Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Establishment of Water Protection Areas: Comparing Benefits of Protecting Groundwater Services to Agricultural Costs

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Master's thesis • 30 credits
Agricultural programme – Economics and Management
Degree project/SLU, Department of Economics, 1224 • ISSN 1401-4084
Uppsala, Sweden 2019

Establishment of Water Protection Areas: Comparing Benefits of Protecting Groundwater Services to Agricultural Costs

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Credits: 30 credits
Level: Second cycle**,** A2E
Course title: Master thesis in Economics
Course code: EX0907
Programme/Education: Agricultural programme – Economics and Management
Course coordinating department: Department of Economics

Place of publication: Uppsala
Year of publication: 2019
Cover picture: Julia Wahtra
Title of series: Degree project/SLU, Department of Economics
Part number: 1224
ISSN: 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: cost-benefit analysis, groundwater services, water protection areas, distributional effects, agriculture

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Acknowledgements

I would like to thank my supervisor, Efthymia Kyriakopoulou at SLU, for all her excellent advice. I would also like to express my sincere gratitude to Henrik Nordzell and Tore Söderqvist at Anthesis, as well as to the other persons involved in the research project which this thesis has been a part of, for their valuable input and support during the entire writing process.

Abstract

In this study, a CBA of expanding a water protection area and imposing more restrictive protection regulations to safeguard a groundwater source used for drinking water supply was performed. The case study area was a location in the Southern part of Sweden. The aim of the study was to contribute to enabling economically motivated water management decisions and to address the distributional effects of water protection measures. Benefits in terms of enhanced protection and secured provision of good quality drinking water supply and other groundwater services were compared to costs for the agricultural sector. Groundwater services were identified by a novel classification system for biotic and abiotic surface and groundwater services, developed based on an extensive literature review. The protection measure alternative was concluded as profitable compared to the reference alternative with a NPV of SEK 128.9 million. Potential uncertainties and omitted cost and benefit items were examined in a sensitivity analysis, but these factors were not considered to have altered the outcome of the CBA. It was deemed challenging to identify all groundwater services supplied by the groundwater source and to determine the relationship between the protection measure and the impact on these services. More research is required to develop the applicability of the classification system. Another conclusion was that the benefits of protecting a drinking water source to a large extent depend on the number of people using it for their drinking water supply.

Sammanfattning

I den här studien genomfördes en kostnadsnyttoanalys av att utvidga ett befintligt vattenskyddsområde och införa mer restriktiva skyddsföreskrifter för att skydda en grundvattenkälla som används för dricksvattenförsörjning. Fallstudieområdet var en plats i södra delen av Sverige. Syftet med studien var att bidra till möjliggörandet av ekonomiskt motiverade vattenförvaltningsbeslut och att adressera fördelningseffekter av vattenskyddsåtgärder. Nyttorna i form av ett ökat skydd och säkerställt tillhandahållande av dricksvatten av god kvalitet samt andra grundvattentjänster jämfördes med kostnader för jordbrukssektorn. Grundvattentjänsterna identifierades utifrån ett nytt klassificeringssystem för biotiska och abiotiska yt- och grundvattentjänster, som utvecklats baserat på en omfattande litteraturöversikt. Skyddsåtgärdsalternativet konkluderades som lönsamt jämfört med referensalternativet med ett nettonuvärde på 128,9 miljoner SEK. Potentiella osäkerhetsfaktorer och utelämnade kostnads- och nyttoposter undersöktes i en känslighetsanalys, men dessa faktorer bedömdes inte förändra analysens utfall. Det ansågs utmanande att identifiera alla grundvattentjänster som tillhandahölls av grundvattenkällan samt att fastställa förhållandet mellan skyddsåtgärden och påverkan på dessa tjänster. Ytterligare forskning behövs för att utveckla klassificeringssystemets tillämplighet i detta avseende. En annan slutsats var att nyttan från skydd av en dricksvattenkälla i stor utsträckning beror på antalet personer som är beroende av den för sin dricksvattenförsörjning.

Abbreviations

CBA – Cost-Benefit Analysis

NPV – Net Present Value

NSB – Net Social Benefits

PV – Present Value

SDR – Social Discount Rate

SEK – Swedish Krona

USD – American Dollars

WTP – Willingness to Pay

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1 Introduction

Access to safe drinking water is fundamental for the economic development and public health of society (WHO, 2017), which was recently recognised by the 2030 Agenda for Sustainable Development. The 2030 Agenda was adopted in 2015 by all members states of the United Nation and contains 17 Sustainable Development Goals, including a specific goal to ensure availability and sustainable management of water sources for all people on earth (UN, 2017). Drinking water is primarily used for drinking, but also for other purposes (Svenskt Vatten, 2016b). Besides granting water for drinking, surface and groundwater sources provide other vital services contributing to human well-being (CICES, 2018). For example, water is a crucial input for the production of food, recreational and cultural experiences as well as a source of energy and habitat for living species.

All inhabitants in Sweden are considered to have access to safe water, but many hazards which could harm the supply of good quality drinking water remain (Government Offices of Sweden, 2018). These are commonly linked to human activities such as road traffic, agricultural production and industrial processes (SOU, 2016:32). Due to climate change and urban development, there is an aggravated risk that these hazards will expose the drinking water supply system. County administrative boards and municipalities have the authority to implement various legal measures to protect the quality and quantity of drinking water sources (SEPA, 2010). One measure is the establishment of water protection areas, regulated in Chapter 7, Section 21-22 of the Environmental Code (SFS 1998:808). The purpose of water protection areas is to give sufficient protection to water bodies that are important for our drinking water supply, from a multi-generational perspective (SEPA, 2010). Establishing water protection areas put different restrictions on activities and pollution sources at its location. The imposed restrictions should support the water protection aims of EU and Swedish legislation to ensure intended use of the drinking water source now and in the future.

Despite the growing importance of securing drinking water sources, local and regional authorities lack methods and material as a basis to plan and implement protective measures (SOU, 2016:32). Another issue is the significant discrepancy in guidelines available for protective actions, with variations both in terms of methods and judgments between local authorities.

The lack of clear guidelines and supportive material counteracts optimal implementation of protection measures and results in economically unmotivated policy decisions, causing conflicts between stakeholders in society. Because property owners practising agricultural activities commonly bear a large part of the economic costs related to water protection areas, due to restrictions on land use and farming activities (SOU, 2016:32), this protection measure causes particularly unfortunate conflicts. The Federation of Swedish Farmers argues that water sources need protection in a way which alleviates conflicts and is reasonable for all stakeholders involved (LRF, 2016). They argue that the production of food and drinking water as a general rule is possible to combine. Alternatively, whenever we take Swedish agricultural land out of production due to water protection restrictions, the same amount of food it used to produce might be replaced by imported food (LRF, 2016). As a consequence, the adverse environmental effects of agricultural production move to another country, possibly with graver environmental impacts on society (LRF, 2016). Proper appraisal of the societal effects of water protection areas and other protection measures is much needed to address these conflicts and to accomplish adequate protection of drinking water sources.

To make well-informed analyses as a basis for decisions concerning protective measures of drinking water sources, further knowledge about the measures' positive and negative societal effects is needed (SOU, 2016:32). This study will contribute to this work by valuing benefits and costs from expanding an existing water protection area and imposing more restrictive protection regulations. A classification system of all services provided to society by surface and groundwater sources will be developed to enable their value to be taken into account in policy decisions in general and to motivate protective measures to assure good quality drinking water in particular. The deficiency in supportive methods and frameworks discourages valuation techniques for environmental goods and services to be used in real-world decisions (Griffiths et al., 2012; Postel and Thompson, 2005). By performing cost-benefit analyses of water protection measures, distributional effects could also be addressed and remediated. Well-informed analyses and prioritisation of which protective measure to use and where will help to establish or expand water protection areas where they are the most beneficial to society.

1.1 Aim and delimitations

The overall aim of this thesis is to contribute to the assessment of effects on society from water protection measures, focusing on water protection areas, to enable informed and more economically motivated management decisions. Costs and benefits of expanding and imposing more restrictive protection regulations on an existing water protection area at a rural location in the Southern part of Sweden with a groundwater source are calculated. The location addresses the conflict of interest between protecting drinking water sources and agricultural production. The specific research question is:

> *What is the net present value of expanding a water protection area when considering benefits of protecting groundwater services and costs for the agricultural sector?*

The results will be of importance to demonstrate the various benefits of protecting drinking water sources, besides ensuring supply of good quality drinking water. They will also pay attention to distributional effects and allow for analysis of uncertainty regarding estimation of benefits, costs, and choice of social discount rate (SDR).

The study will be carried out by an extensive literature review to identify all services usually provided by surface and groundwater drinking sources in Sweden. The services are subsequently structured in a classification system[1] applicable to different types of drinking water sources with a variety of preconditions. The aim is to allow for categorisation and economic valuation of drinking water sources in terms of what services they provide to society. The classification system will give novel contribution to the research by considering both biotic and abiotic services from surface and groundwater drinking sources. It will be used in the cost-benefit analysis (CBA) to assess the protection measure’s impact on services provided by the groundwater source. Costs for the agricultural sector in terms of profit losses and administrative work will also be considered.

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[1] The complete classification system is found in Appendix 1 and should be considered as work-in-progress material for further research.

The study is limited in the sense that it focuses on the impact on groundwater services and the agricultural sector, which are the main activities in the case study area. Only costs and benefits which could be identified based on the material and data available are included in the analysis. A lifetime of 40 years is assumed for the proposed water protection area, with an evaluation period from 2018 to 2058.

1.2 Objectives

The primary objective of the study is to estimate costs and benefits of expanding an existing water protection area and imposing more restrictive protection regulations. The secondary objective is to produce and test the applicability of a classification system of biotic and abiotic services provided by surface and groundwater sources.

2 Drinking water

This chapter gives an overview of drinking water sources in Sweden and the purpose and design of water protection areas. The various pollutants from agricultural activities are also described.

2.1 Surface and groundwater drinking sources in Sweden

Drinking water in Sweden is produced from raw water in water treatment plants (Svenskt Vatten, 2016b). The municipalities are responsible for the production of all drinking water, except for the amount people receive from private wells (Svenskt Vatten, 2016a). Half of the raw water comes from surface water sources and the other half from groundwater sources. It is also common that the two types of sources are interconnected through e.g. induced infiltration[2] (SEPA, 2010). Surface water sources refer to lakes and streams, and groundwater sources consist of either natural or artificial groundwater.

Both surface and groundwater can reach the same good drinking water quality with the right treatment, but groundwater generally has a better immediate quality (Svenskt Vatten, 2016a). The treatment process needed to produce drinking water from surface water is therefore much more complex and includes several steps. By contrast, when the raw water from groundwater sources is well protected, and of particularly good quality, the plant could exclusively subsist of a pumping device. As raw water from groundwater sources constitutes 50% of our drinking water supply, maintaining its high quality is paramount to secure current and future drinking water supply. Protection of the high quality of groundwater also lower cleaning costs and result in a reduced risk of having to use backup sources.

2.2 Water protection areas

Water protection areas are established to protect drinking water sources from activities and land uses which may have an adverse effect on the quality and quantity of the water (SEPA, 2010). They could be established on land and water areas to protect surface or groundwater sources that are used for, or are likely to be used for, water extraction (Chapter 7, Section 21 of the Swedish Environmental Code). The source should have sufficient protection from occasional and continuous anthropogenic pollution, referring to all substances which could potentially harm the current or future supply of drinking water. Point source pollutants stem from a single and identifiable source of pollution, e.g. a sewage treatment plant or an industry, whereas diffuse source pollutants appear over a large area, not attributed to a single source (EPA Victoria, 2018). Agricultural land, woodland, and private sewers are typical examples of sources of diffuse pollutants (SEPA, 2016).

The precautionary principle is fundamental when local authorities form water protection areas and design their regulations (SEPA, 2010). It underlies the general rules of consideration in Chapter 2 of the Swedish Environmental Code (SFS 1998:808) and applies to all activities or measures which may cause damage or detriment to public health, humans and the environment. The principle is however not intended as an argument to establish too large water protection areas as a precaution or to conduct insufficient preparational investigations such as descriptions

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[2] When water from, e.g. watercourses and lakes recharge the groundwater by penetrating the soil (HaV, 2013).

of hydrological conditions and risk assessments. Before deciding whether to establish a water protection area a risk inventory covering the whole catchment area is required, which is the entire area within which the water is moving to the water source (SEPA, 2010). A usual definition of the risk for an undesirable event to happen is the product of its consequences and the probability that it will occur (SEPA, 2010).

The rule of thumb is that the protection regulations should cover the entire catchment area, and when the scope of the water protection area has been determined, it is divided into different protection zones (SEPA, 2010). These are either *water abstraction zone* (encompasses the point where the raw water is abstracted), *primary protection zone*, *secondary protection zone* and, if necessary, *tertiary protection zone* (SEPA, 2010). The regulations are most restrictive at the water abstraction zone and least restrictive in the tertiary protection zone. The regulations should be reasonable when considering the purpose of the water protection area, as they limit individuals' disposal right of their land, and adjustments to local conditions are important (SEPA, 2010).

2.3 Water pollution from agriculture

Industrial agriculture is one of the main reasons for global water pollution (FAO and IWMI, 2018). In the European Union, 38% of all water bodies are under high pressure from agricultural pollutants. Land uses in Swedish agriculture which involve risk to surface and groundwater drinking sources are: use of pesticides and biocides[3], fertiliser and manure, soil tillage causing increased hummus levels in surface water, livestock and drainage (SEPA, 2010). Agricultural point source pollution occurs in connection to e.g. manure and silage facilities and due to accidental pesticide spill. However, the most common water contamination related to agriculture is diffuse pollution (FAO and IWMI, 2018). Diffuse pollutants are very hard to measure and monitor as they do not have a certain point of discharge (SMED, 2013). In modern agriculture, diffuse pollutants come from the intense use of fertilisers and manure (EEA, 2018). Chemical pesticides used to protect plants from fungus, pests or competing plants is another diffuse pollution, mainly transported to surface and groundwater sources by runoff and wind (KEMI, 2016; EEA, 2018).

The adverse effects of diffuse pollutants are harmful to the health of people, domestic animals and wildlife. Because of the long-term effect of diffuse pollutants on surface and groundwater sources, and the difficulty to remediate them, these type of pollutants entail risk to the drinking water supply system (SEPA, 2010) and bring on significant increases in treatment costs (EEA, 2018).

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[3] Pesticides and biocides are chemical or biological products used to preclude or restrain animals, plants or micro-organisms from damaging human health or properties. Of these products, biocides include all pesticides which are not intended to protect plants or plant products (KEMI, n.d.).

3 Literature review

The literature review consists of articles evaluating costs and benefits of water protection measures. Cost-benefit analyses which evaluate specific water protection measures are very limited, especially CBAs which also account for the effect on other surface and groundwater services besides drinking water supply and impacts on the agricultural sector. Hence relevant studies using different methodologies to investigate benefits and costs related to water quality improvements have been covered.

3.1 Costs and benefits of water protection measures

Already thirty years ago, Dixon and Sherman (1991) acknowledged the difficulty to motivate protection of natural areas due to substantial underestimations of associated benefits and because private costs often overweigh private benefits. Thus, even though net social benefits are positive, less area is protected compared to what is socially optimal. Dixon and Sherman (1991) argued that economists play an important role to improve monetary estimates of benefits related to the protection of natural areas, not at least for watersheds. Around twenty years later, Griffiths et al. (2012) deem that despite substantial research on economic values of environmental non-market goods, only slowly has this literature been integrated into analyses of regulation impacts. Their article examines the US Environmental Protection Agency's estimation of benefits related to surface water quality improvements during the last thirty years. Because of variations in available data, different local conditions, objectives and methodologies, they conclude that there is a large variation in the definition of water quality indicators, which entangles transfer of benefit estimates between studies.

Postel and Thompson (2005) discuss the importance of valuation of water services in the light of increased population and development pressure on watersheds. The increased pressure poses a risk to the quality and cost of drinking water and to reliability of water suppliers. Important conclusions are that further research is required on linkages between land use and hydrological effects within watersheds, as well as on the valuation of ecosystem services. Postel and Thompson (2005) argue for the need to develop methods that enable usage of valuation techniques in real-world decisions. Today water suppliers and stakeholders are often unsure about to what degree some measure will generate water service benefits or if the benefits will outweigh the costs. They also add to the discussion of distributional effects by recommending that authorities should only undertake watershed protection with a specific goal of equally distributing the gains. Otherwise, there is a risk of benefiting urban industrial business at the expense of rural communities, increasing social inequities.

Bateman et al. (2006) further examined the distributional effects of water protection measures by analysing possible agricultural costs and non-market benefits of implementing the EU Water Framework Directive. The Directive aimed to achieve "good quality status" of all European water bodies by 2015. They noted that even though the Directive was claimed to deliver considerable benefits, there is no formal economic assessment of such benefits. The authors used GIS techniques to model agricultural land use, hydrology and water quality effects to address the distribution of costs and benefits, with the Humber basin (UK) as case study area. Bateman et al. (2006) conclude that agriculture bears a large share of the implementation costs of the EU Water Framework Directive and that GIS-based methodology is vital to address the aggregation, transfer and distribution of benefits from earlier studies.

Eisen-Hecht and Kramer (2002) performed a CBA of preserving the current level of water quality in the Catawba River basin (USA), which is primarily threatened due to population growth. The Catawba River is used for various commercial business as well as providing surrounding inhabitants with drinking water and recreational and aesthetic qualities. A stated preference survey was designed to evaluate people's willingness to pay (WTP) to protect the water quality by implementing a management plan. The annual mean WTP for five years of payments was USD 139, based on answers from 1085 residents, corresponding to a total economic benefit of USD 340.1 million. The estimated benefits were related to recreational use and the use and non-use value of good quality water. The total cost of the management plan over 10 years was concluded to be USD 244.8 million. The costs included compensation to farmers who had to install buffer strips on productive agricultural land causing a reduction in income. Eisen-Hecht and Kramer (2002) argue that similar analyses reflecting the public good values of water sources are essential to help stakeholders make well-informed management decisions to assure water of good quality. Because high standard contingent valuation studies are both money and time consuming, they highlight the potential for benefit transfer to conduct CBAs at sites with no primary data.

3.2 Contributions to the literature

The most important contribution of this study is that it will add to the scarce literature assessing costs and benefits of water protection measures, which is essential to enable well-informed and economically motivated decisions about water protection measures. Not at least to address distributional effects causing substantial conflicts in water management. Also, much of the existing research focuses exclusively on the valuation of good quality drinking water supply and not on the non-market benefits of protecting groundwater sources. By identifying all services provided by surface and groundwater sources, the total economic value of drinking water sources could be considered in decisions regarding drinking water protection. The classification system developed in this study will give contributions in this matter, as well as the attempt to identify and value the effect on groundwater services through a case study.

4 Cost-Benefit Analysis

In this chapter, the purpose and motivation for conducting CBA to evaluate policies and projects are described. The chapter provides the conceptual basis of CBA and the methodological steps required to perform the analysis.

4.1 Purpose and motivation for conducting CBA

The effects on society from expanding the water protection area and imposing stricter protection regulations will be evaluated using CBA. It is a method aiming to support social decision-making (Boardman et al., 2014), as it helps decision-makers to define costs and benefits from various policies (Johansson and Kriström, 2016). The specific objective of a CBA is to allocate the scarce resources of society efficiently, or as efficient as possible (Boardman et al., 2014). When performing a CBA, all impacts of a policy to every member of society is (as far as possible) quantified in monetary terms. The procedure involves identifying and sorting all impacts affecting human well-being as benefits or costs, valuing them economically and assessing the net benefits relative to status quo. The more precise definition is *net social benefits* (NSB), i.e. social benefits (B) minus social costs (C). There are different types of CBAs, and in this study, an *Ex ante CBA* will be performed. An *Ex ante CBA* gives immediate assistance in decisions regarding whether to allocate society's resources to a specific project or policy as it is executed before the decision about implementation (Boardman et al., 2014).

4.2 Theoretical Framework

The conceptual basis for CBAs is the objective to accomplish *allocative*, or Pareto, *efficiency* – a key concept in modern welfare economics (Alan Yeakley et al., 2016). Pareto efficiency is achieved if no alternative allocation of goods can be made such that at least one person is made better off, without making anyone else worse off. If there is an alternative allocation to status quo, which would generate this outcome, it would be a Pareto improvement. A Pareto improvement, relative to status quo, could be obtained if a policy yields net social benefits (Boardman et al., 2014). Then it is possible to find a set of payment transfers which would compensate those who bear the costs of the policy, making no one worse off and at least one person better off.

In real life, the Pareto criterion is rarely fulfilled, and policies generally have both winners and losers (Johansson and Kriström, 2016). Instead, CBAs usually follow the *Kaldor-Hicks criterion* as a decision rule; only adopt policies that generate a *potential Pareto improvement* (Boardman et al., 2014). The Kaldor-Hicks criterion provides a basis for the CBA decision rule to only undertake a policy if its *net social benefits are positive* because then it is *hypothetically* possible to compensate the losers (Johansson and Kriström, 2016). Following this criterion, water protection areas should be established as long as overall society is made better of due to, e.g. higher viability of services provided by the drinking water sources. However, it is important to have the concept of Pareto efficiency in mind for the discussion of compensation to those who bear the costs from implementing water protection areas as the Kaldor-Hicks criterion undertakes a rather strong ethical assumption (Johansson and Kriström, 2016).

When a market is *allocatively efficient*, the social surplus is maximised (Boardman et al., 2014). In a perfectly competitive market, this is accomplished by the market process itself. On the other hand, when institutions and behaviour deviate from *ideal* circumstances, the market fails to provide an efficient allocation causing a *market failure* (Perman et al., 2011). Market failure is a crucial concept in environmental economics and a strong argument for promoting policy intervention to protect drinking water sources. Because there is no market for most surface and groundwater services provided by water sources, except for the commodity "water for drinking", too little of them might be produced compared to what is allocatively efficient. This is the case because many of these services are *public goods*, which means that once they are produced they are free for everyone to enjoy, resulting in the absence of economic incentives for the private sector to produce such goods and services (Boardman et al., 2014). Without government intervention, nothing or too little is produced. As a result, the social surplus is not maximized, which constitutes a strong argument for establishing water protection areas.

4.3 Conducting a CBA

When conducting a CBA, at least two different alternative projects must be considered (Boardman et al., 2014). If no alternative project is relevant, the comparison is made between the single project and status quo. The two alternatives analysed in this study are: *expansion of a water protection area with a set of new more restrictive regulations, or no expansion of the water protection area.*

Those with standing are households within the water supply area as they are the ones directly benefiting from the groundwater source. Not imposing the new demarcations and protection regulations will be referred to as *the reference alternative*. Not implementing the protection measure could be equivalent to status quo, or it could result in a degradation of the groundwater services. In this analysis, the costs and benefits of maintaining the good quality of the drinking water source (protection measure alternative) are compared to the costs and benefits of proceeding business-as-usual, which implies a risk of degraded drinking water quality and provision of groundwater services (reference alternative). A strong motivation for choosing the CBA methodology is that it addresses the expected distribution of benefits and costs, which is important when imposing regulations which affect several stakeholders.

Performing a CBA includes going through nine major steps which help to structure and manage the analysis (Boardman et al., 2014). The nine main steps are displayed in Table 1. The classification system is an integral part of step (3) to be able to include impacts on groundwater services from the water protection measure. The process of developing the classification system is described in Appendix 1.

Table 1. The nine main steps to perform a cost-benefit analysis of projects and policies

The nine main steps of a CBA
1. Specify the set of alternative projects.
2. Decide whose benefits and costs count (standing).
3. Identify the impact categories, catalogue them, and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project.
5. Monetize (attach dollar values to) all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation.

The decision rule for deciding whether to implement a project relative to status quo is: *adopt the project if its net present value (NPV) is positive* (Boardman et al., 2014). To calculate the NPV, future costs and benefits are discounted to obtain present values. Discounting is necessary due to people's preference for consumption today rather than in the future (Boardman et al., 2014). Adding weight to the discounting of future generations is also legitimate if we assume economic growth such that future generations will be richer compared to the current one (Johansson and Kriström, 2016). The NPV is calculated as

$$(1)\ NPV = \sum_{t=1}^{T} \frac{B_t}{(1+r_t)^t} - \sum_{t=1}^{T} \frac{C_t}{(1+r_t)^t}$$

where T is the lifetime of the specific project, B_t and C_t are costs and benefits that occur in time t and r_t is the SDR at time t. The literature about which SDR to choose is broad and contains several contradictory opinions (see chapter 5.6 for discussion). The European Commission recommends a SDR of 3% for social analyses within the Member States of the EU (European Commission, 2014), and the choice of real SDR in this CBA is 3%, following the recommendation of the European Commission.

Even though the ultimate decision rule is straightforward in a CBA, economic valuation of many significant impacts could be both problematic and litigious (Boardman et al., 2014). For most cases, people's WTP to attain or avoid the impacts of a policy can be derived from market demand curves. Valuation of environmental impacts on the other hand usually presents a great challenge. Because well-functioning markets for most environmental outputs are absent, people's WTP cannot be decided through market behaviour, therefore, indirect market valuation methods are generally applied to value environmental goods. These are either revealed preference methods or stated preference methods (Boardman et al., 2014). With revealed preference methods, WTP is determined from observed behaviour. Usual methods based on reveal preferences are hedonic pricing and the travel cost method. The most common stated preference methods are choice experiments or contingent valuation, where people value environmental goods and services through survey questionnaires.

In a CBA, the net sum of all WTP estimates for a policy of those with standing corresponds to the policy's total economic value (TEV) (OECD, 2018). The TEV could be divided into *use*, and *non-use values* and both must be considered when conducting a CBA (Johansson and Kriström, 2016). Use values are obtained from current, planned or possible use of a good or service, whereas non-use values are either in the form of existence, bequest or altruistic values (OECD, 2018). One significant advantage of stated preference studies is that it is possible to discover such non-use values people obtain from environmental goods and services, which usually do not leave a behavioural trace (Boardman et al., 2014).

When primary studies are either absent, unachievable or too expensive benefit transfer is a valuable tool to elicit values of environmental goods and services (Johnston et al., 2015). Primary studies are by most academics considered as the best way to provide information for policy decisions, but when necessary, benefit transfer is the second-best option (Johnston et al., 2015). Benefit transfer also improves the impact of primary research by expanding their relevance to other settings and time frames. It both provides policymakers with a tool for well-informed analyses of policies and other decisions as well as improving the gains from investing in primary valuation studies. The benefit transfer tool will be used to conduct the CBA in this study as it does not include performing a primary valuation study.

4.4 Limitations of CBA

As is the case for all methods, CBA entails several limitations. A significant limitation is that it might not be possible to quantify and assign monetary values to all impacts identified in the analysis (Boardman et al., 2014). To remediate this problem, impacts which are not possible to monetise should be described in qualitative terms such that the analyst could determine whether the inclusion of these costs or benefits would alter the outcome of the CBA. Another issue is that only a limited number of policy alternatives could be considered in a CBA, resulting in a risk of excluding policy alternatives which could have yielded higher NSB (Boardman et al., 2014). Scholars and philosophers have also criticised the fundamental utilitarian assumption in CBA, which is that the sum of all individuals' utility should be maximised and that it is reasonable to make trade-offs in terms of gains and losses between individuals.

Because monetising benefits generally is the most challenging task in a CBA, an alternative approach is cost-effectiveness analysis (Boardman et al., 2014). This method allows the analyst to compare the ratio of quantified benefits to the total monetary cost to determine which policy alternative is the most cost-effective. Unlike CBA, this approach does not enable the analyst to conclude that the most cost-effective option is also the most efficient one. Another method where monetisation of impacts is not required is multigoal analysis, where different policy options are compared based on relevant goals.

5 Case study

The case study area is a location in the Southern part of Sweden with a groundwater source used for drinking water supply. The reference alternative in the case study is to keep the current water protection area. The water protection measure alternative is to expand the water protection area and impose more restrictive protection regulations. The majority of the information about site-specific conditions, characteristics of the groundwater source, the drinking water supply system and surrounding hazards has been collected by e-mail correspondence with, and from investigations sent by, the person responsible for water and sewage at the municipality. All information has been obtained from the contact at the municipality unless else is stated. The consultancy Sweco (www.sweco.se) developed the proposed water protection regulations and performed the technical description of the groundwater source and its hydrological conditions and the risk assessments. An appraiser at another consultancy performed the investigations on compensation to farmers for profit losses. All investigations were performed on behalf of the municipality. Some information has been left out to keep the anonymity of the case study area to avoid provoking any conflicts regarding the proposed expansion of the water protection area.

5.1 Description of the case study area

The groundwater source is situated in a valley, 5 km outside of an urban centre with around 6500 inhabitants. The remaining settlements in the catchment area consist of smaller communities and rural areas. The case study location with the proposed demarcations for the new water protection area is displayed in Figure 1 below.

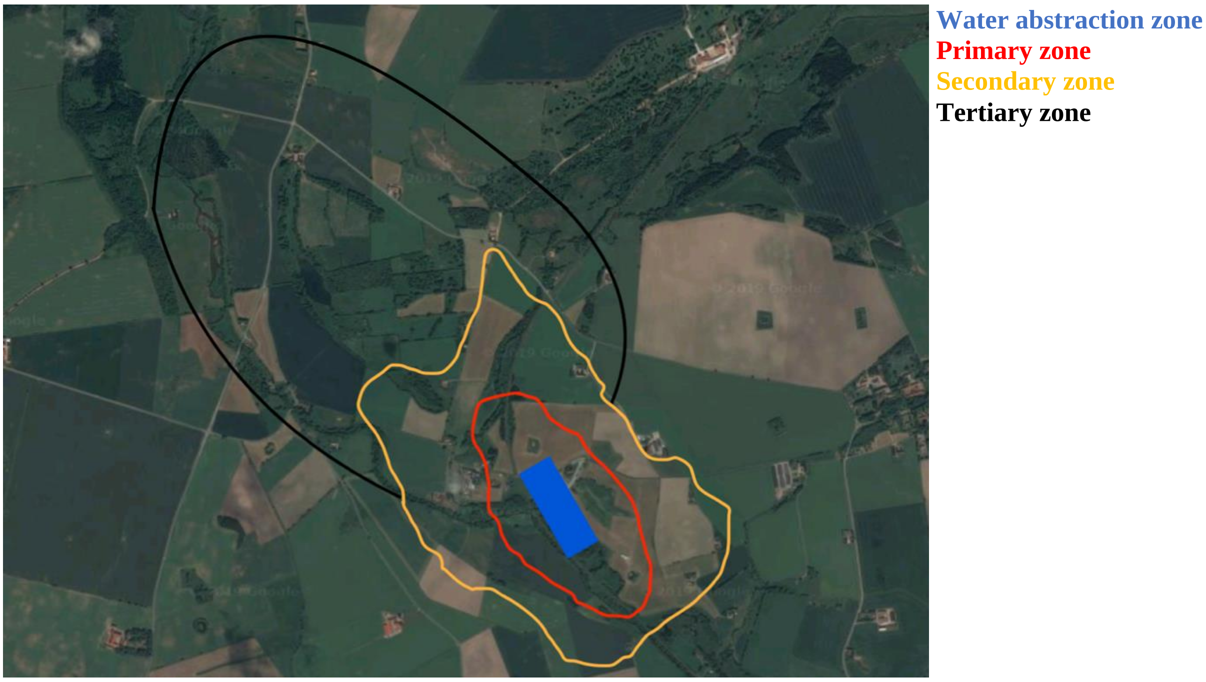

Figure 1. Approximate map of the case study area. The demarcations are not exact.

According to the technical description, the groundwater source lies in a marsh region with a wetland and unexploited land on its western side. The remaining parts of the valley are characterised by open land, pastures and smaller areas of arable land, with surrounding deciduous forests on its steep sides. Parts of the valley have high natural values, and vast regions north of the groundwater source are nature reserves and Natura 2000 areas due to its geological values and high biodiversity associated with, e.g. pastures, broad-leaved deciduous forests, swamp forest and wetlands.

A river runs from north to south throughout the valley, and three other additional rivers connect to it from west and east. The river, as well as the area around the groundwater source, is of national interest for nature conservation. There is a connection and a dependence between the surface and groundwater, but this relation is not fully elucidated. What could be concluded in the technical description is that the water level in the watercourses occasionally is lower than in the surrounding swelling sediment, resulting in induced leakage from the watercourses to the material in which the groundwater source is sited. The surrounding wetlands also depend on water supply from the groundwater source to some extent. The main activity in the catchment area, and around the groundwater source, is agriculture. There are some surrounding forested areas, but these are far away from the water abstraction zone, and the majority of the forests are not used for economic purposes.

5.2 Description of the reference alternative

The reference alternative of expanding the water protection area and impose stricter regulations is to maintain business-as-usual during the evaluation period of 40 years. This section explains the main activities in the case study area and their expected development in the reference alternative. These are activities which would be affected by the water protection measure.

The current water protection area was established in the late eighties and covers around 95 ha (information obtained from the website Water Information System Sweden (WISS), www.viss.lansstyrelsen.se). Because the water protection area was established before today’s guidelines, it only has a single protection zone except for the water abstraction zone, in which only abstraction activities are allowed. According to the current protection regulations, spreading of manure, animal urine and other fertilisers must not take place in larger quantities than is required from a fertiliser point of view. Remaining types of fertilisers, as well as animal pesticides and plant eradication agents, must only be used to the extent necessary for regular use of the agricultural property. Spreading of pesticides is only allowed by the current legislation for usage of chemical products. Stockpiles of toxins and other hazardous substances which are harmful to groundwater require permission from the regional Environmental and Health Care Agency, but this is common practice in Sweden.

According to the contact at the municipality, no alternative protection measures besides an expansion of the current water protection area have been considered or investigated, but one option would be to invest in new cleaning techniques. As pesticide use is the primary concern in the case study area, filters with activated carbon could be installed in a future scenario with critical contamination levels in the untreated water, but this alternative implies other severe risks and costs related to, e.g. malfunctions, programming and maintenance. There are also substantial non-use values connected to naturally clean water (Hasler et al., 2007), which would be lost from this alternative measure. On the other hand, we cannot know for certain that the groundwater source would become contaminated by pesticides by proceeding business-as-usual. To account for this uncertainty, the probability of contamination occurring *without* imposing the water protection measure is assumed to be once during the next 100 years (see 5.7.3 for probability reasoning).

Climate change is an exogenous factor which could harm the drinking water supply in a future scenario. According to the estimations of SMHI (2015) the summers in the most southern parts of Sweden will become warmer and dryer and the winters warmer and wetter. Annual precipitation is expected to increase with 15-25% until the end of 2100, compared to the reference period of 1961-1991. Winter runoffs will be higher and the season with lower flows extended. More intense rainfalls will cause an increased risk of flooding along with pressure on existing risk sources which could give rise to, e.g. increased contaminant dispersion. Higher temperatures and annual precipitation also affect groundwater levels, but it is difficult to predict the exact effects of a future climate (Sydvatten, 2014). Depending on the type of soil, groundwater levels could increase by up to 25% or decrease with 10%. The weather alterations will result in changed conditions for the drinking water supply, but these effects are hard to predict and are not considered in this analysis.

5.2.1 Drinking water supply

The groundwater source in the case study area consists of four wells, and the annual water extraction is approximately 3 million m^3 (information obtained from the municipality's website). The groundwater source provides drinking water to the urban centre with 6 500 inhabitants, another city with around 30 000 inhabitants and several other larger villages. The groundwater is extracted from a depth of 25 m and subsequently cleaned through a purification process with several steps in a water treatment plant. Finally, it is supplied via pumps to the water consumers. The water treatment plant provides around 22 500 persons with drinking water from the groundwater source of analysis (information obtained from the municipality's website). The drinking water is used for food, drink, bath, shower, toilet and irrigation.

The groundwater source is judged to have a very high protection value[4], as it constitutes the main public water supplier for the city, the urban centre and the villages in this region (SEPA, 2010). There are two backup groundwater sources if the current groundwater source were to be unfit for drinking water supply. However, since the distribution nets are not entirely composed to enable pumping of both raw water and treated water back and forth between the sources, they are not enough to fully cover today's abstraction need without additional investments.

5.2.2 Agricultural activities

Seven farmers own or are tenants to ten properties with agricultural businesses within the proposed water protection area, and the total amount of agricultural land is 113 ha. One farmer has non-organic dairy production, one has beef cattle production, and the remaining farmers solely have crop production. The value of the current agricultural operations is assessed based on milk prices, beef cattle prices and estimated yields and prices from crop production. Expected future price developments are also considered.

According to investigations[5] with estimations of profit losses for farmers affected by the new protection regulations (obtained from the contact at the municipality), the crop rotation within the primary zone is composited as per Table 2. The appraiser collected data on yields, absolute prices (henceforth referred to as prices) and production costs from Agriwise (ww.agriwise.se),

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[4] This is the second highest value class out of four different classes (SEPA, 2010).

[5] The investigations were carried out to calculate profit losses for the farmers in the case study area as a basis for compensation. They were performed by a professional appraiser on behalf of the municipality. Names and all personal details about the farmers were anonymised in the investigations.

a farm tool for economic planning and analysis. The information on prices, costs and yields from the investigations were used in this analysis. The prices from the investigations were converted to new prices for 2018, by using the agricultural output price index and the costs by using the agricultural input price index, obtained from the Swedish Board of Agriculture (SJV, n.d.). Contribution margins were rounded off to integers.

Due to lack of data on the exact type of crop per hectare within the secondary and tertiary zone (see section 5.3), it is assumed that the crop rotation is the same in these zones since the natural preconditions are very similar, and several farmers have cultivations in two or all zones. Ley (used to produce silage) is cultivated on 50% of the land (56.5 ha) and the other crops are cultivated on the remaining 50% (56.5 ha) one year each in a four-year crop rotation cycle. One farmer grows winter rye in addition to the other crops.

Table 2. Crop rotation, yields, absolute prices, production costs and contribution margins in the case study area (Source: Investigations on profit losses obtained from the contact at the municipality)

Crop	Yield (kg/ha)	Absolute price (SEK/kg)	Revenues/ha (SEK)	Direct costs (SEK/ha)	Contribution margin (SEK/ha)[a]
Winter wheat	9 500	1.33	12 640	6 966	5 674
Spring barley	7 100	1.20	8 510	4 521	3 989
Winter rye	8 400	1.29	10 807	6 150	4 657
Winter rape	4 300	3.34	14 374	7 360	7 014
Maize silage	9 000	1.70	15 340	10 445	4 894
Silage	7 000	1.76	12 865	4 940	7 925

[a] Net after direct production-related costs have been deducted.
[b] Includes 500 SEK/ha in environmental support for cultivating ley.

Prices in SEK per 100 kg (2018 values) for non-organic milk, fattened calf[6] and young male cattle[7] are displayed in Table 3. There is no data over annual milk deliveries from the dairy farmer or annual slaughter from the beef cattle farmer, but these are assumed to be constant throughout the evaluation period for the reference alternative.

Table 3. Absolute prices for non-organic milk, fattened calf and young male cattle (Source: the Swedish Board of Agriculture's database. Absolute agricultural prices, SEK per 100 kg)

Product	Absolute price (SEK per 100 kg)
Non-organic milk (actual fat content)	376
Fattened calf	2619
Young male cattle	3 273

Based on a thorough analysis of historical and forecasted price developments of agricultural commodities (see Appendix 3), the real price of winter wheat, spring barley and winter rye is assumed to decrease with 1% each year over the evaluation period. From the analysis of price development during recent years and a price forecast made by FAO and OECD (2018), milk prices could be expected to increase during the evaluation period, and beef cattle prices decrease, but due to lack of historical data, a sufficient prognosis could not be made. Annual prices for silage, maize silage and winter rape are also assumed to remain constant due to the same reasons and because different measurement techniques have been applied when collecting price data historically.

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[6] Slaughtered at the age of 8-11 months (Svenskt Kött, n.d.-b).

[7] Meat from male cattle older than 12 months (Svenskt Kött, n.d.-a).

Annual yields typically fluctuate depending on exogenous factors such as weather conditions without specific upwards or downwards trends, hence yields are assumed to remain the same during the evaluation period. The effects of climate change described in 5.2.l may affect agricultural activities positively in terms of, e.g. longer cultivation seasons, but these effects are judged as too uncertain to be included in this analysis. This could result in an under-estimation of yields over the evaluation period.

5.2.3 Groundwater services

Activities affected by the water protection measure, in turn, influence the condition and supply of other groundwater services, besides “water for drinking”, which are important to include such that the TEV of the groundwater source is considered. As the case study area does not have any surface water sources for drinking purposes, only groundwater services are examined. Groundwater services supplied by the groundwater source are presented in Table 4. They have been identified based on the technical description of the water source and its hydrogeological conditions and the classification system of surface and groundwater services (Appendix 1). It is possible that the groundwater source provides other services, which could not be identified based on the material available.

Table 4. Groundwater services supplied by the groundwater source

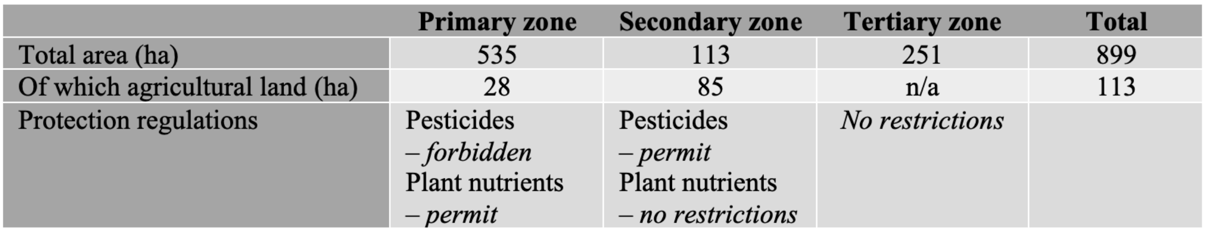
Groundwater service	Type of service	Description	Reference
Water for drinking	Abiotic service	The groundwater source supplies inhabitants with good quality drinking water (see 5.2.1).	CICES (2018)
Maintaining populations and habitats	Ecosystem (biotic) service	Aquatic organisms are an essential part of ecosystems and the food chain. Habitats are, e.g. important as nurseries for organisms.	Grizzetti et al. (2018)
Water supply in groundwater dependent seepage areas	Ecosystem (biotic) service	The wetland in the case study area is partly dependent on the supply of water from the groundwater source.	Tuinstra and van Wensem (2014)
Non-use values (existence and bequest)	Ecosystem (biotic) service and abiotic service	These are, e.g. values related to securing future use of the groundwater, the use of future generations or the value associated with the assurance of sufficient protection of the groundwater, without any plans on utilising it.	CISES (2018)

5.3 Description of the protection measure alternative

The motivation for expanding the water protection area is that the Swedish River Basin District Authorities have introduced a new Programme of Measures as a consequence of the EU water framework directive. The Programme states that all water protection areas established before the introduction of the Environmental Code must be reviewed to ensure adequate protection. Another purpose is to protect the drinking water from pesticide contamination, which constitutes a risk due to the extensive agriculture. The decrease in hectares with pesticide-intensive crops such as cereal and oilseeds have been considerably lower in the most southern parts of Sweden compared to the rest of the country and pesticide use in kg/ha is higher compared to other regions (HaV, 2014). However, no water quality measurements of the raw water from the groundwater source indicate anthropogenic influence or pesticides levels above current target values.

The proposed total water protection area is 899 ha, which includes 113 ha of agricultural land. The zoning is found in Table 5 and has been defined based on how many days it would take a specific pollutant to travel from the outermost part of the zone to the water source. The lifetime of the water protection area, interpreted as the time before it needs to be updated, is 40 years. This time horizon is chosen based on information about the lifetime of this type of water protection measure, obtained from the database Water Information System Sweden (WISS, www.viss.lansstyrelsen.se).

Table 5. Zoning, agricultural land and regulations within the proposed water protection area



	Primary zone	**Secondary zone**	**Tertiary zone**	**Total**
Total area (ha)	535	113	251	899
Of which agricultural land (ha)	28	85	n/a	113
Protection regulations	Pesticides *– forbidden* Plant nutrients *– permit*	Pesticides *– permit* Plant nutrients *– no restrictions*	*No restrictions*	

According to the new protection regulations, spreading of pesticides is forbidden in the primary zone. Spreading and handling of pesticides in the secondary zone requires a permit. Spreading of plant nutrients requires a permit in the primary zone, but not in the secondary zone. Exceptions apply for those farmers operating within the primary zone who have permits for animal keeping regulated by the Environmental Code which includes land for spreading of manure from the animals. Because it is unknown whether the farmers with animals also use commercial fertiliser for their crop production, it is presumed that they have to seek a permit for spreading of plant nutrients as well. There will not be any protection regulations in the tertiary zone.

It is assumed that permit applications are required per farmer, and not per property, and that the farmer needs two separate permits for spreading of pesticides and plant nutrients. A permit may be associated with special conditions which the farmer must follow for the permit to be valid (SEPA, 2010), but for this analysis a permit will imply permission for spreading of pesticides and plant nutrients according to business-as-usual. The permit requirements allow the municipality to monitor the use of pesticides and plant nutrients to ensure these activities are carried out without risk of contamination to the groundwater source. The regional Environmental Confederation (Miljöförbundet) manages all permit applications.

The protection regulations include additional paragraphs regulating other activities in the catchment area, but these pose a relatively low risk to the groundwater source (information collected from risk assessments obtained from the contact at the municipality). Hence, even though this analysis explicitly focuses on the agricultural sector, the effect on these other activities from the protection measure is probably negligible.

5.4 Impacts of the protection measure alternative

Table 6 lists the activities which will be affected by expanding the current water protection area and imposing stricter protection regulations. The drinking water supply and other groundwater services are expected to be positively affected by the new regulations, whereas the agricultural sector is expected to be negatively affected. Benefit and cost items associated with these impacts are identified in Table 7. Benefits are protection of good quality drinking water and reduced risks to other groundwater services related to restricted pesticide use. The agricultural sector will experience costs in terms of reduced profits due to restrictions on pesticide use, and administrative costs related to permit applications.

Table 6. Activities affected by the protection measure relative to the reference alternative. (+) implies positive impact and (–) implies negative impact

Activity	Impact
5.2.1 Drinking water supply	(+)
5.2.2 Agricultural activities	(–)
5.2.3 Groundwater services	(+)

Table 7. Cost and benefit items from implementation of the water protection measure relative to the reference alternative

Costs	Benefits
Administrative costs	Protection of good quality drinking water
Reduced profits in the agricultural sector	Avoided risks from pesticide use

5.5 Quantification

This chapter describes how the different cost and benefit items associated with the protection measure alternative were quantified.

5.5.1 Administrative costs

The new protection regulations will imply administrative costs for the farmers who have to apply for permits. The four farmers with crop production in the primary zone will need a permit to spread plant nutrients within this zone, and since all seven farmers have some production in the secondary zone, they all have to apply for permits to spread pesticides. Administrative costs are quantified based on information from a recent report evaluating costs and benefits from establishing a water protection area on Gotland (Sweco, 2017). Because of the comprehensiveness of the applications, farmers generally hire a consultant to make the applications. The regional Environmental Confederation subsequently decide whether to grant permission or not. On average, a permit application is expected to require six hours of work and the administrator at the Environmental Confederation is expected to need four hours to administrate the application and make a decision. It is assumed that the permits have to be renewed every third year (Sweco, 2017).

5.5.2 Reduced profits in the agricultural sector

Reduced profits were quantified based on the information from the investigations on profit losses to farmers obtained by the contact at the municipality, but the method for calculating the profit losses have some differences in this analysis and assumptions made do not necessarily reflect the ones in the investigations. The reason for these differences is that a CBA is performed from a societal perspective and has other assumptions as a basis, and the results of the analyses are not to be compared with each other.

According to the investigations, the most likely scenario is that the farmers within the primary zone, who are prohibited from using pesticides, will switch to a crop rotation with three years of ley (to produce organic silage) followed by one year of fallow. This cycle is assumed to continue throughout the evaluation period and will result in lower yields per year, enhanced due to one year of fallow. The annual yield is 4400 kg/ha.

5.5.3 Protection of good quality drinking water

The quantification of this benefit was made based on the daily consumption of drinking water from the groundwater source, which is suggested as a relevant indicator of this groundwater service by Grizzetti et al., (2016). Daily consumption of drinking water amounts to 160 litres/person/day for a total of 22 500 persons.

5.5.4 Avoided risks from pesticide use

To quantify the impact on ecosystem services identified by a classification system, the effect on ecosystems' capacity to supply ecosystem services must be clarified in biophysical terms with proper indicators (TEEB, 2010). However, guidelines for choosing good indicators for assessing ecosystem services are still lacking, resulting in inconsistent assessments (Hattam et al., 2015). When the functioning of, and the interdependence between, ecosystem services are poorly understood, as is the case at the location of analysis, the challenge to find adequate indicators is aggravated (Hattam et al., 2015). Due to these issues, the impact on all groundwater services was valued jointly, except for effect on drinking water supply (see 5.5.3).

The value was assessed from peoples WTP to avoid risks to groundwater by reducing pesticide use in the agricultural sector. The value was assumed to be provided to all households within the water supply area, which is approximately 10 227, obtained by dividing 22 500 (water consumers) by 2.2 (average number of persons per household in Sweden, SCB, n.d.). The number of households who are willing to pay to reduce environmental and health risks from pesticide use could be larger than the people receiving drinking water from the groundwater source, hence the estimated benefit could be regarded as a minimum value.

5.6 Discount rate

To evaluate the annual impacts of imposing the protection measure alternative, a central step is to decide which weights to apply to the impacts occurring each year of analysis (TEEB, 2010). By applying weights to all impacts throughout the evaluation period, it is possible to compare the costs and benefits appearing in the future, to the costs and benefits arising today. The decision about the proper set of weights to apply is carried out by selecting a SDR. This choice is of absolute importance when conducting a CBA (TEEB, 2010). Depending on the level of the SDR, the outcome of the CBA and thus the recommendation whether to implement the project or policy, could vary substantially.

Choosing the right SDR is especially challenging regarding environmental projects and policies, since they usually have a long lifetime with impacts taking place far into the future (Boardman et al., 2014). A high SDR severely disfavours projects with benefits occurring far in the future, and costs in the beginning of its lifetime. Hence, it is commonly argued that a declining SDRs over time is more ethical, especially for environmental projects such as reforestation and restoration of ecosystems, where benefits from an investment are realized many years ahead. A declining SDR also gives more weight to future generations (Arrow et al., 2014). Because of the importance and uncertainty associated with the choice of SDR, it is necessary to evaluate the outcome of the CBA depending on different levels of discount rate. In the base scenario of this study, a discount rate of 3% will be applied in accordance with the recommendations of the European Commission (2014). For the sensitivity analysis, the effect of SDRs of 1,5% and 6% will be evaluated, following the suggestion of Johansson and Kriström (2016).

5.7 Valuation

In this chapter, costs and benefits from the protection measure alternative are monetised. That is, expanding the current water protection area to 899 ha and imposing more restrictive regulations. The evaluation period is 40 years, and all values are discounted to the base year 2018 with a 3% SDR. All costs and benefits are expected to occur at the end of every year, except for administrative costs which are assumed to incur at the beginning of every third year.

5.7.1 Administrative costs

Administrative costs were monetised based on hourly consulting rates for managing permit applications and hourly charges for administrating applications (Table 8). All price data was retrieved from the Sweco report (2017)[8]. The PV of administrative costs is SEK 774 233 (calculations in Appendix 2).

Table 8. Work time, price per hour and price per permit for consultancy and administration (Source: Sweco, 2017)

	Time (h)	Price (SEK/h)	Price/permit
Consultant	6	800	4 800
Administrator	4	900	3600

5.7.2 Reduced profits in the agricultural sector

To elicit new 2018 values for organic silage, the same procedure was performed as in the reference alternative (Table 9). To calculate the costs for the agricultural sector, profits from crop production in the reference alternative were compared to the profits from crop production in the protection measure alternative. Based on the analysis in section 5.2.2, the real prices of winter wheat, spring barley and winter rye are assumed to decrease with 1% each year over the

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[8] The authors of the report collected the hourly rates and charges from The Rural Economy and Agricultural Societies and Region Gotland (Sweco, 2017)

evaluation period. Annual yields are assumed to remain constant. Winter rye was excluded from the crop rotation cycle in the reference alternative since only one farmer cultivates this cereal, and its contribution margin is similar to the contribution margins of the other grains. The production of milk and the cattle beef production are not expected to be affected by the protection measure and will continue business-as-usual. Since spreading of pesticides is the primary concern in the case study area, all farmers are assumed to be granted permission for spreading of plant nutrients within the primary zone (spreading of plant nutrients in the secondary zone will not require a permit). However, it is uncertain whether permits will be issued for pesticide use in the secondary zone. Pesticide use in the primary zone will be completely forbidden.

Table 9. Yield, absolute price, production cost and contribution margin from crop production in the protection measure alternative (Source: Investigations on profit losses obtained from the contact at the municipality)

Crop	**Yield (kg/ha)**	**Absolute price (SEK/kg)**	**Revenues/ha (SEK)**	**Direct costs (SEK/ha)**	**Contribution margin (SEK/ha)[a]**
Organic silage	4400	1.76	7741	2453	5838[b]

[a] Net after direct production-related costs have been deducted.

[b] Includes 500 SEK/ha in environmental support for cultivating ley.

The estimated present value (PV) of total profit losses for crop production in the primary zone is SEK 1 235 682, calculated by subtracting the profits in the reference alternative from the profits in the protection measure alternative. If the farmers operating in the secondary zone are not granted permission for spreading of pesticides, additional profit losses are incurred. In that case, the PV of total profit losses for crop production in the secondary zone is SEK 3 751 178 (assuming the farmers switch to the crop rotation with three years if ley and one year of fallow).

Because it is uncertain whether the farmers will be granted permits for using pesticides in the secondary zone, a Monte Carlo simulation was performed in Excel. Monte Carlo simulations model the probability of different outcomes to understand the uncertainty of forecasting models (Boardman et al., 2014). The essence of the Monte Carlo analysis is to play games of chance many times to obtain a distribution of outcomes, from which an expected value can be estimated. The purpose of the Monte Carlo analysis is to elicit the expected value of profit losses for crop production in the secondary zone.

The profit losses were estimated by a lognormal probability distribution, with a 95% confidence interval, and a 3% SDR. The lognormal probability distribution was chosen because the most likely scenario is that all farmers are granted permits, but we do not know this for certain. This probability distribution is positively skewed, giving more weight to outcomes with low profit losses. The simulation was performed by entering a “best guess value” for each year of evaluation. Also, values which were considered to correspond to the 2.5 percentile and the 97.5 percentile were specified for each year of evaluation. The values inserted in Excel were derived from the calculations of administrative costs and profit losses for the agricultural sector, expressed in SEK per year (see Appendix 1 for input data). The "best guess value" is equivalent to the mode (the “top”) of the probability distribution.

The best guess was that all farmers are granted permits for spreading of pesticides in the secondary zone. Hence, the “best guess value” for each year corresponded to the annual cost for applying for permits (administrative costs) plus annual profit losses in the primary zone. Since the farmers only have to apply for permits every third year, average administrative cost for each year was calculated, which is SEK 30 800 per year. The values inserted for the 97.5 percentiles each year was the highest reasonable annual profit loss for the agricultural sector, which equals annual cost for permit applications (administrative costs) plus annual profit losses in the primary zone plus maximum annual profit losses in the secondary zone. The simulation was run with 10 000 trials resulting in an expected discounted total profit loss of SEK 696 251. This PV was obtained by subtracting the PV of profit losses in the primary zone and the administrative costs. By adding the PV of profit losses in the primary zone and the PV of profit losses in the secondary zone, a PV of SEK 1 931 933 was obtained for the total cost in terms of profit losses. All calculations are found in Appendix 2.

The probability distribution of outcomes from the Monte Carlo simulation is displayed in Figure 2. The outcomes are the PVs of total profit losses for the agricultural sector in the protection measure alternative, which includes profit losses in the primary zone, the secondary zone and administrative costs. The y-axis is probability, and the x-axis is PV.

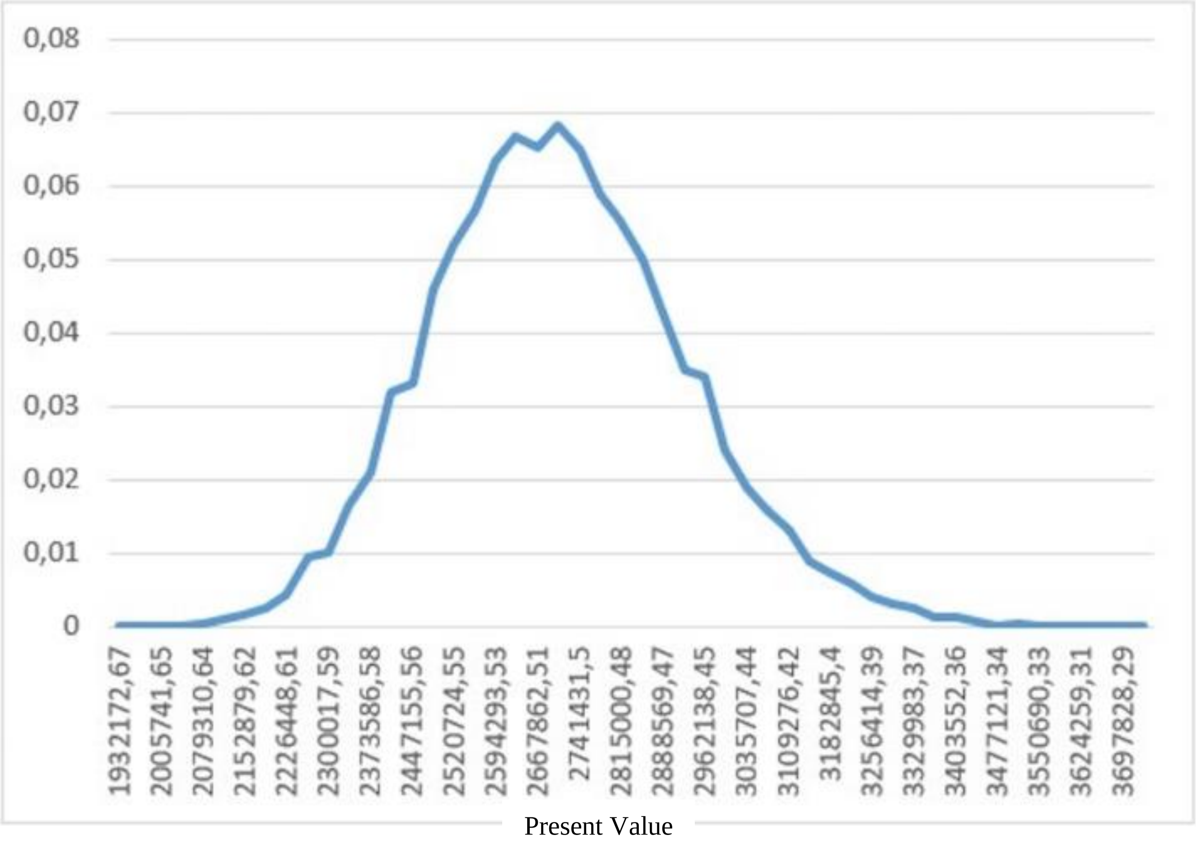

Figure 2. Probability distribution of outcomes from the Monte Carlo simulation.

5.7.3 Protection of good quality drinking water

The direct valuation method was applied to value the benefit of protecting the groundwater source's provision of good quality drinking water. The value of the drinking water was calculated via the drinking water rate paid by the drinking water consumers. The rate is SEK 17.29 per m^3 (information collected from the municipality's website), resulting in a WTP of SEK 1010 person/year. With 22 500 water consumers, the annual (undiscounted) benefit from the groundwater source's drinking water is around SEK 22.7 million.

We cannot know for certain that this drinking water value would be lost without establishing the expanded water protection area with more restrictive regulations. To account for this uncertainty, the drinking water value lost, if a pesticide contamination takes place, is calculated. It is assumed that a contamination would prevent the groundwater source's provision of drinking water during the remaining years of evaluation. A contamination taking place in e.g. year 1 is assumed to contaminate the drinking water source in year 1, and for the rest of the 39 years. In the scenario with contamination in year 1, the total PV of the drinking water would be lost. The protection measure alternative is assumed to protect the groundwater source from contamination throughout the evaluation period.

The benefit of the protection measure depends on the probability of a contamination taking place. If it is anticipated contamination would doubtlessly take place in one of the 40 years, without imposing the water protection measure, the probability of contamination occurring during the evaluation period is 100%. Since it is forecasted to be just as likely that contamination would happen in either one of the years, the average PV of possible outcomes was calculated. Presuming a contamination would take place during the 40 years, without imposing the protection measure, a benefit of SEK 218 594 115 is obtained ($\sum_{i=1}^{40} PV_i/40$). If it instead is expected that a contamination would take place once in 500 years, the probability of a contamination occurring during the 40 years is only 8%, $(\sum_{i=1}^{40} PV_i * 0{,}08)/40$, which implies a PV of SEK 17 487 529. Table 10 lists various PV of protecting the good quality of the drinking water depending on the probability of contamination. In these scenarios, only costs incurring during the evaluation period are accounted for, since it is assumed that a new evaluation period will start when this one ends (in 2058). Then a new valuation has to be conducted based on the, possibly, new circumstances regarding risks to the groundwater source.

Table 10. PV of benefits from protecting the drinking water by the protection measure, depending on probability of a contamination taking place

Time period during which contamination will occur once (years)	Probability that contamination occurs during the 40-year evaluation period	Benefit (SEK 2018)
40	100%	218 594 115
100	40%	87 437 646
200	20%	43 718 823
500	8%	17 487 529

It is not possible to determine the actual risk of contamination during the evaluation period, but based on the information available and motivation for establishing the expanded water protection area, i.e. pesticide contamination risk, a probability of 40% is applied in the base case scenario, $(\sum_{i=1}^{40} PV_i * 0{,}4)/40$, yielding a PV of SEK 87 437 646.

5.7.4 Avoided risks from pesticide use

The positive effect on the other groundwater services; “maintaining populations and habitats“, “water supply in groundwater dependent seepage areas” and “non-use values” was monetised based on people’s WTP to avoid risks to groundwater from pesticide use in the agricultural sector. The estimate for people’s WTP is transferred from a contingent valuation study performed in the USA by Mullen et al. (1997). The motivation for this approach is that pesticides are known to constitute the greatest risk to the groundwater source, and WTP estimates for protecting groundwater sources could vary significantly depending on the type of pollutant considered (Brouwer and Neverre, 2018). The estimate was judged decent for benefit transfer as socioeconomic factors of the surveyed population were similar to the ones with standing in this analysis, as well as the survey scenario. The authors also state the estimates allow for benefit transfer to other case studies.

The survey was sent out to a random sample of 3 000 US citizens throughout the country, and the respondents were asked to state their WTP to avoid high, moderate or low pesticide risks to groundwater by an increase in the monthly grocery bill (Mullen et al., 1997). The risk levels were determined based on soil leaching ratings, which accounts for both soil and specific pesticide characteristics, produced by the US Department of Agriculture’s Soil Conservation Service. The low-risk scenario was assumed comparable to the reference alternative in this analysis to calculate the benefit from avoided pesticide risks to groundwater. The respondents’ WTP was interpreted as the WTP to ensure the state and provision of the identified groundwater services. The estimated WTP/household/year was SEK 290 (converted to SEK in 2018 values by using PPP and CPI, calculations in Appendix 2).

Contingent valuations studies are able to capture the TEV of environmental goods, both use and non-use values (Boardman et al., 2014). This implies a risk of counting the use value of the service “water for drinking” (see 5.7.3) twice if the WTP from Mullen et al. (1997) is transferred without taking this into consideration (even though drinking water was not mentioned in either the survey or the study). To minimise the risk of double counting, only the fraction of the WTP estimate educed to non-use values of protecting groundwater from pesticide risks is included. The average of two different estimates of the WTP fraction associated with non-use values, from two contingent valuation studies, was used. Kaoru (1993) investigated the value of water quality improvements for three coastal ponds in Massachusetts (USA) and appraised the non-use value to constitute 60% of the TEV. Tentes and Damigos (2012) elicited the TEV of restoring the quality and quantity of the Asopos river basin aquifer in Greece. A fraction of 31% was assigned to bequest values for assuring good quality groundwater accessibility to future generations, and 29% was assigned to existence values for accomplishing good quality groundwater accessibility to preserve natural ecosystems. The average of these two fractions equals 64.5%, [(60+69)/2]. The WTP estimate of SEK 290 was multiplied with 0,645 to calculate the annual WTP to avoid pesticide risks to the non-use values of the groundwater, i.e. the identified groundwater services besides the use value “water for drinking”, which is approximately SEK 187/household/year.

The total benefit was calculated by multiplying the annual WTP of SEK 187 with the number of households in the water supply area, which is 10 227, resulting in a PV of SEK 44 177 061 from avoided pesticide risks to the groundwater services.

5.8 Results

The results in the base case scenario CBA (3% SDR) and results from the sensitivity analysis with 1.5% and 6% SDRs are shown in Table 11. The NPV of the protection measure is positive for all SDR, and the NPV in the base case scenario is around SEK 128.9 million. The benefit per person in the base case scenario is around SEK 5 800, assigned to the 22 500 drinking water consumers and the cost per person for the seven farmers is around SEK 387 000.

Table 11. Costs, Benefits, and NPVs with 1.5% SDR, 3% SDR (Base Case Scenario) and 6% SDR (2018 values)

	1.5% SDR	**3% SDR**	**6% SDR**
Costs (SEK)			
Administrative costs	983 397	774 233	526 278
Reduced profits in the agricultural sector	2 408 263	1 931 933	1 335 852
Total Costs	*3 391 660*	*2 706 166*	*1 862 130*
Benefits (SEK)			
Protection of good quality drinking water	125 925 540	87 437 646	45 666 019
Avoided risks from pesticide use	57 175 304	44 177 061	28 756 554
Total Benefits	*183 100 844*	*131 614 707*	*74 422 573*
NPV (SEK)	**179 709 184**	**128 908 541**	**72 560 443**

6 Analysis

There are a lot of uncertainties and several omitted factors which could have affected the outcome of the CBA. A potential cost for the agricultural sector which was omitted is investments in agricultural facilities, whose value would be foregone if the facility cannot be used due to restrictions on agricultural activities. The protection measure entails additional administrative costs for the municipality in terms of payments to consultancies for performing the different assessments and investigations, but including these cost items are not expected to have altered the positive NPV. However, if the profit losses for the farmers are substantial enough, the consequence of the protection measure could be that the farmers have to stop their production completely, i.e. enter bankruptcy. This would imply much higher costs for the agricultural sector and possibly for other people of society who would be WTP to retain vivid Swedish agriculture.

This CBA only included positive effects on groundwater services, but several other natural values are expected to be positively affected by the decrease in pesticide use. These are related to the wetland and the river running through the catchment area and terrestrial ecosystem services such as pollination from bees, recreational activities and habitats for species. Including these positive environmental effects are important to capture the total economic value of water protection measures, and it would have resulted in a higher PV of benefits. Accounting for population growth, which increases the demand for good quality drinking water, would also have affected the benefits positively.

Uncertainties in the analysis are most substantial regarding the benefit valuations. The water rate was used to value the drinking water supply, but this price is not derived from a perfectly competitive market. The municipalities have a natural monopoly on public drinking water services in Sweden, meaning they set the water rate (Svenskt Vatten, 2017). Typically, a monopoly would result in a higher market price, but due to regulations in the Public Water Supply and Wastewater Systems Act (SFS 2006:412), revenues from the water services are not allowed to exceed necessary costs. The rate is therefore set such that it covers operating- and maintenance costs (Svenskt Vatten, 2016). Water consumers could be willing to pay more than this water rate for the provision of good quality drinking water, which would have been captured by a contingent valuation study. On the other hand, a competitive market for public drinking water supply services could push down production costs, resulting in a lower market price for drinking water.

Preferably an average WTP from several valuation studies would have been used to value the positive impact on the other groundwater services. A thorough literature search was carried out to accomplish this intention and over 35 articles were screened, but it was not achievable due to the lack of and different approaches between valuation studies. For example, many studies focus on remediation of a contaminated groundwater source, whereas protection of an uncontaminated groundwater source was relevant in this case study. According to Brouwer and Neverre (2018), who performed a meta-analysis on groundwater quality valuation studies, people's WTP is higher for groundwater remediation compared to protection. Another issue is that WTP estimates from American valuation studies generally are higher compared to the ones in European studies (Brouwer and Neverre, 2018). The estimated WTP for the protection measure in this CBA was compared with the mean WTP in Brouwer and Neverre (2018) (based on 14 European groundwater quality valuation studies) to check the estimate's reasonableness. The estimated WTP for both drinking water (SEK 1010/household/year) and avoided risks from pesticide use (SEK 187/household/year) was SEK 1 197 household/year in this analysis. The mean WTP in the meta-analysis was SEK 1 649 household/year, ranging from minimum SEK 280 household/year to maximum SEK 7906 household/year. One reason for the considerable variation in estimates is because some studies only consider drinking water supply, while some include other values, as does this study.

The most substantial uncertainty regarding the benefit valuations is whether pesticides would pollute the groundwater source if the protection measure is *not* imposed. The assumption in the base case scenario was that a contamination, making the drinking water unusable, would take place once during the next 100 years if the expanded water protection area is not established. If we instead assumed a contamination would only happen once in 500-years, the PV of the drinking water value would still be SEK 17 487 529, resulting in a positive NPV. According to the risk assessment (obtained from the contact at the municipality), spreading of pesticides poses a high risk to the groundwater source. Pesticide usage near the groundwater source is expected to take place once a year or more often, and the consequence if pesticides reach the groundwater source is judged to be significant. Pesticides reaching the groundwater is expected to result in unusable drinking water or a prolonged deterioration of raw water quality. However, this risk assessment also entails many uncertainties and was only used as guidance in this study.

7 Conclusion and discussion

The aim of this study was to contribute to enabling informed and economically motivated management decisions about water protection areas and other water protection measures, and to address distributional effects of such measures. Benefits in terms of enhanced protection and secured provision of good quality drinking water and other groundwater services were compared to costs for the agricultural sector. The protection measure alternative was concluded as profitable compared to the reference alternative with a NPV of SEK 128.9 million.

CBAs evaluating costs and benefits of specific water protection measures are relatively scarce, especially concerning water protection areas, making it difficult to evaluate the reasonableness of the results. The high NPV of establishing the expanded water protection area, SEK 128.9 million, could potentially be subject to questioning. However, it is relatively modest compared to the NPV of USD 95.2 million, obtained in the CBA of preserving the water quality level in the Catawba River basin, conducted by Eisen-Hecht and Kramer (2002). The discrepancy between the NPVs depends on many factors, but one reason is that the number of people dependent on the drinking water source significantly affects the benefits of imposing water protection measures. In this CBA, the number of people who benefited from the protection measure was 22 500, whereas it was around 540 000 people in the study by Eisen-Hecht and Kramer (2002). Another reason is the great variation in data available and local preconditions between case studies, resulting in different approaches to value water quality, which was also concluded by Griffiths et al. (2012).

In this study a classification system was developed to enable policymakers to identify and value services provided by drinking water sources to support water management decisions. However, it was concluded challenging to identify which services were provided by the groundwater source in the case study area and even more so to evaluate the protection measure's physical effect on these services. This relationship could not be resolved from the material available. To enable identification of services provided by specific drinking water sources, more comprehensive investigations about the exchange between surface water, groundwater and terrestrial ecosystems are required. To subsequently be able to determine the impact on these services from various water protection measures, an enhanced understanding of the relation between land uses, hydrology and water quality will be critical, which has also been argued in previous literature (Bateman et al., 2006; Postel and Thompson, 2005).

Developing the applicability of the classification system, together with identifying or conducting adequate valuation studies of surface and groundwater services, will enable their value to be included in real-world decisions. This is not only important to motivate water protection measures, but also to prioritise which drinking sources to protect and how. In this CBA, only the groundwater service “water for drinking” could be valued separately, whereas the three other services identified were valued jointly. Therefore, the WTP to protect the groundwater services would have been the same, even if the groundwater source provided, e.g. two or nine services. As a result, the value of the groundwater source only depends on the number of people with standing. Alternative analytical frameworks which do not require monetisation of benefits associated with the protection of groundwater services are cost-effectiveness analysis and multigoal analysis (Boardman et al., 2014). However, these methods would still require quantification of the groundwater services, which was equally troublesome in this case study. Also, these methods do not allow for comparison between all costs and benefits of water protection measures (Perman et al., 2011) and do thereby not contribute as much as CBA to more thorough economically motived water management decisions.

In conclusion, better water management practices will undoubtedly become even more essential in a future with an uncertain supply of good quality drinking water. Assigning a significant value to this groundwater service could indeed be motivated, especially when considering the effects of climate change, which are expected to put pressure on the demand for good quality drinking water (Brouwer and Neverre, 2018). At the same time, policymakers must keep a holistic view of society to avoid imposing water protection measures at the expense of a few individuals.

8 Recommendation

The recommendation based on the CBA conducted in this study is to establish the expanded water protection area with its more restrictive regulations. Distributional effects should however be appropriately addressed to mitigate conflicts related to water protection measures and to facilitate disbursement of compensation to individuals bearing the costs. This will result in a more efficient allocation of social benefits of water protection measures to society.

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Appendices

Appendix 1: Classification System

Surface and groundwater services

There are several classification systems to apply to identify and assess ecosystem services. Some standard works are: Millennium Ecosystem Assessment (MA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010) and Common International Classification of Ecosystem Services (CICES, 2018). The systems have some fundamental similarities, as well as differences in terms of approach and categorisation. In this study, surface and groundwater services were classified based on the latest version of CICES (V5.1, 2018) with adjustments to fulfil the aim of this particular classification system. CICES was chosen due to its international status and because the Swedish Environmental Protection Agency uses this system as a basis for their ecosystem catalogue (SEPA, 2017). CICES defines ecosystem services as "*the contributions that ecosystems make to human well-being*", and focuses on final ecosystem services dependent on living systems (CICES, 2018). The intention is to emphasise the indispensable contribution of biodiversity and ecosystems to human well-being, and that is why abiotic services have a separate listing in the latest version of CICES (V5.1, 2018).

Because many services provided by surface and groundwater sources have physical characteristics without a biotic component, thereby not essentially considered ecosystem services, ecosystem services could be treated as a subset of all services provided by surface and groundwater source, as suggested by Söderqvist et al. (2014). This study follows this characterisation and refers to both ecosystem (biotic) services and abiotic services as *surface and groundwater services*. The suggested definition of these services is equivalent to the one of CICES (2018), namely *"the contributions that surface and groundwater services make to human well-being".* The motivation for the characterisation is to include all values drinking water sources generate to people in terms of services and to simplify the classification system's applicability for local and regional authorities. A distinction of biotic and abiotic services could be hard to grasp in situations involving several stakeholders and non-experts (CICES, 2018), as is commonly the case for management of drinking water sources, in particular because of the intricate and continuous interaction between biotic and abiotic components of nature (van Ree et al., 2017). Also, exclusion of abiotic services neglects their economic value, and they are not sufficiently addressed in policy decisions (van der Meulen et al., 2016). The classification system should be considered as work-in-progress material for further research.

Method

The classification system was developed based on scientific articles and reports covering surface water services, groundwater services and geosystem (abiotic) services. In accordance with CICES, only the categories: *provisioning*, *regulating and maintenance* and *cultural services* were accounted for. For the literature using other classification systems, the category of *supporting services* was excluded, and the remaining services under the other categories were adopted into the categories of CICES. The procedure started with identifying all services in CICES, both ecosystem and abiotic services, which was deemed relevant for surface and groundwater drinking sources. The same procedure was performed for the Swedish Environmental Protection Agency's ecosystem service catalogue to make sure no services relevant for Swedish drinking water sources were left out. The literature search for groundwater services set out from the report "*The ecosystem services of groundwater and their economic values – an initial survey"*, written by Söderqvist et al. (2014) for the Geological Survey of Sweden. For surface water services, the report "*Ecosystem services from Swedish lakes and streams*" published by the Swedish Agency for Marine and Water Management (2017) and "*Ecosystem services of streams and rivers*" written by Alan Yeakley (2016), served as a basis. The geosystem services were listed based on two important scientific papers within this study area, authored by Gray et al. (2013) and van Ree et al. (2017).

In the subsequent step of the literature review, a systematic search in the search engine Google Scholar was carried out to screen for other relevant articles. This was done to ensure that the final list of surface and groundwater services was exhaustive. The search words used in Google Scholar was: "groundwater services", "water services", "surface water services" and "water ecosystem services". Interesting articles were downloaded, scrutinised and screened for any listing of relevant services as well as other useful references mentioned in the article. The literature review on Google scholar resulted in three additional articles for further investigation, two on groundwater services by Griebler and Avramov (2015) and Tuinstra and van Wensem (2014) and one on ecosystem services in water by Grizzetti et al. (2016). All lists were then copied into an excel sheet. With the ecosystem services and abiotic water services from CICES as a foundation, all other unique services from the complete list of services from all references were picked out and put into a table. Duplicates were removed. The last steps consisted of categorising services relevant for surface or groundwater drinking sources or both and choosing how to express them. Some identical services, but from different literature, had different denomination. For these, one way of expressing the service was chosen, taking into account the purpose of the classification system in the context of drinking water protection. CICES was preferred as a reference whenever possible.

Description

All services potentially relevant for surface and groundwater drinking sources are listed in the left-most column. The other columns indicate whether the service is relevant for groundwater sources, surface water sources or both. Type of service and reference is also given. Abbreviations used in the listing are explained below.

SWS – Surface water source
GWS – Groundwater source
ESS – Ecosystem (biotic) service
Abiotic – Abiotic service

Classification System of Surface and Groundwater Services

Provisioning

Service	SWS	GWS	Type	Author
Food (aquatic or groundwater dependent organisms)	S		ESS	HaV 2017
Food (terrestrial organisms)	S		ESS	HaV 2017
Food (groundwater dependent ecosystems)		G	ESS	Griebler and Avramov 2015
Oxygen (groundwater dependent ecosystems)		G	ESS	Griebler and Avramov 2015
Genetic resources (medicines and cosmetics)	S	G	ESS	HaV 2017
Biomaterials (e.g. algae as fertilizers)	S		ESS	Grizzetti et al. 2016
Materials for energy (e.g. firewood, salix, animal fat)	S		ESS	Grizzetti et al. 2016
Mineral substances used for nutrition, materials or energy	S	G	Abiotic	CICES 2018
Water for drinking	S	G	Abiotic	CICES 2018
Water used as a material (non-drinking purposes)	S	G	Abiotic	CICES 2018
Water used as an energy source	S	G	Abiotic	CICES 2018
Replenishment of aquifers		G	Abiotic	Söderqvist et al. 2014
Geothermal heat/energy		G	Abiotic	CISES 2018
Construction materials (e.g. stone, brick, aggregates, steel, cement, bitumen, slates, glass).		G	GSS	Gray et al. 2013
Industrial minerals (e.g. fertilisers, pharmaceuticals, metals, alloys)		G	GSS	Gray et al. 2013
Ornamental products (e.g. gemstones, precious and semiprecious metals)		G	GSS	Gray et al. 2013

Regulating and maintenance

Service	SWS	GWS	Type	Author
Regulation of the chemical condition of freshwaters by living processes	S	G	ESS	CICES 2018
Erosion prevention	S		ESS	Grizzetti et al. 2018
Flood protection	S	G	ESS	Grizzetti et al. 2018
Drought attenuation	S	G	ESS	Griebler and Avramov 2015
Maintaining populations and habitats	S	G	ESS	Grizzetti et al. 2018
Pest and disease control	S		ESS	Grizzetti et al. 2018
Regulation of toxic substances	S		ESS	Grizzetti et al. 2018
Soil formation and composition	S		ESS	Grizzetti et al. 2018
Climate and atmospheric regulation	S		ESS	HaV 2017
Regulation of temperature and humidity	S		ESS	CICES 2018
Groundwater as a storage medium for heat or coolness		G	ESS	Tuinstra and van Wensem 2014
Maintain groundwater level and prevent subsidence		G	ESS	Tuinstra and van Wensem 2014
Water supply in groundwater dependent surface water regimes		G	ESS	Tuinstra and van Wensem 2014
Water supply in groundwater dependent seepage areas		G	ESS	Tuinstra and van Wensem 2014
Maintenance of hydraulic conductivity		G	ESS	Griebler and Avramov 2015
Regulation of the water cycle (infiltration/exfiltration)		G	ESS	Griebler and Avramov 2015
Dilution by freshwater	S	G	Abiotic	CICES 2018
Water quality regulation (e.g. soil and rock as natural filters)		G	GSS	Gray et al. 2013

Cultural				
Service	SWS	GWS	Type	Author
Tourism and recreation	S		ESS	HaV 2017
Tourism and recreation in e.g. caves and water springs		G	ESS	Griebler and Avramov 2015
Religious, spiritual and symbolic appreciation	S	G	ESS	Grizzetti et al. 2014
Aesthetic values and artistic inspiration	S	G	ESS	HaV 2017
Science and education incl. bioindication	S	G	ESS	HaV 2017
Natural heritage	S	G	ESS	HaV 2017
Preservation of cultural–historical values (e.g. traditional foods and handcraft) and archeological finds	S	G	ESS	Tuinstra and van Wensem 2021
Non-use values (existence, bequest)	S	G	ESS	CISES 2018
Abiotic characteristics of nature that provide cultural services	S	G	Abiotic	CISES 2018
Artistic inspiration (e.g. geology in sculpture, literature, music, poetry, painting).	S	G	Abiotic	Gray et al. 2013

Appendix 2: Calculations

Profit losses, crop production from section 5.7.1

Table A1. Price development, 1% decrease in real prices for winter wheat, spring barley and winter rye

Year	Winter wheat	Spring barley	Winter rye	Winter rape	Maize silage	Silage	Organic silage
1	1.33	1.20	1.29	3.34	1.70	1.76	1.76
2	1.32	1.19	1.27	3.34	1.70	1.76	1.76
3	1.30	1.17	1.26	3.34	1.70	1.76	1.76
4	1.29	1.16	1.25	3.34	1.70	1.76	1.76
5	1.28	1.15	1.24	3.34	1.70	1.76	1.76
6	1.27	1.14	1.22	3.34	1.70	1.76	1.76
7	1.25	1.13	1.21	3.34	1.70	1.76	1.76
8	1.24	1.12	1.20	3.34	1.70	1.76	1.76
9	1.23	1.11	1.19	3.34	1.70	1.76	1.76
10	1.22	1.09	1.18	3.34	1.70	1.76	1.76
11	1.20	1.08	1.16	3.34	1.70	1.76	1.76
12	1.19	1.07	1.15	3.34	1.70	1.76	1.76
13	1.18	1.06	1.14	3.34	1.70	1.76	1.76
14	1.17	1.05	1.13	3.34	1.70	1.76	1.76
15	1.16	1.04	1.12	3.34	1.70	1.76	1.76
16	1.14	1.03	1.11	3.34	1.70	1.76	1.76
17	1.13	1.02	1.10	3.34	1.70	1.76	1.76
18	1.12	1.01	1.08	3.34	1.70	1.76	1.76
19	1.11	1.00	1.07	3.34	1.70	1.76	1.76
20	1.10	0.99	1.06	3.34	1.70	1.76	1.76
21	1.09	0.98	1.05	3.34	1.70	1.76	1.76
22	1.08	0.97	1.04	3.34	1.70	1.76	1.76
23	1.07	0.96	1.03	3.34	1.70	1.76	1.76
24	1.06	0.95	1.02	3.34	1.70	1.76	1.76
25	1.05	0.94	1.01	3.34	1.70	1.76	1.76
26	1.03	0.93	1.00	3.34	1.70	1.76	1.76
27	1.02	0.92	0.99	3.34	1.70	1.76	1.76
28	1.01	0.91	0.98	3.34	1.70	1.76	1.76
29	1.00	0.90	0.97	3.34	1.70	1.76	1.76
30	0.99	0.90	0.96	3.34	1.70	1.76	1.76
31	0.98	0.89	0.95	3.34	1.70	1.76	1.76
32	0.97	0.88	0.94	3.34	1.70	1.76	1.76
33	0.96	0.87	0.93	3.34	1.70	1.76	1.76
34	0.95	0.86	0.92	3.34	1.70	1.76	1.76
35	0.95	0.85	0.91	3.34	1.70	1.76	1.76
36	0.94	0.84	0.91	3.34	1.70	1.76	1.76
37	0.93	0.83	0.90	3.34	1.70	1.76	1.76
38	0.92	0.83	0.89	3.34	1.70	1.76	1.76
39	0.91	0.82	0.88	3.34	1.70	1.76	1.76
40	0.90	0.81	0.87	3.34	1.70	1.76	1.76

New prices/revenues/costs in 2018 values

Absolute prices for 2017 (Table A1) were calculated to new absolute prices for 2018 (Table A2) with the agricultural output price index. Formula: (A-index2018/A-index2017) * Absolute price 2017=Absolute price 2018). Revenues for 2018 were calculated by multiplying the new absolute prices for 2018 (SEK/kg) with yields (kg/ha). Direct production costs were calculated to new direct production costs for 2018 with the agricultural input price index. Formula: (PM index2018/PM-index2017) * Direct production costs 2017=Direct production costs 2018). Contribution margins were calculated by subtracting annual direct production costs from annual revenues. Annual contribution margins for winter rape, maize silage, silage and organic silage are constant, whereas the contribution margins decrease every year for winter wheat and spring barley because of 1 % annual decrease in real absolute prices.

Table A2. Crop rotation data, 2017 values

Crop	Yield (kg/ha)	Absolute price (SEK/kg)	Revenues/ha (SEK)	Direct production costs (SEK/ha)	Contribution margin (SEK/ha)
Winter wheat	9500	1.21	11 495	6513	4982
Spring barley	7100	1.09	7739	4227	3512
Winter rye	8400	1.17	9828	5750	4078
Winter rape	4300	3.04	13 072	6881	6191
Maize silage	9000	1.55	13 950	9766	4184
Silage	7000	1.6	11 700	4619	7081
Organic silage	4400	1.6	7540	2293	5247

Table A3. Agricultural output price index and agricultural input price index for 2017 and 2018 (Source: the Swedish Board of Agriculture's database. Price index with base year 2015=100)

	2017	2018
A-index	109.33	120.22
PM-index	101.47	108.53

Table A4. Crop rotation data, new 2018 values

Crop	Yield (kg/ha)	Absolute price (SEK/kg)	Revenues/ha (SEK)	Direct production costs (SEK/ha)	Contribution margin (SEK/ha)
Winter wheat	9500	1.33	12 640	6966	5674
Spring barley	7100	1.20	8510	4521	3989
Winter rye	8400	1.29	10 807	6150	4657
Winter rape	4300	3.34	14 374	7360	7014
Maize silage	9000	1.70	15 340	10 445	4894
Silage	7000	1.76	12 865	4940	7925
Organic silage	4400	1.76	8291	2453	5838

Table A5. Contribution margins (SEK/ha) for a 4-year crop rotation period in the reference alternative, and for a 4-year crop rotation period in the protection measure alternative. The last column shows the difference between the two alternatives i.e. annual profit loss

Year	**50% not silage**	**50% silage**	**Average (50% not silage, and 50% silage)**	**Organic silage**	**Annual profit loss (SEK/ha) due to water protection area**
1	5393	7925	6659	4379	2280
2	5340	7925	6632	4379	2254
3	5288	7925	6606	4379	2227
4	5236	7925	6580	4379	2201
5	5184	7925	6555	4379	2176
6	5134	7925	6529	4379	2150
7	5083	7925	6504	4379	2125
8	5034	7925	6479	4379	2100
9	4984	7925	6455	4379	2076
10	4935	7925	6430	4379	2051
11	4887	7925	6406	4379	2027
12	4839	7925	6382	4379	2003
13	4792	7925	6359	4379	1980
14	4745	7925	6335	4379	1956
15	4699	7925	6312	4379	1933
16	4653	7925	6289	4379	1910
17	4607	7925	6266	4379	1887
18	4562	7925	6244	4379	1865
19	4518	7925	6221	4379	1843
20	4474	7925	6199	4379	1820
21	4430	7925	6177	4379	1799
22	4387	7925	6156	4379	1777
23	4344	7925	6134	4379	1756
24	4301	7925	6113	4379	1734
25	4260	7925	6092	4379	1713
26	4218	7925	6071	4379	1693
27	4177	7925	6051	4379	1672
28	4136	7925	6031	4379	1652
29	4096	7925	6010	4379	1632
30	4056	7925	5990	4379	1612
31	4016	7925	5971	4379	1592
32	3977	7925	5951	4379	1572
33	3939	7925	5932	4379	1553
34	3900	7925	5913	4379	1534
35	3862	7925	5894	4379	1515
36	3825	7925	5875	4379	1496
37	3788	7925	5856	4379	1477
38	3751	7925	5838	4379	1459
39	3714	7925	5820	4379	1441
40	3678	7925	5802	4379	1423

Table A6. Annual profit losses in the primary and the secondary zone without any pesticide use (primary zone=28 ha and secondary zone=85 ha)

Year	Annual profit loss, primary zone	Annual profit loss, secondary zone	Year	Annual profit loss, primary zone	Annual profit loss, secondary zone
1	63840	193800	**21**	50361	152881
2	63100	191553	**22**	49755	151043
3	62367	189328	**23**	49156	149223
4	61641	187126	**24**	48562	147422
5	60923	184945	**25**	47975	145638
6	60212	182787	**26**	47393	143873
7	59508	180650	**27**	46818	142125
8	58811	178534	**28**	46248	140395
9	58121	176440	**29**	45683	138681
10	57438	174366	**30**	45125	136985
11	56762	172313	**31**	44572	135306
12	56093	170281	**32**	44024	133644
13	55430	168269	**33**	43482	131999
14	54774	166277	**34**	42945	130369
15	54124	164305	**35**	42414	128757
16	53481	162353	**36**	41888	127160
17	52844	160420	**37**	41367	125579
18	52214	158507	**38**	40852	124014
19	51590	156613	**39**	40341	122465
20	50972	154737	**40**	39836	120931

Based on the calculations given in the tables above, the PV of profit losses in the primary zone is SEK 1 235 682 and SEK 3 751 178 for the secondary zone respectively, but the PV of profit losses in the secondary zone was estimated using a Monte Carlo simulation. Table A7 below shows the indata from the Monte Carlo simulation. The best guess value corresponded to annual average administrative cost (SEK 38 000) and annual profit loss in the primary zone. The value for the 97.5 percentile was the best guess value plus the maximum annual profit loss in the secondary zone.

Table A7. Indata, Monte Carlo simulation, profit losses of crop production in the secondary zone

Year	2.5 %ile	Best guess	97.5 %ile	Year	2.5 %ile	Best guess	97.5 %ile
1	0	94640	288440	**21**	0	81161	234042
2	0	93900	285453	**22**	0	80555	231598
3	0	93167	282495	**23**	0	79956	229179
4	0	92441	279567	**24**	0	79362	226784
5	0	91723	276669	**25**	0	78775	224413
6	0	91012	273799	**26**	0	78193	222066
7	0	90308	270958	**27**	0	77618	219743
8	0	89611	268145	**28**	0	77048	217442
9	0	88921	265361	**29**	0	76483	215165
10	0	88238	262604	**30**	0	75925	212910
11	0	87562	259875	**31**	0	75372	210678
12	0	86893	257173	**32**	0	74824	208468
13	0	86230	254499	**33**	0	74282	206280
14	0	85574	251851	**34**	0	73745	204115
15	0	84924	249229	**35**	0	73214	201971
16	0	84281	246634	**36**	0	72688	199848
17	0	83644	244065	**37**	0	72167	197746
18	0	83014	241521	**38**	0	71652	195666
19	0	82390	239003	**39**	0	71141	193606
20	0	81772	236510	**40**	0	70636	191567

Calculation of administrative costs from section 5.7.2

Table A8. Permits for spreading of pesticides

	Time (h)	Price (SEK/h)	Number of permits	Total cost	Frequency
Consultant	6	800	7	33 600	every 3rd year
Administrator	4	900	7	25 200	every 3rd year
Total cost				58 800	

PV of administrative costs for permit applications regarding pesticide use, assuming farmers apply for permits in the beginning of every 3rd year, is SEK 492 694.

Table A9. Permits for spreading of plant nutrients

	Time (h)	Price (SEK/h)	Number of permits	Total cost	Frequency
Consultant	6	800	4	19 200	every 3rd year
Administrator	4	900	4	14 400	every 3rd year
Total cost				33 600	

PV of administrative costs for permit applications regarding spreading of plant nutrients, assuming farmers apply for permits in the beginning of every 3rd year, is SEK 281 539. The PV of total administrative costs is SEK 774 233.

Valuation of protecting the drinking water supply from section 5.7.3

Table A10. General information, number of water consumers, drinking water consumption and charges

Item	Value	Unit
Number of water consumers	22 500	persons
Drinking water rate	17.29	SEK/m^3
Drinking water use	160	litres/day
	0.16	m^3/day
Persons/household in Sweden	2.2	persons
Drinking water cost/value	1009.736	SEK/person/year
Total cost/value	22 719 060	SEK/year

Description of how the values in Table A9 were calculated

First the annual (undiscounted) value of the drinking water was calculated (by using the drinking water rate of SEK 17.29/m^3). Annual cost (value) of the drinking water was obtained by multiplying: 22500 * 1009.736=22719060. Secondly, the value of the drinking water each year was discounted to PVs (base year=2018). It was assumed that the drinking water source could not be used in the future years of evaluation if a contamination takes place. To account for this, the sum of future drinking water value lost if a contamination takes place in one of the years was calculated (right-most column).

Table A11. Valuation of the drinking water used to calculate the NPV depending on the probability of contamination

Year	**Annual value, drinking water (SEK)**	**PV, drinking water value (SEK)**	**Value lost if contamination takes place (SEK)**	**Year**	**Annual value, drinking water (SEK)**	**PV, drinking water value (SEK)**	**Value lost if contamination takes place (SEK)**
1	22719060	22057340	525145891	**21**	22719060	12212614	187143647
2	22719060	21414893	503088552	**22**	22719060	11856907	174931033
3	22719060	20791158	481673659	**23**	22719060	11511560	163074126
4	22719060	20185591	460882500	**24**	22719060	11176272	151562566
5	22719060	19597661	440696910	**25**	22719060	10850750	140386294
6	22719060	19026855	421099249	**26**	22719060	10534708	129535544
7	22719060	18472675	402072394	**27**	22719060	10227872	119000836
8	22719060	17934636	383599719	**28**	22719060	9929973	108772964
9	22719060	17412268	365665083	**29**	22719060	9640750	98842991
10	22719060	16905114	348252816	**30**	22719060	9359952	89202240
11	22719060	16412732	331347701	**31**	22719060	9087332	79842288
12	22719060	15934692	314934969	**32**	22719060	8822652	70754956
13	22719060	15470574	299000277	**33**	22719060	8565682	61932304
14	22719060	15019975	283529703	**34**	22719060	8316196	53366622
15	22719060	14582500	268509728	**35**	22719060	8073977	45050426
16	22719060	14157767	253927228	**36**	22719060	7838812	36976449
17	22719060	13745405	239769461	**37**	22719060	7610497	29137637
18	22719060	13345053	226024056	**38**	22719060	7388832	21527139
19	22719060	12956362	212679003	**39**	22719060	7173624	14138307
20	22719060	12578993	199722640	**40**	22719060	6964683	6964683

Valuation of avoided risks from pesticide use from section 5.7.4

Table A12. Purchasing power parities (PPP) (Source: OECD’s database)

Currency	**PPP_{1992}**
USD	1
SEK	9.186

Table A13. Consumer price indexes for 1992 and 2018 (Source: Statistic's Sweden’s database)

CPI_{1992}	232.4
CPI_{2018}	328.4

Table A14. WTP/household and total WTP for all water consumers (rounded off to integers)

	WTP_{1992}	**WTP_{2018}**	**Non-use value of WTP_{2018}**	**Total WTP_{2018}/year**
USD	22.32			
SEK	205.03	290	187	1 911 205

WTP in SEK 2018 was obtained by using the PPPs (Table A10) and CPIs (Table A12).

Appendix 3: Analysis of the development in agricultural prices

Figure A1 shows the development in historical nominal prices from 1980 to 2017 for winter wheat, rye and barley. Fluctuations between 1980-2005 were relatively low, whereas the period 2005-2016 had a lot of fluctuations. Nominal prices in 2017 were almost back to the same levels as in the latter years of 1980 for all cereals. The nominal price for non-organic milk has also fluctuated to some extent between 2005-2016, now indicating an upward trend since the beginning of 2016 (right axis, Figure A2). Nominal prices for fattened calf and young male cattle have also had an upward trend over the last years, which now seems to have stagnated (left axis, Figure A2).

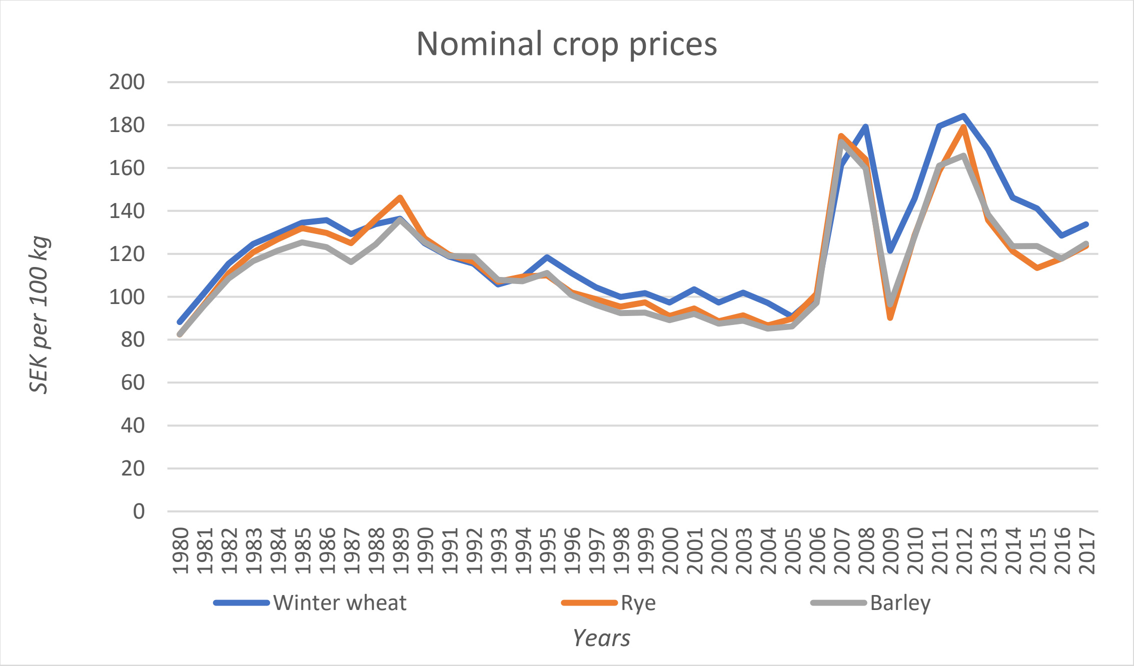

Figure A1. Development in absolute agricultural prices for winter wheat, rye and barley (Source: Statistics Sweden's database for 1980-2004 and the Swedish Board of Agriculture's database for 2005-2017. Absolute agricultural prices, SEK per 100 kg).

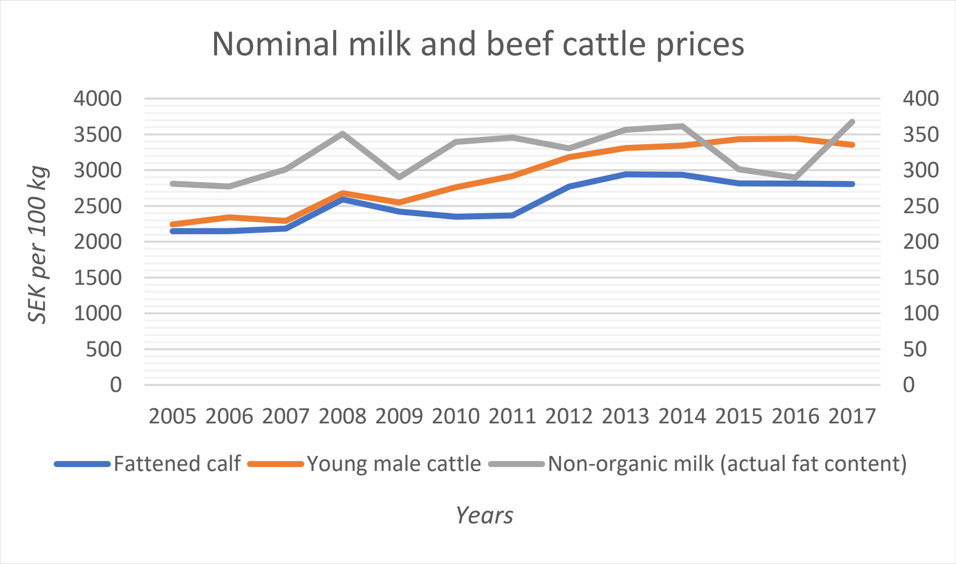

Figure A2. Development in absolute agricultural prices for non-organic milk (right axis) and fattened calf and young male cattle (left axis) (Source: the Swedish Board of Agriculture's database. Absolute agricultural prices, SEK per 100 kg).

Figure A3 shows the historical development in real prices for cereals, calculated with the agricultural output price index. The chart indicates a slight downwards trend from around 1985 to 2005, followed by the similar fluctuations observed in Figure A1. Real prices in 2017 were at the same level as prices in early 2000. Historical real price changes for fattened calf, young male cattle and non-organic milk (Figure A4) indicate a downward trend in beef cattle prices, but an upwards trend in non-organic milk prices, which started around 2016.

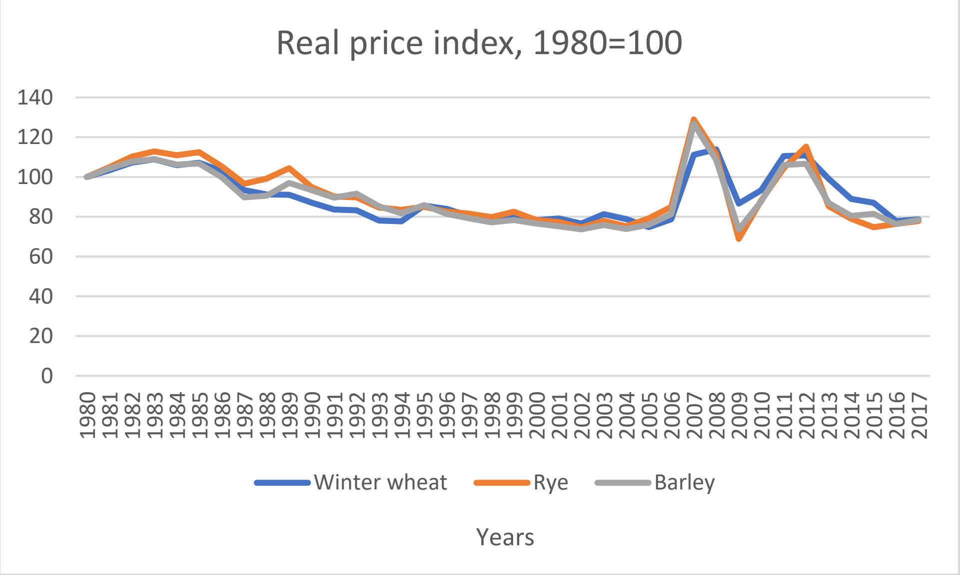

Figure A3. Fixed price development, adjusted with total A-index (1980 = 100), between 1980-2017 for the cereals winter wheat, rye and barley (Source: Author's own calculations based on data from Statistics Sweden's database and the Swedish Board of Agriculture's database. Agricultural Output Price Index (A-index)).

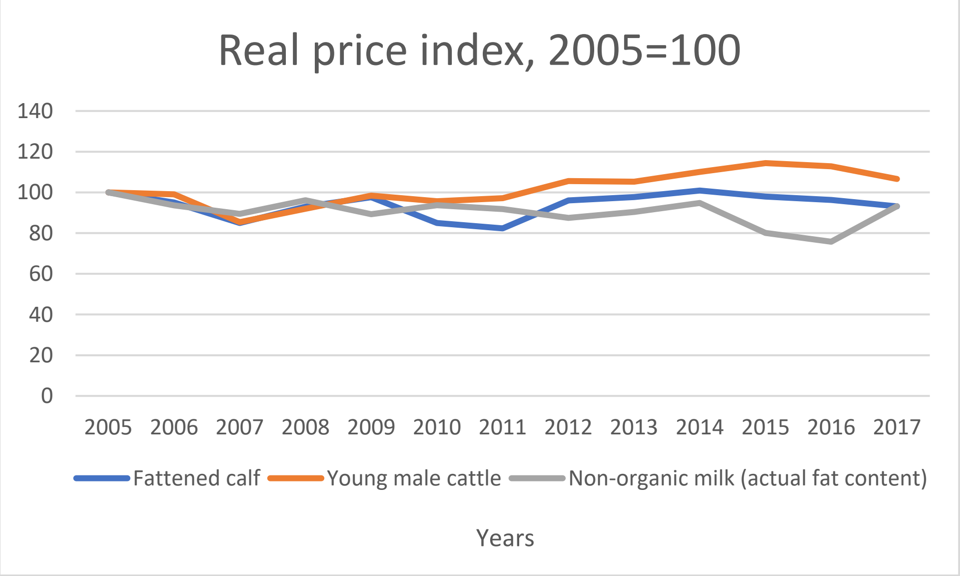

Figure A4. Fixed price development, adjusted with total A-index (1905 = 100), between 2005-2017 for fattened calf, young male cattle and non-organic milk (Source: Author's own calculations based on data from Statistics Sweden's database and the Swedish Board of Agriculture's database. Agricultural Output Price Index (A-index)).

Every year FAO and OECD collaboratively produce the report *Agricultural Outlook*, providing a prognosis on the development of the agricultural commodity market for the next decade (OECD/FAO, 2018). The prognosis is based on historical market data and input from various experts. According to the latest report which covers 2018-2027, global production has continued to grow steeply reaching record levels for many crops in 2017. However, the growth in Western Europe production is predicted to be much lower for the upcoming 10 years. The increase in global demand has also started to diminish and is expected to continue to decline during the next decade.

Consequently, prices of agricultural products are forecasted to remain at low levels. For several commodities, especially for staple foods[9] e.g. cereals, global consumption per capita is expected to remain unchanged. For meat products, the growth in demand is starting to weaken, whereas demand for other animal products e.g. dairy is expected to increase more rapidly until 2027. Overall, the real prices for wheat, maize, oilseeds (not soybean), vegetable oils, white sugar and raw sugar are expected to decrease 1-2% until 2017 (Figure A5, OECD/FAO, 2018, p. 54). The forecast is the same for pork and poultry, while the real price of beef and sheep is expected to decrease 2-3% annually. Increases in productivity mainly drive the reduction in prices. The price projections are performed based on registered prices at main markets and constitute international reference prices for the observed commodities.

The projected prices in the next years of analysis are still affected by recent occurrences such as droughts and policies, whereas the price development in the latter years of the period is driven by supply and demand forces (OECD/FAO, 2018). Factors such as population growth and income level affect demand, while production costs and weather conditions mainly affect the supply.

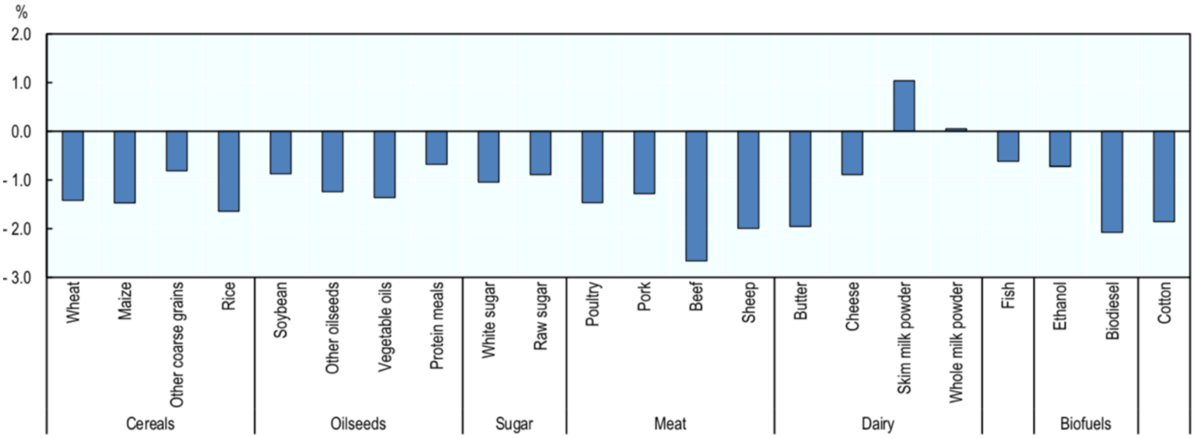

Figure A5. Average annual real price change for agricultural commodities, 2018-27 (Source: OECD/FAO, 2018. Agricultural Outlook 2018-2027. p. 54).

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[9] Staple foods dominate our regular diet and supply a large part of our energy and nutrient need (FAO, n.d.).