6	Increase of vulnerability due to **mining activities, gravel pits, excavations uncovering the GW**, construction of facilities for geothermal power purposes and /or small water supply systems	Contaminated water (chemicals, radionucleids)	✘			
Contamination of aquifers	2.1.7	**Agricultural runoff** and leach-out containing fertilizers, sludge, herbicides, etc.	Contaminated water (pathogens, chemicals). Nutrient load in	✔	13.) Argiculture (5) 14.) Soccer field (1)	13.) Agriculture contributes to the spread of pesticides and nitrogen leakage through fertilizers 14.) Fertilizers at the fotball field	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn" Google Maps
Contamination of aquifers	2.1.8	**Manure** spread or cattle in the zone	Contaminated water (pathogens). Nutrient load in water.	✘			
Contamination of aquifers	2.1.9	**Geophysical incidents** (e.g. extreme hydraulic events such as torrential rain, floods, erosion, landslides, karstic land surface with open dolines; etc.)	Contaminated water (pathogens, chemicals)	✘			
Contamination of aquifers	2.1.10	Accidents or spreading out of **hazardous materials during recreational activities** (e.g. mass rallies, fish ponds, shooting galleries, sports facilities incl. motor sports, horse-race grounds, zoo/animal reserves,	Contaminated water (pathogens, chemicals)	✔	15.) Shooting range (1)	15.) Metalls leaching from the bullets	Data from the report "Riskbedömning av grundvattentäkten i Gräfsnäs-Sollebrunn"
Contamination of aquifers	2.1.11	Contamination by **forestry activities, wild life activities, natural fowls, dead animals**, bird pest (flu)…	Contaminated water (pathogens, chemicals)	✔	16.) Forest (2) 17.) Camp site (1)	16.) Storge of timber and fuel tanks. 17.) Improper disposal of waste 17.) Fuel spills from caravans and camper vans	Google Maps
Infiltration of GW by alien water (e.g.: salt water intrusion, leaching of contaminated surface water...)	2.1.12	**Wetlands & flood plains** not hydraulically separated from the aquifer	Contaminated water (pathogens, chemicals). Nutrient load in water	✘			
Shortage of groundwater resouces	2.1.13	Groundwater **aquifer** is **not sufficiently fed** or **water is abstracted** by others	Unavailability of raw water	✔	Impermeable areas 18.) Household wells in the catchment area	Less groundwater. 18.) Over extraction of household wells.	Data from the land registry on urbanized area Data on household wells from the Swedish Geological Survey
Reduced biological activity in the treatment	2.1.14	**Water temperature** under 4°C	Reduced biological activity in the treatment		19.) Energy wells	19.) Aquifer freezes 19.) Decrease in chemical quality	Data on energy wells from the Swedish Geological Survey

Table A.15: Identified hazards for Sollebrunn-Gräfsnäs with examples, continued.

TECHNEAU - database				Case study site			
Hazard	**Reference**	**Hazardous Event**	**Potential Consequences**	**Present in case study site?**	**Hazards**	**Specific threat**	**Data Source for Determination**
Reduced biological activity in the treatment	2.1.14	**Water temperature** under 4°C	Reduced biological activity in the treatment	✓	19.) Energy wells	19.) Aquifer freezes 19.) Decrease in chemical quality	Data on energy wells from the Swedish Geological Survey
Contamination of aquifers	2.1.15	Radioactivity fall-out	Contaminated water	✓	Possible		
Contamination of aquifers	2.1.16	Terrorist and vandalism actions	Contaminated water (pathogens, chemicals, radionucleids). Insufficient raw water.	✓	Possible		
Sabotage or terrorist attack	12.1.1	Intentional chemical contamination	Contaminated water. No/insufficient water supply. Public concern, bad image.	✓	Possible		
Sabotage or terrorist attack	12.1.2	Intentional microbial contamination	Contaminated water. No/insufficient water supply. Public concern, bad image.	✓	Possible		
Sabotage or terrorist attack	12.1.3	Non accessible information. To prevent sabotage and terrorist attacks information regarding source water, treatment and distribution are classified. Due to this all necessary information might not be available to the	If the personal operating the system does not have all necessary information, actions might be taken that introduce	✓	Drinking water source, information is classfied, risk of unintentional contamination		
Conflicts	12.1.4	Military conflicts	Contaminated water. Technical damage	✓	Possible		
Conflicts	12.1.5	Political conflicts	Political actions leading to water shortage	✓	Possible		
Conflicts	12.1.6	Competing land use	Contaminated water. No/insufficient water	✓	Possible		
New chemicals and changed chemical pathways	12.1.7	Discharge of new chemicals to source waters due to e.g. accidents or continuous leakage	Contaminated water. No/insufficient water supply. Remediation of supply system	✓	Possible		
New chemicals and changed chemical pathways	12.1.8	Discharge of chemicals due to new applications	Because known chemicals are put into new pathways they may cause contaminated water, no/insufficient water supply,	✓	Possible		
Emergin pathogens	12.1.9	Presence of emerging pathogens able to overcome existing barriers	Insufficient water quality. Increased number of waterborne infections. Remediation of supply system	✓	Possible		
Climate changes	12.1.10	New precipitation and evaporation patterns	No/insufficient water supply	✓	Possible		
Climate changes	12.1.11	The climate changes' effects on water quality (changed surface runoff and material transport effecting water quality)	No/insufficient water supply. Contaminated water (including higher temperature of supplied water)		Possible		
Other		Pest and diseases, invasive species			Possible	• Lower degree of biodiversity • Low freshwater quality	

A.5 Visualization of linking at Mjörn

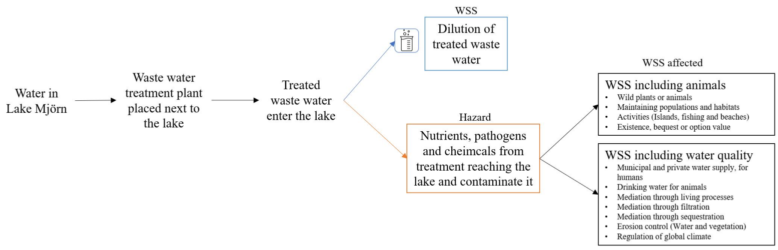

Figure A.1: Linkage between the hazard and service of the waste water treatment plant.

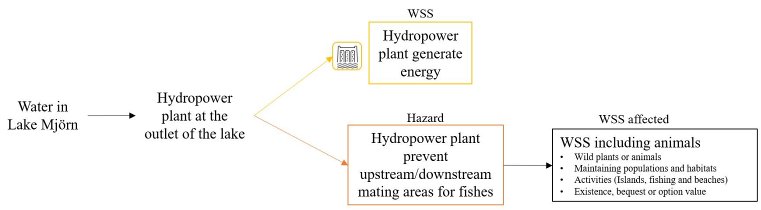

Figure A.2: Linkage between the hazard and service of the hydropower plant.

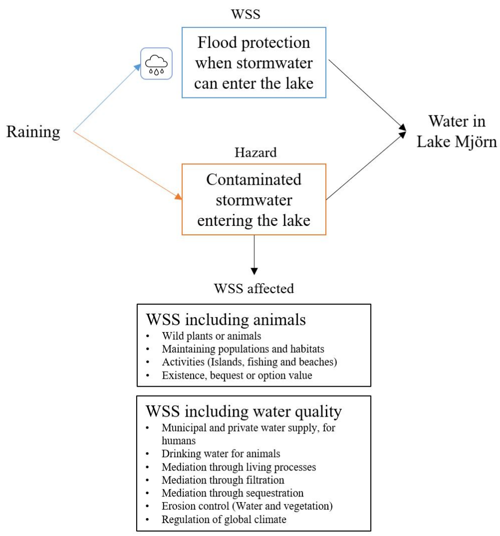

Figure A.3: Linkage between the hazard and service of the stormwater.

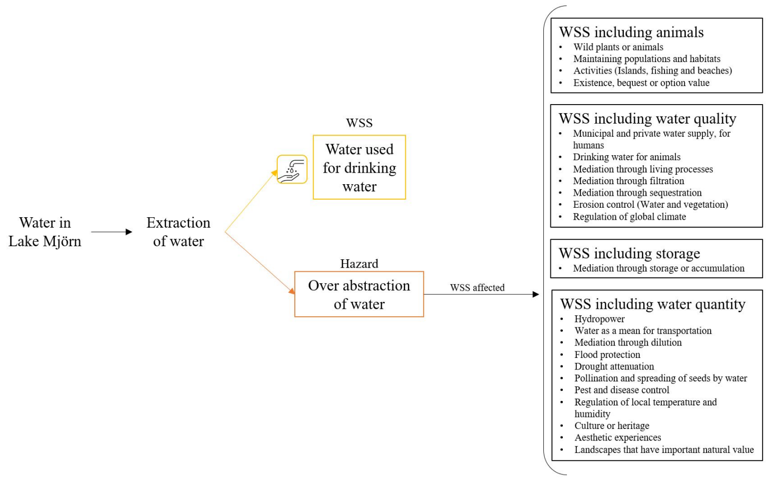

Figure A.4: Linkage between the hazard and service of the drinking water.

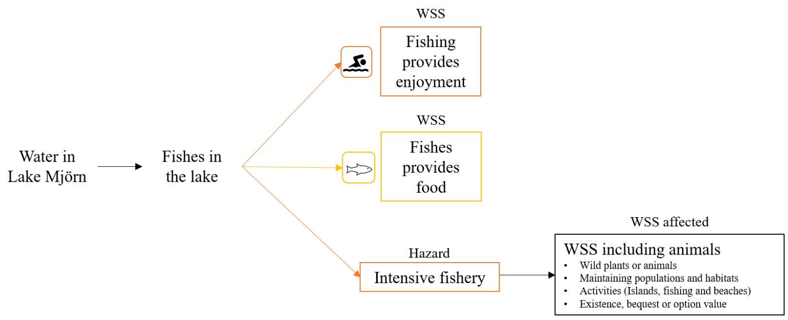

Figure A.5: The fishes in the lake provides services like food and the opportunity for fishing, while intensive fishery is a risk to destroy the service.

A.6 Visualization of linking at Sollebrunn-Gräfsnäs

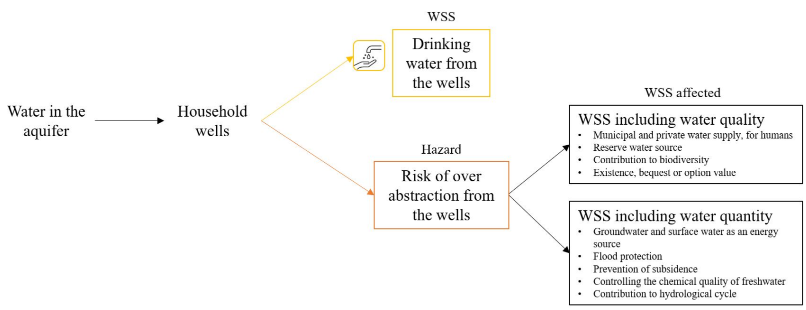

Figure A.6: Household wells provides services but also poses a risk of over abstraction.

A.7 Risk assessment results

Table A.16: The risk assessment for Mjörn.

Hazard:	**Boat traffic**											
WSS:		Wild plants or animals	Maintaining populations and habitats	Activities (Islands, fishing and beaches)	Existence, bequest or option value	Municipal and private water supply, for humans	Drinking water for animals	Mediation through living processes	Mediation through filtration	Mediation through sequestration	Erosion control (Water and vegetation)	Regulation of global climate	Mediation through storage or accumulation
Weighting of how often the services are used		0.03	1	1	1	1	1	1	1	1	1	1	1
Probability hazardous event occur	0.14												
Vulnerability of the water source (how the hazard spread)	5												
Specific threat:	**Leaking oil**												
Consequences that effect the capability of the service		4	4	3	4	4	4	3	3	3	3	3	1
Risk each WSS:		0.09	2.86	2.14	2.86	2.86	2.86	2.14	2.14	2.14	2.14	2.14	0.71
Risk total specific threat:		25											
Specific threat:	**Turbidity and destroying the bottom**												
Consequences that effect the capability of the service		5	5	5	1	3	3	5	1	1	3	4	5
Risk each WSS:		0.12	3.57	3.57	0.71	2.14	2.14	3.57	0.71	0.71	2.14	2.86	3.57
Risk total specific threat:		26											

Table A.17: The risk assessment for Mjörn, continued.

Hazard:	**Boat traffic**												
WSS:		Wild plants or animals	Maintaining populations and habitats	Activities (Islands, fishing and beaches)	Existence, bequest or option value	Municipal and private water supply, for humans	Drinking water for animals	Mediation through living processes	Mediation through filtration	Mediation through sequestration	Erosion control (Water and vegetation)	Regulation of global climate	Mediation through storage or accumulation
Weighting of how often the services are used		0.03	1	1	1	1	1	1	1	1	1	1	1
Probability hazardous event occur	0.14												
Vulnerability of the water source (how the hazard spread)	5												
Specific threat:	**Noise from the boats**												
Consequences that effect the capability of the service		5	5	3	1	1	1	1	1	1	1	1	1
Risk each WSS:		0.12	3.57	2.14	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Risk total specific threat:		12											

Table A.18: The risk assessment for the Sollebrunn-Gräfsnäs aquifer.

Hazard:	**Energy wells**					
WSS:		Municipal and private water supply, for humans	Reserve water source	Groundwater and surface water as an energy source	Contribution to biodiversity	Existence, bequest or option value
Weighting of how often the services are used		1	1	1	1	1
Probability specifc threat occur (and reach water)	0.14					
Probability specific threat reaches the aquifer	5					
Specific threat:	**The aquifer freezes**					
Consequences that effect the capability of the service		2	2	5	2	1
Risk each WSS:		1.43	1.43	3.57	1.43	0.71
Risk total specific threat:		8.57				
Specific threat:	**Decrease in chemical water quality**					
Consequences that effect the capability of the service		2	2	1	4	1
Risk each WSS:		1.43	1.43	0.71	2.86	0.71
Risk total specific threat:		7.14				

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