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The Value of Water

– A valuation study of groundwater in Uppsala municipality

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Abstract

Groundwater plays an essential role in the supply of fresh water around the world. Population growth and climate change might change how groundwater is used, managed and valued. This study looks at the total economic value of groundwater through a case study of the groundwater in the esker Uppsalaåsen. Two of the values – the use value and the value of groundwater of good quality – are monetised using the cost of production and the transfer method. It is also tested whether population growth and climate change are likely to affect the value of the groundwater. Population growth is found to have a positive correlation with the value of groundwater whereas the effect of climate change is limited. The use value is estimated to between 2.0 to 2.9 billion SEK and the value of groundwater of good quality to between 1.1 to 3.2 billion SEK. The total economic value of the groundwater is worth more. Several error terms shall however be kept in mind when interpreting the results.

Abbreviations & Concepts

NPV – Net Present Value
CVM – contingent valuation method
CE – choice experiment
WTP – willingness to pay
WTA – willingness to accept
Aquifer – layers of rock with the capacity to contain and release water
Esker – a long ridge made up of stratified sand and gravel shaped by the ice age

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1 Introduction

1.1 A valuable resource

Groundwater is one of the primary sources of freshwater in the world (Gleeson *et al.*, 2010). It is the most easily accessible freshwater after surface water (Wada *et al.*, 2010), supplying two billion people worldwide with drinking water (Gleeson *et al.*, 2010). In many parts of the world overexploitation of groundwater sources or groundwater depletion is an increasing problem (Wada *et al.*, 2010). This occurs when the abstraction of water exceeds the natural groundwater recharge for longer periods of time and over big areas. The European Union has emphasised the importance of the resource through the Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC). With the two directives as guidance, the member states have agreed on framing similar water management directives (*SGU Vattenförvaltning*, 2017). The goal is to further a long term sustainable use of water as well as a good environment for animals and plants in freshwater and in terrestrial ecosystems (European Commission, 2008). *Groundwater of good quality* is also one of the 16 environmental goals of Sweden for 2020 (*Miljömål*, 2017; *Naturvårdsverket*, 2017). The goal states that groundwater shall contribute to a secure and sustainable supply of drinking water as well as sustain good habitats for plants and animals in lakes and watercourses. In environmental economics, the optimal use of groundwater is a problem well addressed. The focus is often on irrigation and the balance between consumption of groundwater and surface water. Groundwater quality has also been addressed by several studies trying to capture the value of clean water. Generally hydro-economic studies either focuses on quality or quantity of groundwater, and research done to capture the total economic value is rare. Knowledge of the total economic value of the resource could be of use when deciding upon the price of groundwater – which often only reflects the cost of mining – as well as the optimal level of protection to sustain a good water quality and groundwater recharge.

Climate change is thought to increase the importance of groundwater as a freshwater source when droughts and floods become more frequent (Bates *et al.*, 2008; Döll, 2009). A greater variability in precipitation might also lead to a decline in surface water availability (Parry *et al.*, 2007). With a growing world population, the demand for water is expected to increase (Taylor *et al.*, 2013), not least in urban areas (Drangert & Cronin, 2004). This study takes a closer look at the value of groundwater in Uppsala municipality, Sweden.

1.2 Purpose and research question

This study aims to contribute to the knowledge of the economic value of groundwater through a case study of the groundwater resources in Uppsala municipality. The research question addressed is: What are the values to the society of the groundwater in the esker *Uppsalaåsen*, how big are these values in monetary terms and are they likely to change due to climate change or an increase in population?

1.3 Delimitations

The paper is limited to the one aquifer in the esker *Uppsalaåsen* in the municipality of Uppsala. This area is chosen for two reasons: 1) the responsibility to govern the freshwater is placed by the municipalities of Sweden why it is reasonable to limit the area to a municipality and 2) the esker *Uppsalaåsen* with connected water supply system has been suggested to be classified as a national interest for its importance to water security.

The values monetised will be limited to the use value and the value of good groundwater quality. These values are chosen since there are available data for the estimations and collecting new data for the study is not possible due to the limited timeframe.

1.4 Structure of study

The study is structured through seven sections. Section two contains a theoretical framework with the different values of natural resources and environmental goods, how to value them and how groundwater functions as a resource. In section three earlier studies of the different aspects of groundwater are presented. Then follows a description of the case study. Section five is dedicated to method and data followed by section six containing the results with different aspects being analysed and discussed. The last section summarises how the results answer the research question.

2 Theoretical Framework

Natural resources and environmental goods can have many different values, many of them applicable to groundwater. To identify the values from groundwater use it is essential to understand how groundwater functions as a resource. In this section theory and methods for valuing natural resources and environmental goods are presented and the nature of groundwater is explained.

2.1 The value of natural resources and environmental goods

One of the basic ideas in modern economics is that markets will give resources their right price, reflecting their value, and allocate resources efficiently (Perman *et al.*, 2011). For many natural resources and environmental goods, well-functioning markets do not exist. To decide upon the right price, the value of the resources must therefore first be estimated in other ways. Many different values can be derived from environmental goods, commonly divided in to *use value* and *non-use value*. The *total economic value* captures both of these. The use value can in turn be divided into two sub categories: *consumptive use*, destroying the environmental good in the act of using them e.g. logging of a forest, and *non-consumptive use* e.g. using the forest for recreation. Likewise, non-use values can be divided into three sub categories: *existence value*, being the satisfaction that there exist e.g. pandas, *altruistic value*, arising from the satisfaction that other people can e.g. visit a national park even if the individual never will go there, and *bequest value*, the value of preserving the good for future generations. Two additional non-use values arise from incomplete knowledge and uncertainty about the future: *option value*, the value of possible future use of a good, and *quasi-option value*, the value of preserving a good until more information can be obtained.

There are several reasons for valuing environmental goods and natural resources. One of its main applications is for including the environmental impact in cost-benefit analysis (Perman *et al.*, 2011). It is also used for determining the optimal level of environmental taxes, quotas or subsidies to compensate for external effects. Additionally, two applications for environmental evaluation is to decide the amount of compensation from causing environmental damage and for including environmental damage when measuring economic performance.

Environmental and nature resource economics originates from neoclassical economics which adapts a utilitarian philosophy (Perman *et al.*, 2011). Utilitarianism assumes a diminishing marginal utility for any normal good and a positive time preference for consumption. To postpone consumption, and hence utility, a payment of interest is required. When comparing benefits and costs in different time periods a positive discount rate is therefore used. Environmental goods and natural resources are limited and the consumption or destruction thereof can be irreversible. Some of these goods, like untouched nature, are expected to be even more scarce in the future (Brännlund & Kriström, 2012). It has therefore been argued that a positive discount rate is not suitable for environmental goods and natural resources (Perman *et al.*, 2011; Brännlund & Kriström, 2012). A positive discount rate does also imply that the consumption of future generations is worth less than that of today's consumers. Even a negative discount rate might therefore be appropriate. When experts in environmental economics were asked in a survey what they considered a reasonable discount rate, a positive discount rate is however recommended (Almansa & Martínez-Paz, 2011). The discount rate is also recommended to be declining the longer the timeframe of the valuation. This is to make up for intergenerational discrimination.

2.2 Groundwater as a resource

Much more freshwater is stored underground than in all the world's surface water bodies (Grey & Sadoff, 2007). Groundwater make up 22% of all freshwater globally and a whole 97% of the liquid freshwater available for human use (Jha *et al.*, 2007). It is estimated to supply 36% of water for domestic uses, 42% of water used in agriculture and 27% of water used for industrial purposes (Taylor *et al.*, 2013; Grey & Sadoff, 2007).

Groundwater exist in groundwater bodies called aquifers. Aquifers can extend uniformly over large land areas, but since located underground very little water is lost by direct evaporation. There exists an intimate link between groundwater and surface water through the hydrological cycle (Foster & Ait-Kadi, 2012); aquifer discharges to surface water bodies, and are in turn recharged from surface water. During periods with little or no precipitation, groundwater discharges sustain rivers, lakes and wetlands with water (Taylor *et al.*, 2013). Water stored in aquifers functions as a buffer and transforms highly variable recharge into a constant discharge to the surface water (Grey & Sadoff, 2007). The contemporary recharge rate varies a lot between different aquifers. Generally, the recharge rates make up only a tiny fraction of the total groundwater storage (Taylor *et al.*, 2013). Some aquifers are also artificially recharged.

Groundwater commonly has the characteristics of a renewable resource: left unharvested, the stock grows, and the rate of growth depends on the stock (Roumasset & Wada, 2014). Therefore, the optimal groundwater extraction would be – as by other renewable stock resources e.g. fish – to limit the extraction to the maximum sustainable yield (MSY). MSY being the amount of recharge that would occur at the water level that maximises groundwater recharge. Fossil groundwater refers to groundwater in deep and confined aquifers, having been recharged more than 5 000 years ago when the climate was cooler and wetter (Grey & Sadoff, 2007; Foster & Macdonald, 2014). For these aquifers, the recharge today is minimal. Fossil groundwater is therefore considered non-renewable on a human timescale (Grey & Sadoff, 2007; Gleeson *et al.*, 2010).

2.3 Methods to capture the value

There are two main categories of valuation methods: direct and indirect, focusing either on stated or revealed preferences (Desvousges *et al.*, 1999; Perman *et al.*, 2011; Brännlund & Kriström, 2012). Revealed preferences are gathered from peoples' actual behaviour and are therefore considered quite accurate. These methods include (but are not limited to) the travel cost method, hedonic pricing, adverting behaviour, restoration- and replacement-cost methods. Another common indirect method uses a production function where an environmental good is used as an input. The shadow price of the environmental good can then be derived. The shadow price represents the value of either the quantity or quality of the environmental good. The main disadvantage with the indirect methods is that they only capture the user value. The methods commonly used for stated preferences are the contingent valuation method (CVM) and choice experiment (CE). They are both based on surveys and, although time-consuming and costly, capture both use and non-use values. Since the non-use value often makes up a big part of the total economic value of environmental goods, this is a great advantage. Respondents of the CVM or CE surveys are asked for their willingness to pay (WTP) or willingness to accept (WTA) for changes in quantity or quality of an environmental good.

Most of the valuation methods described above can be applied to groundwater (Council *et al.*, 1997). Since water often is as an essential input – not least in agriculture – valuation based on the production function is common for valuing groundwater quantity. When valuing groundwater quality, CVM is common or indirect methods like cost of illness or avoidance cost.

3 Literature review

Groundwater is a complex resource important for society and the economy in many ways. Many economic studies have been made regarding different aspects of groundwater resource management and the value thereof. Not surprisingly – the agricultural sector being the main user of groundwater in the world – there is an overweight of studies focusing on groundwater used for irrigation. In recent years, some studies have focused on groundwater in an urban context. There is still a lack of studies investigating the impact of climate change on groundwater from an economic perspective, although

Burnett & Wada (2014) and Rupérez-Moreno *et al.* (2017) have made attempts to capture the effect. In this section, some of these studies are presented in short. The aim is to give a wide picture of different approaches to capture the value of groundwater. The last part of the section is about the demand for water, especially focusing on the Swedish case.

3.1 Value of water

There are many reasons to establish the value of groundwater. When groundwater is a scare resource the use of it in one activity implies a trade of from another (Bann & Wood, 2012). Knowledge of the value of groundwater in its different uses is important to achieve an optimal management of the resource. In addition to decision basis, an economic value can raise awareness of the importance of groundwater. To facilitate in the valuation, a tool for estimating the total economic value of groundwater has been developed for the Southern African Development Community (SADEC) (Bann & Wood, 2012). The tool identifies potential services and benefits from groundwater as well as step by step instruction on how to define the most relevant values in each case. Through three different categories of groundwater services – provisioning services, regulating services, and cultural services – the different benefits from groundwater are identified and linked to different stakeholders. Examples of provisioning services is water supply and energy source. Regulating services are, among others, flooding regulation and cultural services are tourism, religious practise and education.

Groundwater has also a buffer value, first estimated by Tsur & Graham-Tomasi (1991). They argue that groundwater has two purposes: it increases the total supply of freshwater and it mitigates fluctuations in the water supply by functioning as a buffer. Defining the buffer value as "the difference between the maximal value of a stock of groundwater under uncertainty and its maximal value under certainty where the supply of surface water is stabilized at its mean" they show that the buffer value is positive. Applying their results to a case study of the Negev region in Israel, they demonstrate that the buffer value can be as high as 84% of the value of the groundwater stock. Using Tsur & Graham-Tomasi's model as a starting point, Cutter (2007) develops a model for estimating the buffer value of groundwater and the value of recharge. Cutter then applies his model to the case of Los Angeles, estimating the value of groundwater in an urban context. Urbanisation can lead to a reduced groundwater recharge over time. In urban areas, the amount of land covered by impermeable surfaces, such as concrete and asphalt, is generally high. This prevents rainwater from filtering down reducing groundwater recharge as well as increasing the risk of flooding. Water quality can also be negatively affected due to the high concentration of traffic and industries. At the same time, the high concentration of people increases water demand. Together these factors imply that urbanisation may increase the value of groundwater resources. Cutter's results show high buffer values – exceeding hundred million US$ for some conditions – although not making up such a large percentage of the stock value as Tsur's & Graham-Tomasi's findings. Cutter also suggests, as a policy measure in urban areas, to incorporate the decrease in recharge to the cost of land development. He points out that artificial recharge can be used in the form of spreading basins and injection wells or substituted by increased surface water storage, but these require use of land usually having a high value in urban areas. Both Tsur & Graham-Tomasi and Cutter observe that additional water storage lowers the groundwater buffer value since it evens out the variability of surface water supplies.

3.2 The optimal use of groundwater

Groundwater is a resource of which it often is hard to establish the ownership (Koundouri, 2004). This has the implication that scarcity rents are hard to estimate, the price of groundwater is not optimal and the resource is not efficiently allocated. According to resource economics theory, an optimal pricing and allocation can be achieved through an efficient management. However, Gisser & Sánchez, (1980b; a) compared the social benefits of efficient groundwater management to a competitive solution, and found there to be no significant benefit of management. Several studies have since followed questioning the robustness of Gisser's & Sánchez's results (see Koundouri (2004) for a summary). The results indicate that management can be of value in circumstances where the extraction costs are non-linear, land productivity is heterogeneous, demand is non-stationary, the aquifer is near depletion, when preferences are risk averse and when water quality considerations are included. With increasing impact of climate change, these circumstances might become more common and the benefit of groundwater management could thereby increase. Stating that groundwater management might be of use, the next question is how it best shall be managed.

An issue often raised in groundwater management is how much water shall be pumped from the aquifer, how much of the surface water shall be used and to what extent the aquifer shall be artificially recharged with surface water. A case study of the Burdekin delta, Australia, addresses this issue by combining a farmers production function, where water is an input factor, with the equation of groundwater stock (Hafi, 2003). The cost of pumping groundwater increases as the water head gets lower (i.e. it is further down to the water). Costs of artificial recharge consists of construction and maintenance of recharge pits. According to the results, artificial recharge shall only be used when the present value of its effect on future profits are greater than the value of forgone marginal product of surface water and the recharge cost per unit. With high pumping costs for groundwater, the demand for surface water for artificial recharge will be higher. At the same time, the demand for surface water for irrigation, and thereby the opportunity cost for artificial recharge, will increase. Included in the opportunity cost shall also be the forgone value of return flow from irrigation to the aquifer.

Aquifers vary in their characteristics. Different rock compositions will affect how the resource can be used and to what extent it can be shared (Edwards, 2016). Edwards (2016) analyses the relationship between aquifer characteristics and the benefit of management. He shows that aquifers with a fast water flow, high hydraulic conductivity and with a small yearly recharge are subject to a more costly common property problem and will therefore benefit the most from management. Furthermore, the study shows that management of such aquifers can increase land value by up to 8%.

Burt (1964) is one of the earliest economic studies investigating the connection between surface water and groundwater. He models groundwater as a renewable resource partly renewed by a stochastic process. The model regards surface water and groundwater as substitutes but does not consider the flow from groundwater to surface water. A development of the model was made by Burness & Martin (1988) by looking at tributary aquifers, although they either considers the flow from groundwater to the surface. However, the model captures the river effect i.e. water filtering down from rivers to the groundwater thus reducing the amount of surface water available. Knapp & Olson (1995) further develop the model by including stochastic surface supplies and artificial recharge. Their results show that artificial recharge pays off when water level in the aquifer is low since the stock is insufficient to buffer stochastic surface water flows. At intermediate water levels, the gain is smaller: the water is sufficient as buffer but the low water head implies high pumping costs. When the water level is high the marginal benefit of artificial recharge is high, pumping costs being low and possible future withdrawals large.

Climate change can affect groundwater both directly or indirectly, through changes in precipitation patterns and quantities, land cover, evaporation and transpiration (Burnett & Wada, 2014). In a case study of the Pearl Harbor aquifer system on the island Oʻahu, Hawaiʻi, Burnett & Wada develops a model for optimal groundwater extraction under two different climate scenarios. They extend standard groundwater economic models – computing changes in the stock of a renewable resource – to include changes in recharge over time. The net present value of water for the different scenarios is then calculated. The present value in the Hawaiʻi case ranges from $31.1 million to $1.5 billion. Burnett & Wada conclude that recharge supporting measures have a potentially high value. A second study addressing the economic effect of climate change on groundwater has been made in southern Spain (Rupérez-Moreno *et al.*, 2017). The cost-benefit study investigates the socio-economic profitability of artificial groundwater recharge under two different climate change scenarios for a 30-year period (2021-2050). The results are also calculated for different future demands for irrigation water, an important factor since the area today is being highly irrigated. Costs considered include cost of extraction, distribution and the environmental cost of the today overexploited aquifer, estimated through CVM. The benefits consist of private benefits – value of agricultural products – and socio-environmental benefits – value of preservation of groundwater dependent ecosystems and ecological status of the aquifer. The results show a potentially high profitability of artificial recharge.

3.3 Groundwater quality

The value of protecting groundwater quality can be viewed as costs avoided through groundwater protection (Abdalla, 1994). Spofford *et al.* (1989, see Abdalla, 1994) identifies five cost categories: 1) effects on human heath, 2) increased fear and anxiety, 3) avoidance cost, 4) ecological damage and loss of recreational use and 5) loss of non-use values. The first cost mainly results from increased medical treatment and the second to the insecurity of what a reduced groundwater quality can result in, e.g. effects on health or production. The third cost is related to the second and result from measures to prevent or mitigate impacts of pollution - a government's avoidance costs can be to secure alternative water supplies, for a household, these can be to buy bottled water instead of drinking tap water. The fourth cost is a result of the link between surface water and groundwater; a contaminated groundwater will sooner or later affect the ecosystems on the surface. The last cost is the reduction of option value and existence value. To measure one or several of these costs different methods have been used.

Productivity of agricultural land is affected by groundwater quality as well as quantity. Some earlier studies used the hedonic pricing method adopted on farmland to value groundwater quality (Milliman, 1959; Hartman & Anderson, 1962). A well-used method for valuing groundwater quality is the CVM. Harrington (1992) uses this method to measure the value of avoiding illness due to groundwater contamination as well as consumers reduced expenses of averting behaviour. Avoidance costs can be significant, generally ranging from $125 to $330 per household, per year (Abdalla, 1994). Powell (1992) estimated willingness to pay (WTP) for an increased water supply protection to $82 for respondents aware of contamination in their area and $56 for those unaware. Abdalla *et al.* (1992) as well show the influence of water quality knowledge on a household's WTP. In addition to this, the strongest impact on a household's WTP for water quality protection is the presence of young children and level of income.

One of few studies valuing groundwater quality in Europe uses the CVM to measure the value of preserved groundwater quality in the Alsatian aquifer (Stenger & Willinger, 1998). Estimating a WTP for preserved groundwater quality, the study tries to incorporate both the use and non-use values. Respondents were mainly users of the aquifer but also potential users of the aquifer in the future. The study found that respondents value groundwater quality as current water users, as future water users and for the sake of others, especially future generations. Households in polluted areas show a higher WTP for preservation measures than the other households. The potential users' WTP for a preserved water quality were 60% of that of households using the aquifer today. A more recent study has been made in Denmark, valuing the protection of groundwater quality both for the purpose of drinking water and the impact on adjacent ecosystems (Hasler *et al.*, 2005). Both a CVM and CE method is used, the CE giving substantially higher WTP. The results indicate that the protection of groundwater quality is greater than the value of purified water. The study also found a significant WTP for groundwater protection. Interesting to note is that the WTP for drinking water quality exceeds that of surface water quality – possibly explained by drinking water having a greater impact on human health and production than surface water. Both applied methods indicate a correlation between a households WTP and income, level of education and the households' water consumption. WTP is also higher in urban areas than rural and higher for female respondents than for male. In contrast to Abdalla *et al.* (1992) number or age of children where not found to be significant. There has also been made a study in Sweden using CVM to estimate WTP for groundwater quality (Silvander, 1991). In the study, respondents are asked about their WTP for a reduced level of nitrates in groundwater. Different WTP are estimated for respondents with levels of nitrates over health recommendations and respondents with acceptable levels. In addition, different groups where given different information about the health effects of high nitrate levels resulting in four different WTP in total.

3.4 Demand for water

Research over water demand is dominated by studies concerning irrigation. When estimating irrigation demand and elasticity, a programming method is commonly adopted (Koundouri, 2004). By estimating a production function and the amount of water maximising a farmer's profit, a shadow price for groundwater can be derived. Irrigation demand has shown to be inelastic to a certain price, but elastic beyond (Iglesias et al., 1998; Varela-Ortega et al., 1998; Bontemps & Couture, 2002). At how high a price the threshold is depends mainly on weather conditions; a year with plentiful precipitation the threshold is lower than a dry year. The inelastic price has resulted in scepticism of the effectiveness of a tax as economic instrument to reduce the use of groundwater to sustainable levels. A few studies have however been made. Yang *et al.* (2003) found that attempts to conserve irrigation water in northern China through an increase in water price were ineffective. The same result was found in a similar study conducted in the Netherlands (Schuerhoff *et al.*, 2013), although farmers had used political pressure to relive themselves of the tax. A study conducted in Colorado, USA, found that a groundwater-pumping tax had a positive and quite extensive impact on the reduced use of irrigation water (Smith *et al.*, 2017). The reduction of groundwater withdrawals was found to be as high as 32%, corresponding to a price elasticity of -0.77. The reduction was both due to less intense irrigation and a shift towards more drought resistant crops. What differentiates the Colorado case from the other two is foremost that farmers in the area themselves agreed upon implementing a tax, perceiving the groundwater use as unsustainable.

A household's water demand are also found to be price inelastic (Höglund, 1999). In a study over households' water consumption in Sweden 1980–1982, the price elasticity was found to be 0.10-0.20 in absolute values, the lower using a marginal price model and the higher using a model with average prices. The elasticities are based on the households' total water demand. However, Höglund argue that the demand can be divided in two parts: direct demand for drinking water and indirect demand for water complementing activities such as cooking, gardening, washing and hygiene. As drinking water, water is a necessity good while the indirect demand might have a substitute. The different demands are thus likely to differ in elasticity. Several earlier studies have estimated households' price elasticity of water, although not for Sweden. The elasticities estimated by Höglund are in line with the lower range of estimates and close to the estimate for Finland (0.11 in absolute values). Höglund then applies her results to investigate the effect of a potential tax on water consumption. A tax of 1SEK per m^3 of water – equivalent to a 5% increase in mean average price – would reduce water consumption by approximately 1%. The lag for households to adopt to the price change is 3-4 years (or approximately 30% per year). Since the income elasticity is inelastic – ranging between 0.07 and 0.13 – households with a low income will be hit relatively hard compared to high income households. Water shortage implies a cost which could be reflected in the water price through a tax, Höglund reasons. A similar tax was implemented in Denmark in 1994.

4 Area of study

This section gives a presentation of the case study. The role of groundwater in the water supply system of Uppsala municipality is also explained. Possible future scenarios for population growth and climate change are also presented.

4.1 Freshwater supply in Uppsala municipality

The groundwater in Sweden is commonly available in eskers dating back to the ice age (Lewis *et al.*, 2013). They usually contain shallow aquifers of good water quality, a big storage capacity and high hydraulic conductivity (i.e. water can easily move through the pores in the eskers). The water supply system of Uppsala today supplies the main part of Uppsala's population, ca 150 000 people, with drinking water (Uppsala kommun, 2017c). Groundwater make up 95% of the drinking water supply (Uppsala Vatten, 2015). The water supply system is dimensioned for 200 000, but can be extended to supply up to 300 000 people (Uppsala kommun, 2017c). The yearly production of drinking water in the municipality amounts to approximately 17 million cubic meters (Uppsala Vatten, 2015). However, only 14.3 million cubic meters of water is sold, the difference primarily made up by leakages (Uppsala Vatten, 2017). Of the produced water, households consume roughly 75%, 15% is used by industry and the remaining 10% is consumed by e.g. restaurants, sport facilities, shops and schools (Uppsala Vatten, 2015). The agricultural land around Uppsala is not irrigated and the heavy clay the earth mainly consist of is good at keeping water. Irrigation is therefore unnecessary (Ahlgren, 2017). In addition, the earth's moisture is mainly affected by precipitation and not the level of groundwater.

Uppsala municipality belongs to the water management district Northern Baltic Sea Water District (*Norra Östersjöns vattendistrikt*), one of five water districts in Sweden (*Vattenmyndigheterna - Norra Östersjöns vattendistrikt*, 2017). Several eskers containing large, and easily accessible, aquifers crisscross the district. Two of these eskers, Uppsalaåsen and Vattholmaåsen, are of special importance, supplying the municipality with freshwater of good quality (Uppsala Vatten, 2015; Uppsala kommun, 2017c; *Uppsala Vatten - Dricksvatten*, 2017). In addition, surface water is artificially recharged to the aquifers by Tunåsen, an adjacent esker to Uppsalaåsen. By artificial infiltration, big fluctuations in the groundwater level can be avoided. Approximately 50% of the groundwater is artificially recharged (Ahlgren, 2017). The surface water is gathered from the river Fyrisån (Uppsala Vatten, 2015; *Vattenmyndigheterna - Fyrisåns avrinningsområde*, 2017). With a catchment area encompassing a third of the surface of Uppsala County, Fyrisån is the largest river in the region. An extensive ditching has increased the rivers water flow. Because of this, the water in Fyrisån is not enough to cover the water demand of the municipality during low water levels. The current solution consists of directing water from the lake Tämnaren to Fyrisån. In the long run, this solution might result in a water supply shortage in the north of Uppland. This might also affect the recreational values of Tämnaren (*Syfte | Tämnarens Vatten*, 2017). The aquifer in the two adjacent eskers contains around 100 million m^3 of water (Ahlgren, 2017). The great volume makes the aquifer resilient to fluctuations in recharge patterns. If recharge levels would be low – as they have been in 2017 – the stored water is enough to sustain the water supply for a five years period.

There is no water catchment in reserve for the municipality and no alternative to today's water supply system in the near future (Uppsala kommun, 2017c). Uppsala is part of Stockholm Mälar Region. A bigger part of the region is dependent on the surface water from the lake Mälaren for its drinking water supply. From a water security perspective, it is of importance to protect the alternative freshwater sources in the nearby regions to Stockholm. Due to Uppsalaåsen's great importance to the drinking water supply, it is suggested that the esker with connected water supply system ought to be classified as a national interest.

4.2 Future scenarios

Two future scenarios that possibly will affect the use of water in the municipality are population growth and climate change. Below follow descriptions of the two scenarios.

4.2.1 A growing population

Stockholm Mälar Region is a very expansive region with many people moving in and an extensive expansion of housing, work places and infrastructure (Uppsala kommun, 2017c). By the end of 2016, the number of citizens in Uppsala municipality amounted to 215 000 (Statistiska centralbyrån, 2017c). Both the net birth and net migration are forecasted to be positive, resulting in a continues population growth (Uppsala kommun, 2017b). Until 2021 the prognosis is a yearly increase of 3 800 citizens, or 19 000 citizens for the whole period. By 2030 the population is expected to reach 260 000 and to pass 300 000 a couple of years before 2050 (Uppsala kommun, 2017a). The main part of the population growth is expected in areas where new housing is built. The development of Uppsala as a regional node will strengthen the surrounding region and increase the availability of housing and work (Uppsala kommun, 2017c).

4.2.2 Climate change

In all parts of the climate system, water is involved (Bates *et al.*, 2008). When the climate changes, it has a number of impacts on different parts of the hydrological cycle. Over the last decades, observed changes affecting the hydrological cycle and considered related to a changed climate include: changing precipitation patterns, melting of snow and ice, increasing atmospheric water vapour, increasing evaporation as well as changes in soil moisture and runoff. All of these changes have a direct or indirect effect on groundwater recharge. With a warmer climate, less precipitation will fall as snow during winter and the snow will melt earlier in spring (Barnett *et al.*, 2005; Bates *et al.*, 2008). Both of these effects will shift the peak of the winter runoff to earlier in the year. Where the meltwater cannot be stored – as can be the case with shallow aquifers – much of the water will directly end up in the oceans. This lead to a reduced water supply later in the season when the water demand is higher. Increased evaporation and transpiration can further reduce soil moisture and groundwater recharge (Pachauri *et al.*, 2014).

Climate change can affect groundwater systems either directly through changed recharge flows or indirectly through changes in the use of groundwater (Taylor *et al.*, 2013). The direct impact on the groundwater resource has two dimensions: resilience to long term climate change and resilience to short term climate shocks (Foster & Macdonald, 2014). The degree of resilience depends on factors such as aquifer storage volume, permeability and long-term recharge. Groundwater in large aquifer systems tend to have higher resilience given their very large natural storage functions as a buffer to climate change. Fossil groundwater is also highly resilient to both climate changes and climate shocks since the recharge rate, per definition, under normal conditions is too small to affect the water storage. Far more sensitive is low storage aquifers since they are highly dependent on a continuous recharge. The effect of short term climate shocks on these aquifers are therefore highly dependent on the long-term recharge rate. The indirect impacts include, among others, a changed use of crops in agriculture and the increased use of irrigation (Bates *et al.*, 2008).

The Geological Survey of Sweden (SGU) has retrieved data for the effect of climate change on groundwater levels in Sweden (Vikberg *et al.*, 2015). The calculations are based on nine climate models and two emission scenarios and considers a reference period (1961-1990) and two future periods (2021-2050 and 2069-2098). Only the aquifers with a correlation coefficient over 0.6 between the model and the reference period have been included in the study. No aquifer in Uppsala municipality is included. However, climate predictions for other aquifers in the Northern Baltic Sea Water District have been made. The area is predicted to be one of the least affected in Sweden. Groundwater levels in small aquifers will be a little higher than normal (0.05 to 0.15m) during winter and a little lower than normal (–0.05 to –0.15m) during spring. Groundwater levels in the big aquifer in the water district included in the study, is not predicted to be affected. There are however several uncertainties when predicting complex processes as climate. Many non-climate related factors may also have a big impact locally (Bates et al., 2008). For example, the extent of success of measures already made to mitigate impacts of climate change on freshwater systems are uncertain. In addition, effects like longer growing season enabled by a warmer climate are not fully included in climate change impact predictions. Together these uncertainties still make it interesting to investigate possible impacts of climate change.

5 Method and Data

The following section begins with a conceptual framework of the methods used, directly or indirectly, in the study. Then follows an explanation of the applied method. The data used is presented and its reliability discussed. Also discussed are the disadvantages with the applied method, why it is used and alternative methods.

5.1 Conceptual framework

In this study, the transfer method is used. The transfer is made from two studies using the CVM and CE. The conceptual frameworks of the three methods are here described.

5.1.1 Transfer method

Transfer studies provide an economical way to do research when data for the particular study is hard to get at (Desvousges *et al.*, 1999). When using the transfer method, data gathered for different purposes in earlier studies is used to address questions in a new context. The data will be adjusted to fit the case study. Although the method is resource efficient, saving both time and money, the downside is the dependence on the quality of the earlier studies. A study using transferred data can never reach a higher quality than the original studies. It is therefore crucial to evaluate the reliability of the data and to pick data from a context as similar as possible. Another factor that can have a great impact on the outcome of the study, is how the data is transferred. To transfer data, linkages between the original study and the new study are used to compensate for differences. When the data has been adapted to its new environment, it must be dimensioned. Values for WTP or WTA are often defined per household or inhabitant. To get the full value, the value is therefore to be multiplied by e.g. number of household affected in the new study.

5.1.2 Contingent valuation method and choice experiment

Both CVM and CE are non-market valuation methods. The CVM has traditionally been the most commonly used whereas the CE is relatively new (Jin *et al.*, 2006). In a CVM survey, respondents choose between one base case and one or several defined alternative scenarios (Adamowicz *et al.*, 1998). They are then asked for their WTP or WTA for reaching a different scenario, or for remaining at status quo (Perman *et al.*, 2011). A CE survey is instead constructed to make respondents choose between different cases described by their attributes – one of the attributes is commonly a price, often a tax. This enables trade-offs between different attributes allowing researchers to decide the relative value between them (Adamowicz *et al.*, 1998). In contrast to CVM the respondents are not asked for their WTP or WTA; the monetary value is only implicitly expressed through the relative value (Perman *et al.*, 2011). One of the problems with CVM is its hypothetical form. Respondents are not used to act on a market for environmental goods. The concept of the CE method might therefore be easier to understand and give more reliable results. A drawback with the CE compared to the CVM is the cognitive difficulty of juggling all different attributes in all the different cases. This might lead to respondents only focusing on one of the attributes, giving a biased result.

5.2 Applied method

There are three main steps to the method applied in this study:

1. Identification of values
2. Monetarisation of values
3. Investigation of possible changes in values due to population growth and climate change

5.2.1 Identification of values

The different values of the groundwater in Uppsalaåsen are identified through the literature review presented in section 3. The selection of hydro-economic studies using a variety of methods and focusing on different aspects of groundwater are meant to give a broad idea of its different values. Together with section 2 and 4, the different values relevant for the case study are identified. These values are together the total economic value. The values are presented in two different ways: based on the services and benefits identified by Bann & Wood (2012) and based on the different aspects of the total economic value described in 2.1.

5.2.2 Monetarisation of values

Since collection of new data is out of the scope of this study, already available data is used. Data for valuing the total economic value of the groundwater is not available. This is the reason why the monetarisation is limited to two values: use value and value of good groundwater quality. The use value is determined through the production cost of drinking water. In Sweden, the price of water is based on the cost of production (Höglund, 1999) thus being the value of water communicated to the consumers. According to Council *et al.* (1997) the price of groundwater shall reflect the cost of extraction as well as the opportunity cost. Since the agricultural land in Uppsala municipality is not irrigated, there is no large alternative consumption of the groundwater. The alternative cost would therefore be forgone future consumption, but since the aquifer is continuously recharged todays consumption will not affect future consumption as long as the groundwater is not overexploited. For these two reasons, only the cost of production will represent the use value. Data of cost of production is collected from Uppsala Vatten, the communal firm supplying Uppsala with drinking water. The calculations are presented in Appendix 1.

To estimate the value of good groundwater quality, the transfer method is used. WTP values are transferred from a valuation study made in Denmark (Hasler *et al.*, 2005) and from a Swedish study (Silvander, 1991) – both are presented more fully in the literature review. As neighbouring countries, Sweden and Denmark are likely to have similar attitudes to environmental goods. Although the countries have slightly different nature and land use, and thus also different conditions for their water supply, which might affect attitudes. Silvander's WTP are collected from surveys in Sweden, and should therefore reflect the citizens of Uppsala quite well. The study is however made for the whole of Sweden and local varieties in WTP might exist that are not reflected in the results. In addition, the study is not new and attitudes might have changed. Silvander estimates WTP of respondents with both groundwater of good quality and contaminated groundwater. Only the values from respondents with groundwater of good quality is used, since the groundwater of Uppsala maintains a good quality. The two studies together will hopefully give fair estimates of WTP for a good groundwater quality in Uppsala municipality. The values of Hasler *et al.* are converted from DKK to SEK using the annual aggregated exchange rate of 2005, one DKK being equivalent to 1.246 SEK (Sveriges Riksbank, 2017). The values from both studies are converted to monetary value of 2017, using the consumer price index (CPI) shown in table 1. This is done by dividing the CPI of 2017 by that of 1991 and multiplying the WTP values of 1991 by the product ($CPI_{2017}/CPI_{1991}*WTP_{1991} = WTP_{2017}$). The same procedure is applied with the CPI and WTP values of 2005.

Table 1: Consumer Price Index (1980 = 100)

August 2017	323.18
Average 2005	280.40
Average 1991	227.20

Source: Statistiska centralbyrån (2017a)

Since not all citizens of Uppsala municipality are supplied with communal water, households with private water supply are assumed at 60% WTP compared to those with communal water, following the results of Stenger & Willinger (1998). The Swedish study uses the CVM whereas the Danish study uses CVM and CE, the two methods has given quite different results. WTP for the groundwater quality in Uppsalaåsen is therefore calculated as an average of all WTP and as an average of the estimates using CVM. Calculations are presented in Appendix I.

Finally, the net present value (NPV) of the two monetised values will be calculated for the period 2017-2050. This period is chosen since it is the period the regional plan for Uppsala municipality is valid and therefore the current time horizon for the development of the municipality. The Swedish Environmental Protection Agency (Naturvårdsverket) recommend a discount rate of 4%, although stresses that the optimal discount rate is not the same for all cases (Naturvårdsverket, 2008). The discount rate suggested by Almansa & Martínez-Paz (2011) for the actual time period is 3%. In addition, they suggest two different discount rates: a social discount rate (SDR) applied to economic effects and an environmental discount rate (EDR), lower than SDR, for the environmental effects. The NPV is therefore calculated using equation 1, a SDR of 4% and an EDR of 3%. In the equation, F_t is the annual net financial cost, in this case the production cost of water, and N_0 is the annual net environmental cost or benefit, in this case the value of groundwater quality.

Equation (1)

$$NPV = \sum_{t=0}^{t=n}\left(\frac{F_t}{(1+SDR)^t}\right) + \sum_{t=0}^{t=n}\left(\frac{N_0}{(1+EDR)^t}\right) \qquad (1)$$

5.2.3 Impact of population growth and climate change

Two theoretical scenarios are applied to the monetised values to investigate if and to what extent the values will be affected. The first scenario tests how the groundwater values might change given the predictions for population growth. A bigger population means more households willing to pay for good groundwater quality, but also more people to supply with water. Since the population is expected to grow until 2050, an estimate of the use value accounting for the population growth should give a more exact value for the period 2017-2050. A linear relationship between the cost of production and produced volume is assumed as well as a linear relationship between the use of water and the number of citizens.

Uppsala municipality's prognosis for population growth does only forecast the number of citizens, not the number of households. To estimate the growth of number of households, the percentage increase of the population is calculated. The number of households is assumed to increase by the same percentage. It is also assumed that all households are supplied by communal water. This assumption is made since the bigger part of the population growth is expected to take place in newly built housing and therefore most probably will be supplied with communal water. Private water supply will likely keep existing, but the ratio of citizens with private water supply is more likely to decrease than to stay constant. The water demand is calculated in two different ways. The first method uses data from Uppsala Vatten on the volume of consumed water per person to calculate the yearly average consumption of water per household. With the second method, the total water demand of the municipality – not only that of households – is attempted to be encompassed. When the population grows, so will likely the number of firms, schools, etc. If they will grow by the same amount as the population and whether their water consumption will grow proportionately is unsure. Still, only looking at the water demand of the households leaves out a big part of the water consumption. Assuming a uniform growth of the total water demand of the municipality, linear with the population growth, will give an idea of how big the water demand may become. Equation 2 shows the calculation for the use value per year. The total volume of sold water per year (VSW) is divided by the number of households in 2016 (H_0). The total water demand for each year is thus the number of households that year (H) times VSW/H_0. To calculate the use value, the production cost of water (C_w) is divided by the volume sold water and multiplied by the demanded volume for each year.

Equation (2)

$$use\ value = \frac{C_w}{VSW} * \frac{VSW}{H_0} * H \tag{2}$$

The value of good groundwater quality is calculated with the same two WTP as for the constant population. The WTP is then multiplied by the number of households for each year. Finally, the NPV of the values is calculated using equation 1 for the period 2017-2050. The same discount rates are used as by the calculations for a constant water demand. Calculations are shown in appendix II.

The second scenario tests for climate change by assuming a higher and a lower groundwater recharge. Changed natural recharge levels will affect the amount of water that need to be artificially recharged. This in turn will affect the infiltration cost. For this study, there is no data on how the infiltration cost varies with the amount of infiltrated water. Instead it will be tested by how the production cost is affected if the infiltration cost increases or decreases by 10%. The production costs of the climate change scenario are then used to calculate the use value. The use value is calculated using three different demands for water: 1) constant demand of 2016, 2) demand of all households when the population is growing and 3) demand of the whole municipality when the population is growing. Same as above, linear relationships between the cost of production and produced volume and between the use of water and the number of citizens are assumed. However, for the years 2021-2050 the infiltration cost is assumed to either increase or decrease by 10% – changing the cost per produced volume of water. The infiltration cost is assumed to be changed for this particular period (2021-2050) since this is when the report from SGU (Vikberg *et al.*, 2015) predicts the first impacts of climate change on groundwater. Since neither Silvander (1991) nor Hasler *et al.* (2005) investigate climate change, it is unknown how it will affect the WTP for groundwater quality. Only the impact of climate change on the use value is therefore studied. The NPV for 2017-2050 is calculated with equation 1 and a 4% discount rate is used. Calculations are shown in appendix III.

5.3 Data

Costs of producing drinking water for Uppsala municipality in 2016 are shown in table 2. The numbers are obtained from Uppsala Vatten and are approximates - they depend on how members of staff have reported the values and on how well the flow measuring devices function.

Table 2: Costs of production of Uppsala's two water treatment plants and infiltration for artificial groundwater recharge, numbers in kSEK

Costs	Water treatment plant Bäcklösa	Water treatment plant Gränby	Infiltration	Total
Operating cost and cost of maintenance	22 203	27 862		
Personnel cost	3 968	5 869		
Cost of energy	3 744	6 558		
Cost of chemicals	5 107	4 582		
Cost of analysis	3 905	1 123		
Cost of contract management	220	736		
Other costs of operation and maintenance	5 259	8 994		
Capital cost	10 000	9 550		
Total	54 406	65 274	6 200	125 880

Source: Ekholm (2017)

Table 3 contains data of the number of citizens of Uppsala municipality supplied by communal drinking water. The data is gathered from the Statistic Database of Sweden (SCB) and is from 2014, since no more recent data is available. In table 4 the number of citizens and households in the municipality are shown.

Table 3: Distribution of water supply of citizens of Uppsala municipality 2014

Means of water supply	Number of citizens	Percentage of citizens
Communal water, whole year around	180 269	86.9%
Private water, whole year around	25 829	12.5%
Other (no water, no data, holiday house)	1 264	0.6%
Total	207 362	100%

Source: Statistiska centralbyrån (2017b)

Table 4: Number of citizens and households in Uppsala municipality

	2014	2015	2016
Number of citizens	207 362	210 126	214 559
Number of households	94 726	96 344	98 536

Source: Statistiska centralbyrån (2017b)

Estimates for the WTP of groundwater of good quality from the two studies used for the data transfer are shown in table 5. The two Danish values incorporate both the value of naturally clean groundwater and very good conditions for plant and animal life (Hasler *et al.*, 2005). From the CVM, there is only one common estimate for both values. The CE however differentiates between the two values, valuing naturally clean groundwater to 1 899 DKK and very good conditions for plant and animal life to 1 204

DKK. For this study, the aggregated value is used. There are two reasons for this choice: firstly, for both Danish values to reflect the same value and secondly because the intimate link between groundwater and surface water will result in good conditions for plants and animals if the groundwater is of good quality, and if the surface water is of bad quality the groundwater quality will be negatively affected as well. The Swedish values do only incorporate the value of good groundwater quality for drinking water, defined as levels of nitrates under the levels recommended by WHO. The respondents were first informed about health risks of methemoglobinemia for infants associated with contaminated water. Additional information about the risk of cancer were then given resulting in a second estimate.

Table 5: WTP for groundwater of good quality

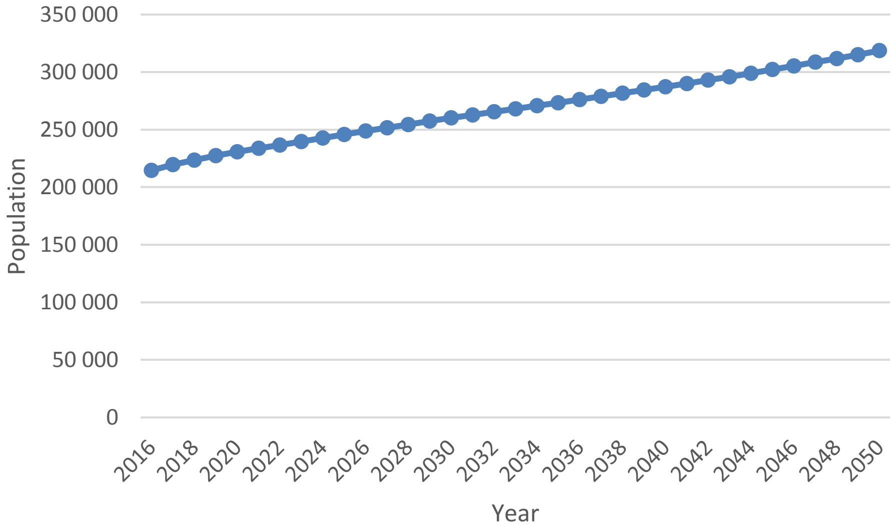
	Method	WTP
Denmark[1]	CVM	711 DKK
	CE	3 104 DKK
Sweden[2]	CVM basic info health risk	592 SEK
	CVM additional info health risk	340 SEK

Sources: 1) Hasler *et al.* (2005); 2) Silvander, (1991)

Uppsala Vatten reports the daily consumption of water per person to be 144 litre (Uppsala Vatten, 2017). The number of citizens supplied by communal water in 2016 amounted to 191 000. The produced volume of water in 2016 was 17 000 000 m^3 and the sold volume 14 300 000 m^3.

Uppsala municipality does each year a forecast for the population growth (Uppsala kommun, 2017a). The forecast is based on time series data for immigration, fertility and deaths. The fertility in Sweden deviate a lot from year to year and is therefore hard to predict. The municipality’s fertility prediction is based on numbers from Statistics Sweden (SCB) and the births relative to the age of the women for the last three years. In opposite to fertility, the relative number of deaths tend to be stable. Predictions for immigration is also based on statistics for the previous three years. Immigration to the municipality is dominated by new students in the age of 20-25, followed by emigration some years later. The movement of students has historically been influenced by the labour market in the rest of the country as well as the number of people in the age of 20-25 in the population at large. Since 2006 the positive immigration numbers have significantly been influenced by immigration from abroad. This immigration is expected to increase until 2020 when it is thought to stabilise. A higher immigration is usually followed by a higher emigration. Therefore, as the population grows, a more mobile population is expected. The uncertainties in the immigration assumptions are quite large. Figure 1 shows the predicted population growth until 2050. The exact numbers are to be found in table 18 (appendix II) or table 21 and 22 (appendix III).

Figure 1: Expected population in Uppsala municipality 2016-2050



Source: Uppsala kommun (2017a)

5.4 Disadvantages with method of choice and alternative methods

By using the cost of production for a specific volume of produced water the use value for this specific volume can be estimated. With production function on the other hand the use value for all different volumes as well as the marginal value could be estimated. By adding an uncertainty variable to the function, the buffer value could be obtained as well. A production function would however require time series data of production costs and water flows to and from the aquifer. This would be a more demanding method. This is the motivation for not adopting this method in spite of its advantages.

The value of groundwater of good quality is estimated through the transfer method. Its main disadvantages are the dependence on the quality of the earlier studies whose values are transferred and the adaptation of these values to the new scenario. The values transferred in this study are from two studies made closely geographically, culturally as well as politically. The values are therefore well chosen for the case study. In addition, the CVM and CE method have the advantages of being direct methods incorporating non-use values. Nevertheless, more accurate values for the case study could be obtained if a CVM and/or a CE would be conducted in Uppsala municipality. An alternative, indirect method for valuing the water quality would be to look at avoidance costs. But since the water today is of good quality, data would have to be taken from a different area with less good water quality.

Alternative methods for valuing the groundwater in Uppsalaåsen would be the replacement cost method – the cost of supplying the municipality with drinking water in a different way representing the value of the groundwater. This method would require a lot of knowledge about the preconditions for water production. Another alternative method is the protection cost method. The money spent on protecting the groundwater from contamination or over extraction would then represent its value. Since one of the advantages with knowing the value of the groundwater in Uppsalaåsen would be to help deciding how much money it is reasonable to lay down on protecting the groundwater, the protection cost method is not a good choice. Both mentioned methods are indirect methods not capturing the non-use values.

6 Results and Analyses

This section begins with a presentation of the results. First the total economic value of the groundwater in the esker Uppsalaåsen is shown. This is followed by the results of the monetarisation of the use value and the value of good groundwater quality. Different aspects of the results are then discussed and analysed. Error terms, important to have in mind when interpreting the results, are observed. The last part of the section is dedicated to implications of the results and suggestions for further research are given.

6.1 Results

Below the results are presented. The calculations for section 6.1.2 are to be found in appendix I and those for section 6.1.3 are found in appendices II to III.

6.1.1 Identification of values

Based on the groundwater in Uppsalaåsen's ecosystem services, its different benefits are presented in table 6. Both households as well as industries receive their water from the communal water supply, the reason there is only one benefit of the provisioning service. The groundwater prevents subsidence through filling out hole-spaces underground. If groundwater levels were to get too low, risk of compositions in Uppsala would arise. Cultural services – as defined by Bann & Wood (2012) – include supporting habitats for species typical for the area. The cultural service of educational practise could be both from studying the geological formation of the esker and associated ecosystems.

Table 6: Services and benefits from the groundwater in Uppsalaåsen

Ecosystem service category	**Service**	**Benefit**
Provisioning services	Water supply	Communal water supply
Regulating services	Recharge to surface water	Surface water supply for direct and indirect consumption (e.g. recreation)
	Flooding regulation	Reduction of flood risk
	Buffer value	Buffer supply of water
	Sink for carbon dioxide from the atmosphere	Carbon capture
	Dilution of pollutants	Reduced impact of contaminants
	Attenuation of pollutants	Reduced impact of contaminants
	Prevent subsidence	Avoidance of subsidence
Cultural services	Biodiversity non-use	Diversity of species and habitats
	Educational practices	Education

In table 7, the total economic value of the groundwater in Uppsalaåsen is broken down to its different segments. All the use values also exist as bequest values, but in the future. Citizens not supplied by communal water can subscribe the groundwater an altruistic value. The existence value geological heritage could for example be the value of preserving a geological formation shaped during the ice age.

Table 7: Values of the groundwater in Uppsalaåsen

Type of value		Service	Benefit
Use value	Consumptive use	Water supply	Communal water supply
	Non-consumptive use	Flooding regulation	Prevent flooding
		Recharge to surface water	Sustain water supply for recreation
		Dilution and attenuation of pollutants	Reduced impact of contaminants
		Buffer service	Buffer supply of water
		Sink for carbon dioxide from the atmosphere	Carbon capture
Non-use value	Altruistic value	Water supply	Supplying others with water
	Existence value	Recharge to surface water	Sustain habitats
		Geological heritage	Educational benefit
	Bequest value	Water supply	Sustaining future generations with water
		Regulating service	Preventing future generations from flooding
		Recharge to surface water	Sustaining future generations water supply for recreation
		Dilution and attenuation of pollutants	Reduced impact of contaminants for future generations
		Buffer service	Buffer supply of water for future generations

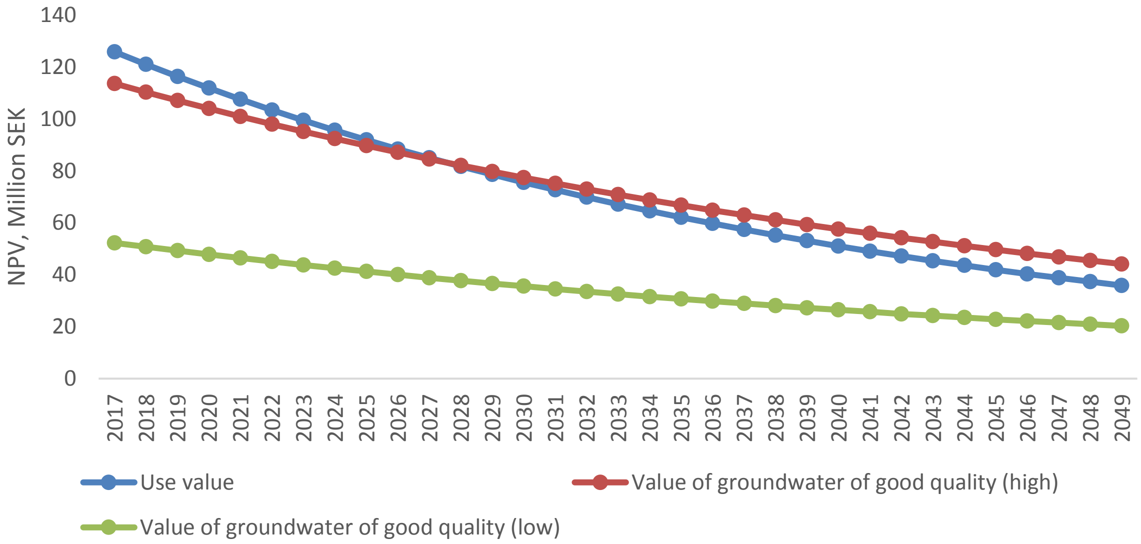
6.1.2 Monetarisation of values

The NPV of use value and value of groundwater quality for the 33-year period 2017-2050 for a constant population and constant water consumption are shown in table 8. The calculations are to be found in table 11 to 16 in appendix I and will here be explained. In table 11 the estimates for WTP are converted to SEK and adjusted for inflation. The averages of the estimates are shown in table 12. In table 13 the WTP per household in Uppsala municipality is calculated using both an average of all WTP and an average of the WTP estimated with CVM. Those citizens with a private water supply are assumed to be willing to pay 60% of the WTP of those with communal water supply. In table 14, the data in table 3 and 4 is combined to obtain the number of households supplied with communal water. The total WTP for all households in the municipality is then calculated. The annual use value and value of good groundwater quality are shown in table 15. In table 16, the NPV for the period 2017-2050 is calculated using a 4% discount rate for the use value and a 3% discount rate for the value of groundwater quality. The results are summarised in table 8. A higher and a lower value for the value of groundwater quality can be seen in the table. The higher value is calculated with all estimates whereas the lower is calculated only using the estimates from the CVM. Figure 2 shows the NPV of the groundwater for each year. The negative slope of the graph is due to the positive discount rate, signifying a loss in value the further in the future the resource is to be used. The values in table 8 are aggregates of the NPV for each year. If a longer time period would be considered this would hence imply a higher NPV. Although, since the marginal NPV is constantly declining the impact of an additional year would gradually decline towards zero.

Table 8: NPV of groundwater 2017-2050 given a constant water demand, SEK

Use value	Value of groundwater of good quality (high)	Value of groundwater of good quality (low)
2 410 305 637	2 474 275 862	1 137 830 812

Figure 2: Trends in NPV of groundwater 2017-2050 given a constant water demand, SEK



6.1.3 Impact of population growth and climate change

The NPV of the use value and value of groundwater quality when the forecasted population growth is considered, is presented in table 9. There are two estimates for each value. The difference between values of groundwater of good quality is the same as explained above for table 8. The two estimates of the use value are based on either the water demand for only the households or the demand for the whole municipality – including industry, firms, schools etc. Figure 3 shows the NPV for each year.

Here follows an explanation of the calculations, of which the main part is to be found in table 17 to 19 in appendix II. The cost of production per cubic meter of water is calculated to 8.8 SEK/m^3 by dividing the total cost of production (125 880 000 SEK) by the sold volume (14 300 000 m^3). Table 17 shows the demand for communally produced water. The household demand is calculated by multiplying the demand per person and day (144 litre) by 365 and by the number of people provided by communal drinking water (191 000). The water demand for the whole municipality is the amount of sold water. Both demands are then divided by the number of households in 2016. In table 18, the predicted population growth is used to calculate the increase in number of households. The number of households in 2016 is multiplied by the percentage increase in population to get the number of households in 2017, and so on for each year. The cost of production for the two different demands is calculated by multiplying the number of households by the water demand per household and by the production cost per m^3. Table 19 shows the calculations for NPV of use value and value of groundwater quality for the growing population. The results are summarised in table 9.

Table 9: NPV of groundwater 2017-2050 adjusted for population growth, SEK

Use value (water demand households)	Use value (water demand whole municipality)	Value of groundwater of good quality (high)	Value of groundwater of good quality (low)
2 041 442 591	2 907 933 596	3 192 839 524	1 468 272 492

Figure 3: Trends in NPV of groundwater 2017-2050 adjusted for population growth, SEK

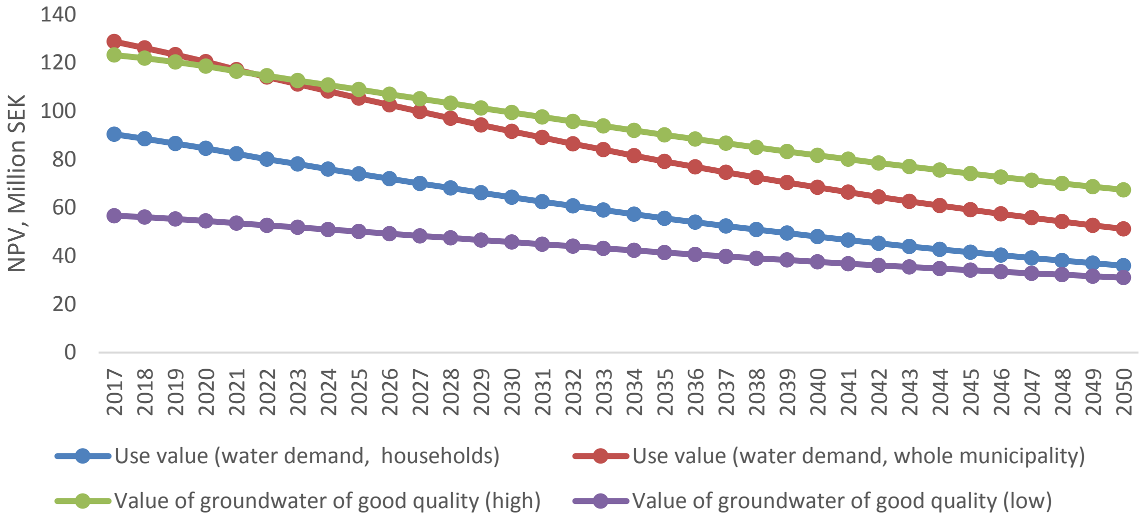


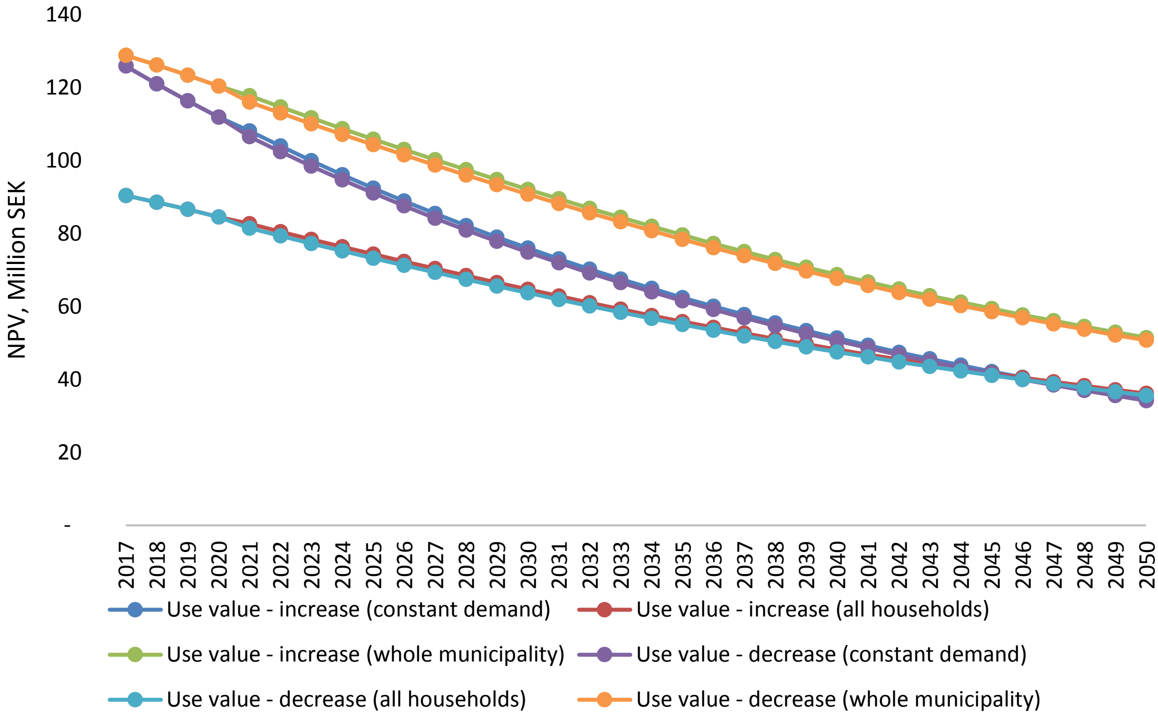
Table 10 shows the NPV of the use value influenced by climate change by either an increase or decrease in infiltration cost. The use value is calculated using three different demands for water as well as three different scenarios for climate change. The first of the demands is based on a constant demand for water – defined in the same way as in table 8. The second and third demands are based on an increasing water demand due to population growth – defined in the same ways as in table 9. Figure 4 shows trends of NPV for each year. Both table 10 and figure 4 show that the differences between the climate scenarios are small.

Calculations for the climate change scenarios are to be found in table 20-24 in appendix III and are here explained. Three different costs of production are calculated in table 20; the first is the cost of production in 2016 and the second and third are the climate change scenarios. The first is obtained by adding the different costs in table 2 and dividing the sum by the sold volume of water (14 300 000 m^3). For the climate change scenarios, the cost of infiltration is assumed to increase respectively decrease by 10% before all production costs are added and divided by the volume of water. In table 21 and 22, the costs of producing the three different demands of water for each year is calculated. From 2021 the infiltration cost increases by 10% in table 21, respectively decreases by 10% in table 22. This to stage the impact of climate change starting from the same time period as used by SGU. For the costs of producing the water demanded by all households and by the whole municipality, the number of households for each year is multiplied by the two different demanded volumes per household shown in table 17 (appendix II). The demanded volumes are then multiplied by the production cost – the same cost per m^3 as for 2016 for the first four years and the 10% increased respectively decreased infiltration cost from 2021-2050. The NPV of the three different use values are calculated in table 23 and 24. Table 10 summarises the results.

Table 10: NPV of groundwater 2017-2050 impacted by climate change, SEK

	Use value (constant water demand)	Use value (water demand households)	Use value (water demand whole municipality)
No impact of climate change	2 410 305 637	2 041 442 591	2 907 933 596
Increase in infiltration cost	2 419 836 621	2 049 772 925	2 919 799 742
Decrease in infiltration cost	2 391 243 669	2 024 781 924	2 884 201 302

Figure 4: Trends in NPV of groundwater 2017-2050 impacted by climate change, SEK



6.2 Analysis

Below follows an analysis of the results presented in section 6.1. Error terms are brought up and implications of the results and areas of future research are discussed.

6.2.1 Total economic value

From tables 6 and 7 can be seen that the total economic value of groundwater is complex and made up of many different values. The mapping of the values based on their ecosystem services is a concrete way to visualise the values. For the purpose of groundwater management table 6 might therefore be the most useful. Table 7 on the other hand have an advantage when monetising the values; it shows which values can be captured by a direct or indirect method. Table 7 also shows that the main part of the use values is non-consumptive and that all non-use values, except existence values, originates from the same ecosystem services only benefitting different stakeholders. That said, the non-use values would amount to zero if the citizens of Uppsala municipality would not care for the future.

The most obvious, and maybe the greatest value, is the service of supplying drinking water. An interesting question is whether the value should only be attributed to the water consumed or to the whole water volume of the aquifer. On the one hand it is only the mined water that creates a benefit, but on the other hand without the rest of the water the aquifer would be overexploited or depleted. The non-consumptive use values – or the regulating services – are more clearly connected to the whole aquifer. Since the water supply system of Uppsalaåsen is interfered with and do not function as it would naturally, it is hard to say how much the system contributes to recharge of surface water in relation to how much surface water is instead artificially infiltrated. However, the recharge to surface water is spread over the esker whereas the surface water used for artificial recharge is taken from one place. The recharge can therefore still be of benefit locally. For the same reason, the service of flooding regulation can be argued to be greater than naturally since water levels are regulated both naturally and artificially. It can be questioned whether the services of diluting and attenuating pollutants shall be attributed to the groundwater or if it mainly is the many layers of gravel and sand in the esker supplying the service. Prevent subsidence is a service the groundwater provides by purely existing. It is also connected with a risk; should the water level get too low, it could destabilise buildings and infrastructure on the esker. Bann & Wood (2012) classify the prevention of subsidence as a regulating service. There are however reasons to question if this really is a service or rather mainly a risk associated with shifting groundwater levels. If it should be classified as a value it would best fit in the category of non-consumptive use values. To what extent groundwater can capture and store carbon dioxide is not investigated in this study and how big this value might be is therefore unknown. Apart from Bann's & Wood's (2012) valuation tool no valuation study has looked at groundwater and carbon dioxide. This might indicate that the value of the service is insignificant in the context or that the area has been overlooked and is valid further study.

The buffer value depends partly on the amount of excess water stored in the aquifer – additional to the water used for drinking water – partly on how predictable the future is and partly on the risk aversion of the population. The higher the risk aversion the greater the buffer value. If the population would not be risk averse at all, the buffer value would be zero, no matter how big the volume of excess water was. If the population would be risk adverse a more unsure future would mean a higher buffer value. The volume of the aquifer matters in that the marginal buffer value decreases with the volume. According to both Tsur & Graham-Tomasi (1991) and Cutter (2007), the buffer value of the groundwater is reduced by water stored as surface water. With both Fyrisån and Tämnaren to prevent fluctuations in the water supply, the buffer value of the groundwater might not be very big.

A larger population in Uppsala municipality means more people enjoying the benefits of the groundwater. If this will affect the values is foremost an ethical contemplation. Since all values except the altruistic value and the existence value are foremost perceived by people in the municipality, the values can be argued to increase. To connect the value to the number of people benefiting from the services is the most common approach in environmental and nature resource economics and is also the approach used in this study. It can however also be argued that the values of the groundwater are incorporated in the resource and do not depend on the number of humans living in its proximity.

Both the buffer value and the value of flooding regulation are likely to increase because of climate change. Even though Vikberg *et al.* (2015) do not predict any changed groundwater levels, heavy precipitation can increase the risk of flooding. With winter runoff earlier in the year – as predicted by Barnett *et al.*, (2005) and Bates *et al.* (2008) – water as a buffer might be needed during summer, at least for compensating low water levels in small aquifers used by citizens with private water supply.

6.2.2 Monetised values

The results give nine different numbers for the use value, ranging from 2.0 to 2.9 billion SEK. This is a big span and do raise the question of which one that is the most accurate. All predictions show a population growth for the years until 2050. Assuming a constant water demand would therefore underestimate how much water will be consumed and the value thereof. Which of the use values in table 9 that is the most accurate is hard to decide: the lower value is likely an underestimate whereas the higher value might be both under or over estimated. It can also be argued that only todays citizens of Uppsala municipality attribute a use value to the water. Instead, it would be a bequest value to supply future citizens with water. One of the purposes of this study is to determine if the values of the groundwater is likely to change due to population growth. The different use values in table 8 and 9 do show that the use value is likely to increase as the population grows. As shown in table 10, the test for climate change does not show any large impact on the use value. If the climate change impact assessment on groundwater made by SGU and Vikberg *et al.* (2015) holds, even smaller impacts on the use value can be expected.

The value of groundwater quality shows an even bigger range than the use value – 1.1 to 3.2 billion SEK. The largest difference is whether the values are estimated through CVM and CE or only CVM. To explain the big difference between the CVM and CE estimates, Hasler *et al.* (2005) argues that this usually is the case and compare with several studies (among them Boyle *et al.* (2004) looking at several comparing studies). An additional explanation is possibly different perception by the respondents of the environmental good between the two methods and that substitutes are more clearly explained in CE encouraging trade-offs (Hasler *et al.*, 2005). Since both methods have different benefits and disadvantages, it can be argued that by using estimates from both methods they compensate for each other’s weakness. The higher estimate would by this reasoning be the most accurate. Same as for the use value, table 9 show higher values of groundwater of good quality compared to table 8. This indicate that also this value will increase due to population growth. But equivalently to the use value, the question is whether only the citizens of today shall be considered or also the value for the future population.

Common for both monetized values are their dependence on the discount rate and the time period the values are calculated for. The choice of discount rate greatly affects how the value of the groundwater changes over time. In figure 2-4, the declining NPV is visualised. As long as the discount rate is positive, the marginal NPV will be declining. A lower discount rate would only signify doing so at a slower rate. Where the discount rate instead to be positive, the NVP would show a positive slope. Since the population is expected to grow, signifying more people to share the same water, it can be argued that the value of the water rather should increase than decrease. On the other hand, new technology might make the water production more effective and a higher discount rate could then be appropriate. The values are only calculated for the period 2017-2050. However, the groundwater will most likely be used longer than that. Estimating the values for a longer period would incorporate the benefits for more years and result in higher values. Although, with the negative discount rate the additional NPV for each year is gradually declining towards zero. Both the discount rate and the choice of time period amounts down to an ethical consideration on how to value future resources today.

As seen in table 7, there are several use values. The use value monetised would be the consumptive use value. The value of groundwater of good quality does not as clearly fit in under any of the categories. It is connected to the consumptive use value since if the water quality would be bad it would have to be purified raising the production cost. It is also connected to the non-consumptive use value of dilution and attenuation of pollutants since the services improves the water quality. But the main reason the water is of good quality is because the water never has gotten contaminated. This is partly due to the enclosed nature of the aquifer and partly due to careful use of environmentally unfriendly substances in the area. The value of groundwater of good quality thus reflects the costs avoided by keeping the water pure.

Together the two monetized values amount to between 3.2 to 6.1 billion SEK. Only incorporating two of many values, the total economic value of the groundwater in Uppsalaåsen is higher.

6.2.3 Error terms

Only the production cost is used for the calculations of use value since there does not seem to exist any alternative use of the groundwater. There does however exist an alternative use for the surface water artificially infiltrated. Both Fyrisån and Tämaren have recreational values and aesthetic values possibly negatively affected by the water extraction. The alternative value of the surface water could for example be captured through looking at the profit from canoe rentals, boat clubs, ice skating, angling and the number of visitors of adjacent parks, cafés and restaurants.

For the calculations including population growth and climate change, linear relationships are assumed between the production cost and produced volume of water. A linear relationship simplifies the calculations, but might not be a correct representation of reality. The production costs are likely to have a start-up cost indicating a diminishing marginal cost per cubic metre of produced water. Over a certain volume, the water treatment plants might have to be expanded to cope with the bigger volumes and thus increasing the production cost. For a better model of the production cost more knowledge of the production would be necessary. A linear relationship between the number of citizens and the total volume consumed water is also assumed. The average volume consumed per household will likely not change as the population grows. The exception would be if the composition of an average household would change, however no prognosis for the number or composition of households exists. Until 2050 the everyday use of water might also be more effective. An uncertainty exists regarding the future water use of industries, firms etc. A growing population will affect the number of firms, industries, schools and similar. This could indicate an increase in water consumption, but not necessarily. The water consumption would depend on the composition of industries and firms in the municipality and how water intense they are. Measures to improve efficiency and change of production might even reduce the water consumption.

As with all transfer studies, the original study the data is transferred from sets the limits of its quality. The accuracy of the WTP for good water quality therefore relies on how well the two former studies are executed. How the transfer is performed do also affect the results. In this study, the data has only been adjusted for currency and inflation before dimensioned for the size of the population. Adjustments for differences in water prices and tax levels could possibly have improved the results.

Another uncertainty important to have in mind when interpreting the results is the reliability of the data. Not least the predictions for population growth are hard to know how accurate they will turn out.

6.2.4 Implication of results and future research

Defining the values to the society of the groundwater in the esker Uppsalaåsen has visualised the many benefits of the groundwater. Most useful is likely the two monetised values since they can be included in cost benefit analysis for different projects. These projects could for example be how much resources to dedicate to groundwater protection when building on the esker. Knowledge of the economic value is further relevant should the water get contaminated to determine if the value of clean groundwater exceeds the abatement cost and, if relevant, decide on an appropriate fee for the polluter. A danger with not monetising the total economic value of the groundwater is that it might get underestimated. It could therefore be useful to extend the study to monetise the total economic value. If only focusing on one more value, the buffer value would be of interest since both Tsur & Graham-Tomasi (1991) and Cutter (2007) have found that it can amount to a substantial value. The values of the groundwater in Uppsalaåsen are not unique and could also be adapted to other cases in Sweden.

Hasler *et al.* (2005) found that the value of groundwater protection exceeds that of purification. Through this study, it cannot be demined if this also holds for Sweden. However, if that is the case it would further support the work with the Swedish environmental goal *Groundwater of good quality*. The good quality of the water in Uppsalaåsen is partly owing to the nature of the esker with its natural filter made up by many layers of sand and gravel. It is also the filter capacity of the esker that enables the artificial recharge without further purification. In this study, the groundwater in the esker is valuated. The esker itself – and its infiltration quality – has likely an extensive value that can be worth investigating.

A question raised by the calculations of increased water consumption due to population growth, is if the water will be enough in the future. The water supply system of today can be extended to supply 300 000 people with water, but the population forecast predicts a bigger population until 2050. With a limited amount of water that can be taken from Fyrisån and Tämnaren, projects increasing the natural recharge could get more interesting. As Cutter (2007) describes, the natural recharger is negatively affected by urbanisation. Since Uppsala is likely to keep growing, a future area of study would be to investigate how to increase the natural recharge in an urban context without increasing the risk of groundwater contamination.

From a water security perspective, it would be relevant to study the optimal use of groundwater and surface water in the whole Stockholm Mälar Region. A big part of the region gets its drinking water supply from surface water. Recently, a study has been made of the value of surface water quality in Stockholm for recreational purposes (Soutukorva *et al.*, 2017). Even though the surface water used for drinking water is a smaller volume than all water with a recreational value, it could still be interesting to investigate the value of improving the water quality to a level suitable for drinking water. Hasler *et al.* (2005) found that WTP for drinking water exceeds that of surface water, suggesting that the value of Stockholm's surface water would be even higher.

Finally, the value of the groundwater is relevant when deciding on the optimal price of water. For normal goods, the price reflects the value. Water in Sweden has a cheap price but its value is high.

Increasing the price would increase the water costs greatly for many since it is an inelastic good. Low income groups would be affected most since also the income elasticity is inelastic. It can therefore seem unnecessary to increase the price even though it only reflects a small part of the value of the water.

7 Conclusion

In this study, different aspects of the total economic value to the society of the groundwater in the esker Uppsalaåsen have been addressed. The results show that the groundwater in the esker has many different values. Two of the values – the use value and the value of groundwater of good quality – have been monetized. They are worth between 2.0 to 2.9 billion SEK and 1.1 to 3.2 billion SEK respectively. The total economic value of the groundwater is worth more. Both monetised values will be positively affected by population growth. Climate change might have a small impact on the use value. How the value of groundwater quality will be affected cannot be determined through this study. Remaining values might increase due to population growth. The buffer value and value of flooding regulation might increase if the climate changes.

Appendix I

This appendix contains calculations of the monetarisation of the use value and the value of groundwater quality.

Table 11: WTP for groundwater of good quality

	Method	WTP	WTP SEK	WTP SEK 2017
Denmark	CVM	711 DKK	885.9	733.6
	CE	3 104 DKK	3 867.6	3 202.5
Sweden	CVM basic info health risk	592 SEK	592	605.0
	CVM additional info health risk	340 SEK	340	347.5

Table 12: Average WTP per household for groundwater of good quality

Average WTP Sweden	Average WTP Denmark	Average WTP Total	Average WTP CVM
476.2	1 968.0	1 222.1	562.0

Table 13: WTP for groundwater of good quality per households in Uppsala municipality depending on source of water supply

	WTP per household	WTP (CVM) per household
Communal water	1 222.1	562
Private water	733.3	337.2

Table 14: WTP for groundwater of good quality of households in Uppsala municipality depending on source of water supply

	Percentage of citizens	Number of households	WTP	WTP (CVM)
Communal water	86.9%	85 627.8	104 645 709.9	48 122 812.4
Private water	12.5%	12 317.0	9 031 563.4	4 153 292.4
Total	99.40%	97 944.8	113 677 273.4	52 276 104.8

Table 15: Annual use value and value of groundwater quality

	Use value	Value of groundwater of good quality (high)	Value of groundwater of good quality (low)
Annually	125 880 000	113 677 273	52 276 105

Table 16: NPV of use value and value of groundwater quality, 2017-2050

Year		Use value	Value of groundwater of good quality (high)	Value of groundwater of good quality (low)
2017	0	125 880 000	113 677 273	52 276 105
2018	1	121 038 462	110 366 285	50 753 500
2019	2	116 383 136	107 151 733	49 275 243
2020	3	111 906 862	104 030 809	47 840 041
2021	4	107 602 752	101 000 785	46 446 642
2022	5	103 464 184	98 059 015	45 093 827
2023	6	99 484 792	95 202 927	43 780 415
2024	7	95 658 454	92 430 026	42 505 257
2025	8	91 979 283	89 737 889	41 267 240
2026	9	88 441 618	87 124 164	40 065 281
2027	10	85 040 018	84 586 567	38 898 331
2028	11	81 769 248	82 122 881	37 765 370
2029	12	78 624 277	79 730 952	36 665 408
2030	13	75 600 266	77 408 692	35 597 484
2031	14	72 692 563	75 154 070	34 560 664
2032	15	69 896 696	72 965 116	33 554 042
2033	16	67 208 361	70 839 919	32 576 740
2034	17	64 623 424	68 776 620	31 627 903
2035	18	62 137 908	66 773 417	30 706 702
2036	19	59 747 988	64 828 561	29 812 332
2037	20	57 449 989	62 940 350	28 944 012
2038	21	55 240 374	61 107 136	28 100 982
2039	22	53 115 744	59 327 317	27 282 507
2040	23	51 072 831	57 599 336	26 487 871
2041	24	49 108 491	55 921 686	25 716 380
2042	25	47 219 703	54 292 899	24 967 359
2043	26	45 403 561	52 711 552	24 240 154
2044	27	43 657 270	51 176 264	23 534 130
2045	28	41 978 144	49 685 694	22 848 670
2046	29	40 363 600	48 238 537	22 183 175
2047	30	38 811 154	46 833 531	21 537 063
2048	31	37 318 417	45 469 448	20 909 770
2049	32	35 883 093	44 145 095	20 300 747
2050	33	34 502 975	42 859 316	19 709 464
2017–2050		2 410 305 637	2 474 275 862	1 137 830 812

Appendix II

This appendix contains calculations for the use value and the value of good groundwater quality given a growing population.

Table 17: Demand for communal water per year in 2016, m^3

	Water demand households	Water demand whole municipality
All households	10 038 960	14 300 000
Per households	101.9	145.1

Table 18: Population growth in number of citizens and households and their corresponding demand for water, 2017-2050

Year	Population	Increase from previous year	Increase in % from previous year	Number of households	Cost of production, water demand households m^3	Cost of production, water demand whole municipality m^3
2016	214 559			98 536		
2017	219 520	4 960	2,31%	100 814	83 554 490	119 019 222
2018	223 630	4 110	1,87%	102 701	85 118 853	121 247 579
2019	227 440	3 810	1,70%	104 451	86 569 029	123 313 283
2020	230 860	3 420	1,50%	106 022	87 870 762	125 167 537
2021	233 690	2 830	1,23%	107 321	88 947 926	126 701 904
2022	236 700	3 010	1,29%	108 704	90 093 603	128 333 864
2023	239 730	3 030	1,28%	110 095	91 246 893	129 976 668
2024	242 760	3 030	1,26%	111 487	92 400 182	131 619 471
2025	245 760	3 000	1,24%	112 865	93 542 053	133 246 010
2026	248 730	2 970	1,21%	114 228	94 672 505	134 856 282
2027	251 650	2 920	1,17%	115 569	95 783 926	136 439 446
2028	254 520	2 870	1,14%	116 888	96 876 316	137 995 501
2029	257 340	2 820	1,11%	118 183	97 949 674	139 524 447
2030	260 110	2 770	1,08%	119 455	99 004 002	141 026 284
2031	262 810	2 700	1,04%	120 695	100 031 685	142 490 168
2032	265 490	2 680	1,02%	121 925	101 051 757	143 943 209
2033	268 140	2 650	1,00%	123 142	102 060 409	145 379 985
2034	270 790	2 650	0,99%	124 359	103 069 062	146 816 760
2035	273 440	2 650	0,98%	125 576	104 077 714	148 253 535
2036	276 110	2 670	0,98%	126 803	105 093 979	149 701 154
2037	278 810	2 700	0,98%	128 043	106 121 663	151 165 039
2038	281 540	2 730	0,98%	129 296	107 160 765	152 645 189
2039	284 330	2 790	0,99%	130 578	108 222 705	154 157 869
2040	287 160	2 830	1,00%	131 877	109 299 870	155 692 237
2041	290 030	2 870	1,00%	133 195	110 392 259	157 248 292
2042	292 970	2 940	1,01%	134 546	111 511 293	158 842 299
2043	295 960	2 990	1,02%	135 919	112 649 357	160 463 416
2044	299 020	3 060	1,03%	137 324	113 814 066	162 122 484
2045	302 140	3 120	1,04%	138 757	115 001 611	163 814 084
2046	305 320	3 180	1,05%	140 217	116 211 994	165 538 215
2047	308 550	3 230	1,06%	141 701	117 441 408	167 289 454

2048	311 850	3 300	1,07%	143 216	118 697 466	169 078 646
2049	315 200	3 350	1,07%	144 755	119 972 555	170 894 947
2050	318 600	3 400	1,08%	146 316	121 266 675	172 738 357

Table 19: NPV of use value and value of groundwater quality taking population growth into account, 2017-2050

Year		Use value (water demand households)	Use value (water demand whole municipality)	Value of groundwater of good quality (high)	Value of groundwater of good quality (low)
2017	0	90 413 816	128 789 991	123 204 637	56 657 398
2018	1	88 564 042	126 155 080	121 855 685	56 037 063
2019	2	86 608 571	123 369 609	120 322 087	55 331 816
2020	3	84 529 710	120 408 374	118 574 138	54 527 997
2021	4	82 274 922	117 196 540	116 531 728	53 588 766
2022	5	80 129 469	114 140 450	114 594 848	52 698 064
2023	6	78 033 854	111 155 350	112 681 338	51 818 110
2024	7	75 980 905	108 231 025	110 782 080	50 944 709
2025	8	73 961 411	105 354 358	108 884 575	50 072 114
2026	9	71 976 185	102 526 501	106 990 719	49 201 198
2027	10	70 020 345	99 740 505	105 093 933	48 328 934
2028	11	68 095 104	96 998 094	103 196 603	47 456 420
2029	12	66 201 515	94 300 771	101 300 959	46 584 681
2030	13	64 340 487	91 649 829	99 409 087	45 714 677
2031	14	62 508 034	89 039 591	97 515 510	44 843 889
2032	15	60 716 787	86 488 048	95 640 702	43 981 732
2033	16	58 964 264	83 991 666	93 781 887	43 126 930
2034	17	57 256 732	81 559 372	91 950 217	42 284 610
2035	18	55 593 324	79 189 930	90 145 688	41 454 772
2036	19	53 977 081	76 887 672	88 374 674	40 640 346
2037	20	52 408 565	74 653 398	86 639 674	39 842 482
2038	21	50 886 278	72 484 976	84 939 822	39 060 780
2039	22	49 413 990	70 387 776	83 283 065	38 298 897
2040	23	47 986 364	68 354 193	81 662 136	37 553 490
2041	24	46 601 885	66 382 071	80 076 021	36 824 093
2042	25	45 263 734	64 475 941	78 531 789	36 113 956
2043	26	43 967 007	62 628 818	77 022 593	35 419 931
2044	27	42 713 069	60 842 646	75 552 376	34 743 831
2045	28	41 498 790	59 112 965	74 117 181	34 083 836
2046	29	40 322 655	57 437 620	72 715 785	33 439 384
2047	30	39 181 953	55 812 746	71 344 708	32 808 875
2048	31	38 077 895	54 240 071	70 007 528	32 193 953
2049	32	37 006 674	52 714 170	68 698 614	31 592 031
2050	33	35 967 171	51 233 449	67 417 138	31 002 726
2017–2050		2 041 442 591	2 907 933 596	3 192 839 524	1 468 272 492

Appendix III

In this appendix, the calculations for impacts of climate change on the use value are shown.

Table 20: Production cost of water, SEK

	Cost of production, 2016	Cost of production, 10% increase in infiltration cost	Cost of production, 10% decrease in infiltration cost
Total	125 880 000	126 500 000	124 640 000
Per m^3	8.80	8.85	8.72

Table 21: Population growth in number of citizens and households and the cost of producing demanded water when infiltration costs are increasing, 2017-2050

Year	Population	Increase from previous year	Increase in % from previous year	Number of households	Cost of production, constant water demand	Cost of production, households water demand	Cost of production, water demand whole municipality
2017	219 520	4 960	2,31%	100 814	125 880 000	90 413 816	128 789 991
2018	223 630	4 110	1,87%	102 701	125 880 000	92 106 604	131 201 283
2019	227 440	3 810	1,70%	104 451	125 880 000	93 675 831	133 436 569
2020	230 860	3 420	1,50%	106 022	125 880 000	95 084 428	135 443 046
2021	233 690	2 830	1,23%	107 321	126 500 000	96 724 084	137 778 655
2022	236 700	3 010	1,29%	108 704	126 500 000	97 969 920	139 553 287
2023	239 730	3 030	1,28%	110 095	126 500 000	99 224 035	141 339 710
2024	242 760	3 030	1,26%	111 487	126 500 000	100 478 149	143 126 134
2025	245 760	3 000	1,24%	112 865	126 500 000	101 719 846	144 894 870
2026	248 730	2 970	1,21%	114 228	126 500 000	102 949 127	146 645 919
2027	251 650	2 920	1,17%	115 569	126 500 000	104 157 712	148 367 489
2028	254 520	2 870	1,14%	116 888	126 500 000	105 345 603	150 059 580
2029	257 340	2 820	1,11%	118 183	126 500 000	106 512 798	151 722 192
2030	260 110	2 770	1,08%	119 455	126 500 000	107 659 299	153 355 325
2031	262 810	2 700	1,04%	120 695	126 500 000	108 776 826	154 947 187
2032	265 490	2 680	1,02%	121 925	126 500 000	109 886 076	156 527 258
2033	268 140	2 650	1,00%	123 142	126 500 000	110 982 909	158 089 642
2034	270 790	2 650	0,99%	124 359	126 500 000	112 079 741	159 652 026
2035	273 440	2 650	0,98%	125 576	126 500 000	113 176 574	161 214 409
2036	276 110	2 670	0,98%	126 803	126 500 000	114 281 684	162 788 584
2037	278 810	2 700	0,98%	128 043	126 500 000	115 399 212	164 380 447
2038	281 540	2 730	0,98%	129 296	126 500 000	116 529 157	165 989 997
2039	284 330	2 790	0,99%	130 578	126 500 000	117 683 935	167 634 922
2040	287 160	2 830	1,00%	131 877	126 500 000	118 855 270	169 303 429
2041	290 030	2 870	1,00%	133 195	126 500 000	120 043 160	170 995 520
2042	292 970	2 940	1,01%	134 546	126 500 000	121 260 024	172 728 882
2043	295 960	2 990	1,02%	135 919	126 500 000	122 497 582	174 491 722
2044	299 020	3 060	1,03%	137 324	126 500 000	123 764 113	176 295 833
2045	302 140	3 120	1,04%	138 757	126 500 000	125 055 478	178 135 319
2046	305 320	3 180	1,05%	140 217	126 500 000	126 371 678	180 010 179

2047	308 550	3 230	1,06%	141 701	126 500 000	127 708 572	181 914 519
2048	311 850	3 300	1,07%	143 216	126 500 000	129 074 439	183 860 128
2049	315 200	3 350	1,07%	144 755	126 500 000	130 461 001	185 835 217
2050	318 600	3 400	1,08%	146 316	126 500 000	131 868 258	187 839 785

Table 22: Population growth in number of citizens and households and the cost of producing demanded water when infiltration costs are decreasing, 2017-2050

Year	Population	Increase from previous year	Increase in % from previous year	Number of households	Cost of production, constant water demand	Cost of production, households water demand	Cost of production, water demand whole municipality
2017	219 520	4 960	2,31%	100 814	125 880 000	90 413 816	128 789 991
2018	223 630	4 110	1,87%	102 701	125 880 000	92 106 604	131 201 283
2019	227 440	3 810	1,70%	104 451	125 880 000	93 675 831	133 436 569
2020	230 860	3 420	1,50%	106 022	125 880 000	95 084 428	135 443 046
2021	233 690	2 830	1,23%	107 321	124 640 000	95 301 896	135 752 818
2022	236 700	3 010	1,29%	108 704	124 640 000	96 529 414	137 501 357
2023	239 730	3 030	1,28%	110 095	124 640 000	97 765 088	139 261 514
2024	242 760	3 030	1,26%	111 487	124 640 000	99 000 763	141 021 670
2025	245 760	3 000	1,24%	112 865	124 640 000	100 224 203	142 764 400
2026	248 730	2 970	1,21%	114 228	124 640 000	101 435 408	144 489 702
2027	251 650	2 920	1,17%	115 569	124 640 000	102 626 223	146 185 959
2028	254 520	2 870	1,14%	116 888	124 640 000	103 796 647	147 853 170
2029	257 340	2 820	1,11%	118 183	124 640 000	104 946 681	149 491 336
2030	260 110	2 770	1,08%	119 455	124 640 000	106 076 324	151 100 456
2031	262 810	2 700	1,04%	120 695	124 640 000	107 177 420	152 668 912
2032	265 490	2 680	1,02%	121 925	124 640 000	108 270 360	154 225 751
2033	268 140	2 650	1,00%	123 142	124 640 000	109 351 065	155 765 162
2034	270 790	2 650	0,99%	124 359	124 640 000	110 431 770	157 304 573
2035	273 440	2 650	0,98%	125 576	124 640 000	111 512 476	158 843 984
2036	276 110	2 670	0,98%	126 803	124 640 000	112 601 337	160 395 013
2037	278 810	2 700	0,98%	128 043	124 640 000	113 702 433	161 963 470
2038	281 540	2 730	0,98%	129 296	124 640 000	114 815 764	163 549 354
2039	284 330	2 790	0,99%	130 578	124 640 000	115 953 563	165 170 092
2040	287 160	2 830	1,00%	131 877	124 640 000	117 107 674	166 814 067
2041	290 030	2 870	1,00%	133 195	124 640 000	118 278 099	168 481 278
2042	292 970	2 940	1,01%	134 546	124 640 000	119 477 070	170 189 153
2043	295 960	2 990	1,02%	135 919	124 640 000	120 696 432	171 926 073
2044	299 020	3 060	1,03%	137 324	124 640 000	121 944 340	173 703 657
2045	302 140	3 120	1,04%	138 757	124 640 000	123 216 718	175 516 096
2046	305 320	3 180	1,05%	140 217	124 640 000	124 513 564	177 363 389
2047	308 550	3 230	1,06%	141 701	124 640 000	125 830 801	179 239 728
2048	311 850	3 300	1,07%	143 216	124 640 000	127 176 585	181 156 730
2049	315 200	3 350	1,07%	144 755	124 640 000	128 542 760	183 102 778
2050	318 600	3 400	1,08%	146 316	124 640 000	129 929 325	185 077 872

Table 23: NPV of use value when infiltration costs are increasing, 2017-2050

Year		Use value (constant demand)	Use value (all households)	Use value (whole municipality)
2017	0	125 880 000	90 413 816	128 789 991
2018	1	121 038 462	88 564 042	126 155 080
2019	2	116 383 136	86 608 571	123 369 609
2020	3	111 906 862	84 529 710	120 408 374
2021	4	108 132 730	82 680 152	117 773 771
2022	5	103 973 779	80 524 133	114 702 629
2023	6	99 974 788	78 418 196	111 702 826
2024	7	96 129 603	76 355 135	108 764 098
2025	8	92 432 311	74 325 695	105 873 262
2026	9	88 877 222	72 330 691	103 031 477
2027	10	85 458 867	70 365 218	100 231 759
2028	11	82 171 988	68 430 495	97 475 841
2029	12	79 011 527	66 527 579	94 765 233
2030	13	75 972 622	64 657 385	92 101 234
2031	14	73 050 598	62 815 907	89 478 140
2032	15	70 240 960	61 015 837	86 914 030
2033	16	67 539 384	59 254 682	84 405 352
2034	17	64 941 716	57 538 741	81 961 079
2035	18	62 443 957	55 867 139	79 579 966
2036	19	60 042 267	54 242 936	77 266 368
2037	20	57 732 949	52 666 694	75 021 090
2038	21	55 512 451	51 136 910	72 841 988
2039	22	53 377 356	49 657 370	70 734 458
2040	23	51 324 381	48 222 713	68 690 860
2041	24	49 350 367	46 831 415	66 709 025
2042	25	47 452 275	45 486 672	64 793 506
2043	26	45 627 188	44 183 559	62 937 285
2044	27	43 872 296	42 923 445	61 142 316
2045	28	42 184 900	41 703 185	59 404 116
2046	29	40 562 404	40 521 257	57 720 519
2047	30	39 002 311	39 374 937	56 087 642
2048	31	37 502 223	38 265 441	54 507 221
2049	32	36 059 829	37 188 944	52 973 804
2050	33	34 672 913	36 144 321	51 485 791
2017–2051		2 419 836 621	2 049 772 925	2 919 799 742

Table 24: NPV of use value when infiltration costs are decreasing, 2017–2050

Year		Use value (constant demand)	Use value (all households)	Use value (whole municipality)
2017	0	125 880 000	90 413 816	128 789 991
2018	1	121 038 462	88 564 042	126 155 080
2019	2	116 383 136	86 608 571	123 369 609
2020	3	111 906 862	84 529 710	120 408 374

2021	4	106 542 794	81 464 460	116 042 078
2022	5	102 444 995	79 340 142	113 016 092
2023	6	98 504 802	77 265 169	110 060 397
2024	7	94 716 156	75 232 443	107 164 879
2025	8	91 073 227	73 232 843	104 316 549
2026	9	87 570 411	71 267 172	101 516 548
2027	10	84 202 318	69 330 599	98 757 996
2028	11	80 963 767	67 424 323	96 042 600
2029	12	77 849 776	65 549 387	93 371 847
2030	13	74 855 554	63 706 691	90 747 018
2031	14	71 976 494	61 892 289	88 162 493
2032	15	69 208 168	60 118 687	85 636 085
2033	16	66 546 315	58 383 428	83 164 293
2034	17	63 986 841	56 692 716	80 755 959
2035	18	61 525 809	55 045 694	78 409 857
2036	19	59 159 432	53 445 372	76 130 278
2037	20	56 884 069	51 892 306	73 918 013
2038	21	54 696 220	50 385 015	71 770 952
2039	22	52 592 519	48 927 230	69 694 410
2040	23	50 569 730	47 513 667	67 680 860
2041	24	48 624 741	46 142 826	65 728 165
2042	25	46 754 558	44 817 856	63 840 811
2043	26	44 956 306	43 533 903	62 011 883
2044	27	43 227 217	42 292 318	60 243 307
2045	28	41 564 632	41 090 000	58 530 664
2046	29	39 965 992	39 925 451	56 871 822
2047	30	38 428 839	38 795 985	55 262 954
2048	31	36 950 807	37 702 803	53 705 771
2049	32	35 529 622	36 642 134	52 194 901
2050	33	34 163 098	35 612 871	50 728 766
2017–2051		2 391 243 669	2 024 781 924	2 884 201 302

References

Abdalla, C. W. (1994). Groundwater Values from Avoidance Cost Studies: Implications for Policy and Future Research. *American Journal of Agricultural Economics*, 76(5), pp 1062–1067.

Abdalla, C. W., Roach, B. A. & Epp, D. J. (1992). Valuing Environmental Quality Changes Using Averting Expenditures: An Application to Groundwater Contamination. *Land Economics*, 68(2), pp 163–169.

Adamowicz, W., Boxall, P., Williams, M. & Louviere, J. (1998). Stated Preference Approaches for Measuring Passive Use Values: Choice Experiments and Contingent Valuation. *American Journal of Agricultural Economics*, 80(1), pp 64–75.

Ahlgren, S. (2017). Telefonintervju - Planeringschef Uppsala Vatten.

Almansa, C. & Martínez-Paz, J. M. (2011). What weight should be assigned to future environmental impacts? A probabilistic cost benefit analysis using recent advances on discounting. *Science of The Total Environment*, 409(7), pp 1305–1314.

Bann, C. & Wood, S. C. (2012). Valuing groundwater: a practical approach for integrating groundwater economic values into decision making - A case study in Namibia, Southern Africa. *Water SA*, 38(3), pp 461–466.

Barnett, T. P., Adam, J. C. & Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, 438(7066), pp 303–309.

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P. (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change* [online]. Geneva, Switzerland: IPCC. (ISBN: 978-92-9169-123-4).

Bontemps, C. & Couture, S. (2002). Evaluating irrigation water demand. *Current Issues in the Economics of Water Resource Management: Theory, Applications and Policies*, pp 69–83.

Boyle, K. J., Morrison, M. & Taylor, L. O. (2004). Why Value Estimates Generated Using Choice Modelling Exceed Contingent Valuation: Further Experimental Evidence. *Proceedings of Australian Agricul- tural and Resource Economics Society Conference*, Melbourne, Australia, februari 11 2004. p 25. Melbourne, Australia: Australian Agricultural and Resource Economics Society (AARES).

Brännlund, R. & Kriström, B. (2012). *Miljöekonomi*. Lund: Studentlitteratur. ISBN 978-91-44-08086-4.

Burness, H. S. & Martin, W. E. (1988). Management of a tributary aquifer. *Water Resources Research*, 24(8), pp 1339–1344.

Burnett, K. & Wada, C. A. (2014). Optimal groundwater management when recharge is declining: a method for valuing the recharge benefits of watershed conservation. *Environmental Economics and Policy Studies; Tokyo*, 16(3), pp 263–278.

Burt, O. R. (1964). Optimal Resource Use Over Time with an Application to Ground Water. *Management Science*, 11(1), pp 80–93.

Council, N. R., Studies, D. on E. and L., Geosciences, E. and R. C. on & Water, C. on V. G. (1997). *Valuing Ground Water: Economic Concepts and Approaches* [online]. Washington: National Academies Press. Available from: https://www.nap.edu/nap-cgi/skimchap.cgi?recid=5498&chap=i%E2%80%93xiv. [Accessed 2017-09-05].

Cutter, W. B. (2007). Valuing Groundwater Recharge in an Urban Context. *Land Economics*, 83(2), pp 234–252.

Desvousges, W. H., Johnson, F. R. & Banzhaf, H. S. (1999). *Environmental Policy Analysis With Limited Information: Principles and Applications of the Transfer Method*. First Edition edition. Cheltenham: Edward Elgar Pub. ISBN 978-1-85898-655-5.

Drangert, J.-O. & Cronin, A. A. (2004). Use and abuse of the urban groundwater resource: Implications for a new management strategy. *Hydrogeology Journal*, 12(1), pp 94–102.

Döll, P. (2009). Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment. *Environmental Research Letters*, 4(3), p 035006.

Edwards, E. C. (2016). What Lies Beneath? Aquifer Heterogeneity and the Economics of Groundwater Management. *Journal of the Association of Environmental and Resource Economists*, 3(2), pp 453–491.

Ekholm, K. (2017). Uppsala Vatten - unpublished data provided via e-mail. [Accessed 2017-09-19].

Foster, S. & Ait-Kadi, M. (2012). Integrated Water Resources Management (IWRM): How does groundwater fit in? *Hydrogeology Journal*, 20(3), pp 415–418.

Foster, S. & Macdonald, A. (2014). The ”water security” dialogue: why it needs to be better informed about groundwater. *Hydrogeology Journal; Heidelberg*, 22(7), pp 1489–1492.

Gisser, M. & Sánchez, D. A. (1980a). Competition versus optimal control in groundwater pumping. *Water Resources Research*, 16(4), pp 638–642.

Gisser, M. & Sánchez, D. A. (1980b). Some additional economic aspects of ground water resources and replacement flows in semi-arid agricultural areas. *International Journal of Control*, 31(2), pp 331–341.

Gleeson, T., VanderSteen, J., Sophocleous, M. A., Taniguchi, M., Alley, W. M., Allen, D. M. & Zhou, Y. (2010). Groundwater sustainability strategies. *Nature Geoscience*, 3(6), pp 378–379.

Grey, D. & Sadoff, C. W. (2007). Sink or Swim? Water security for growth and development. *Water Policy*, 9(6), pp 545–571.

Hafi, A. (2003). Conjuctive Use of Groundwater and Surface Water in the Burdekin Delta Area. *Economic Record*, 79(SpecialIssue), pp S52–S62.

Harrington, D. H. (1992). Management issues relating to policy analysis. *Costs and Returns for Agricultural Commodities: Advances in Concepts and Measurement*, 1992, pp 43–56.

Hartman, L. M. & Anderson, R. L. (1962). Estimating the Value of Irrigation Water from Farm Sales Data in Northeastern Colorado. *Journal of Farm Economics*, 44(1), pp 207–213.

Hasler, B., Lundhede, T., Martinsen, L., Neye, S. & Schou, J. S. (2005). *Valuation of groundwater protection versus water treatment in Denmark by Choice Experiments and Contingent Valuation* [online]. Denmark: National Environmental Research Institute. (543).

Höglund, L. (1999). Household demand for water in sweden with implications of a potential tax on water use. *Water Resources Research*, 35(12), pp 3853–3863.

Iglesias, E., Garrido, A., Sumpsi, J. & Varela-Ortega, C. (1998). Water demand elasticity: implications for water management and water pricing policies. *World Congress of Environmental and Resource Economists, Venice*, 1998, pp 26–28.

Jha, M. K., Chowdhury, A., Chowdary, V. M. & Peiffer, S. (2007). Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. *Water Resources Management*, 21(2), pp 427–467.

Jin, J., Wang, Z. & Ran, S. (2006). Comparison of contingent valuation and choice experiment in solid waste management programs in Macao. *Ecological Economics*, 57(3), pp 430–441.

Knapp, K. C. & Olson, L. J. (1995). The Economics of Conjunctive Groundwater Management with Stochastic Surface Supplies. *Journal of Environmental Economics and Management*, 28(3), pp 340–356.

Koundouri, P. (2004). Current Issues in the Economics of Groundwater Resource Management. *Journal of Economic Surveys*, 18(5), pp 703–740.

Lewis, J., Sjöström, J., Höök, M. & Sundström, B. (2013). The Swedish model for groundwater policy: Legal foundations, decision-making and practical application. *Hydrogeology Journal*, 21(4), pp 751–760.

M. L. Parry J.P. Palut, O. F. C. (2007). *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [online]. (M. L. Parry, O. F. C., Ed) Cambridge, UK: Cambridge University Press. Available from: http://plymsea.ac.uk/5834/. [Accessed 2017-03-25].

Miljömål. [online] (2017) (Miljömål.se). Available from: http://www.miljomal.se/Miljomalen/9-Grundvatten-av-god-kvalitet/. [Accessed 2017-07-04].

Milliman, J. W. (1959). Land Values as Measures of Primary Irrigation Benefits. *Journal of Farm Economics*, 41(2), pp 234–243.

Naturvårdsverket (2008). *Samhällsekonomisk konsekvensanalys av miljöåtgärder* [online]. Stockholm: Naturvårdsverket. (2008:4).

Naturvårdsverket. [online] (2017) (Naturvårdsverket). Available from: https://www.naturvardsverket.se/Miljoarbete-i-samhallet/Sveriges-miljomal/Miljokvalitetsmalen/Grundvatten-av-god-kvalitet/. [Accessed 2017-07-04].

Pachauri, R. K., Meyer, L. A., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., Dubash, N. K., Edenhofer, O., Eligizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestvedt, J., Gomez-Echeverri, L., Hallegatte, S., Hegerl, G., Howden, M., Jiang, K., Jimenez Cisneros, B., Kattsov, V., Lee, H., March, K. J., Marotzke, J., Mastrandrea, M. D., Meyer, L., Minx, J., Mulugetta, Y., O'Brien, K., Oppenheimer, M., Pereira, J. J., Pichs-Madruga, R., Plattner, G.-K., Pörtner, H.-O., Power, S. B., Preston, B., Ravindranath, N. H., Reisinger, A., Riahi, K., Rusticucci, M., Scholes, R., Seyboth, K., Sokona, Y., Stavins, R., Stocker, T. F., Tschakert, P., van Vuuren, D. & van Ypersele, J.-P. (2014). *IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC. (ISBN 978-92-9169-143-2).

Perman, D. R., Ma, D. Y., Common, D. M., Maddison, D. D. & Mcgilvray, D. J. (2011). *Natural Resource and Environmental Economics*. 4 edition. Harlow, England London New York Boston San Francisco Toronto Sydney Tokyo Singapore Hong Kong Seoul Taipei: Addison Wesley. ISBN 978-0-321-41753-4.

Powell, J. R. (1992). The value of groundwater protection: Measurement of willingness-to-pay information, and its utilization by local government decisionmakers.

Roumasset, J. & Wada, C. (2014). *Integrated Groundwater Resource Management* [online]. University of Hawaii at Manoa, Department of Economics, Working Papers: 201414.

Rupérez-Moreno, C., Pérez-Sánchez, J., Senent-Aparicio, J., Flores-Asenjo, P. & Paz-Aparicio, C. (2017). Cost-Benefit Analysis of the Managed Aquifer Recharge System for Irrigation under Climate Change Conditions in Southern Spain. *Water*, 9(5), p 343.

Schuerhoff, M., Weikard, H.-P. & Zetland, D. (2013). The life and death of Dutch groundwater tax. *Water Policy*, 15(6), pp 1064–1077.

SGU Vattenförvaltning. [online] (2017) (Sveriges geologiska undersökning). Available from: http://www.sgu.se/grundvatten/vattenforvaltning/. [Accessed 2017-07-04].

Silvander, U. (1991). *Betalningsvillighetsstudier för sportfiske och grundvatten i Sverige = The willingness to pay for angling and ground water in Sweden*. Uppsala: Avhandlingar / Sveriges lantbruksuniversitet, Institutionen för ekonomi, 2. ISBN 91-576-4437-3.

Smith, S. M., Andersson, K., Cody, K. C., Cox, M. & Ficklin, D. (2017). Responding to a Groundwater Crisis: The Effects of Self-Imposed Economic Incentives. *Journal of the Association of Environmental and Resource Economists*, 4(4), pp 985–1023.

Soutukorva, Å., Wallström, J., Ivarsson, M. & Wallentin, E. (2017). *Värdering av vattenförekomster i Stockholm* [online]. Stockholm: Anthesis Enveco AB. (2017:5).

Spofford, W. O., Krupnick, A. J. & Wood, E. F. (1989). Uncertainties in estimates of the costs and benefits of groundwater remediation: Results of a cost-benefit analysis. *Quality of the Environment Division, Resources for the Future.*, 1989.

Statistiska centralbyrån (2017a). *Konsumentprisindex* [online]. Stockholm: Statistiska centralbyrån.

Statistiska centralbyrån (2017b). *Statistikdatabasen* [online]. Stockholm: Statistiska centralbyrån.

Statistiska centralbyrån (2017c). *Uppsala Kommunfakta 2017* [online]. Stockholm: Statistiska centralbyrån.

Stenger, A. & Willinger, M. (1998). Preservation value for groundwater quality in a large aquifer: a contingent-valuation study of the Alsatian aquifer. *Journal of Environmental Management*, 53(2), pp 177–193.

Sveriges Riksbank (2017). *Årsgenomsnitt valutakurser (ackumulerat)* [online]. Stockholm: Sveriges Riksbank.

Syfte | Tämnarens Vatten. [online] (2017) (Tämnarens Vatten). Available from: http://www.tamnaren.se/?page_id=924. [Accessed 2017-10-09].

Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J. S., Edmunds, M., Konikow, L., Green, T. R., Chen, J., Taniguchi, M., Bierkens, M. F. P., MacDonald, A., Fan, Y., Maxwell, R. M., Yechieli, Y., Gurdak, J. J., Allen, D. M., Shamsudduha, M., Hiscock, K., Yeh, P. J.-F., Holman, I. & Treidel, H. (2013). Ground water and climate change. *Nature Climate Change*, 3(4), pp 322–329.

Tsur, Y. & Graham-Tomasi, T. (1991). The buffer value of groundwater with stochastic surface water supplies. *Journal of Environmental Economics and Management*, 21(3), pp 201–224.

Uppsala kommun (2017a). *Befolkningsprognos för Uppsala kommun 2017–2050* [online]. Uppsala: Uppsala kommun.

Uppsala kommun (2017b). *Befolkningsprognos för Uppsala kommuns delområden 2017–2021* [online]. Uppsala: Uppsala kommun.

Uppsala kommun (2017c). *Översiktsplan 2016 för Uppsala kommun* [online]. Uppsala: Uppsala kommun.

Uppsala Vatten (2015). *Vattenförsörningen i Uppsala stad* [online]. Uppsala: Uppsala vatten.

Uppsala Vatten (2017). *Årsredovisning 2016*. Uppsala: Uppsala vatten.

Uppsala Vatten - Dricksvatten. [online] (2017) (uppsalavatten.se). Available from: http://www.uppsalavatten.se/sv/om-oss/verksamhet-och-drift/dricksvatten/. [Accessed 2017-07-04].

Varela-Ortega, C., M. Sumpsi, J., Garrido, A., Blanco, M. & Iglesias, E. (1998). Water pricing policies, public decision making and farmers' response: implications for water policy. *Agricultural Economics*, 19(1), pp 193–202.

Vattenmyndigheterna - Fyrisåns avrinningsområde. [online] (2017) (Vattenmyndigheterna). Available from: http://www.vattenmyndigheterna.se:80/Sv/vattendistrikt-sverige/norra-ostersjon/Sidor/Fyrisans-avrinningsomrade-.aspx?keyword=vattenbrist. [Accessed 2017-07-04].

Vattenmyndigheterna - Norra Östersjöns vattendistrikt. [online] (2017) (Vattenmyndigheterna). Available from: http://www.vattenmyndigheterna.se:80/Sv/vattendistrikt-sverige/norra-ostersjon/Sidor/default.aspx. [Accessed 2017-07-04].

Vikberg, E., Thunholm, B., Thorsbrink, M. & Dahné, J. (2015). *Grundvattennivåer i ett förändrat klimat – nya klimatscenarier* [online]. Uppsala: Sveriges geologiska undersökning. (SGU-rapport 2015:19).

Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S. & Bierkens, M. F. P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters*, 37(20), p L20402.

Yang, H., Zhang, X. & Zehnder, A. J. B. (2003). Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. *Agricultural Water Management*, 61(2), pp 143–161.