Including Climate Change Resilience in Multi-Criteria Decision Analysis of Potential Drinking Water Sources

Method Development for Early-Stage Water Supply Planning

Master's thesis in Infrastructure and Environmental Engineering

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Abstract

Drinking water is a fundamental resource for societal functioning and human health. Sweden has historically had good access to high-quality raw water, but climate change is increasingly posing challenges to both water availability and quality. Therefore, it is essential to consider these factors in the early stages of planning and decision-making regarding new potential drinking water sources. A common approach for selecting new drinking water sources is the application of multi-criteria decision analysis. In this study, the decision support tool WISER was used, which incorporates relevant criteria, scoring, and weighting through a multi-criteria decision analysis framework. The aim of the study was to develop a method to integrate climate resilience as a key aspect in multi-criteria decision analysis and apply this within a case study. Two different versions of the method were developed. In the first version, new criteria addressing climate change resilience were added. In the second, this aspect was incorporated into the already existing set of criteria. Both versions were subsequently applied in a case study carried out in Västra Götaland County, Sweden. The case study includes three potential drinking water sources: a groundwater source, an artificial infiltration facility, and a surface water source. The results indicate that both methodological versions are applicable for incorporating climate resilience, although they exhibit different strengths and weaknesses. To assess future capacity under different climate scenarios, hydrological modelling was conducted using the SWAT+ software, simulating surface water flows and groundwater recharge for the period 2070-2100.

Keywords: Drinking Water Sources, Climate Change, Multi-Criteria Decision Analysis (MCDA)

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Sammanfattning

Dricksvatten är en grundläggande resurs för samhällets funktion och människors hälsa. Sverige har historiskt sett haft god tillgång till råvatten av hög kvalitet, men klimatförändringarna medför allt större utmaningar, både vad gäller råvattentillgång och kvalitet. Det är därför av stor vikt att dessa faktorer beaktas redan i de inledande skedena av planering och beslut av nya potentiella dricksvattentäkter. En vanlig metod vid val av ny vattentäkt är att tillämpa multikriterieanalyser. I denna studie har beslutsstödsverktyget WISER använts som inkluderar relevanta kriterier, poängsättning och viktning genom multikriterianalys. Studiens syfte har varit att utveckla en metod för att inkludera klimatresiliens som en integrerad aspekt i multikriterieanalyser, och applicera detta i en fallstudie. Två olika metodversioners utvecklades. I den första versionen adderades nya kriterier där motståndkraften för klimatförändringar togs i beakting. I den andra versionen var denna aspekt inkluderad i de redan existerande kriterierna. Båda metodversionerna tillämpades i en fallstudie belägen i Västra Götalands län, Sverige. Fallstudien omfattar tre förslag till nya dricksvattentäkter: en grundvattentäkt, en anläggning för konstgjord infiltration samt en ytvattentäkt. Resultaten visar att båda metodversionerna är tillämpbara för att inkludera klimatresiliens, även om de uppvisar olika styrkor och svagheter. För att bedöma framtida kapacitet för olika klimatscenarier har modellering genomförts med hjälp av mjukvaran SWAT+, där flöden till ytvattentäkten och grundvattenbildning har simulerats för år 2070-2100.

Nyckelord: Dricksvattenkällor, Klimatförändring, Multikriterieanalys (MKA)

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Elin Blad & Sara Rydsmo, Gothenburg, June 2025

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1

Introduction

Throughout the world, people depend on access to clean drinking water. The Swedish Government Official Reports (SOU) indicate that the drinking water system is considered the most critical infrastructure for ensuring a well-functioning society (SOU, 2016:32). A drinking water supply is typically described based on its three main components: the raw water source, treatment, and distribution. The most common raw water sources are surface water and groundwater. There are significantly more groundwater sources in Sweden than surface water sources. However, surface water sources generally allow for greater water extraction. Overall, the Swedish drinking water supply consists of roughly 50% surface water and 50% groundwater. In Sweden, the provision of drinking water is predominantly managed by municipal water utilities (Swedish Agency for Marine and Water Management, 2023).

Drinking water systems are exposed to various risks that combined with climate change present significant challenges (SOU, 2016:32). In recent years, both climate change and societal changes have garnered increasing attention. Long-term planning is thus essential to ensure a safe and reliable drinking water supply. This includes identifying and securing suitable raw water sources. Evaluating appropriate water sources requires a robust decision-making process that considers natural conditions, risks, vulnerability to climate change, and other relevant factors. Currently, there is no established method for assessing and comparing potential drinking water sources with a specific focus on risks and vulnerabilities to climate change.

1.1 Background

Swedish water regulation is based on the European Union Water Framework Directive, WFD (Directive 2000/60/EC of the European Parliament, 2000). The WFD is a common framework for all member countries of the EU incorporating groundwater, inland, coastal and transitional surface water bodies (Water Authority, n.d.). The aim of the WFD is to achieve good ecological and chemical status in all water bodies through protection and restoration. In addition, there is an EU Drinking Water Directive (DWD) affecting the Swedish water regulation (Directive (EU) 2020/2184 of the European Parliament, 2020). The DWD regulates water management, quality, and supply requirements from raw water source to consumer, while the WFD protects the raw water, ensuring access to safe drinking water sources (Swedish Agency for Marine and Water Management, 2023). Swedish water regulation and management are distributed across several authorities, with the provision of drinking water being a municipal responsibility. While the local municipal council assembly holds overarching responsibility, each municipality maintains its own internal coordination to ensure sustainable drinking water management (Enberg & Sävenstrand, 2024). Since water sources are highly affected by their surroundings and catchment area, the planning and management of water resources are often complex subjects. This includes stakeholders with different interests and knowledge within the municipality, but also external actors sharing the same catchment area. The stakeholders typically are municipal or regional administrations, land owners, companies, or associations in the catchment area of concern.

According to World Meteorological Organization (2025), 2024 was the warmest year observed since pre-industrial times. This entailed an annual averaged global mean near-surface temperature rise of 1.55 °C from the reference years 1890-1900. As the Paris Agreement, established to mitigate the negative effects of climate change, approaches its tenth anniversary, 2024 stands out as the first year in which the internationally agreed limit of 1.5 °C temperature rise was exceeded. This does not mean that the agreement is broken, but indicates that climate change is a critical issue important to consider in future infrastructure planning, including raw water sources. There are several aspects of climate change that may effect drinking water sources, including water quality and availability (Leveque et al., 2021). A common feature among them is that they must be considered when assessing future drinking water sources and their vulnerability to climate change.

1.2 Aim

To achieve strategic and sustainable water supply planning, the aim of this thesis is to integrate the perspective of climate change into multi-criteria decision analysis (MCDA) for evaluating and comparing potential drinking water sources during the early stages of the planning process. This will be conducted by developing an approach, including appropriate tools, for describing climate-related risks in relation to drinking water sources and utilizing this information as input for a MCDA. The investigation will consider climate change projections up to the target year 2100, with a specific focus on risks posed to raw water sources and their resilience to climate change. The developed approach together with MCDA will serve as a decision support tool for strategic planning of future drinking water supply.

Further, the aim is to analyse climate change-related risks impacting the quantity and quality of potential future raw water sources in a case study area located in the southwest of Sweden. This will include a more detailed examination of a selected number of drinking water sources, covering both natural and artificial groundwater and surface water.

1.3 Limitations

This thesis is limited to the early planning process and focuses on offering an overview of the most important aspects of potential drinking water sources. This study is based on climate projections of changing precipitation patterns and temperature as a result of climate change. Other potential changes are discussed, but not considered in the modelling. Further, safe drinking water is a sensitive product protected by confidentiality. This limits the amount of accessible literature and available information. It also affects the level of detail of the case study presented in this thesis.

1.4 Research questions

To further refine the purpose and clarify the objective, the following research questions have been formulated:

- How can the climate change aspect be incorporated into the decision-making process using MCDA to prioritize future drinking water sources?
- Can modelling the effects of climate change on potential drinking water sources be used to assess and compare them in terms of both water quantity and quality?
- How applicable is the developed decision support tool to the case study area in Västra Götaland, Sweden, when resilience to climate change is considered?

2

Theory

The theory is based on a literature review aimed at providing a fundamental understanding of the characteristics and challenges associated with different drinking water sources. It also explores the impacts of climate change on drinking water, as well as current decision-support methods used to evaluate and assess potential drinking water sources. Additionally, the theory includes an overview of modelling water availability, with a focus on its application in estimating water quantity and quality.

2.1 Drinking water sources

The vast majority of the world's water is saltwater (Katsanou & Karapanagioti, 2017). Barely 3% of the Earth's total water supply is freshwater, of which approximately 30% is groundwater, while just about 1% is surface water. Drinking water sources are usually derived from either surface water or groundwater. Globally, 33% of the population relies on groundwater for drinking water, whereas in Europe, this figure rises to 75%. Surface water and groundwater have distinct characteristics, making them suitable for different situations, each with its own advantages and disadvantages.

Surface water typically refers to lakes, rivers, or streams (Katsanou & Karapanagioti, 2017). The volume of a surface water body depends on the balance between input and output. The primary input consists of precipitation within the catchment area, which varies seasonally and is unevenly distributed throughout the year. Groundwater flowing to surface water bodies also contributes to the input. In some cases, treated wastewater discharged back into the water body can also contribute to the input. The output consists of water either extracted by humans or naturally transported further through the hydrological system.

Surface water is commonly used for larger urban water supply systems due to its greater availability and volume (Schmoll et al., 2006). It is also relatively easy to abstract through direct pumping (Katsanou & Karapanagioti, 2017). However, because surface water is exposed to the atmosphere, it is more vulnerable to contamination, including microorganisms. Additionally, factors such as increased eutrophication contribute to the need for more extensive treatment processes to ensure good water quality.

Groundwater is stored in aquifers, which are bodies of water-bearing materials (Hölting & G Coldewey, 2018). Water infiltrates through soil layers and accumulates in the aquifer. As it percolates through the soil, it undergoes natural filtration, resulting in higher water quality compared to surface water and reducing the need for as extensive treatment before distribution to consumers. The formation of an aquifer requires specific soil properties that allow water to flow and be extracted effectively. Since water infiltration takes time, the recharge rate of groundwater is more evenly distributed throughout the year compared to surface water, although some seasonal variations still occur. Groundwater can be either natural or artificially recharged. Natural groundwater forms when water naturally percolates through the soil and accumulates in an aquifer, while artificial groundwater recharge is created when water, such as lake water, is actively pumped and then infiltrated into an aquifer. This approach aims to increase capacity while using the natural purification process, a method commonly referred to as Managed Aquifer Recharge (MAR) (Casanova et al., 2016). In Sweden, approximately 50% of drinking water is sourced from groundwater (Schmoll et al., 2006). Of this, half is derived from natural groundwater, while the other half comes from artificial infiltration. Groundwater extraction is carried out by drilling and pumping (Hölting & G Coldewey, 2018). Unlike surface water, groundwater is not always as readily accessible, as it requires drilling and may have some uncertainties regarding the available volume.

Groundwater is commonly used as a drinking water source in smaller communities where lower water volumes are required (Katsanou & Karapanagioti, 2017). The reduced need for treatment makes it a cost-effective solution. Additionally, groundwater is less vulnerable to external contamination. The more protected the source, the easier and more cost-effective it is to treat the water and ensure its safety for consumption. However, increasing chemical use and environmental pollution pose a growing risk to both groundwater and surface water quality, potentially affecting its suitability as a drinking water source.

Both surface water and groundwater are exposed to various contamination risks that can pose threats to human health (Katsanou & Karapanagioti, 2017). The primary pollution pathways include runoff carrying soils and chemicals from agricultural and industrial activities, leachate from waste disposal sites, and atmospheric pollutants from rain or snow, all of which transport contaminants into drinking water sources. Human activities have significantly contributed to the deterioration of water quality, particularly through the presence of heavy metals and nutrients such as total nitrogen and total phosphorus (Cao et al., 2019). Surface water sources are more vulnerable to contamination, and according to Katsanou and Karapanagioti (2017), 20% of Europe's surface water is at significant risk of pollution. Cao et al. (2019) conducted tests on arsenic concentrations in a case study area, revealing that surface water had higher concentrations than groundwater, further highlighting its vulnerability. On the other hand, contaminants that infiltrate groundwater can be more challenging to control and remediate due to the complexity of hydrological flows of groundwater, which are often uncertain and difficult to predict and remediation techniques are often extensive (Mays & Scheibe, 2018). Although surface water is more exposed to contamination than groundwater, pollutants can still spread between these two water sources (Katsanou & Karapanagioti, 2017). Surface water is also more vulnerable to fluctuations in water levels and inflow variations. At the onset of wet periods, the risk of fecal contamination is high as runoff washes fecal matter into rivers. However, increased water flow during these periods also enhances dilution, mitigating some health risks. Conversely, during dry periods, lower silt levels reduce turbidity, but dissolved solids become more concentrated, potentially deteriorating water quality.

2.2 Climate change

An investigation from the SOU (2016) states that the climate change as a result of global warming will continue to increasingly negatively affect the Swedish drinking water provision in the future. This includes changing precipitation patterns as an effect of rising temperatures that directly affect the water levels and quantity (SMHI, 2025b). A warmer climate leads to increased evaporation together with warmer air that has a higher capacity of containing greater amounts of vaporized water. Among other things, this results in more extreme rain events with cloudbursts and precipitation during longer periods of time. Projections predict that the impact of climate change will differ across various regions of Sweden, causing problems such as heavy rainfall and flooding in some areas, while others may experience water scarcity and drought to a greater extent. However, climate change also increases the risk for qualitative challenges, including microbial and chemical contamination, waterborne outbreaks, and technical failure in water treatment plants (SOU, 2016). Both surface water and groundwater serve as important sources of drinking water and are affected by climate change in different ways and to varying degrees.

Groundwater aquifers are typically recharged by precipitation that percolates into the ground (Barthel et al., 2021). However, recharge patterns vary seasonally and geographically across Sweden. In the northern regions, groundwater recharge is limited during winter due to frozen ground and snowfall instead of rain. As a result, groundwater levels tend to decrease in winter, with recharge occurring in the spring when temperatures rise and ground frost and snow melts. In contrast, the southern regions of Sweden experience more rainfall than snow during winter. When temperatures are low but above freezing, evaporation rates are minimal and the ground is more susceptible to percolation. This facilitates significant groundwater recharge during this period. However, during the longer summers and growing seasons in southern Sweden, groundwater recharge remains low, even with high precipitation, due to the combined effects of higher temperatures and increased evapotranspiration driven by vegetation growth. Since groundwater recharge is highly affected by temperature, climate change and global warming are likely to disrupt this process in the future (Swedish Portal for Climate Change Adaptation, 2020). Projections predict that rising temperatures will shorten the winters in northern Sweden, initially resulting in higher groundwater levels and increased recharge during the winter months. However, in southern Sweden, the increasing temperatures are expected to lengthen the vegetative season. This will shorten the period of groundwater recharge, with recharge beginning later in the fall, while vegetation growth will start earlier in the spring, causing groundwater levels to decrease earlier than in the past. This is likely to lead to generally lower groundwater levels that may lead to challenges related to groundwater levels and availability.

As mentioned, climate change will lead to higher atmospheric temperatures, which in turn will increase the temperature of water bodies (Salerno et al., 2018). The rise in water temperature is primarily driven by higher air temperatures and increased solar radiation. Elevated water temperatures accelerate chemical reaction kinetics, leading to an increase in dissolved substances. Conversely, dissolved oxygen levels decrease, negatively impacting aquatic life and the decomposition of organic material. Additionally, higher temperatures enhance soil microbial activity and promote the production of dissolved organic matter (Lipczynska-Kochany, 2018). There is also evidence suggesting that rising soil and groundwater temperatures can lead to decreased oxygen saturation and pH levels in groundwater (Riedel, 2019). This occurs primarily due to the enhanced metabolic activity of oxygen-consuming microbes, which results in increased carbon dioxide (CO_2) production. The CO_2 partly dissolves in the groundwater, forming carbonic acid that lowers the pH and potentially increases the solubility of soil minerals. This may negatively impact the groundwater quality, depending on the soil content in and around the aquifer, and increase the need for drinking water treatment.

Different surface water bodies vary in their vulnerability to rising temperatures due to climate change (Delpla et al., 2009). Shallow surface water bodies are more susceptible to short-term temperature increases, as they warm more rapidly, accelerating the adverse effects mentioned above. In contrast, deeper lakes are more vulnerable to long-term temperature rises due to their greater heat storage capacity, which prolongs the impact of elevated temperatures. Climate change will also alter precipitation patterns, making smaller surface water bodies more vulnerable than larger ones (Delpla et al., 2009). During drought periods, smaller lakes are at a higher risk of drying out more quickly. In conclusion, climate change will make surface water more vulnerable and exposed to increased risks, significantly impacting human health (Delpla et al., 2009). These effects will become particularly pronounced during extreme meteorological events.

As previously mentioned, climate change is expected to result in more extreme rain events such as cloudburst (SMHI, 2025b). According to Eekhout et al. (2018), heavy rainfall results in soil erosion, and as climate change causes these extreme rain events to become more frequent, the incidence of soil erosion is expected to increase. Intense rainfall that exacerbates erosion is causing more particles to be transported by runoff (Bates et al., 2008). This may increase the turbidity in surface waters, along with higher concentrations of nutrients, pathogens, and other contaminants. According to Salerno et al. (2018), another concern is that increased precipitation will lead to more frequent combined sewer overflows, further negatively impact surface water quality and increase the risk of contamination. According to their study, total phosphorus concentrations are projected to double by 2100, primarily due to these overflows, further deteriorating surface water quality.

Another contamination risk intensified by climate change is the increasing frequency and severity of wildfires, primarily driven by prolonged drought periods (Hohner et al., 2019). Hohner et al. (2019) states that wildfires cause major changes to forest ecosystems by altering vegetation structure, affecting soil properties and disrupting watershed processes that regulate streamflow, soil erosion, nutrient transport and downstream water chemistry. Following intense wildfires, heavy rainfall often leads to increased surface runoff that transports large amounts of ash and soil from burned areas. This significantly raises turbidity and increases concentrations of nutrients and dissolved organic carbon (DOC) in surface waters, creating immediate challenges for water management and treatment.

2.3 Representative Concentration Pathways

Due to the complexity of climate change modelling, various emission scenarios have been developed to support and simplify predictive climate change calculations (SMHI, 2024). These scenarios are called Representative Concentration Pathways (RCPs) and describe the greenhouse gas concentrations in the atmosphere up to the year 2100. The RCPs describe different scenarios that depend on how greenhouse gas emissions proceed in the future (van Vuuren et al., 2011). The RCPs are based on projections of several societal factors, including global economy, population change, and how well society manages the transition to environmentally sustainable technology. In the RCP scenarios, climate change is expressed as radiative forcing. Radiative forcing refers to the change in the earth's energy balance based on the amount of energy from the sun that is retained within the atmosphere (US EPA, 2025). Greenhouse gases trap this energy, leading to an increase in the temperature on earth. Radiative forcing is measured in watts per square meter (W/m^2), where higher emissions leads to higher radiative forcing resulting in greater climate change effects. The RCP scenarios are named after the radiative forcing used when defining the specific scenario, for instance RCP2.6 is calculated with 2.6 W/m^2 radiative forcing (SMHI, 2024). According to SMHI (2024), RCP2.6 is considered a low emission scenario that corresponds to the ambitions of the Paris Agreement to limit global warming. However, RCP8.5 is a more extreme scenario taking increasing greenhouse gas emissions into account. Although several RCP scenarios exist, this thesis focuses on RCP2.6 and RCP8.5, as they represent two contrasting futures: an ambitious emission scenario and a high-emissions scenario.

2.4 Other future changes

Shared Socioeconomic Pathways (SSPs) are scenarios used to describe future societal development under climate change (Bergion et al., 2025). The SSPs consider many different societal factors that in turn can influence the risk posed to drinking water sources, including population change and land use change. According to Eurostat (2023), the population in the EU is projected to decrease by approximately

7% between 2022 and 2100. In contrast, Sweden's population is expected to increase by 27% over the same period. The population in Västra Götaland county, where the case study area is located, is predicted to increase by 25%, which is similar to the overall population growth forecast for Sweden (City of Gothenburg, 2024). However, no projections beyond 2050 have been made for Västra Götaland. Additionally, the future population development within the region remains uncertain, posing challenges in selecting drinking water sources while considering both their location and the demand for water supply.

Land use is another factor that may change over time and has the potential to affect future drinking water supply. According to (Cheng et al., 2022), urban development and land use changes can affect both water volume and quality. For example, development of urban areas often increases the amount of impervious surfaces, enhancing surface runoff. Surface runoff may carry contaminants and pathogens that enter the drinking water source directly, bypassing the natural filtration and retention processes provided by soil percolation. Other land use types, such as agricultural land and forested land, may also alter the natural hydrological cycle and release pollutants that can negatively affect the water source. Blanco et al. (2017) has examined how climate change, based on different Representative Concentration Pathway (RCP) scenarios, will impact land use across Sweden. The findings suggest similar trends across the RCP scenarios, with a slight regional variation in forest types. Overall, forested land is expected to decrease, while agricultural land is projected to expand.

2.5 Decision support methods

According to Aven (2010) a common definition of risk is that "Risk is the combination of probability of an event and its consequences" (s.623). The term "water risk" is derived from the aforementioned definition of risk in relation to water-related challenges (CEO Water Mandate, 2017). Mentioned challenges may for instance include water scarcity or flooding. The consequences considered are often dependent on the vulnerability of the raw water source and its resilience to change. Risk, in the context of a drinking water source, and the focus of this report, generally pertain to human health, animal populations, physical infrastructure, and ecosystems (SOU, 2016:32).

Risk assessment is an important decision support tool used to make informed and conscious decisions (Aven et al., 2014). Risk inventory and identification are early steps in the risk assessment process when potential threats are identified in the surroundings. The inventory is unique for each raw water source, but often focus on potential emissions of petroleum products, pesticides, fertilizers, hazardous waste, and microbial pathogens (Frycklund et al., 2015). Common activities considered in Sweden are for instance agriculture, forestry, gas stations, industries, roads and private sewers.

MCDA is a common approach used in decision-making processes (Ishizaka & Nemery, 2013). MCDA is a tool that incorporates various disciplines, such as mathematics, management, informatics, psychology, social sciences, and economics, allowing for a comprehensive comparison of different aspects. Since MCDA evaluates possible alternatives while accounting for multiple conflicting criteria, it has a wide range of applications (Ceballos et al., 2016). Various methods can be applied within MCDA, one of the most common being the use of weighting, where different aspects are assigned scores based on their relevance and importance (Triantaphyllou, 2000).

A method introduced in 2021 and currently in use in Sweden, is WISER (Water Investments for Sustainability Enhancement and Reliability) (Sjöstrand et al., 2021). WISER is a MCDA method that can be employed to identify suitable future raw water sources but is not limited to this purpose. It is also often used to evaluate various measures throughout the entire drinking water supply system. WISER is an Excel-based tool that compares different action options using technical, social, environmental, and economic assessment criteria. Each criterion is both scored and weighted according to its relative importance by a group of experts in the field, i.e. decision makers and stakeholders. Certain crucial criteria are predetermined in WISER, minimizing the risk of overlooking key considerations, but users can also add criteria of their choice. WISER can evaluate both a large number of potential actions at a general level and a smaller set of options in greater detail. Furthermore, it is stated that the final output identifies which measures are most suitable in relation to the four assessment areas. In WISER, uncertainties can be taken into account to investigate how they affect the interpretation and evaluation of alternatives. The uncertainties in the WISER model are considered using the Excel add-in software @RISK (Sjöstrand et al., 2021). @RISK is a software provided by Lumivero using Monte Carlo simulations to perform probabilistic risk analysis (Lumivero, n.d.). In WISER, this produces uncertainty intervals based on the maximum, most likely, and minimum scores provided by the user (Sjöstrand et al., 2021). However, the calculations can also be performed without uncertainties. Although WISER primarily targets Swedish municipalities, it is available freely online. However, the user needs to purchase a license for @RISK to enable uncertainty inclusion.

2.6 Modelling water availability

Various hydrological and hydrogeological models are available for simulating water availability. This section provides a brief description of the Soil and Water Assessment Tool (SWAT+), the modelling software used in this thesis.

Hydrological modelling can be a powerful tool when assessing water sources and predicting future impact (Texas A&M University & USDA - ARS, n.d.). A widely used hydrological modelling software is SWAT+, developed and provided by Texax A&M University and the United States Department of Agriculture-Agricultural Research Service (USDA-ARS). SWAT+ is a QGIS compatible modelling software that enables modelling of both surface water and groundwater (Chawanda et al., 2020). SWAT+ models watersheds, channels, and streams based on the topography provided in a Digital Elevation Model (DEM). Using DEM slope class together with soil properties and land use, SWAT+ delineates hydrologic response units (HRUs)

(James Chawanda et al., 2020). The HRUs are areas with unique properties used by SWAT+ to calculate and simulate both water quantity and quality within the watershed. Incorporating weather data, such as precipitation, air temperature, wind speed, relative humidity, and solar radiation, enables modelling of water flow as well as nutrient and sediment transport. This facilitates the assessment of the current state of water sources, but also allows predictions of future changes in climate or land use (Texas A&M University & USDA - ARS, n.d.).

Although groundwater flow is simulated in the original SWAT+ model, there is a specific module (*gwflow*) embedded in SWAT+ better suited for groundwater flow modelling (Bailey et al., 2020). The gwflow module is developed for unconfined aquifers and aims to provide understanding of the hydrological connections between groundwater aquifers and streams while calculating groundwater head and flow. The watershed and weather data are prepared similarly as in the original SWAT+ model while more information about the aquifer, streambeds and potential groundwater pumping is needed for *gwflow*.

3

Methodology

To develop a methodology for evaluating and selecting drinking water sources in an early stage, with risks and resilience to climate change included, several steps were carried out. The project involved conducting a literature review, creating a reference MCDA, and modelling surface water flow and groundwater recharge. See Figure 3.1 for a schematic illustration of the methodology. The included steps are further described below.

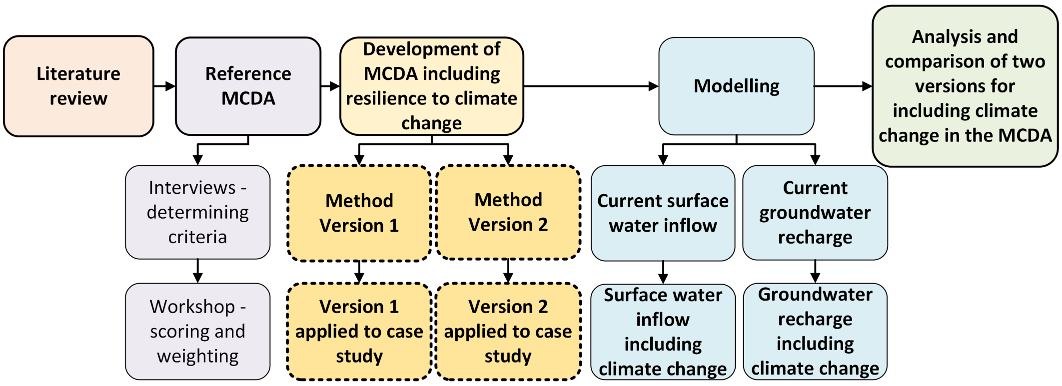


Figure 3.1: Schematic illustration of the methodology.

3.1 Literature review

The project started with an initial literature review to identify relevant decision support methods. This established a foundational understanding of existing methodologies and their applicability to evaluating and selecting drinking water sources, particularly in relation to risk and resilience to climate change. The literature review included an analysis of the effects of climate change on raw water quality and quantity in Sweden up to the year 2100 together with other potential future changes, such as land use and population.

As a part of the literature review, a general comparison and analysis of differences and similarities between surface water and groundwater sources was conducted. This analysis was performed to describe both types of water sources in terms of the risks they are exposed to and their vulnerability to climate change. The goal was to gain a comprehensive understanding of the unique challenges and strengths associated with each type of source. The results of the literature review are presented in Chapter 2.

3.2 MCDA

A multi-criteria decision analysis (MCDA) was conducted for three potential drinking water sources in the case study municipality. The criteria to be considered in the MCDA was determined through interviews with two professionals working with the strategic water planning in the municipality and experts in the field from Sweco Sverige AB. These interviews identified the key criteria that a decision support tool of this kind should include. The insights from the municipal workers was crucial in ensuring that the MCDA addresses the practical needs and considerations of those involved in water resource management. The MCDA criteria was also inspired by the predefined criteria and the division of criteria into technical, social, environmental and economic criteria in the Excel tool WISER (Sjöstrand et al., 2021). For each criterion, an evaluation basis was formulated in which every possible score received a description to enable systematic scoring. These details are compiled in Appendix A.

The MCDA was then tested and refined through a case study application. As previously mentioned, the case study and its drinking water sources are presented anonymously due to confidentiality considerations. The aim of the case study was to allow for practical implementation and adjustment of the methodology to ensure its relevance and effectiveness under Swedish conditions. The scoring of the criteria was conducted during a workshop, which included two representatives from the municipality and two experts from Sweco Sverige AB with expertise in strategic water planning, MCDA, and drinking water-related issues. During the workshop, three alternatives were evaluated: one groundwater source, one artificial infiltration source, and one surface water source. In this study, these drinking water sources were referred to as Alternative 1, Alternative 2 and Alternative 3. These alternatives were selected based on the municipality's request and to provide value to the thesis by including one source of each type. To ensure a common understanding among participants, each alternative was first presented with relevant background information to establish a foundational knowledge of the potential drinking water sources. Each criterion was then presented together with background information for each alternative. After the presentation of every two or three criteria, participants were given time to perform individual scoring. This scoring was based on the predefined evaluation basis formulated for each criterion. Each participant received a stencil where they recorded their most likely score, along with the minimum and maximum scores they considered appropriate for each criterion and alternative. Following the individual scoring, a group discussion was held where each participant had the opportunity to present their scoring and discuss any differences in scoring. The final scores were determined after the workshop and entered into the WISER tool, the details about the scoring are complied in Appendix B. In WISER, the criteria were weighted according to their relevance based on the municipality's wishes and requests which is compiled in Appendix C. When the scoring and weighting was done, the results from WISER and @RISK represented the reference MCDA. Two MCDAs were carried out, one excluding the economic aspect which is referred to as the reference MCDA and one including the economic aspect. This approach was chosen due to significant uncertainties associated with the economic aspect.

3.3 Inclusion of climate change in MCDA

The inclusion of climate change in the MCDA was performed by developing the reference MCDA previously designed. The MCDA was developed in two versions to facilitate comparison of advantages and disadvantages with different approaches. Similarly to the reference MCDA, the two climate change MCDA versions were tested and refined through the case study application. However, the scoring of the climate change aspects were rather based on literature study, previous investigations in the case study area, and hydrological modelling. The literature study focused on risks related to precipitation and temperature change assessed to impact water quantity and quality in the case study area. After the scoring was set, the scores and weighting, including the uncertainty intervals, were entered into WISER. The developed MCDA versions including climate change resilience along with the case study application results are presented in the results.

3.4 Modelling

Modelling was performed to provide a clearer understanding of the performance differences between a surface water source and a groundwater source in terms of raw water availability, including how the quantity fluctuates throughout the year due to changing climate. Modelling of how changed precipitation and temperature as a result of climate change may affect two potential drinking water sources within the case study area was conducted. One surface water source and one groundwater source was modelled using the QGIS add-in SWAT+ (Soil and Water Assessment Tool).

3.4.1 Surface water

For the surface water source, SWAT+ was used to simulate the inflow from channels and streams into the surface water body based on the topography, soil properties, land use, and weather observations in the area. The sources from which geodata and soil properties were gathered are listed in Table D.1 in Appendix D. The geodata was processed, and the vectors were transformed to rasters in QGIS to fit the input requirements in SWAT+. Standard values for user soil from ArcSWAT 2012 was used to assign soil properties to the different soil types (Soil & Water Assessment Tool, n.d.). A period of 30 years, 1995-2024, was chosen as a reference period for the simulation. The choice of period was based on a brief analysis of historical weather observations which showed no apparent deviating trend further back in time, along with the intention to analyse a 30-year period. The simulation was performed with a warm-up period of three years. The weather data used for the simulations included daily values for precipitation, air temperature, wind speed, relative humidity and solar radiation, see Table D.1 in Appendix D. The available weather data was processed in Excel to match the required time step format for SWAT+ before the simulations were carried out. To validate the results from the surface water simulation, the simulated flow in one of the incoming channels was compared to the observed flow in that channel from SMHI's measuring station for the same time period. After minor adjustment of the default soil properties to represent local soil conditions, see Table D.2 in Appendix D, the NSE index was 0.75 when comparing the simulated flow to the observed flow. According to Moriasi et al. (2007), $NSE \leq 0.75$ is considered good performance rating, and the model was considered satisfactory.

After the model was validated and calibrated to match the observed data, the weather data was updated in SWAT+ to simulate future water fluctuations under projected climate change. Precipitation and temperature data were retrieved from SMHI's future climate projections for RCP2.6 and RCP8.5 for the period 2070–2100, see Table D.1 in Appendix D. Projection data from SMHI were obtained in the form of anomaly values representing expected changes in climate parameters relative to the reference period 1970–2000. These anomalies were provided on both an annual and quarterly basis, allowing for consideration of future seasonal variations. To assess changes in precipitation, the anomaly values were expressed as percentage deviations from historical monthly totals. These anomaly factors were then applied to the reference values, also obtained from SMHI, to generate adjusted future projections. For the temperature projections, the anomaly values were added to the reference values. Weather data for wind speed, relative humidity and solar radiation remained the same as in the reference simulation. The data were processed in Excel to fit the SWAT+ input requirements regarding time steps and units. After the simulation, the total inflow from the reference model was compared to the simulations reflecting weather changes due to climate change for RCP2.6 and RCP8.5. The results was used as input for scoring of the surface water source's resilience to climate change in terms of capacity in the MDCA.

3.4.2 Groundwater

The groundwater modelling in SWAT+ was set up with the module *gwflow*. Similarly to the surface water model, topography, soil properties, and land use data was used to set up the watershed. Since the groundwater source is located close to the surface water source, the same weather data was used for this simulation, see Appendix D, Table D.1. The validation of the groundwater model was performed by comparing the simulated groundwater head and recharge to the literature provided by the Geological Survey of Sweden (SGU) and Sweco Sverige AB. However, the validation showed that the quality of the model was insufficient and difficult to calibrate. The model was therefore abandoned, and the groundwater recharge was instead calculated according to the simplified water balance equation, see Equation 3.1.

$$R = P - E \tag{3.1}$$

R - Groundwater recharge [mm]

P - Precipitation [mm]

E - Evapotranspiration [mm]

The precipitation and evapotranspiration was assumed to be the same as for the surface water modelling since the groundwater source is located nearby. The potential evapotranspiration was calculated by SWAT+ using the Penman-Monteith method (SWAT+ Documentation, 2024b). The input weather data included precipitation, air temperature, wind speed, relative humidity, and solar radiation. The actual evapotranspiration was then calculated by SWAT+ that in addition to the potential evapotranspiration, also considered plant canopy, transpiration and soil evaporation (SWAT+ Documentation, 2024a). Surface runoff was assumed negligible as the soil in the catchment area is highly permeable. The groundwater runoff and connections to other aquifers or surface water sources were also ignored, as the groundwater source is mainly surrounded by thick clay layers.

The reference model results were validated to the existing literature, with satisfactory result, before the recharge was calculated for RCP2.6 and RCP8.5. Equation 3.1 was then used, but the precipitation and evapotranspiration data was updated based on SMHI's future climate projections calculated by SWAT+ for each scenario.

4

Results

The results consist of a reference MCDA where the criteria are formulated. Based on this reference MCDA, three additional MCDAs were developed. One includes the economic aspect, while the other two incorporate resilience to climate change. Results from the modelling of surface water flow and groundwater recharge for the case study are also presented. Finally, the results of the scoring and weighting in WISER for the different MCDAs are provided.

4.1 Reference MCDA Criteria

The key criteria retrieved from the interviews with stakeholders and experts are presented in Table 4.1. The criteria are divided into four categories. The categories are technical, social, environmental and economic. Some of the criteria and descriptions are inspired by or retrieved from the WISER tool (Sjöstrand et al., 2018).

Table 4.1: Criteria used in the MCDA for the case study are based on the WISER tool, interviews with municipal representatives, and input from experts.

Criteria	Description
Technical	
Capacity	The ability to extract the required quantity from the potential drinking water source in relation to future water demand.
Permits	The possibility of obtaining the necessary permits such as water rights.
Risk of contamination	The main risks of contamination to the drinking water source from point sources within the catchment area.
Water Quality	The current microbiological and chemical water quality of the drinking water source.
Social	
Conflicting interests	Potentially conflicting interests of different stakeholders.
Environmental	

Criteria	Description (continued)
Ecosystems	Effects on flora, fauna, habitats, and biodiversity.
Economic	
Cost of pipeline	Rough estimation of pipeline cost from drinking water source to water treatment plant.
Cost of WTP	Rough estimation of water treatment plant cost.

Initially, the reference MCDA was performed with the economic aspect included. Due to significant uncertainties regarding the cost of a water treatment plant and the early stage of the decision-making process, rough estimations must be made. These may have significant influence on the results and the economic aspect was therefore excluded from the reference MCDA. However, an additional MCDA was carried out with this criterion included to assess potential differences in the outcome.

4.2 MCDA - Criteria including climate change

The development of how to include climate change in the MCDA is explored through two approaches, referred to as Version 1 and Version 2. For both versions, the aspect of climate change is expressed as *Resilience to climate change*. The criteria for each version are described below. The most important criteria to consider when addressing climate change aspects for the case study are capacity, risk of contamination and water quality.

4.2.1 Version 1

For Version 1, resilience to climate change is added as new criteria to be considered. The description of the added criteria are described in Table 4.2. As previously mentioned, the criteria adjusted to address climate change are capacity, risk of contamination and water quality. The other criteria remain the same as in the reference MCDA.

Table 4.2: Description of criteria used in the MCDA when including resilience to climate change for Version 1.

Criteria	Description
Technical	
Capacity	The ability to extract the required quantity from the potential drinking water source in relation to future water demand.
Permits	The possibility of obtaining the necessary permits such as water rights.

Criteria	**Description (continued)**
Risk of contamination	The main risks of contamination to the drinking water source from point sources within the catchment area.
Water Quality	The current microbiological and chemical water quality of the drinking water source.
Social	
Conflicting interests	Potentially conflicting interests of different stakeholders.
Environmental	
Ecosystems	Effects on flora, fauna, habitats, and biodiversity.
Economic	
Cost of pipeline	Rough estimation of pipeline cost from drinking water source to water treatment plant.
Cost of WTP	Rough estimation of water treatment plant cost.
Resilience to climate change	
Capacity	The drinking water source's resilience to changes in capacity due to climate change.
Risk of contamination	The drinking water source's resilience to accidental events leading to risk of contamination as a result of climate change.
Water quality	The drinking water source's resilience to changes in water quality due to climate change.

4.2.2 Version 2

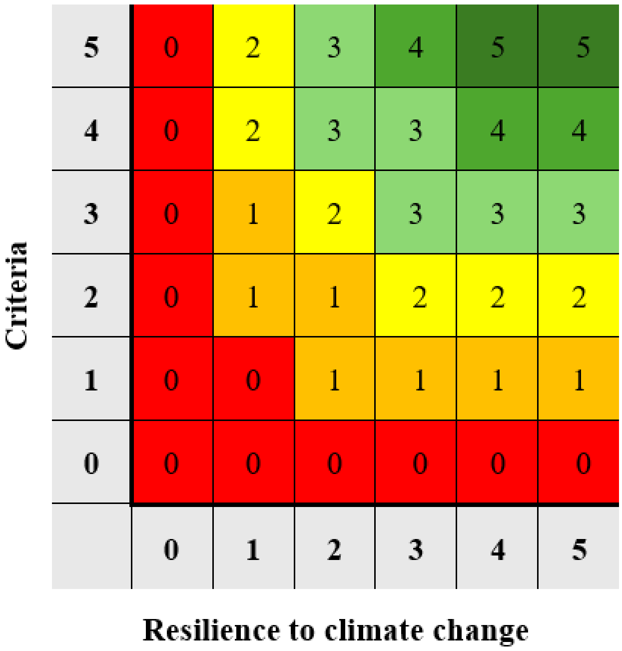
For Version 2, resilience to climate change is integrated into the same criteria used in the reference MCDA, but the descriptions are adapted to also reflect the considerations of climate change. The descriptions of the criteria are seen in Table 4.3. As previously mentioned, the criteria adjusted to address climate change are capacity, risk of contamination, and water quality. The other criteria remain unchanged compared to reference MCDA.

Table 4.3: Description of criteria used in the MCDA when including resilience to climate change for Version 2.

Criteria	**Description**
Technical	
Capacity	The ability to extract the required quantity from the potential drinking water source in relation to future water demand and projected climate change.

Criteria	**Description (continued)**
Permits	The possibility of obtaining the necessary permits such as water rights.
Risk of contamination	The main risks of contamination to the drinking water source from accidental events within the catchment area, as well as from extreme weather events related to climate change.
Water Quality	The current microbiological and chemical water quality of the drinking water source and its vulnerability to future climate change.
Social	
Conflicting interests	Potentially conflicting interests of different stakeholders.
Environmental	
Ecosystems	Effects on flora, fauna, habitats, and biodiversity.
Economic	
Cost of pipeline	Rough estimation of pipeline cost from drinking water source to water treatment plant.
Cost of WTP	Rough estimation of water treatment plant cost.

After adapting the descriptions of the criteria to include resilience to climate change, a matrix is developed to account for both the original criterion score and the resilience to climate change score. The matrix is presented in Figure 4.1. It is constructed by combining the original criterion score (y-axis) with the score for resilience to climate change (x-axis), resulting in a final score that incorporates climate change. Uncertainties can also be considered by assessing the uncertainty in both the original criterion and the resilience score, which generates a score interval. The final score for a criterion, after accounting for resilience to climate change, is designed such that it cannot exceed the original criterion score.



5	0	2	3	4	5	5
4	0	2	3	3	4	4
3	0	1	2	3	3	3
2	0	1	1	2	2	2
1	0	0	1	1	1	1
0	0	0	0	0	0	0
	0	**1**	**2**	**3**	**4**	**5**

Figure 4.1: Guiding matrix for scoring when including resilience to climate change in Version 2.

4.3 Case study results

The case study area consists of one surface water source and one groundwater source, both located in the western part of Sweden, specifically in Västra Götaland County. The groundwater source receives both natural and artificial infiltration. Modelling of surface water flow and natural groundwater recharge was carried out to estimate how capacity may vary under different climate change conditions. Two climate change scenarios, RCP2.6 and RCP8.5, have been investigated. Due to confidentiality, information that could reveal the geographical location of the potential drinking water sources is excluded. However, results related to flow to the surface water source and recharge to the groundwater source are presented.

4.3.1 Modelling results for surface water

The flow to the surface water source has been simulated for a reference period (1995-2024) and for two climate change scenarios, RCP2.6 and RCP8.5, for the period 2070 to 2100. The results are presented as average monthly flow in Figure 4.2. Due to the large amount of data covering many years, it is difficult to observe the detailed results in the Figure 4.2. However, it can be seen that the simulated flows for both RCP2.6 and RCP8.5 generally follow the same overall trend.

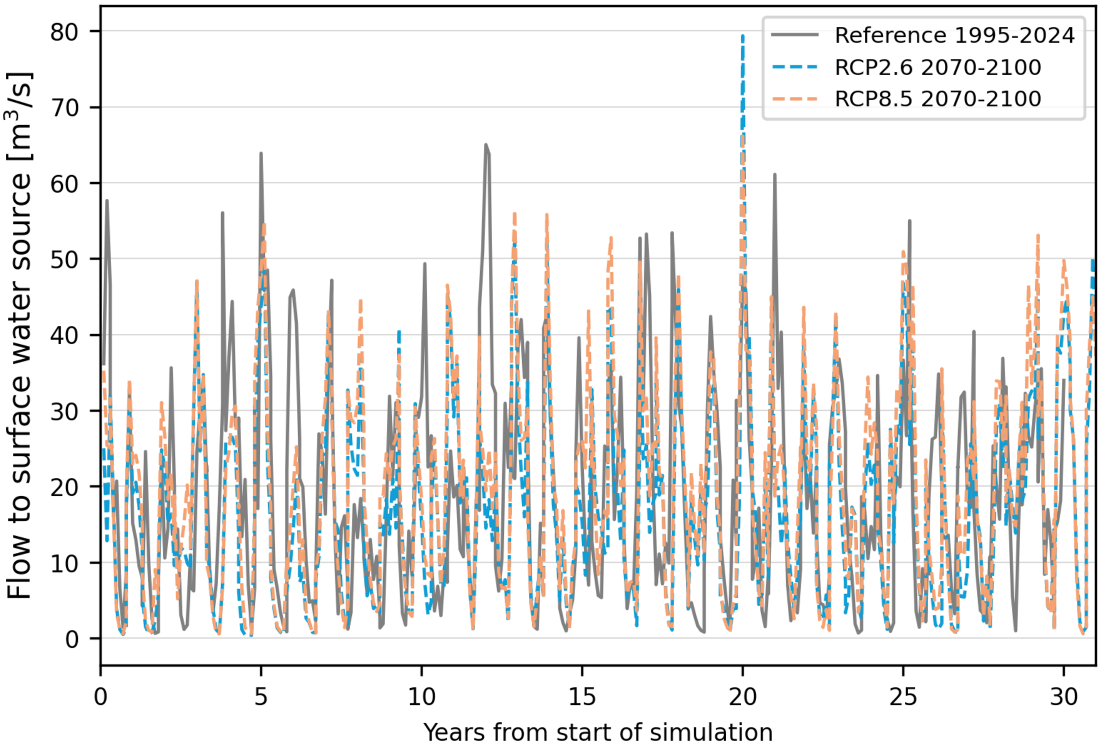


Figure 4.2: Simulated flow to surface water source in m^3/s for the reference years 1995-2024, RCP2.6 and RCP8.5 for the years 2070-2100.

For a more detailed comparison between the reference flow and the simulated flow where seasonal variations can be seen as average weekly flow, see Figure 4.3. To illustrate these variations, only three years are displayed. Three distinct declines in flow are visible, corresponding to the summer months. In general, the flow for the climate scenario RCP8.5 is slightly higher compared to both the reference flow and RCP2.6. This is due to increased precipitation projected for this specific region under RCP8.5.

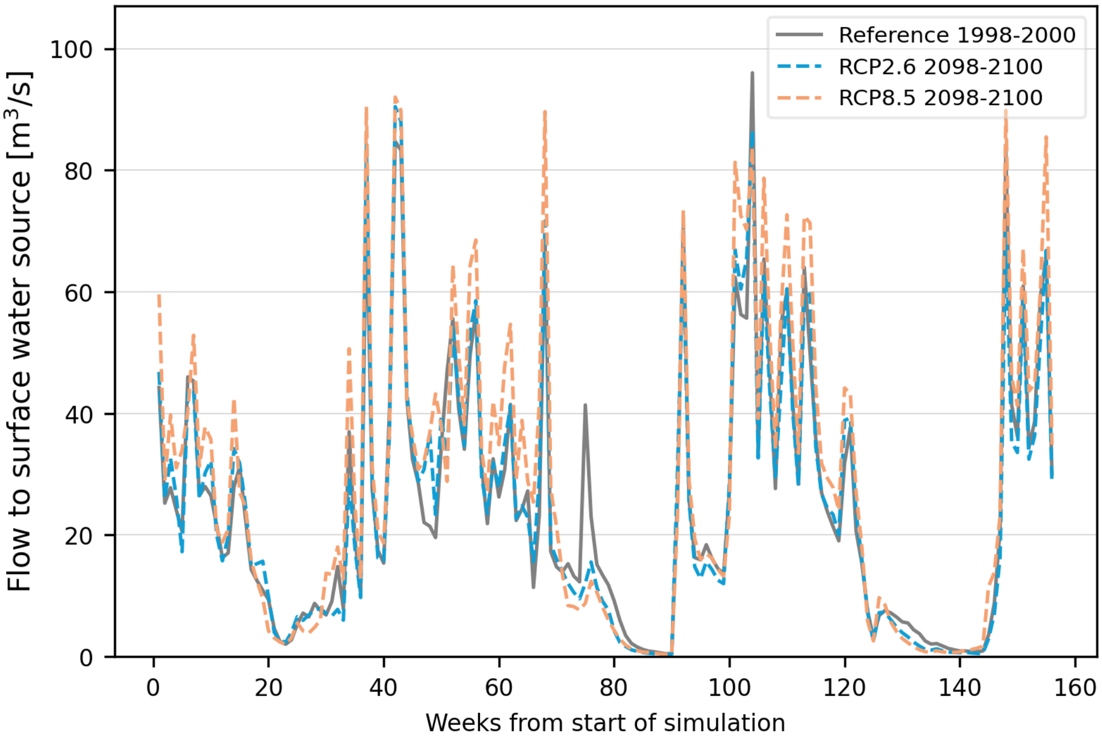


Figure 4.3: Simulated flow to surface water source in m^3/s for reference years 1998-2000, RCP2.6 and RCP8.5 for years 2098-2100.

4.3.2 Modelling results for groundwater

Groundwater recharge has been calculated using a water balance approach for a reference period (1995–2024) and for two climate change scenarios, RCP2.6 and RCP8.5 for 2070-2100. The cumulative recharges are presented in Figure 4.4. The simulation for the reference period is based on weather data from SMHI. For the climate scenarios, precipitation and temperature were adjusted according to SMHI's climate projections, and the same projections used in SWAT+ for the surface water modelling were applied.

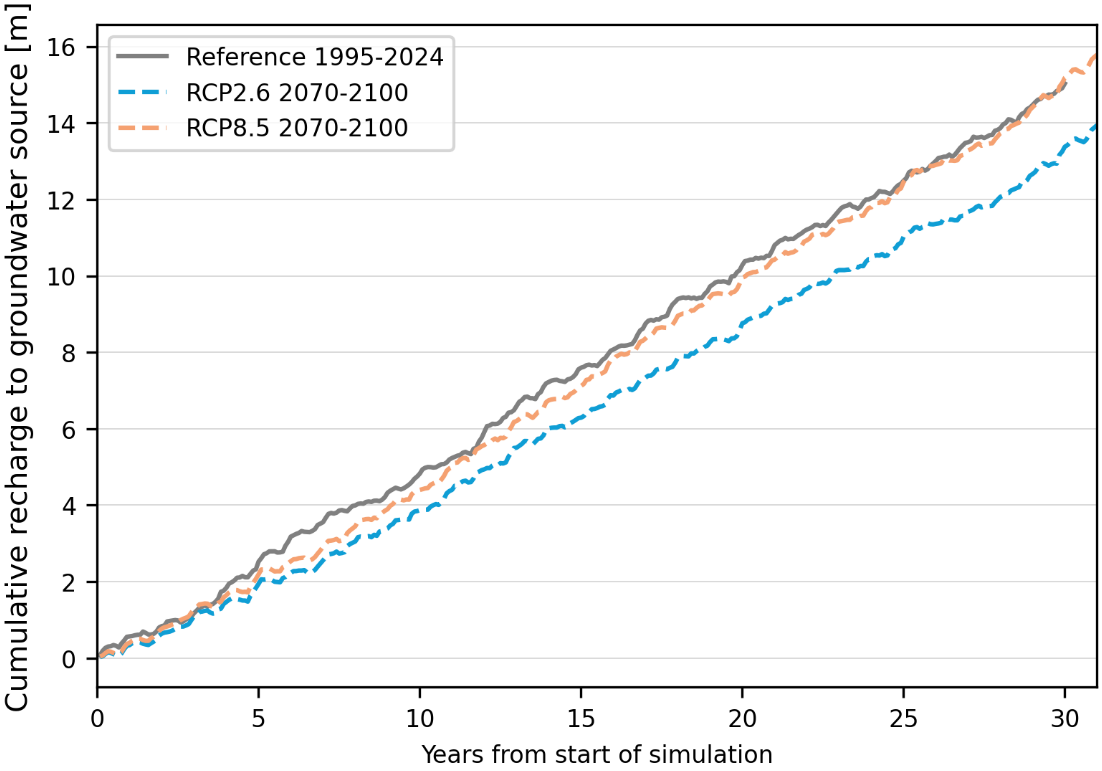


Figure 4.4: Simulated cumulative recharge to the groundwater source for reference years 1995-2024, RCP2.6 and RCP8.5 for years 2070-2100 in meters.

To illustrate seasonal variations, only three years are displayed in Figure 4.5. Minor seasonal changes in the cumulative recharge can be observed, such as the curve flattening slightly during the summer months, although this effect is not very distinct.

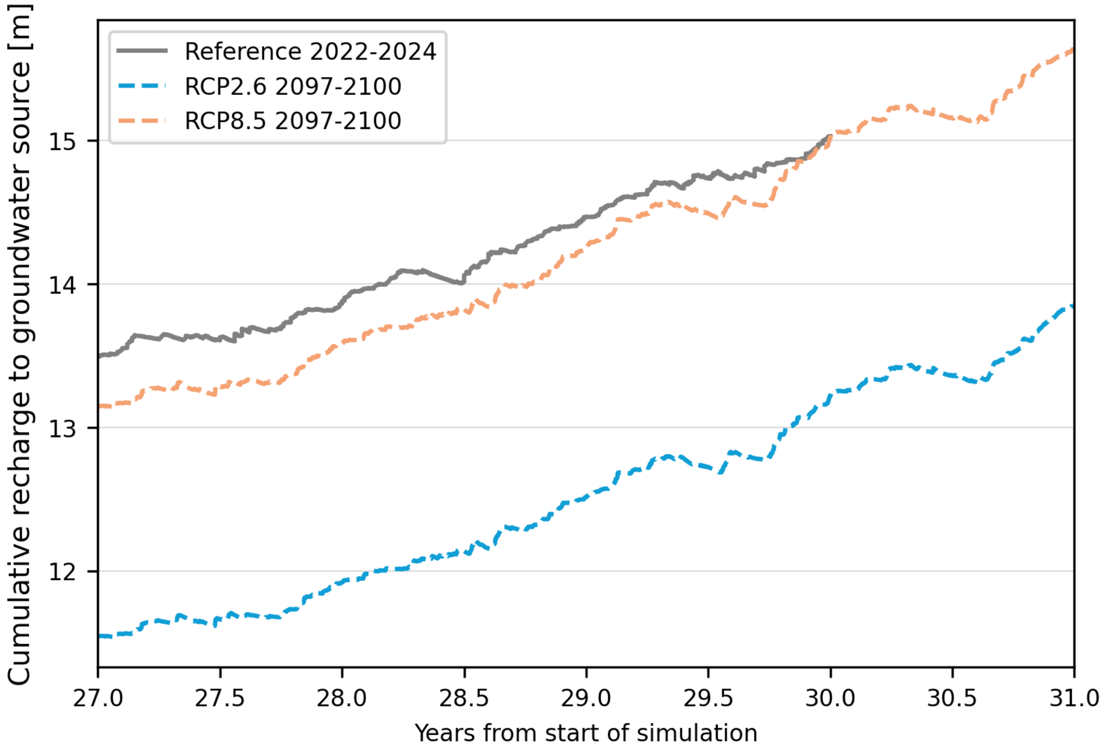


Figure 4.5: Simulated cumulative recharge to groundwater source in meters for the reference years 2022-2024, RCP2.6 and RCP8.5 for the years 2097-2100.

The change in groundwater recharge compared to the reference period, shown in percentage, is presented in Figure 4.6. The first years show more variation before the values stabilize. The simulation for both climate scenarios shows lower groundwater recharge than in the reference period. For RCP8.5, the recharge after 30 years is almost the same as in the reference period, while for RCP2.6 it is slightly more than 10% lower. Figure 4.7 shows the same change over 30 years, but presented in meters. This corresponds to a decrease of approximately 1.5 to 2 meters.

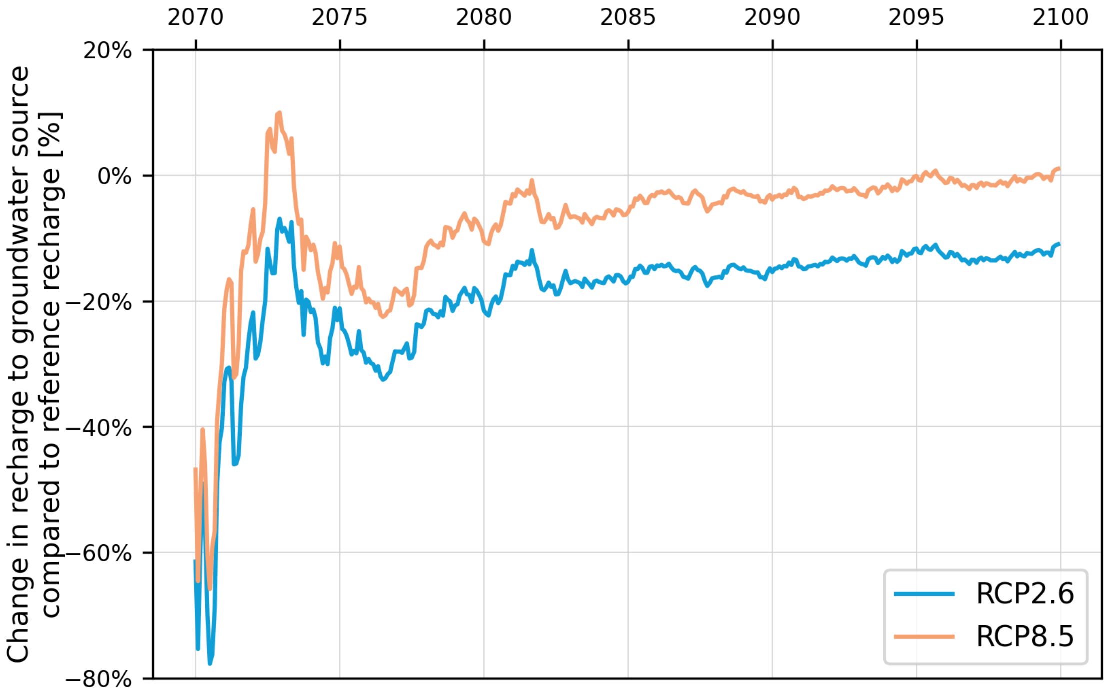


Figure 4.6: Simulated cumulative groundwater recharge for RCP2.6 and RCP8.5 (2070–2100), compared to the 1995–2024 reference period presented as a percentage.

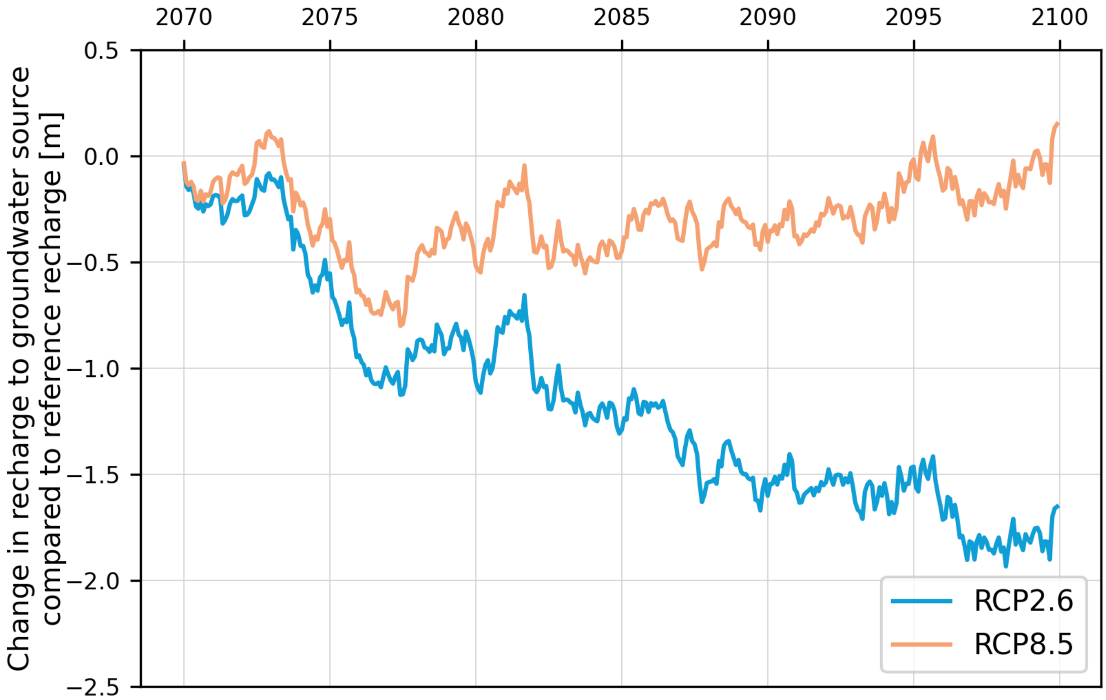


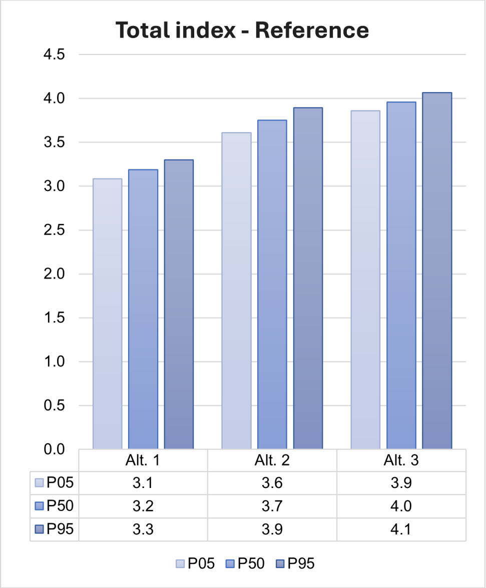
Figure 4.7: Simulated cumulative groundwater recharge for RCP2.6 and RCP8.5 (2070–2100), compared to the 1995–2024 reference period presented in meters.

4.3.3 WISER results

The results from WISER presented in this section compile the scores and weights from the reference MCDA and the two versions that include climate change for the case study area. The results are shown as total index values for each alternative, where Alternative 1 is groundwater, Alternative 2 is artificial infiltration, and Alternative 3 is surface water. Due to confidentiality, the basis for the scores, such as specific risks of contamination in the area, is not presented. Instead, only the final scoring results are presented in Appendix B.

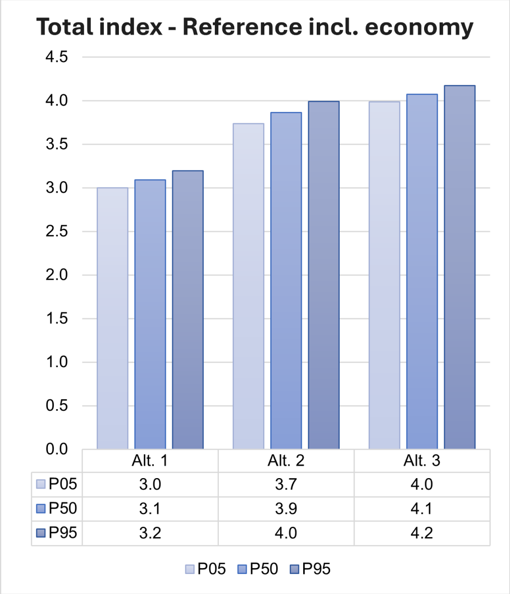
4.3.3.1 Reference MCDA

The result from the WISER analysis for the reference MCDA is presented in Figure 4.8. The result is presented for the three different alternatives, where P50 represents the most likely total index score for each alternative. P05 and P90 illustrate the uncertainty interval. The total index is based on the scoring in Table B.1 in Appendix B. The scoring of the economic criterion was conducted such that the most cost-efficient alternative, expressed in terms of cost per litre per second (l/s), was awarded the highest score. The scores for the remaining alternatives were calculated by dividing their respective cost per l/s by the maximum score on the scoring scale assigned to the most favourable option. The final scores for the economic criteria are presented in Appendix B, Table B.2. The weightings for both analyses are presented in Tables C.1 and C.2 in Appendix C respectively. Figure 4.9 presents the result from the reference MCDA, including the economic aspect. When including the economic aspect, the total index score decreases for alternative 1 in the reference MCDA, while it increases the scores for alternatives 2 and 3.



	Alt. 1	Alt. 2	Alt. 3
P05	3.1	3.6	3.9
P50	3.2	3.7	4.0
P95	3.3	3.9	4.1

Figure 4.8: Total index for the reference MCDA, retrieved from WISER (Sjöstrand et al., 2021).



	Alt. 1	Alt. 2	Alt. 3
P05	3.0	3.7	4.0
P50	3.1	3.9	4.1
P95	3.2	4.0	4.2

Figure 4.9: Total index for reference MCDA, including the economic aspect. Retrieved from WISER (Sjöstrand et al., 2021).

4.3.3.2 Version 1

The results of total index for Version 1 for RCP2.6 and RCP8.5 are presented in Figures 4.10 and 4.11. P50 represents the most likely total index score for the different alternatives. Scoring for the different scenarios are presented in Appendix B, Table B.3 and B.4. The weighting for the criteria that include resilience to climate change was determined according to Figure C.3 in Appendix C. The same weighting was used for both RCP2.6 and RCP8.5. The total index differs slightly between RCP2.6 and RCP8.5, where RCP8.5 generates a higher total index for alternative 1, while it decreases for alternatives 2 and 3.

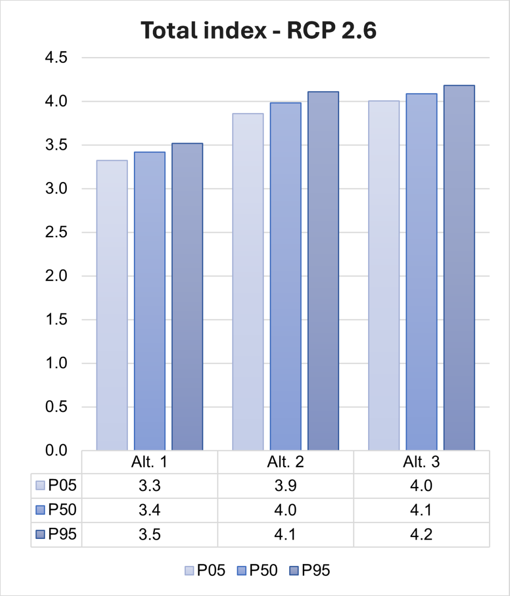


Figure 4.10: Total index for Version 1, RCP2.6. Retrieved from WISER (Sjöstrand et al., 2021).

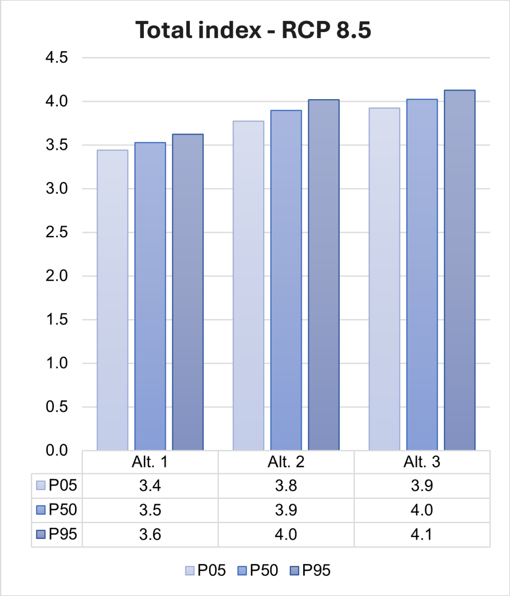
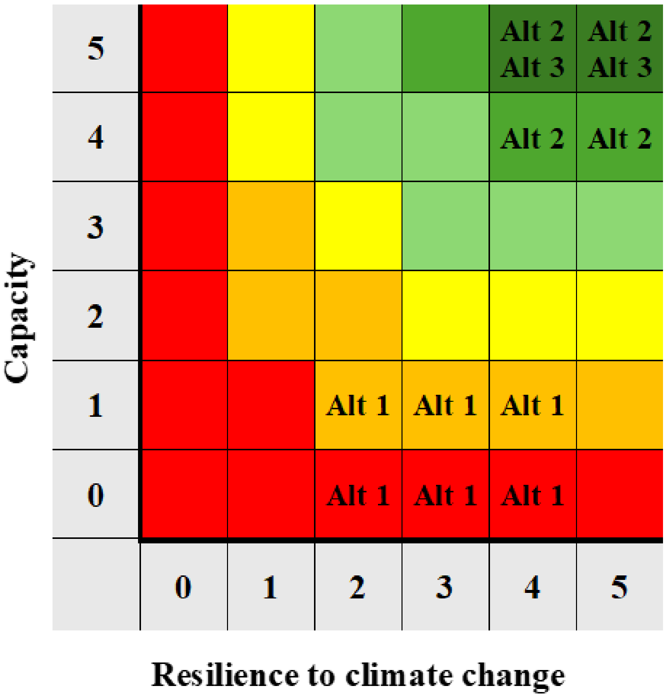


Figure 4.11: Total index for Version 1, RCP8.5. Retrieved from WISER (Sjöstrand et al., 2021).

4.3.3.3 Version 2

For Version 2, the scoring matrix was used, and Figure 4.12 provides an example of the scores for the different alternatives when applying the matrix.



5					Alt 2 Alt 3	Alt 2 Alt 3
4					Alt 2	Alt 2
3						
2						
1			Alt 1	Alt 1	Alt 1	
0			Alt 1	Alt 1	Alt 1	
	0	1	2	3	4	5

Figure 4.12: Scoring matrix for resilience to climate change (RCP2.6) regarding capacity, Version 2.

The results of total index for Version 2 for RCP2.6 and RCP8.5 are presented in Figures 4.13 and 4.14. The results are identical to each other, as well as to the reference MCDA. The scoring for RCP2.6 is based on the scoring matrixes in Figure B.1, B.2 and B.3 in Appendix B. The final scoring is seen in Table B.5. Similarly, the scores for RCP8.5 is presented in Figure B.4, B.5 and B.6 in Appendix B and are assembled in Table B.6. The assigned weighting is presented in Appendix C, Figure C.1.

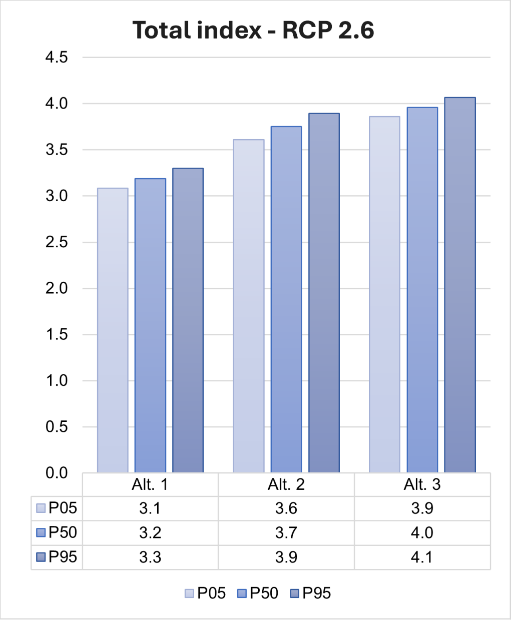


Figure 4.13: Total index for Version 2, RCP2.6. Retrieved from WISER (Sjöstrand et al., 2021).

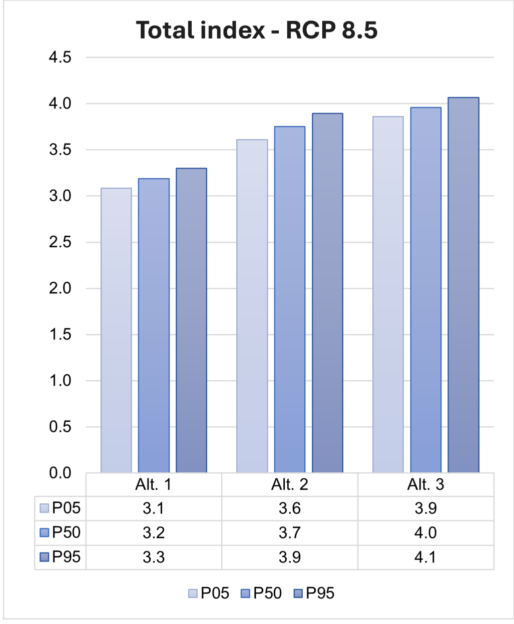


Figure 4.14: Total index for Version 2, RCP8.5. Retrieved from WISER (Sjöstrand et al., 2021).

5

Discussion

The following chapter presents a discussion of the results, including aspects related to the different MCDA versions, the SWAT+ modelling process, the calculation of groundwater recharge, the use of projected climate data, geographical variations influencing the result, as well as limitations and sources of uncertainty.

5.1 MCDA

For the reference MCDA, the scoring was based on a workshop with experts, during which assessments were made using the information provided. However, the information gathered and presented during the workshop before the scoring may have been incomplete and additional data could potentially have been collected. On the other hand, this MCDA is intended for use in the early stage of decision making for a potential future drinking water source. At this stage, it is not feasible to include for example a wide range of contamination risks or water quality parameters. Instead, the focus should be and has been on the most important aspects. The weighting could also have been done more carefully or in a different way, but it is based on what the municipality considered important and on what is generally regarded as relevant in the early stage of decision making for new drinking water sources. The main purpose of the reference MCDA is to serve as a baseline for comparison with Version 1 and Version 2 where climate change is included.

To investigate how the climate change aspect can be incorporated into the decision-making process for future drinking water sources, two MCDA versions have been developed. Version 1 adds the aspect of resilience to climate change as separate criteria corresponding to the existing criteria assessed most affected by climate change. In this study, capacity, risk of contamination and water quality are the criteria considered. This makes the scoring process easy to understand as the new criteria are simply added to the total score of the MCDA. This also enables separate weighting of the resilience to climate change dimension and each criterion. This makes the MCDA method easy to customize depending on the users needs. However, a key aspect of the MCDA approach is that the criteria should be independent and non-overlapping. In practical application, particularly as structured in Version 1, this may prove challenging.

Version 2 is slightly less intuitive and is structured around a matrix system in which resilience to climate change is integrated into the original set of criteria. This approach reduces the total number of criteria, which can be advantageous as it avoids creating a complex structure with too many criteria to manage. In this version, due to the structure of the matrix-based scoring system, resilience to climate change does not positively contribute to the overall score. Rather, it can only reduce the score if the alternative under evaluation is assessed to be vulnerable to climate change.

As demonstrated by the results, Alternative 3 (the surface water source), was identified as the most suitable drinking water source across all scenarios and MCDA versions applied to the case study. However, all investigated alternatives received high scores in both the reference MCDA and the climate change resilience assessments. The high scores of Alternative 3 are mainly attributed to its characteristics as a large surface water body with relatively high water quality. These features contribute to high scores in the criteria most heavily weighted by the municipality. Moreover, the size of the water source not only supports a high capacity but also improves its resilience to contamination, negative ecosystem impact, and climate change.

The total index for Alternative 1 (the groundwater source) is also relatively high but may be misleading. While Alternative 1 performs well across most criteria, it fails to meet the municipality's required water quantity, resulting in a capacity score of zero. This could justify excluding the groundwater source as a viable option for drinking water supply. However, its strong performance on the remaining criteria suggests that it could still be a suitable source when combined with another alternative that offers greater capacity. This effect arises because the applied MCDA technique allows for compensation between criteria. One way to address this is to include only alternatives that meet the minimum capacity requirement. However, the intention may also be to evaluate the performance of the alternatives regardless of their capacity. If the municipality considers capacity to be the most critical criterion, it could be assigned a higher weight in the evaluation. This would lead to a lower total index for Alternative 1.

Alternative 2, the artificial infiltration option, represents a hybrid of Alternative 1 and Alternative 3, in which surface water is infiltrated into a groundwater aquifer. This alternative also receives high scores in both the reference MCDA and the versions incorporating climate change resilience. These high scores are primarily due to its dependence on the performance of Alternative 3, particularly in terms of capacity, water quality, and climate change resilience. Since alternative 3 is assessed with high scores, alternative 2 also scores high, as seen in Figure 4.10-4.14. Moreover, Alternative 2 is considered advantageous because the infiltration process not only improves the quality of the surface water but also contributes to increased aquifer capacity.

The overall scoring for the case study area is very similar across the different MCDA versions, making it challenging to distinguish the differences between the methodologies developed to incorporate climate change. For the case study area, the consistently high scores and close alignment with the reference scenario are positive, as they suggest that climate change is likely to have a limited impact on the area's drinking water sources up to the year 2100. However, the study would have benefitted from investigating a region where drinking water sources are expected to be more vulnerable to climate change. Such a context might have revealed shortcomings in the methodologies and provided greater opportunities for refinement and further development.

5.2 Modelling

Based on the findings of this study, modelling the effects of climate change on potential drinking water sources using SWAT+ appears to be a valuable approach for assessing resilience to climate change. The ability of the software to simulate both surface water and groundwater systems enhances user-friendliness and efficiency, as it allows the analysis to be conducted within a single software. However, many of SWAT+'s features were not utilized in this study. Future research could benefit from incorporating the model's water quality modules to, for instance, simulate pollutant transport to the drinking water sources. This would also provide quantitative input for the water quality criterion in the MCDA. It should also be noted that the groundwater modelling was limited in this study, primarily due to time constraints and lack of expertise. Achieving reliable results from the gwflow module in SWAT+ would have strengthened the analysis and improved the comparability between the different types of drinking water sources. However, since this is an early stage of the decision making process, the aim is to avoid investing too much effort, expertise or time in developing a highly detailed model. A more detailed model could be more appropriate and useful in a later stage of the decision process. At the same time, there are several important uncertainties in the assumptions, mainly related to projected temperature and precipitation depending on how climate change develops. Therefore, even though a slightly more detailed model could add some value, the changes in results would likely be small compared to the overall uncertainty in the input assumptions.

The data for temperature and precipitation projected for the period 2070 to 2100, which was used as input in SWAT+, was based on climate projections from SMHI. One limitation in applying the projected precipitation factors was that when the factor was multiplied with the reference values, any day in the reference data with no precipitation remained dry regardless of the projected factor. This means that if the projection indicated more precipitation, the result was still zero precipitation for originally dry days. If the projection indicated less precipitation, it could result in too little precipitation even on wet days. This is a known weakness in the simulated weather data.

SMHI provides projections for the longest dry period. These show only a very small increase compared to the reference period in the case study area. According to SMHI, the longest dry period between 2070 and 2100 is projected to increase from 20.2 days to 20.3 days for RCP8.5, which is less than 1% increase (SMHI, 2025a).

The number of dry days is projected to remain roughly the same for both RCP2.6 and RCP8.5, and the risk of contamination due to wildfires is therefore not assumed to increase significantly for the case study area. However, this comparison is based on annual values. When looking at seasonal variations and how the longest dry period is projected for each quarter, a more noticeable change can be observed. For RCP8.5 during the summer months, the longest dry period is projected to increase from 13 days to 14.3 days, which corresponds to about a 10% increase (SMHI, 2025a). Overall, seasonal variations in the distribution of precipitation are not fully reflected in the simulation, and it is likely that surface water flow and groundwater levels are slightly more vulnerable during the summer months than the simulations shows.

Another factor that is not included in the climate projections for 2070 to 2100 was the number of days with extreme precipitation. If this parameter had been included, the results would probably have shown a different distribution of precipitation, with higher peaks in surface water flow and groundwater levels. For both RCP2.6 and RCP8.5, an increase in the number of days of extreme precipitation is projected each year, with the increase more noticeable for RCP8.5 (SMHI, 2025a). For RCP8.5, the number of days with extreme precipitation is expected to increase from 4.0 to 6.8 which is a rise of 70%. For RCP2.6, the number is projected to rise from 4.0 to 4.9, corresponding to a 23% increase. For RCP2.6, the increase is relatively evenly distributed throughout the year. For RCP8.5, there is a clear peak during the winter months. This implies an even greater vulnerability of surface water flow and groundwater levels during the summer than what is shown in the current simulation results in Figure 4.3 and 4.5. With more extreme precipitation, soil erosion is more likely to occur and affect the criterion *Risk of contamination*. Due to conflicting information about extreme precipitation from both the literature review and the modelling results, it is difficult to set a clear score for this criterion. This uncertainty influences the scoring in the MCDAs that include resilience to climate change, Version 1 and Version 2. In the case study, the scores were set in the range of 3 to 5, depending on the alternative and the climate scenario. These scores reflect a moderate to minimal vulnerability to negative effects of climate change. It is important to keep in mind that the scores are uncertain.

Another consequence of an increase in days with extreme precipitation is that surface runoff may vary significantly during such events. When calculating groundwater levels using the water balance equation, surface runoff was assumed to be negligible because the dominant soil types in the area generally have good infiltration capacity. However, during extreme precipitation, surface runoff can increase due to the intensity of the rainfall, which may prevent sufficient infiltration. As a result, less water may reach the aquifer, leading to reduced groundwater recharge. This aspect is not accounted for in the groundwater model.

The results might also have been different if other weather parameters such as wind speed, solar radiation and relative humidity had been included. However, temperature and precipitation are considered the most fundamental factors for estimating surface water flow and groundwater recharge.

5.3 Climate change

The results regarding groundwater recharge showed lower recharge for RCP2.6 compared to RCP8.5 (see Figure 4.4). The recharge was mainly influenced by precipitation data, but also by temperature which was used to simulate evapotranspiration. When examining the precipitation data for Västra Götaland County, it could be seen that projected precipitation volumes were higher for RCP8.5 than for RCP2.6 (SMHI, 2025a). This supports the simulated results. In addition, RCP2.6 showed lower projected precipitation compared to the reference period, which also aligns with the simulation outcomes. If the projected climate data had been different, as it is for other parts of Sweden, the results for groundwater recharge under the different RCPs would also have differed. It is important to note that these relationships and trends are not universal. Climate projections vary by geographic location, which leads to different outcomes in groundwater recharge simulations.

6

Conclusion and further research

The main findings are presented below. The conclusions include the methods main characteristics, applicability, and the relevance of modelling. Moreover, suggestions further research are presented.

6.1 Conclusion

- Two MCDA versions including resilience to climate change has been developed based on a reference MCDA. Both versions are considering the same criteria while the scoring method differentiates them.
- Version 1 is intuitive and user-friendly, where climate change resilience is added as additional criteria enabling separate weighting.
- Version 2 is a matrix-based scoring system that integrates climate change resilience directly into the relevant criteria. This approach reduces the total number of criteria in the MCDA, thereby maintaining a more manageable evaluation process.
- Modelling can be a useful tool for gaining a better understanding of future drinking water capacity and quality in the early stage of the decision making process, and SWAT+ appears to be a suitable software for this purpose.
- For the case study, the developed decision support tool proved to be applicable and provided an indication of how climate change may affect the alternative drinking water sources and how this would influence the overall evaluation.
- The developed desicion support tool appears to be applicable under Swedish conditions, although each case requires customization to reflect the unique circumstances and needs of the respective municipality.

6.2 Further research

To further improve the inclusion of the climate change aspect and to develop the two versions, they should be applied to more case studies located in different geographical areas. With more applications over time, the strengths and weaknesses of each version will become clearer.

Another aspect that could support the inclusion of climate change in MCDA at an early stage is modelling how water quality may change due to climate change. This has strong potential to be implemented in SWAT+, especially since the model is already built for quantity, and the software includes functions for water quality simulations.

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A

Evaluation basis

Table A.1: Evaluation basis for reference MCDA.

Criteria	**Evaluation basis**
Technical	
Capacity	5: **Clearly** meets the withdrawal requirement with a **very substantial margin**, even **under extreme conditions**. 4: **Highly likely** to meet the withdrawal requirement with a **good margin**. 3: Assessed as **likely** to meet the withdrawal requirement **under normal conditions**. 2: **Uncertain** whether the withdrawal requirement is met. 1: **Very uncertain** whether the withdrawal requirement is met. 0: The withdrawal requirement is not met – not a relevant option.
Permits	5: Assessed as having **very strong** prospects of obtaining an approved water permit. 4: Assessed as having **good** prospects of obtaining an approved water permit. 3: Assessed as having **reasonable** prospects for obtaining an approved water permit. 2: Assessed as having **limited** prospects of obtaining an approved water permit. 1: Assessed as having **very limited** prospects of obtaining an approved water permit. 0: Considered unlikely to obtain a permit.

Criteria	**Evaluation basis (continued)**
Risk of contamination	5: **No significant** sources of risk within the catchment area. 4: **Very few significant** sources of risk within the catchment area. 3: **Some significant** sources of risk within the catchment area. 2: **Many** significant sources of risk within the catchment area. 1: **Extensive** sources of risk within the catchment area, with **unavoidable impact**. 0: The sources of risk are so extensive that the water source is unsuitable for drinking water supply.
Water Quality	5: The raw water is of **very high quality** and is **highly suitable** for drinking water production. 4: The raw water is of **good quality** and is **well suited** for drinking water production. 3: The raw water is of **relatively good quality** and is **suitable** for drinking water production. 2: The raw water shows **certain quality deficiencies** that hinder its use for drinking water production. 1: The raw water quality poses **significant challenges** for drinking water production. 0: The raw water is of unacceptable quality, and the water source is excluded.
Social	
Conflicting interests	5: **No** known conflicting interests have been identified. 4: **Some** conflicting interests exist, but they are not considered significant. 3: The option entails **certain** conflicting interests. 2: **Several significant** conflicting interests have been identified. 1: **Very extensive** and **significant** conflicting interests have been identified. 0: The conflicting interests are so extensive that the water source is excluded.
Environmental	

Criteria	**Evaluation basis (continued)**
Ecosystems	5: The option is **not** expected to cause any negative impact on the ecosystem. 4: The option is expected to cause a **minor** negative impact on the ecosystem. 3: The option is expected to cause **some** negative impact on the ecosystem. 2: The option is expected to cause a **significant** negative impact on the ecosystem. 1: The option is expected to cause a **very substantial** negative impact on the ecosystem. 0: The option is expected to cause such extensive negative impact on the ecosystem that the water source is excluded.
Economic	
Cost of pipeline	After information regarding this criterion was gathered, the results were similar and showed negligible differences.
Cost of WTP	For the MCDA that includes economic aspects, scores were calculated in relation to each other and the most cost-efficient alternative was given a score of 5. See Appendix B.2 for details regarding the calculation.

Table A.2: Evaluation basis for MCDA when including climate change, Version 1.

Criteria	**Evaluation basis**
Technical	
Capacity	5: **Clearly** meets the withdrawal requirement with a **very substantial margin**, even **under extreme conditions**. 4: **Highly likely** to meet the withdrawal requirement with a **good margin**. 3: Assessed as **likely** to meet the withdrawal requirement **under normal conditions**. 2: **Uncertain** whether the withdrawal requirement is met. 1: **Very uncertain** whether the withdrawal requirement is met. 0: The withdrawal requirement is not met – not a relevant option.
Permits	5: Assessed as having **very strong** prospects of obtaining an approved water permit. 4: Assessed as having **good** prospects of obtaining an approved water permit. 3: Assessed as having **reasonable** prospects for obtaining an approved water permit. 2: Assessed as having **limited** prospects of obtaining an approved water permit. 1: Assessed as having **very limited** prospects of obtaining an approved water permit. 0: Considered unlikely to obtain a permit.
Risk of contamination	5: **No significant** sources of risk within the catchment area. 4: **Very few significant** sources of risk within the catchment area. 3: **Some significant** sources of risk within the catchment area. 2: **Many** significant sources of risk within the catchment area. 1: **Extensive** sources of risk within the catchment area, with **unavoidable impact**. 0: The sources of risk are so extensive that the water source is unsuitable for drinking water supply.

Criteria	**Evaluation basis (continued)**
Water Quality	5: The raw water is of **very high quality** and is **highly suitable** for drinking water production. 4: The raw water is of **good quality** and is **well suited** for drinking water production. 3: The raw water is of **relatively good quality** and is **suitable** for drinking water production. 2: The raw water shows **certain quality deficiencies** that hinder its use for drinking water production. 1: The raw water quality poses **significant challenges** for drinking water production. 0: The raw water is of unacceptable quality, and the water source is excluded.
Social	
Conflicting interests	5: **No** known conflicting interests have been identified. 4: **Some** conflicting interests exist, but they are not considered significant. 3: The option entails **certain** conflicting interests. 2: **Several significant** conflicting interests have been identified. 1: **Very extensive** and **significant** conflicting interests have been identified. 0: The conflicting interests are so extensive that the water source is excluded.
Environmental	
Ecosystems	5: The option is **not** expected to cause any negative impact on the ecosystem. 4: The option is expected to cause a **minor** negative impact on the ecosystem. 3: The option is expected to cause **some** negative impact on the ecosystem. 2: The option is expected to cause a **significant** negative impact on the ecosystem. 1: The option is expected to cause a **very substantial** negative impact on the ecosystem. 0: The option is expected to cause such extensive negative impact on the ecosystem that the water source is excluded.
Resilience to climate change	

Criteria	Evaluation basis (continued)
Capacity	5: The vulnerability to negative changes in capacity due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to negative changes in capacity due to climate change is **low**. 3: The vulnerability to negative changes in capacity due to climate change is **moderate**. 2: The vulnerability to negative changes in capacity due to climate change is **substantial**. 1: The vulnerability to negative changes in capacity due to climate change is **very substantial**. 0: The vulnerability to negative changes in capacity due to climate change is so critical that the water source is excluded.
Risk of contamination	5: The vulnerability to accidental events leading to risk of contamination due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to accidental events leading to risk of contamination due to climate change is **low**. 3: The vulnerability to accidental events leading to risk of contamination due to climate change is **moderate**. 2: The vulnerability to accidental events leading to risk of contamination due to climate change is **substantial**. 1: The vulnerability to accidental events leading to risk of contamination due to climate change is **very substantial**. 0: The vulnerability accidental events leading to risk of contamination due to climate change is so critical that the water source is excluded
Water quality	5: The vulnerability to negative changes in water quality due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to negative changes in water quality due to climate change is **low**. 3: The vulnerability to negative changes in water quality due to climate change is **moderate**. 2: The vulnerability to negative changes in water quality due to climate change is **substantial**. 1: The vulnerability to negative changes in water quality due to climate change is **very substantial**. 0: The vulnerability to negative changes in water quality due to climate change is so critical that the water source is excluded.

Table A.3: Evaluation basis for MCDA when including climate change, Version 2.

Criteria	Evaluation basis
Technical	
Capacity	**Score on the y-axis** 5: **Clearly** meets the withdrawal requirement with a **very substantial margin**, even **under extreme conditions**. 4: **Highly likely** to meet the withdrawal requirement with a **good margin**. 3: Assessed as **likely** to meet the withdrawal requirement **under normal conditions**. 2: **Uncertain** whether the withdrawal requirement is met. 1: **Very uncertain** whether the withdrawal requirement is met. 0: The withdrawal requirement is not met – not a relevant option. **Score on the x-axis** 5: The vulnerability to negative changes due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to negative changes due to climate change is **low**. 3: The vulnerability to negative changes due to climate change is **moderate**. 2: The vulnerability to negative changes due to climate change is **substantial**. 1: The vulnerability to negative changes due to climate change is **very substantial**. 0: The vulnerability to negative changes due to climate change is so critical that the water source is excluded.
Permits	5: Assessed as having **very strong** prospects of obtaining an approved water permit. 4: Assessed as having **good** prospects of obtaining an approved water permit. 3: Assessed as having **reasonable** prospects for obtaining an approved water permit. 2: Assessed as having **limited** prospects of obtaining an approved water permit. 1: Assessed as having **very limited** prospects of obtaining an approved water permit. 0: Considered unlikely to obtain a permit.

Criteria	**Evaluation basis (continued)**
Risk of contamination	**Score on the y-axis** 5: **No significant** sources of risk within the catchment area. 4: **Very few significant** sources of risk within the catchment area. 3: **Some significant** sources of risk within the catchment area. 2: **Many** significant sources of risk within the catchment area. 1: **Extensive** sources of risk within the catchment area, with **unavoidable impact**. 0: The sources of risk are so extensive that the water source is unsuitable for drinking water supply. **Score on the x-axis** 5: The vulnerability to negative changes due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to negative changes due to climate change is **low**. 3: The vulnerability to negative changes due to climate change is **moderate**. 2: The vulnerability to negative changes due to climate change is **substantial**. 1: The vulnerability to negative changes due to climate change is **very substantial**. 0: The vulnerability to negative changes due to climate change is so critical that the water source is excluded.

Criteria	**Evaluation basis (continued)**
Water Quality	5: The raw water is of **very high quality** and is **highly suitable** for drinking water production. 4: The raw water is of **good quality** and is **well suited** for drinking water production. 3: The raw water is of **relatively good quality** and is **suitable** for drinking water production. 2: The raw water shows **certain quality deficiencies** that hinder its use for drinking water production. 1: The raw water quality poses **significant challenges** for drinking water production. 0: The raw water is of unacceptable quality, and the water source is excluded. **<u>Score on the x-axis</u>** 5: The vulnerability to negative changes due to climate change is **minimal** and therefore **negligible**. 4: The vulnerability to negative changes due to climate change is **low**. 3: The vulnerability to negative changes due to climate change is **moderate**. 2: The vulnerability to negative changes due to climate change is **substantial**. 1: The vulnerability to negative changes due to climate change is **very substantial**. 0: The vulnerability to negative changes due to climate change is so critical that the water source is excluded.
Social	
Conflicting interests	5: **No** known conflicting interests have been identified. 4: **Some** conflicting interests exist, but they are not considered significant. 3: The option entails **certain** conflicting interests. 2: **Several significant** conflicting interests have been identified. 1: **Very extensive** and **significant** conflicting interests have been identified. 0: The conflicting interests are so extensive that the water source is excluded.
Environmental	

Criteria	**Evaluation basis (continued)**
Ecosystems	5: The option is **not** expected to cause any negative impact on the ecosystem. 4: The option is expected to cause a **minor** negative impact on the ecosystem. 3: The option is expected to cause **some** negative impact on the ecosystem. 2: The option is expected to cause a **significant** negative impact on the ecosystem. 1: The option is expected to cause a **very substantial** negative impact on the ecosystem. 0: The option is expected to cause such extensive negative impact on the ecosystem that the water source is excluded.
Economic	
Cost of pipeline	After information regarding this criterion was gathered, the results were similar and showed negligible differences.
Cost of WTP	This criterion will be considered negligible due to the high level of uncertainty in the information gathered and its limited relevance at the early stage of the decision-making process.

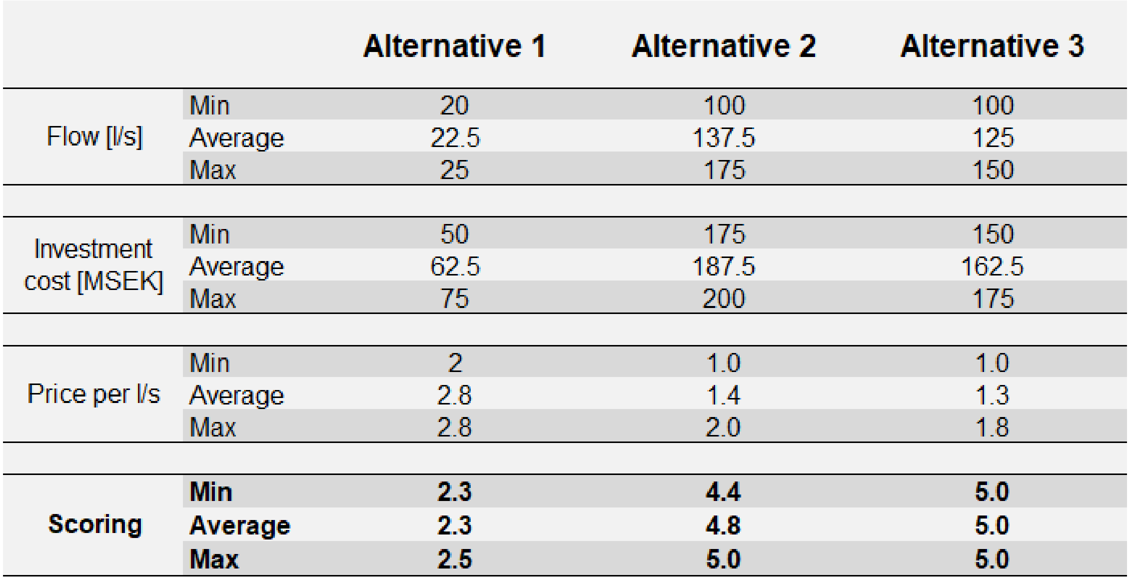
B

Scoring for MCDA

Table B.1: Scoring for reference MCDA with uncertainties. The most likely score for each criterion is located in the middle column under each alternative.

Criteria	**Alternative 1** Groundwater			**Alternative 2** Artificial infiltration of surface water into an aquifer			**Alternative 3** Surface water		
Technical									
Capacity	0	**0**	1	4	**4**	5	5	**5**	5
Permits	3	**3**	4	3	**4**	5	5	**5**	5
Risk of contamination	4	**5**	5	3	**4**	4	3	**3**	4
Water quality	5	**5**	5	3	**4**	4	3	**3**	4
Social									
Conflicting interests	3	**4**	5	2	**3**	4	2	**3**	4
Environmental									
Ecosystems	3	**3**	4	3	**3**	4	4	**4**	5
Economic									
Cost of pipeline		-			-			-	
Cost of WTP		-			-			-	

Table B.2: Cost calculation of the water treatment plant as input for economic scoring.



		Alternative 1	Alternative 2	Alternative 3
Flow [l/s]	Min	20	100	100
	Average	22.5	137.5	125
	Max	25	175	150
Investment cost [MSEK]	Min	50	175	150
	Average	62.5	187.5	162.5
	Max	75	200	175
Price per l/s	Min	2	1.0	1.0
	Average	2.8	1.4	1.3
	Max	2.8	2.0	1.8
Scoring	**Min**	**2.3**	**4.4**	**5.0**
	Average	**2.3**	**4.8**	**5.0**
	Max	**2.5**	**5.0**	**5.0**

Table B.3: Scoring for MCDA with uncertainties including climate change RCP2.6, Version 1. The most likely score for each criterion is located in the middle column under each alternative.

Criteria	**Alternative 1** Groundwater			**Alternative 2** Artificial infiltration of surface water into an aquifer			**Alternative 3** Surface water		
Technical									
Capacity	0	**0**	1	4	**4**	5	5	**5**	5
Permits	3	**3**	4	3	**4**	5	5	**5**	5
Risk of contamination	4	**5**	5	3	**4**	4	3	**3**	4
Water quality	5	**5**	5	3	**4**	4	3	**3**	4
Social									
Conflicting interests	3	**4**	5	2	**3**	4	2	**3**	4
Environmental									
Ecosystems	3	**3**	4	3	**3**	4	4	**4**	5
Economic									
Cost of pipeline		-			-			-	
Cost of WTP		-			-			-	
Resilience to climate change									
Capacity	2	**3**	4	4	**5**	5	4	**5**	5
Risk of contamination	5	**5**	5	4	**5**	5	4	**5**	5
Water quality	5	**5**	5	4	**5**	5	4	**4**	5

Table B.4: Scoring for MCDA with uncertainties including climate change RCP8.5, Version 1. The most likely score for each criterion is located in the middle column under each alternative.

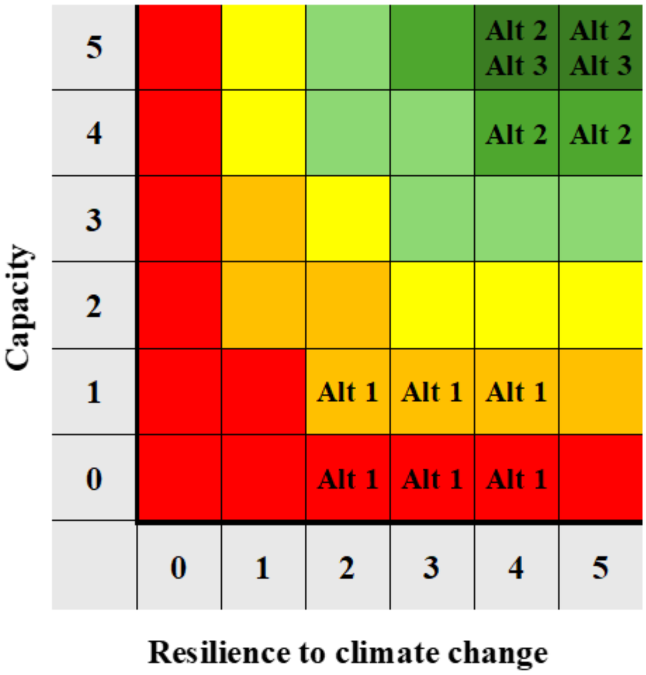
Criteria	**Alternative 1** Groundwater			**Alternative 2** Artificial infiltration of surface water into an aquifer			**Alternative 3** Surface water		
Technical									
Capacity	0	**0**	1	4	**4**	5	5	**5**	5
Permits	3	**3**	4	3	**4**	5	5	**5**	5
Risk of contamination	4	**5**	5	3	**4**	4	3	**3**	4
Water quality	5	**5**	5	3	**4**	4	3	**3**	4
Social									
Conflicting interests	3	**4**	5	2	**3**	4	2	**3**	4
Environmental									
Ecosystems	3	**3**	4	3	**3**	4	4	**4**	5
Economic									
Cost of pipeline	**-**			**-**			**-**		
Cost of WTP	**-**			**-**			**-**		
Resilience to climate change									
Capacity	4	**5**	5	4	**5**	5	4	**5**	5
Risk of contamination	4	**5**	5	4	**4**	5	3	**4**	5
Water quality	5	**5**	5	4	**4**	5	3	**4**	5

Table B.5: Scoring for MCDA with uncertainties including climate change RCP2.6, Version 2. The most likely score for each criterion is located in the middle column under each alternative.

Criteria	**Alternative 1** Groundwater			**Alternative 2** Artificial infiltration of surface water into an aquifer			**Alternative 3** Surface water		
Technical									
Capacity	0	**0**	1	4	**4**	5	5	**5**	5
Permits	3	**3**	4	3	**4**	5	5	**5**	5
Risk of contamination	4	**5**	5	3	**4**	4	3	**3**	4
Water quality	5	**5**	5	3	**4**	4	3	**3**	4
Social									
Conflicting interests	3	**4**	5	2	**3**	4	2	**3**	4
Environmental									
Ecosystems	3	**3**	4	3	**3**	4	4	**4**	5
Economic									
Cost of pipeline	-			-			-		
Cost of WTP	-			-			-		

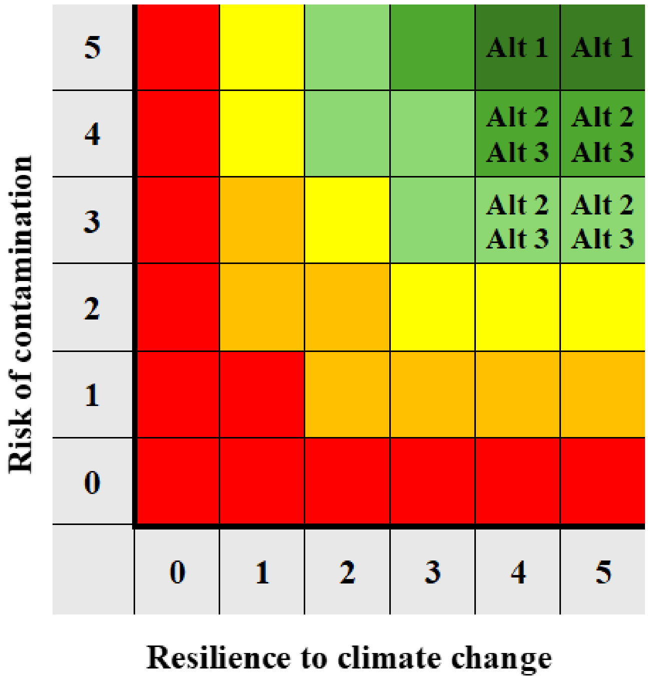
Table B.6: Scoring for MCDA with uncertainties including climate change RCP8.5, Version 2. The most likely score for each criterion is located in the middle column under each alternative.

Criteria	**Alternative 1** Groundwater			**Alternative 2** Artificial infiltration of surface water into an aquifer			**Alternative 3** Surface water		
Technical									
Capacity	0	**0**	1	4	**4**	5	5	**5**	5
Permits	3	**3**	4	3	**4**	5	5	**5**	5
Risk of contamination	4	**5**	5	3	**4**	4	3	**3**	4
Water quality	5	**5**	5	3	**4**	4	3	**3**	4
Social									
Conflicting interests	3	**4**	5	2	**3**	4	2	**3**	4
Environmental									
Ecosystems	3	**3**	4	3	**3**	4	4	**4**	5
Economic									
Cost of pipeline	-			-			-		
Cost of WTP	-			-			-		



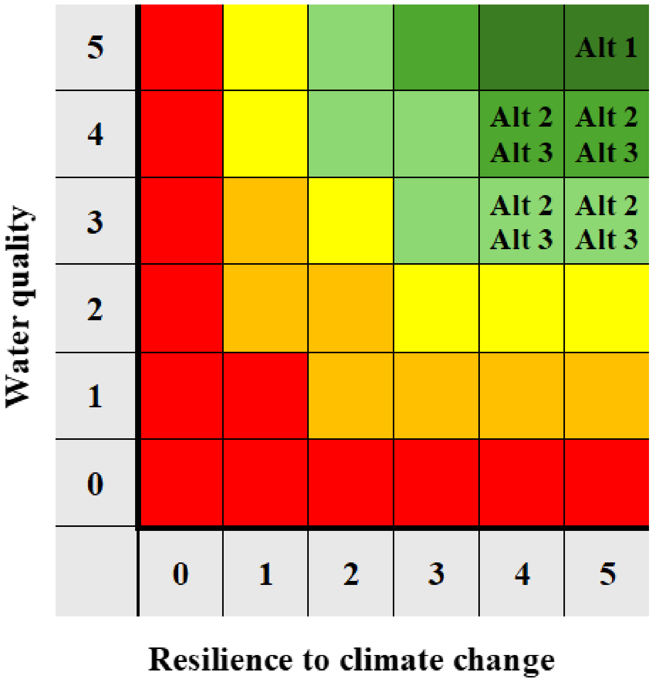
5					Alt 2 Alt 3	Alt 2 Alt 3
4					Alt 2	Alt 2
3						
2						
1			Alt 1	Alt 1	Alt 1	
0			Alt 1	Alt 1	Alt 1	
	0	1	2	3	4	5

Figure B.1: Scoring matrix for resilience to climate change (RCP2.6) regarding capacity, Version 2.



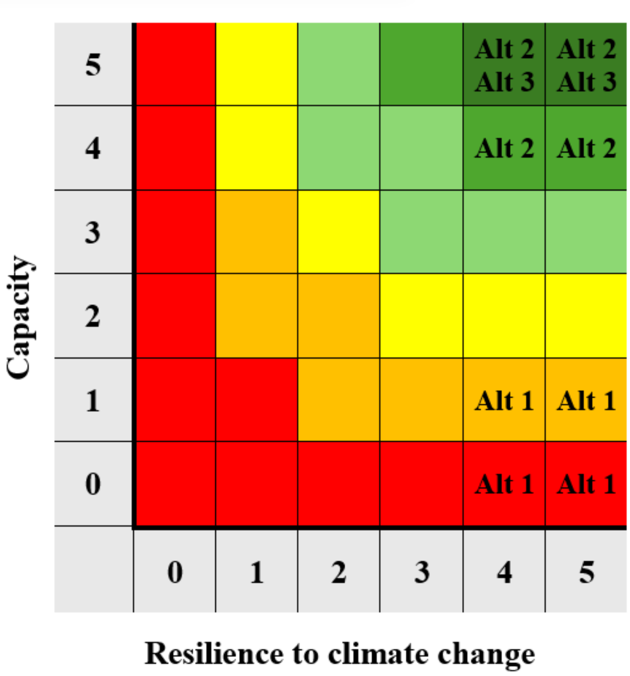
5					Alt 1	Alt 1
4					Alt 2 Alt 3	Alt 2 Alt 3
3					Alt 2 Alt 3	Alt 2 Alt 3
2						
1						
0						
	0	1	2	3	4	5

Figure B.2: Scoring matrix for resilience to climate change (RCP2.6) regarding risk of contamination, Version 2.



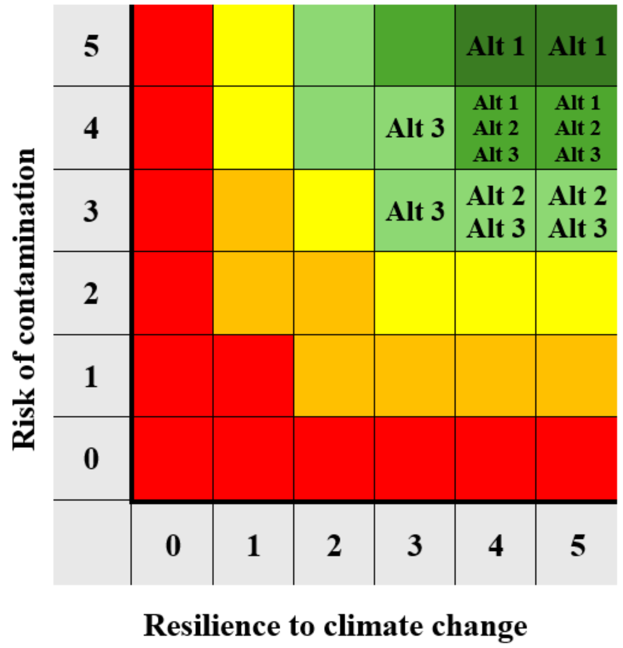
5	🟥	🟨	🟩	🟩	🟩	🟩 Alt 1
4	🟥	🟨	🟩	🟩	🟩 Alt 2 Alt 3	🟩 Alt 2 Alt 3
3	🟥	🟧	🟨	🟩	🟩 Alt 2 Alt 3	🟩 Alt 2 Alt 3
2	🟥	🟧	🟧	🟨	🟨	🟨
1	🟥	🟥	🟧	🟧	🟧	🟧
0	🟥	🟥	🟥	🟥	🟥	🟥
	0	1	2	3	4	5

Figure B.3: Scoring matrix for resilience to climate change (RCP2.6) regarding water quality, Version 2.



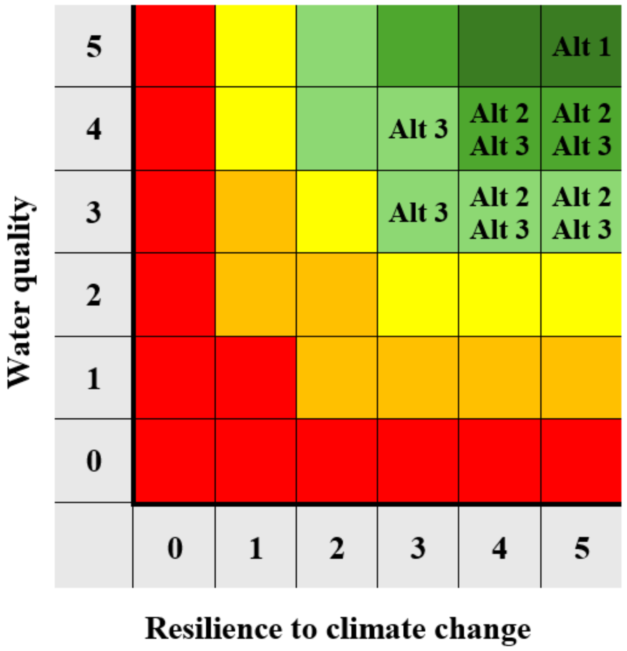
5	🟥	🟨	🟩	🟩	🟩 Alt 2 Alt 3	🟩 Alt 2 Alt 3
4	🟥	🟨	🟩	🟩	🟩 Alt 2	🟩 Alt 2
3	🟥	🟧	🟨	🟩	🟩	🟩
2	🟥	🟧	🟧	🟨	🟨	🟨
1	🟥	🟥	🟧	🟧	🟧 Alt 1	🟧 Alt 1
0	🟥	🟥	🟥	🟥	🟥 Alt 1	🟥 Alt 1
	0	1	2	3	4	5

Figure B.4: Scoring matrix for resilience to climate change (RCP8.5) regarding capacity, Version 2.



5					Alt 1	Alt 1
4				Alt 3	Alt 1 Alt 2 Alt 3	Alt 1 Alt 2 Alt 3
3				Alt 3	Alt 2 Alt 3	Alt 2 Alt 3
2						
1						
0						
	0	1	2	3	4	5

Figure B.5: Scoring matrix for resilience to climate change (RCP8.5) regarding risk of contamination, Version 2.



5						Alt 1
4				Alt 3	Alt 2 Alt 3	Alt 2 Alt 3
3				Alt 3	Alt 2 Alt 3	Alt 2 Alt 3
2						
1						
0						
	0	1	2	3	4	5

Figure B.6: Scoring matrix for resilience to climate change (RCP8.5) regarding water quality, Version 2.

C

Weighting for MCDA

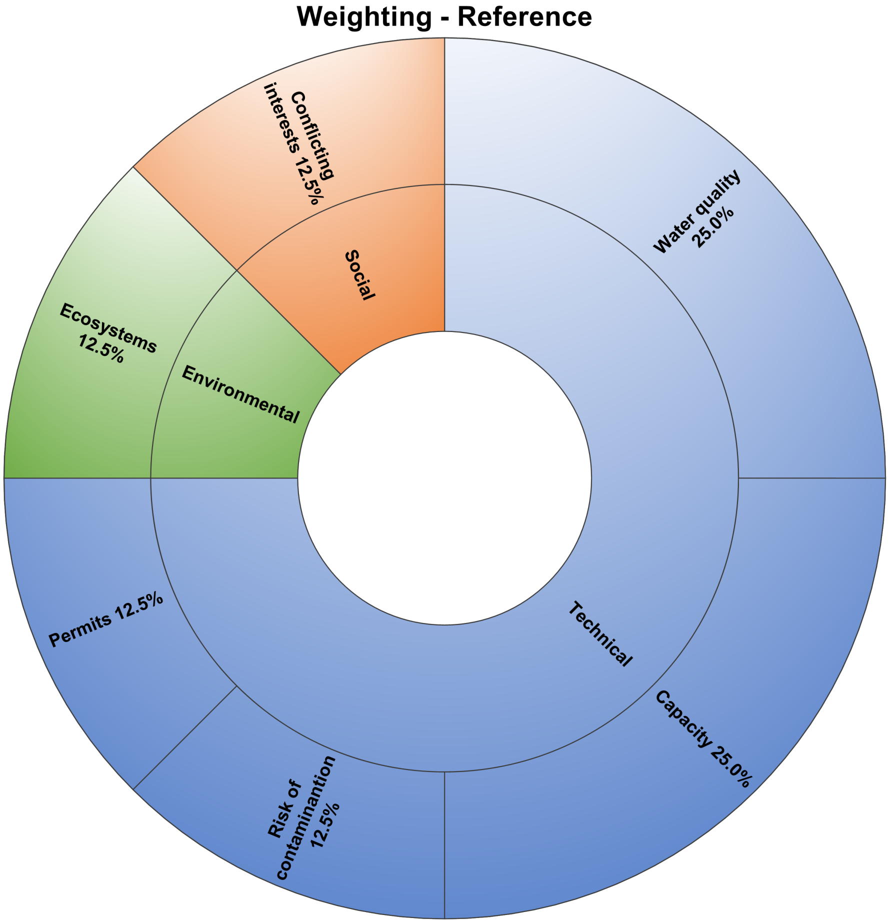


Figure C.1: The assigned weighting for the reference MCDA.

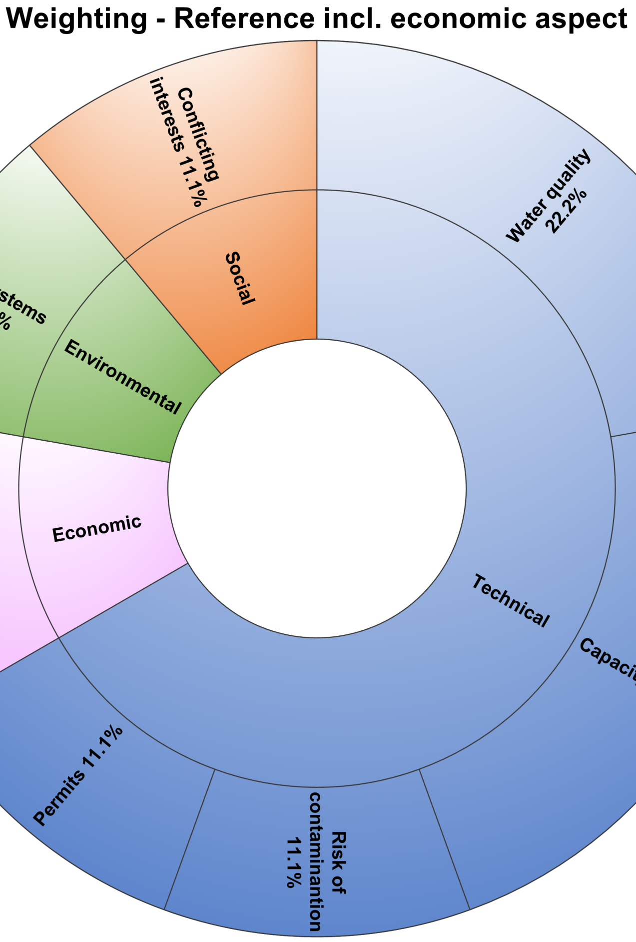


Figure C.2: The assigned weighting for the reference MCDA, including the economic aspect.

Figure C.3: The assigned weighting for Version 1. The weighting applies for both RCP2.6 and RCP8.5.

D

Modelling

Table D.1: Geodata and weather data sources used for modelling in SWAT+. The data has been processed and transformed to fit the input data requirements in SWAT+.

Data	**File type**	**Resolution**	**Source**
Digital Elevation Model	Raster	50x50 m	©The National Land Survey of Sweden (2017)
Land use	Vector	1:15 000 - 1:50 000	©The National Land Survey of Sweden (2024)
Soil type	Vector	1:25 000 - 1:100 000	©The Geological Survey of Sweden (2024)
User soil	Comma Separated Values (CSV)	-	Soil & Water Assessment Tool (n.d.)
Precipitation	Text	One station, daily, monthly	**Observed data:** SMHI (n.d.) **Climate change projection data:** SMHI (2025a)
Temperature	Text	One station, daily, monthly	**Observed data:** SMHI (n.d.) **Climate change projection data:** SMHI (2025a)
Wind	Text	One station, daily	SMHI (n.d.)
Relative humidity	Text	One station, daily	SMHI (n.d.)
Solar radiation	Text	One station, hourly	SMHI (n.d.)

Table D.2: Adjusted user soil properties used to match the soil conditions in the case study area.

Soil type	SOL_ZMX	SOL_Z	SOL_BD	SOL_AWC	SOL_K	SOL_CBN
Bucksport	3000	3000	1.08	0.5	36	96
Panton	3000	3000	1.78	-	0	0.2
Kingsbury	3000	3000	1.78	-	36	0
Hinckley	3000	3000	1.96	-	3600	0
Pillsbury	3000	3000	1.96	-	3600	-
Scarboro	3000	3000	1.92	-	36	-
Fredon	-	-	-	-	360 000	-
Rock outcrop	235.3	235.3	-	-	-	-
Water	3000	3000	1.72	0.01	-	-

Table D.2: Continued.

Soil type	CLAY	SILT	SAND	ROCK	SOL_ALB	USEL_K
Bucksport	50	50	0	0	0.05	0.4
Panton	44	48	8	-	0.25	0.25
Kingsbury	7	70	23	-	0.3	0.24
Hinckley	5	15	80	20	0.36	0.15
Pillsbury	0	10	80	10	0.36	0.15
Scarboro	-	-	-	45.6	0.13	0.18
Fredon	-	-	-	-	-	-
Rock outcrop	-	-	-	-	-	-
Water	-	-	-	-	-	-

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