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# SUMMARY

This report is part of a research project funded by the Swedish Research Council Formas with support from RISE Research Institutes of Sweden, The Göteborg Region Association of Local Authorities (GR) and the City of Göteborg. The study was performed at the centre for drinking water research (DRICKS). The research project aims to develop a decision support model for sustainability assessments of regional water supply interventions and cooperations based on a combination of multi-criteria decision analysis (MCDA) and cost-benefit analysis (CBA). This report focuses on the CBA part of the model.

In the process of developing the model, five alternative water supply interventions for the Göteborg region were evaluated. By applying the decision model to alternatives focusing on establishing inter-municipal organizations, (de)centralization of water production, as well as source water quality and redundancy aspects, the model was tested for some common decision situations in the water supply sector. The application in the Göteborg region was a way to develop the model, and at the same time demonstrate and evaluate its feasibility. This report presents input parameters of the CBA for the alternative interventions.

For the Göteborg region, it was found that the alternative which comprised a regionalized governance and maintained semi-decentralized production had the highest probability of being the most profitable solution, whereas the alternative which comprised maintained governance with additional source waters and treatment plants had the second highest probability of being the best solution.

# CONTENT

# 1 INTRODUCTION

This report is part of a research project funded by the Swedish Research Council Formas with support from RISE Research Institutes of Sweden, The Göteborg Region Association of Local Authorities (GR) and the City of Göteborg, performed at the centre for drinking water research (DRICKS). The research project aims to develop a decision support model for sustainability assessments of regional water supply interventions and cooperations based on a combination of multi-criteria decision analysis (MCDA) and cost-benefit analysis (CBA).

In the process of developing the model, a case-study was performed evaluating five alternative water supply interventions for the Göteborg region. By applying the decision model to alternatives focusing on establishing inter-municipal organizations, (de)centralization of water production, and source water quality and redundancy aspects, the model was tested for some common decision situations in the water supply sector. The application in the Göteborg region was a way to develop the model and evaluate its feasibility. This report presents the application of the CBA in the Göteborg region.

## 1.1 Background

As part of a governmental initiative, the Swedish drinking water sectors was investigated between the years 2013 and 2016 with the aim of identifying current and potential challenges for a safe drinking water supply, and if necessary propose appropriate measures. The inquiry, (SOU, 2016), mentions several challenges for the Swedish water providers, including an ageing infrastructure, and effects of climate change and urbanization. In addition, several water providers are suffering from limited financial and personnel resources, reducing their ability to handle the challenges accordingly. To cope with present and future challenges and to uphold a safe and reliable water supply, the inquiry recommends a further regionalization of the Swedish water sector, including an increase of inter-municipal cooperations.

Municipalities, in several countries, have cooperated to improve their water supply provision for decades. In Sweden for example, about 35 percent of the water providers operate the water supply in some form of inter-municipal cooperation. There is, however, limited research focusing on a regionalized water supply provision, and hence a limited understanding of resulting effects (Frone, 2008; Kurki et al., 2016).

In order to support decisions on regional interventions, such as establishments of regional cooperations, a well-structured method to assess and compare societal effects of alternative interventions is needed. Cost-benefit analysis (CBA) is an acknowledged method to assess societal effects, allowing for evaluation of costs and benefits due to a changed provision of market goods and services as well as non-market ones (Johansson & Kriström, 2016). According to CBA, an intervention is considered economically profitable when its total benefits for society are larger than its total costs for society.

## 1.2 Aim and Objectives

The aim of this report is to present and apply a probabilistic cost-benefit analysis approach to assess costs and benefits that may arise from regional water supply interventions, including inter-municipal cooperations. Specific objectives are to: (1) present valuation methods of some key effects; and (2) exemplify the CBA approach by application in the Göteborg region in Sweden.

# 2 WATER SUPPLY ALTERNATIVES IN THE GÖTEBORG REGION

Five alternative interventions, Table 1, were evaluated for the Göteborg region in Sweden, which consists of 13 municipalities. The alternatives were evaluated over the time horizons 30 and 70 years, respectively, to study effects of choosing a shorter versus longer time horizon. The alternatives were analyzed for the constant discount rates of 1.4% and 3.5% (ASEK, 2016; Stern, 2006). A linear population growth was assumed from the year 2017 (year 1 in the analysis), when the region had about one million inhabitants, through the year 2050, when there will be about 1.3 million inhabitants according to municipal prognoses. Based on 2011 values, the drinking water production per capita was assumed to be constant over the evaluated time horizons, i.e. 250 L per capita and day (GR, 2014).

*Table 1 Description of alternative interventions evaluated for the Göteborg region*

| Alternative interventions | Description |
|---|---|
| A1: Regionalized governance & centralized production from lake Vänern | The entire region transforms to a centralized production system, in which Sweden's largest lake, Vänern, is the main source water. A 100 km long source water tunnel leads the water from Vänern to two treatment plants located in the City of Göteborg. The drinking water production is operated by a regional organization of cooperating municipalities. Costs associated with regionalization are expected initially. Operation and maintenance costs are thereafter expected to decrease as a result of economies of scale. The two treatment plants are initially adapted to the drinking water demand associated with the entire time horizon. Old water treatment plants and water protection areas are shut down. |
| A2: Regionalized governance & centralized production from the river Göta älv | This alternative is similar to A1 with the exception that the main source water for the entire region is the river Göta älv. The new source water tunnel and other new source water facilities of A1 are hence not included in A2. |
| A3: Regionalized governance & maintained semi-decentralized production | The region maintains its semi-decentralized production system as well as its source waters, treatment facilities and water protection areas. The drinking water production is however operated by a single regional organization of cooperating municipalities. Costs associated with regionalization of water utilities and an increased maintenance are expected initially. Operation and maintenance costs are thereafter expected to decrease as a result of a regionalized organization. |
| A4: Maintained governance & decentralized production with a maximized groundwater usage | Current water treatment plants, water protection areas and source waters, except Göta älv, are maintained and supplemented with increased/new withdrawals from several groundwater resources as well as some lakes. Four new groundwater treatment plants and two new surface water treatment plants are constructed initially, decentralizing the drinking water production compared to the reference alternative. The capacity increase in the region's distribution system is partly performed initially and partly at the same time as the reference alternative. New water protection areas and restrictions are established for the new source waters. |
| A5: Maintained governance, with additional source waters and treatment plants | Current water treatment plants, source waters and water protection areas are maintained, and supplemented with two new water treatment plants and an increased proportional use of the region's largest lakes. One new water protection area is established initially. The capacity increase in the region's distribution system is partly performed initially and partly at the same time as the reference alternative. |

All alternatives were evaluated in relation to a reference alternative. This means that if similar investments or other costs or benefits were expected to occur in both the reference alternative and an evaluated alternative, these costs and benefits were cancelled out and hence not included in the calculations or mentioned in the descriptions of the alternatives. To handle expected population growths within the time horizons, treatment and distribution capacities were increased in all alternatives, including the reference alternative.

The reference alternative is a continuation of the current water supply system, in which the region's water production is highly dependent on the river Göta älv. The region has all in all 30 water treatment plants supplied with surface water (12), groundwater (15) and artificial groundwater (3). Four of the region's thirteen municipalities are dependent on water produced in the City of Göteborg. Major treatment and capacity improvements are implemented between the year 2045 and 2055 as part of the reference alternative.

# 3 IDENTIFICATION AND ESTIMATION OF COST AND BENEFIT ITEMS

## 3.1 Cost benefit analysis

A probabilistic cost-benefit model was used to evaluate effects of the alternative interventions. Cost and benefit items were identified and quantified according to descriptions in this chapter. Further details of the analysis is presented in (Sjöstrand et al., 2018).

Net present values (*NPV*) of the alternative interventions were calculated as the sum of discounted benefits minus the sum of discounted costs as

$$NPV_a = \sum_{t=0}^{T} \frac{1}{(1+r_t)^t}[B_{a,t}] - \sum_{t=0}^{T} \frac{1}{(1+r_t)^t}[C_{a,t}] \tag{1}$$

where $a$ is the alternative intervention, $t$ is the time when benefit or cost occur, $T$ is the time horizon, $r_t$ is the discount rate at time $t$, $C$ are the costs and $B$ are the benefits in relation to the reference alternative. Uncertainties of quantified values were represented by lognormal probability distribution functions and handled by means of Monte Carlo simulations.

## 3.2 Identification of cost and benefit items

A stakeholder workshop, including 33 stakeholders from water authorities, municipal community planners, municipal environmental professionals, water utility managers, water resource organizations, fishing organizations, local politicians, and the agriculture, transport and hydropower sectors, was arranged to identify cost and benefit items and to prioritize which of those to be monetized and included in the evaluation of the five alternatives, see Table 2 for the resulting list.

*Table 2 Costs and benefits to be included in the CBA for the Göteborg region.*

| Cost and benefit items | Description |
|---|---|
| Water utility items | Investments<br>Operational and maintenance costs |
| Water supply reliability | Lost value added in economic sectors<br>Losses for residential consumers |
| Water related health effects | Costs for healthcare<br>Lost production<br>Discomfort |
| Ecosystem services | Effects on hydroelectric production |
| Effects on agriculture due to water protection restrictions | Effects on agricultural production due to pesticide regulations |

## 3.3 Estimation of cost and benefit items

This section describes how identified costs and benefits were estimated. Information about the estimated values and uncertainty distributions can be found in Appendix A to E.

### 3.3.1 Water utility items

Water utility costs for implementing the alternatives, e.g. costs for new treatment plants, water protection areas, and tunnel constructions, were estimated based on information gathered from past and ongoing Swedish projects as well as from water utility experts. As three of the alternatives involved establishments of regional utilities, a model relating operation and maintenance (O&M) costs per cubic meter to number of connected consumers was developed to get an estimate of effects on O&M costs when local utilities are replaced by larger regional ones. Water utility information from two benchmarking databases, i.e.

VASS and IBNET, were used in this model development (IBNET, 2016; VASS, 2015). The VASS database includes information from Swedish water utilities collected by the Swedish Water and Wastewater Association. IBNET is the World Banks database including water utility information from 135 countries worldwide (Danilenko et al., 2014). Swedish O&M costs reported to VASS were here combined with O&M costs from eight European countries reported to IBNET to compensate the lack of information from large water utilities in Sweden. These countries were selected based on availability and distribution of O&M costs from small and large utilities in each country. There are other countries more similar to Swedish conditions; however we still consider it reasonable to assume that the overall trend in terms of costs versus number of consumers in these countries may be used to generate estimates of Swedish O&M costs.

O&M costs from the different countries were converted to US dollar by the official exchange rate (The World Bank, 2017) and adjusted to 2016 prices by Consumer Price Index (US Inflation Calculator, 2017). The IBNET cost data, which consisted of information from 550 utilities from the years 2000 to 2015, is shown in Figure 1 as the mean and standard error O&M costs grouped by number of consumers served by the utilities.

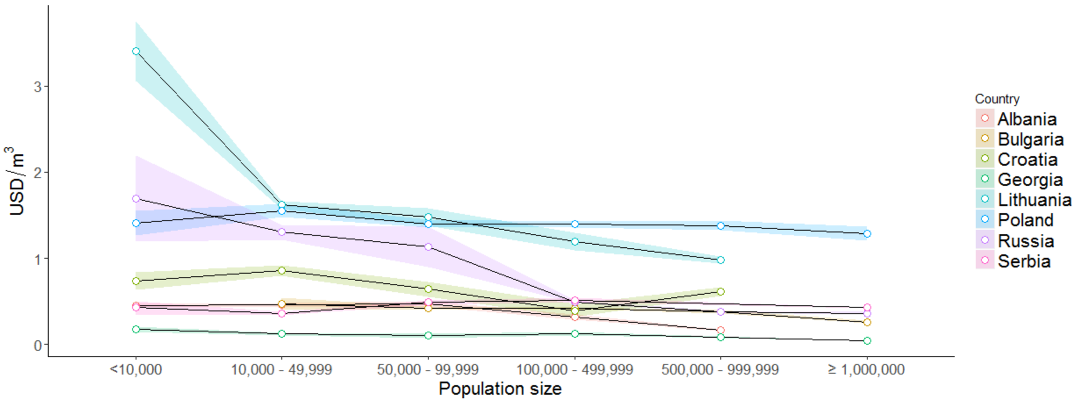


*Figure 1 Mean and standard error of IBNET O&M costs per country by number of consumers.*

Descriptive statistics for both the IBNET and VASS data is shown in Table 3, in which *n* is number of data points, *$* is US dollar and *std* is standard deviation (IBNET, 2016; VASS, 2015).

*Table 3 Descriptive statistics of O&M costs (USD in 2016 prices) reported to IBNET between 2000 and 2015 and to VASS between 2010 and 2015.*

| Country | Descriptive statistics | Population size served by water utilities | | | | | |
|---|---|---|---|---|---|---|---|
| | | < 10,000 | 10,000 - 49,999 | 50,000 - 99,999 | 100,000 - 499,999 | 500,000 - 999,999 | ≥ 1,000,000 |
| Albania | n | 139 | 291 | 93 | 67 | 11 | 0 |
| | mean ($/m$^3$) | 0.45 | 0.46 | 0.47 | 0.32 | 0.17 | |
| | std | 0.28 | 0.37 | 0.26 | 0.26 | 0.04 | |
| Bulgaria | n | 0 | 10 | 36 | 190 | 16 | 10 |
| | mean ($/m$^3$) | | 0.47 | 0.42 | 0.42 | 0.38 | 0.26 |
| | std | | 0.21 | 0.12 | 0.17 | 0.07 | 0.05 |
| Croatia | n | 10 | 44 | 20 | 15 | 5 | 0 |
| | mean ($/m$^3$) | 0.74 | 0.86 | 0.64 | 0.39 | 0.61 | |
| | std | 0.33 | 0.39 | 0.38 | 0.29 | 0.11 | |
| Georgia | n | 24 | 110 | 19 | 21 | 5 | 4 |
| | mean ($/m$^3$) | 0.17 | 0.12 | 0.10 | 0.12 | 0.08 | 0.04 |
| | std | 0.16 | 0.12 | 0.12 | 0.08 | 0.03 | 0.01 |
| Lithuania | n | 9 | 138 | 46 | 22 | 9 | 0 |
| | mean ($/m$^3$) | 3.40 | 1.62 | 1.48 | 1.19 | 0.98 | |
| | std | 1.04 | 0.53 | 0.68 | 0.49 | 0.12 | |
| Poland | n | 8 | 67 | 63 | 184 | 44 | 13 |
| | mean ($/m$^3$) | 1.41 | 1.55 | 1.40 | 1.39 | 1.38 | 1.29 |
| | std | 0.40 | 0.63 | 0.34 | 0.49 | 0.38 | 0.29 |
| Russia | n | 7 | 174 | 120 | 665 | 282 | 175 |
| | mean ($/m$^3$) | 1.69 | 1.30 | 1.13 | 0.50 | 0.38 | 0.36 |
| | std | 1.32 | 1.10 | 2.57 | 0.30 | 0.19 | 0.15 |
| Serbia | n | 20 | 175 | 60 | 63 | 0 | 2 |
| | mean ($/m$^3$) | 0.43 | 0.36 | 0.49 | 0.51 | | 0.43 |
| | std | 0.34 | 0.28 | 0.20 | 0.20 | | 0.00 |
| Sweden | n | 237 | 428 | 84 | 44 | 8 | 2 |
| | mean ($/m$^3$) | 1.56 | 1.45 | 0.33 | 2.18 | 0.20 | 0.12 |
| | std | 6.89 | 6.04 | 0.22 | 6.75 | 0.07 | 0.002 |

To remove effects of national general cost differences, the data was normalized according to the following. Let $p_i$ be the group population size for group index $i \in (1,6)$, and $c_{i,j,k}$ be the $k$th O&M cost per cubic meter for group $i$ and country $j$. The mean cost per cubic meter for group $i$ and country $j$ is then

$$c_{i,j} = \frac{1}{n_{i,j}} \sum_{k=1}^{n_{i,j}} c_{i,j,k} \qquad (2)$$

The mean cost per cubic meter for each country is then

$$c_j = \frac{1}{n_j}\sum_{i=1}^{n_j} c_{i,j} \tag{3}$$

and the grand average cost per cubic meter over all countries is

$$C = \frac{1}{9}\sum_{j=1}^{9} c_j \tag{4}$$

The costs for each country were then normalized according to

$$\hat{c}_{i,j} = \frac{C}{c_j} c_{i,j} \tag{5}$$

where $\hat{c}_{i,j}$ is the normalized cost per cubic meter, Figure 2.

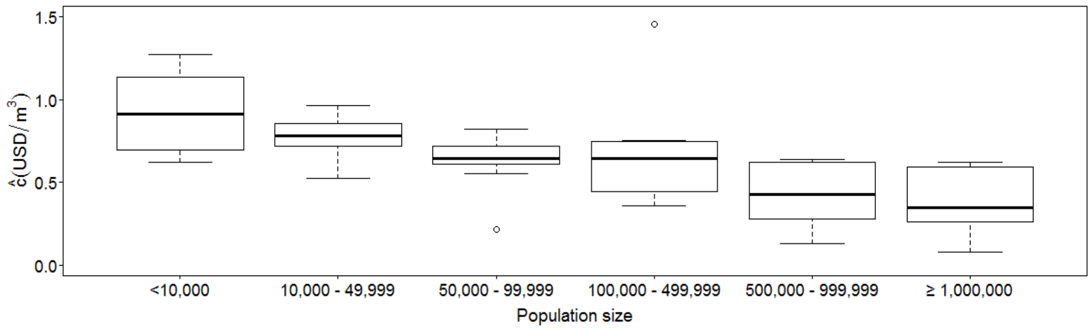


*Figure 2 Boxplot showing the normalized O&M costs per cubic meter by number of consumers.*

To find the rate of change we regress over normalized costs per cubic meter (Figure 3).

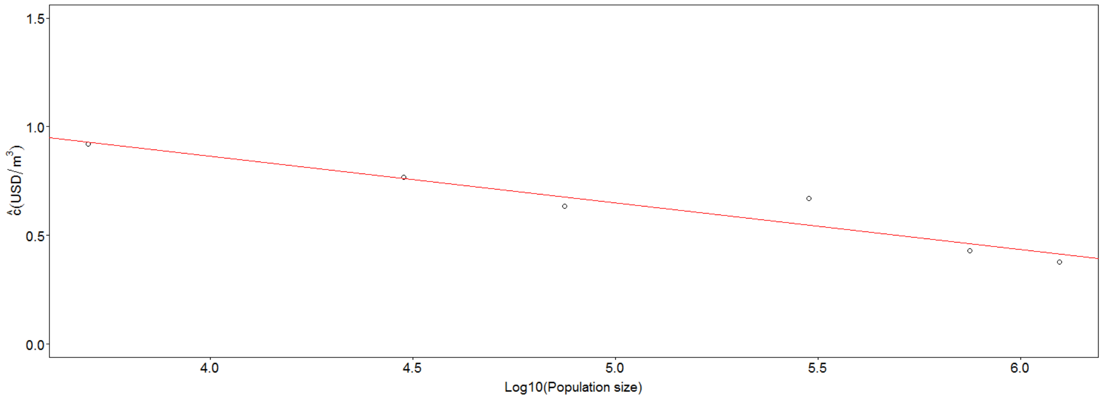


*Figure 3 Linear log model of normalized O&M costs and number of consumers.*

The estimated model is

$$\hat{c}(p) = -0.215 \cdot log_{10}(p) + 1.7. \quad \textit{R2=0.9061, significance level <0.01} \qquad (6)$$

For a utility of size $p$ at current cost $c$ per cubic meter, the projected cost $\tilde{c}$ per cubic meter at size $\tilde{p}$ can be estimated by

$$\tilde{c}(c, p, \tilde{p}) = c \cdot \frac{\hat{c}(\tilde{p})}{\hat{c}(p)} \qquad (7)$$

The O&M costs at year 2015 and the number of consumers of the Göteborg region were then used to project new O&M costs for a regional utility (VASS, 2015).

### 3.3.2 Water supply reliability

Four of the evaluated alternatives were assessed to affect the total risk of water supply delivery failure compared to the reference alternative, hence affecting both residential consumers and economic sectors in society. The risk is here expressed as the number of minutes per year the average consumer is lacking water supply, i.e. customer minutes lost (CML). Based on prior risk analyses performed for the municipalities in the Göteborg region (GR, 2014; Lindhe et al., 2009; Lindhe et al., 2011), the risk level of the reference alternative was assumed to be 200 CML on average in the region with a lognormal distribution. This is a somewhat higher level than the acceptable level of 144 CML set by the city of Göteborg (Lindhe et al., 2009). The risk levels of the two centralized alternatives (A1 and A2), as well as the alternatives with increased number of source waters and treatment plants (A4 and A5) were assumed to be 80 CML on average, based on previous calculations of possible risk levels due to increased capacities. The risk level of A3 was assumed to stay the same as the reference alternative. These risk estimations were then combined with economic valuations of lost water supply.

The economic valuation of lost water supply followed a methodology currently used by the US Federal Emergency Management Agency (FEMA, 2011) to derive a value of loss of potable water service per capita and day. The methodology combines effects on economic activity in different economic sectors with effects on residential consumers (ATC, 1991; Brozović et al., 2007). It was here assumed that Swedish economic sectors have the same percentage reduction as US sectors from a water supply disruption. To estimate the impact on economic activity, the value added lost per economic sector (ATC, 1991) was combined with information on Swedish GDP per economic sector (SCB, 2017) and number of inhabitants in Sweden in mid-2016 (SCB, 2016b), Table 4.

*Table 4 Economic consequence per capita and day of lost water service per economic sector. 1 million Swedish Krona (MSEK) is approximately 125,000 USD.*

| Economic sector | Percent reduction | GDP 2016 (MSEK) | GDP 2016 per capita per day (SEK) | Cost per capita per day of lost water service (SEK) |
|---|---|---|---|---|
| Food & Tobacco | 70% | 41,509 | 11.5 | 8.0 |
| Textile & Leather | 65% | 5,072 | 1.4 | 0.9 |
| Pulp, Paper, Lumber & Wood | 55% | 69,146 | 19.1 | 10.5 |
| Chemicals, Petroleum & Coal | 65% | 93,093 | 25.7 | 16.7 |
| Rubber & Plastic | 50% | 30,280 | 8.4 | 4.2 |
| Primary & Secondary Metal Products | 85% | 83,880 | 23.2 | 19.7 |
| Instruments | 90% | 78,947 | 21.8 | 19.7 |
| Electronic Equipment | 90% | 19,271 | 5.3 | 4.8 |
| Machinery Except Electricial | 60% | 70,565 | 19.5 | 11.7 |
| Transport Equipments | 60% | 107,525 | 29.7 | 17.8 |
| Furniture & Miscellaneous Manufacturing | 55% | 37,248 | 10.3 | 5.7 |
| Construction | 50% | 237,607 | 65.7 | 32.9 |
| Utilities | 40% | 115,422 | 31.9 | 12.8 |
| Wholesale & Retail Trade | 20% | 421,682 | 116.6 | 23.3 |
| Transportation & Warehousing | 20% | 163,618 | 45.3 | 9.1 |
| Accommodation & Food Service | 80% | 69,905 | 19.3 | 15.5 |
| Information & Communication | 20% | 226,663 | 62.7 | 12.5 |
| Finance, Insurance & Real Estate | 20% | 881,218 | 243.7 | 48.7 |
| Health, Education & Social Care | 40% | 146,691 | 40.6 | 16.2 |
| Arts, Entertainment & Recreation | 80% | 27,691 | 7.7 | 6.1 |
| Public authorities | 25% | 785,080 | 217.1 | 54.3 |
| TOTAL | | | | 351.1 |

For residential loss estimation, an equation for estimation of consumer WTP to avoid water supply interruptions developed by Brozović et al. (2007) was used. The approach is adapted from Jenkins et al. (2003) using integration of consumers' demand curves for water services, calibrated to local water prices and quantity data:

$$W = \frac{\eta}{1+\eta} P_{baseline} Q_{baseline} \left[ 1 - \left( \frac{BWR}{Q_{baseline}} \right)^{\frac{1+\eta}{\eta}} \right] \quad (8)$$

in which $W$ is the daily loss of welfare per capita, $\eta$ is the price elasticity of water demand, $P_{baseline}$ is the average water price when no interruptions, $Q_{baseline}$ is the average amount of water consumed per capita per day when no interruptions, and $BWR$ is the Basic Water Requirement for drinking and sanitation per capita day. According to SOU (2016), the average amount of water consumed in Sweden in 2015 was 160 L per capita and day to a price of about 0.035 SEK/L. The BWR was set to 25 L/day (Gleick, 1996; Howard & Bartram, 2003; OHCHR, 2010) and the price elasticity was set to -0.378 (Sebri, 2013), giving a daily welfare loss of 69 SEK per capita per day (-0,378/(1-0,378))·0,035·160·(1-(25/160)^((1-0,378)/-0,378)).

As Equation (8) does not value how much consumers are willing to pay for having the BWR provided during the water interruption period but, the cost of bottled water was used to proxy that value. In Sweden, bottled water costs about 250 times as much as tap water (Swedish Water and Wastewater Association, 2017), giving a total economic effect on residential consumers of 288 SEK per capita and day (69 SEK + 250·0.035SEK/L·25L), and a total for both economic sectors and residential consumers of 639 SEK per capita and day (288 + 351 (see Table 4)).

### 3.3.3 Water related health effects

In previous risk assessments (e.g. GR, 2014), the human health risk has been considered acceptable within the region, although the probability of infection has not been calculated. There is no defined acceptable level of risk in terms of probability of infection in Swedish legislation. Instead, for the purpose of this study, the original and acceptable level of risk was assumed equal to an annual probability of infection of $10^{-4}$ per person. This is an often-used benchmark in quantitative microbial risk assessment applications, suggested by e.g. Regli et al. (1991) and Macler and Regli (1993) and further discussed by e.g. Haas (1996) and Signor and Ashbolt (2009). In treatment plants where additional measures had been taking place since last assessment, and in groundwater treatment plants, the microbiological barriers were presumed to be 2 and 1 log higher, assuming risk levels of $10^{-6}$ and $10^{-5}$, respectively. These risk estimations were then combined with estimated economic costs per infection.

The economic cost of infections was calculated as the sum of healthcare costs, costs of lost production due to work absence, and costs of dis-utility (Hurley et al., 2005). The health care costs were estimated to approximately 5,900 SEK per hospital visit, based on 2016 health care costs associated with gastroenteritis caused by Campylobacter, rotavirus and other unspecified causes was (SKL, 2017). The costs of lost production were calculated as the sum of direct and indirect costs of work absence. The average direct costs were estimated to 2,352 SEK per day based on direct sick leave costs for Swedish employers for the average monthly salary in Sweden in 2016 (SCB, 2016a; Swedish Social Insurance Agency, 2017). The indirect costs of work absence were calculated as 8.9% (SHRM/Kronos, 2014) of the average monthly salary in Sweden 2016, giving an approximate cost of 139 SEK per day (assuming 21 workdays per month). The costs of dis-utility were estimated to 576 SEK per day in 2016 prices based on what individuals are willing to pay to avoid a day of symptoms that are common to gastrointestinal infections (Ready et al., 2004). Assuming that a case of infection cause 13 days of symptoms, 2.5 days of work absence and on average 0.1 hospital visits (Hunter et al., 2004; Morgan & Owen, 2008; Palmer et al., 1990; Ridderstedt et al., 2017; Robertson et al., 2002) the total cost of healthcare, lost production and dis-utility add up to 14,305 SEK per case (13·576+2.5·2,352+2.5·139+0.1·5,900).

### 3.3.4 Hydroelectric production

To estimate the effects on hydroelectric production over time due to reduced discharge in the river Göta älv when the entire region is supplied with water from lake Vänern (i.e. in A1), a linear relationship between market spot prices in the year 2016 and predicted prices by the SKM Long Term Power Outlook for the year 2050 was assumed (Nord Pool, 2016; SKM, 2016).

### 3.3.5 Agriculture

To estimate the economic consequences for farmers from not receiving permits for pesticide use for certain crops, the difference of conventional and organic production yields was used as a proxy. The annual yield difference for certain crops which have been assessed as difficult to cultivate in Swedish water protection areas due to pesticide restrictions, i.e. potatoes, peas, beans, and spring and autumn rape, was calculated (Persson & Germundsson, 2010). The annual yield *Y* of the crops in question was calculated as:

$$Y = \sum N_{C,K} \cdot H_C \cdot P_{C,K} - \sum N_{C,O} \cdot H_C \cdot P_{C,O} \quad (9)$$

where *C* is the specific crop, *K* is conventional production, *O* is organic production, *N* is the norm harvest (kg/hectare), *H* is the area harvested within the water protection area (hectare), and *P* is the crop price (SEK/kg). The same valuation method was used to calculate costs due to an increase in water protection areas and benefits due to a reduction of water protection areas.

Information about present water protection areas, areas harvested, crop prices and conventional and organic norm harvest were accessed through the Swedish Environmental Protection Agency, Statistics Sweden and the Swedish Board of Agriculture (Jordbruksverket, 2016; Naturvårdsverket, 2017; SCB, 2016c). Land areas of new water protection areas due to implementation of the alternatives were estimated based on information gathered from the local municipalities, other municipalities and the Göteborg region. The same agricultural distribution was assumed to exist throughout the Göteborg region as in the county of Västra Götaland, for which areas and norm harvests were reported. The crop prices were assumed to be the same for conventional and organic crops, and the prices and norm harvest were assumed to stay the same over the evaluated time horizons.

## 3.4 Uncertainty and sensitivity analyses

Uncertainties about quantified cost and benefit values were assessed based on the information gathered for each cost/benefit item and represented by lognormal probability distribution functions. The lognormal distribution is widely used in economics and cost analysis (Garvey et al., 2016). It is closely related to the normal distribution but positively skewed and always nonnegative. The parameters defining the distribution are the mean value and standard deviation of the specific cost or benefit, assessed in the monetization process and reported for each alternative in Appendix A to E, respectively. Monte Carlo simulations, with 10,000 iterations each, were then used to model the uncertainties using Palisade's risk analysis software @RISK. Scenario analysis was used to study the impact of different discount rates and time horizons.

# 4 RESULTS

The input data of costs and benefits for each alternative are presented in Appendix A to E. The net present values for the five alternatives are presented as cumulative distribution functions in Figure 4, Figure 5, Figure 6 and Figure 7. The descriptions of the alternative interventions are summarized here:

- A1: Regionalized governance & centralized production from lake Vänern
- A2: Regionalized governance & centralized production from the river Göta älv
- A3: Regionalized governance & maintained semi-decentralized production
- A4: Maintained governance & decentralized groundwater dependent production
- A5: Maintained governance, with additional source waters and treatment plants

The two centralized alternatives, A1 and A2, showed the most negative *NPV* values for all analyzed time horizons and discount rates. This was mainly due to that the major treatment and capacity investments were expected early in the time horizon in those alternatives compared to later on in the other alternatives. Costs associated with tunnel construction and other new source water facilities in A1 contributed to making that alternative the least economically profitable one.

A3 was associated with the lowest degree of uncertainty in *NPV* estimation and was also the alternative most likely to be economically profitable. The positive economic outcome was mainly due to that the alternative had no major investments relative to the reference alternative, and that the formation of a regional organization led to an assumed decrease in O&M costs. The model used to project new O&M costs may however have overemphasized the benefits of merging for this alternative, as the model is based on water utilities likely to fewer treatment facilities per number of connected consumers than A3.

The *NPV* outcome of A4 and A5 were quite similar, although A5 were slightly more profitable. The alternatives both preserved the municipal governance but differed in source waters and production system. A4 relied on a decentralized groundwater dependent production, whereas A5 expanded the current system with additional treatment plants and source waters. Generally, all alternatives were considered more economically beneficial when assessed over a longer time horizon and with a lower the discount rate.

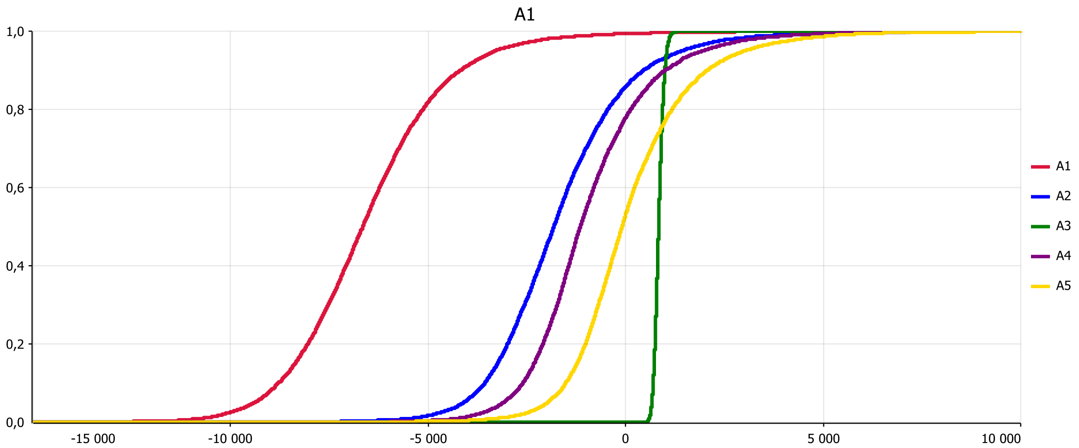


*Figure 4* *Cumulative graph of net present values of the five alternatives evaluated for the discount rate* ***1.4%*** *and the time horizon* ***30 years*** *(MSEK)*

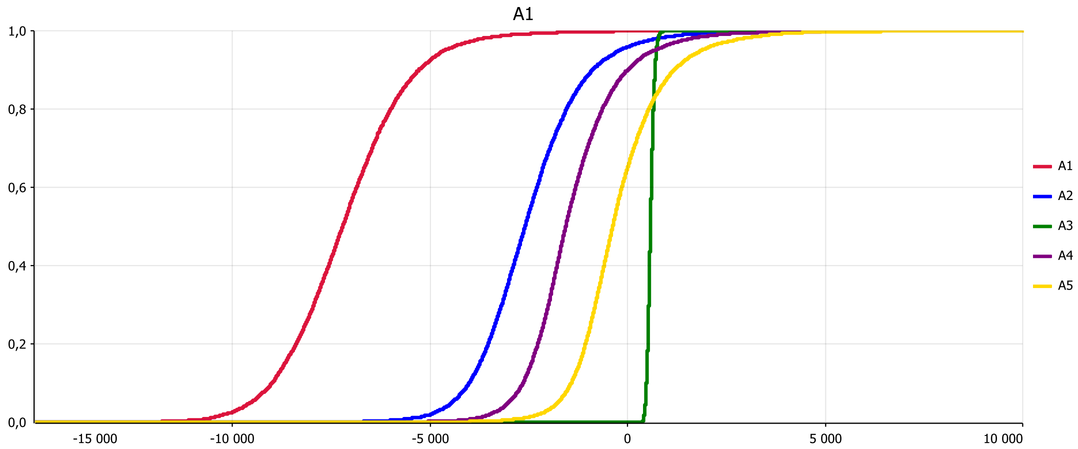


*Figure 5* *Cumulative graph of net present values of the five alternatives evaluated for the discount rate* ***3.5%*** *and the time horizon* ***30 years*** *(MSEK)*

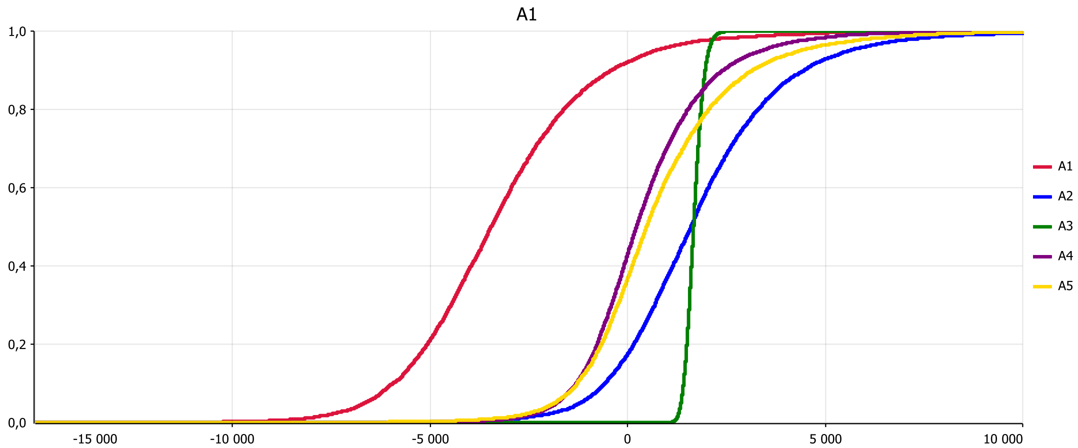


*Figure 6* *Cumulative graph of net present values of the five alternatives evaluated for the discount rate* ***1.4%*** *and the time horizon* ***70 years*** *(MSEK)*

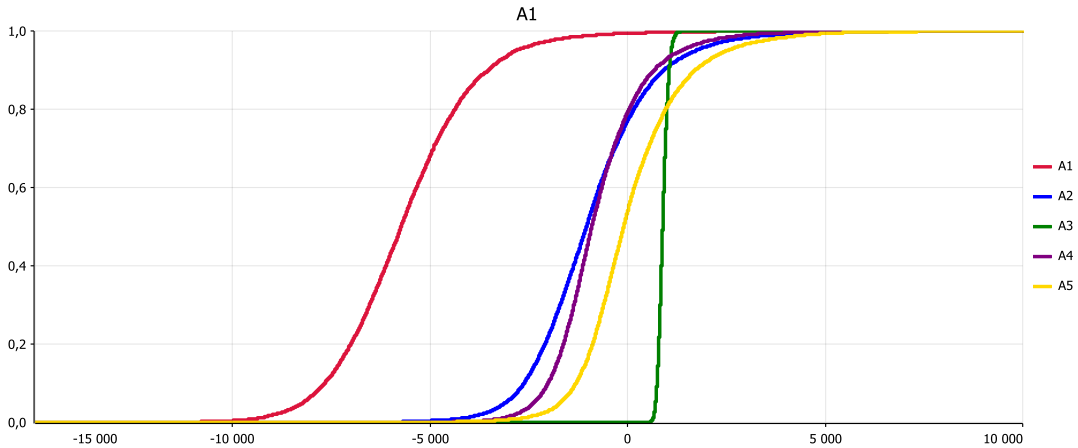


*Figure 7* *Cumulative graph of net present values of the five alternatives evaluated for the discount rate* ***3.5%*** *and the time horizon* ***70 years*** *(MSEK)*

Figure 8 presents the probabilities for each alternative being the most economically profitable one. A3 had the highest probability of being the most beneficial alternative for all evaluated settings except one, indicating that regionalized governance has potential to create large benefits. However, as mentioned earlier, the benefits of decreased O&M costs may be overestimated for this alternative.

A5 had the second highest probability of being the most profitable alternative, partly due to benefits from a redundant supply system with decreased risk of delivery failure. A1, A4 and A5 had all fairly stable probabilities, hardly affected by discount rates and time horizons, whereas A2 benefited largely by a long time horizon and low discount rate.

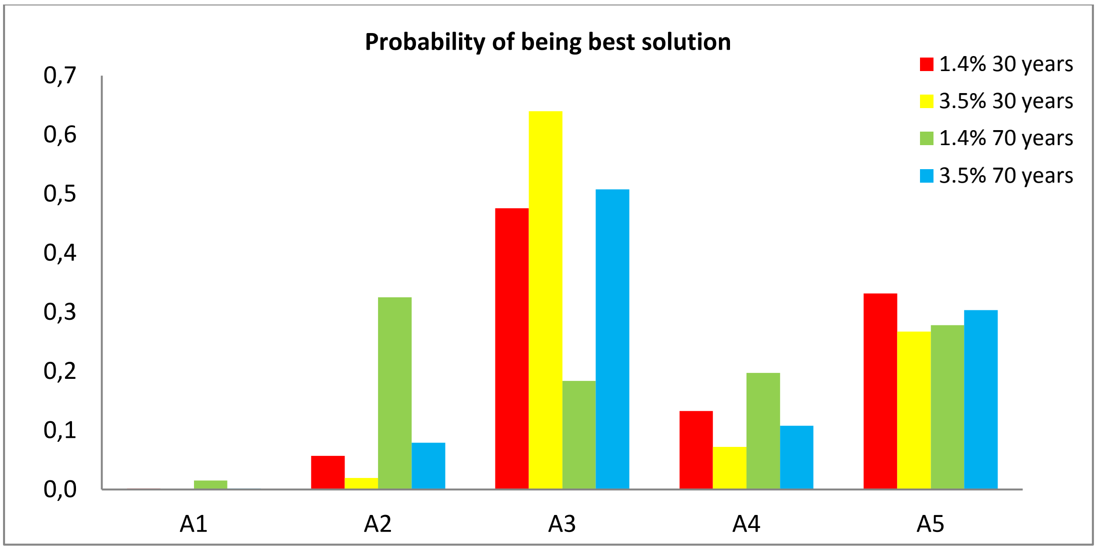


*Figure 8* *Probabilities of each alternative being the best solution for 1.4% and 3.5% discount rates and 30 and 70-year time horizons*

Sensitivity analyses of the alternatives are shown in Figure 9 to Figure 13. The analyses are based on the Monte Carlo simulations and show the contribution of costs and benefits on outcome uncertainty. The risk of delivery failure contributed most to outcome uncertainty in all alternatives except in A3 in which O&M costs had the highest contribution. The risk of delivery failure in A3 was assumed to be the same as in the reference alternative, and hence not included in the assessment for that alternative.

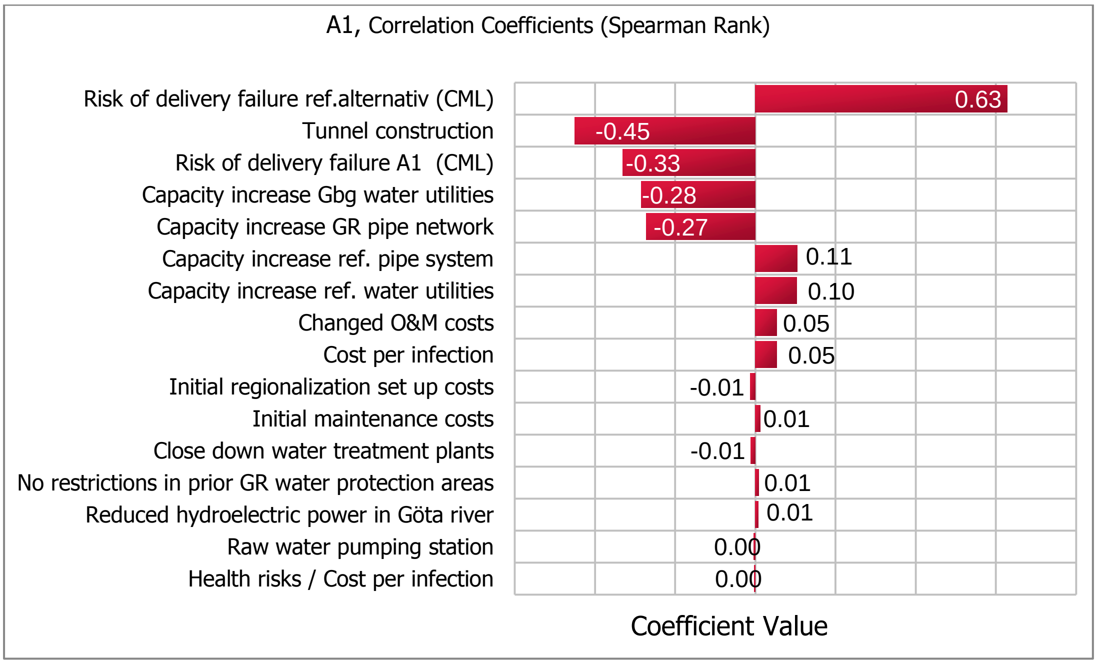


*Figure 9* *Sensitivity analysis. A1 costs and benefits presented by the strength and direction of correlation between the variables.*

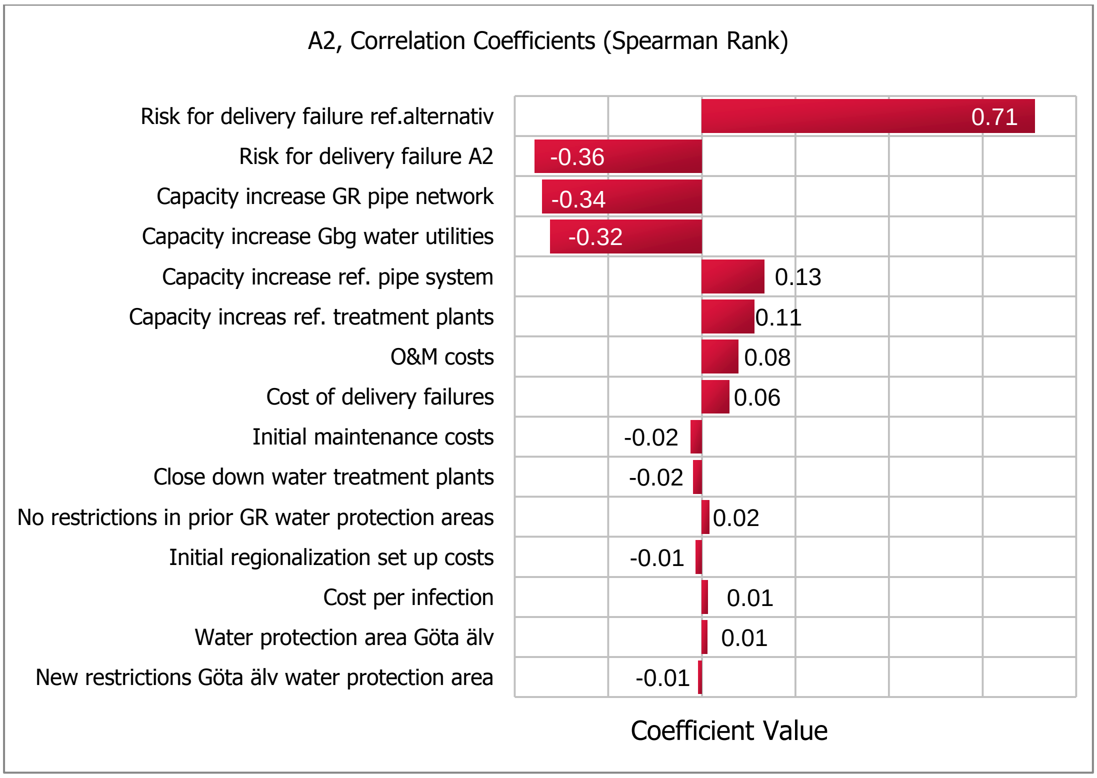


*Figure 10* *Sensitivity analysis. A2 costs and benefits presented by the strength and direction of correlation between the variables.*

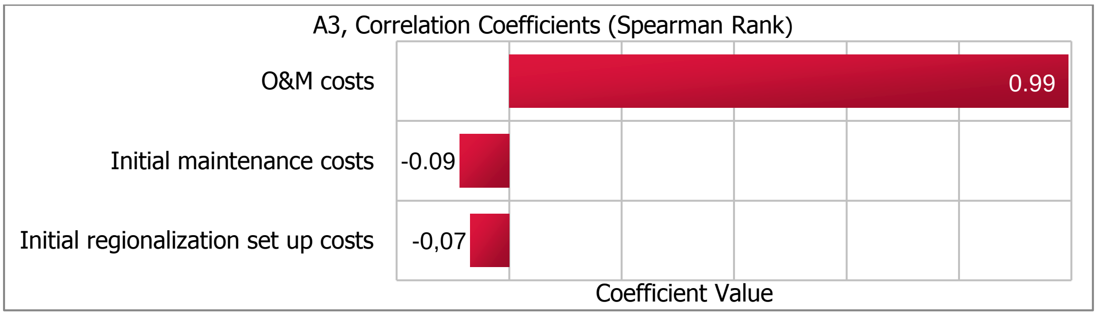


*Figure 11* *Sensitivity analysis. A3 costs and benefits presented by the strength and direction of correlation between the variables.*

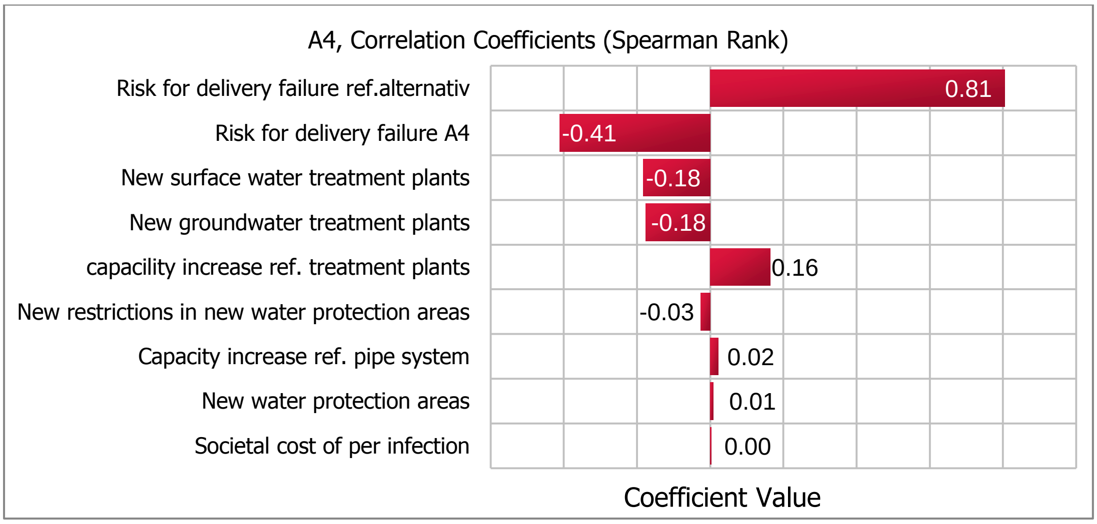


*Figure 12* *Sensitivity analysis. A4 costs and benefits presented by the strength and direction of correlation between the variables.*

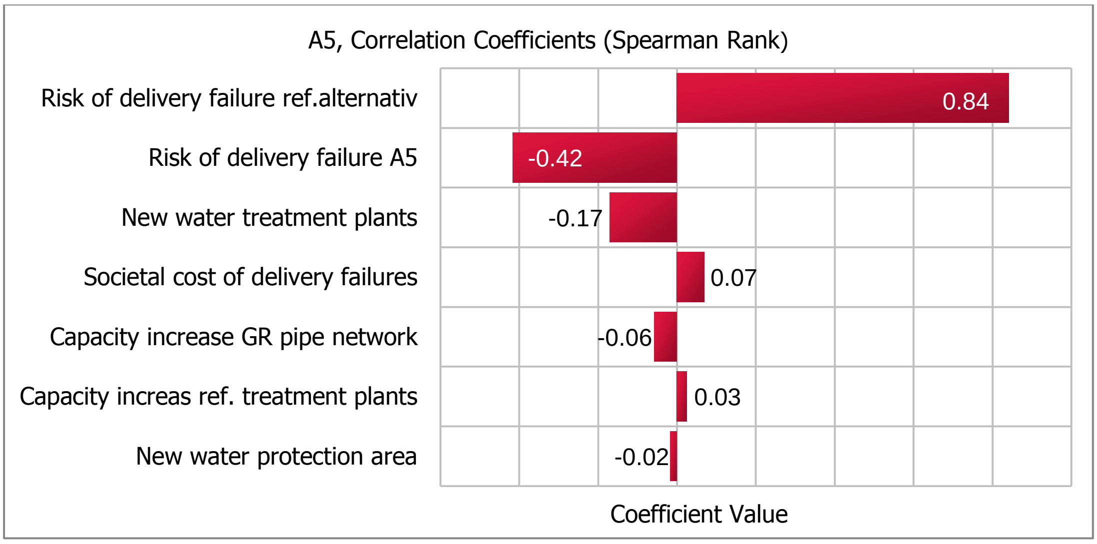


*Figure 13* *Sensitivity analysis. A5 costs and benefits presented by the strength and direction of correlation between the variables.*

# 5 DISCUSSION

The purpose of this report was to present and exemplify a probabilistic CBA to assess costs and benefits that may arise from regional water supply interventions. Five regional water supply interventions were evaluated for the Göteborg region in Sweden, for which costs and benefits were identified and quantified.

In order to get an estimate of the economic benefit of merging water utilities, a model was developed based on water utility information from the databases IBNET and VASS to provide a general relationship between number of connected consumers and O&M costs per cubic meter. Economic valuations of water related health effects, water supply reliability, hydroelectric power generation, and agricultural costs of pesticide regulations were also provided and tested.

The A3 alternative, which comprised regionalized governance and maintained semi-decentralized production, had the highest probability of being the economically most profitable solution in the Göteborg region. This alternative may however have received over-estimated benefits from the developed O&M model due to its maintained semi-decentralized production. The A5 alternative, which comprised maintained governance with additional source waters and treatment plants, thus appear as a rather advantageous alternative considering it had the second highest probability of being best solution. It was also assumed to benefit from decreased risk of delivery failure, which contributed significantly to overall outcome uncertainties.

The application of the cost-benefit analysis approach demonstrates its possibilities as decision support for coherent comparisons of regional water supply interventions. The method enables analysis of the alternatives' performance and facilitates analyses of uncertainties associated with each alternative. It enables inclusion and assessments of effects normally overlooked in evaluation processes and provides for structured and well-informed decisions on a regional level.

# 6 CONCLUSIONS

The main conclusions of this report are:

- This report presents a cost-benefit analysis approach which enables economic comparisons of regional water supply alternatives, including formations of inter-municipal cooperations.
- Access to relevant and sufficient data represents a challenge when performing economic analyses.
- The report describes how available data can be handled to estimate different cost and benefit items.
- The probabilistic approach allows for a transparent handling of uncertainties and enables calculations of probabilities that alternatives e.g. are economically profitable.

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# APPENDIX A: INPUT DATA FOR ALTERNATIVE 1

Estimated mean values and standard deviations (std) of lognormal probability distributions for the different cost and benefit items, as entered in Palisade's risk analysis software @Risk, are presented in the table below.

<table>
<tr><th>Main costs & benefits</th><th colspan="2">Description</th><th>Cost (-1) Benefit (1)</th><th>Mean (MSEK)</th><th>Std</th><th>Year</th></tr>
<tr><td rowspan="13">Water utility items</td><td colspan="2">Close down water treatment plants</td><td>-1</td><td>56</td><td>5</td><td>3</td></tr>
<tr><td colspan="2">Raw water intake facilities</td><td>-1</td><td>20</td><td>2</td><td>1-3</td></tr>
<tr><td colspan="2">Intake pipelines</td><td>-1</td><td>60</td><td>6</td><td>1-3</td></tr>
<tr><td colspan="2">Raw water pumping station</td><td>-1</td><td>75</td><td>8</td><td>1-3</td></tr>
<tr><td colspan="2">Tunnel, Vänern -Göteborg</td><td>-1</td><td>4,750</td><td>800</td><td>1-3</td></tr>
<tr><td colspan="2">Capacity increase GR pipe network</td><td>-1</td><td>2,340</td><td>500</td><td>1-3</td></tr>
<tr><td colspan="2">Capacity increase Gbg water utilities</td><td>-1</td><td>2,400</td><td>500</td><td>1-3</td></tr>
<tr><td colspan="2">Water protection area Vänern</td><td>-1</td><td>5</td><td>1</td><td>1-2</td></tr>
<tr><td colspan="2">Initial regionalization set up costs</td><td>-1</td><td>59</td><td>5</td><td>1-2</td></tr>
<tr><td colspan="2">Capacity increase ref. pipe system</td><td>1</td><td>2,340</td><td>500</td><td>29-39</td></tr>
<tr><td colspan="2">Capacity increase ref. water utilities</td><td>1</td><td>2,400</td><td>500</td><td>29-39</td></tr>
<tr><td colspan="2">Changed O&M costs</td><td>1</td><td>42</td><td>5</td><td>3-70</td></tr>
<tr><td colspan="2">Initial maintenance costs due to higher ambition</td><td>-1</td><td>25.5</td><td>5</td><td>1-2</td></tr>
<tr><td>Water services</td><td colspan="2">Reduced hydroelectric production</td><td>-1</td><td>3.7 *</td><td>0.4</td><td>3-70</td></tr>
<tr><td rowspan="2">Effects on agriculture</td><td colspan="2">New restrictions water protection area at Vänern</td><td>-1</td><td>1</td><td>0.4</td><td>2-70</td></tr>
<tr><td colspan="2">No restrictions in prior GR water protection areas</td><td>1</td><td>1</td><td>0.4</td><td>2-70</td></tr>
<tr><td rowspan="2">Health effects</td><td>Risk of infection Reference alternative</td><td>Risk of infection A1</td><td rowspan="2">1</td><td colspan="2">Cost/ infection (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>2.971E-05</td><td>1.00E-06</td><td>14,305</td><td>1,500</td></tr>
<tr><td rowspan="2">Water supply reliability</td><td>Risk of delivery failure Ref.alt. (CML) (P05;Mean;P95)</td><td>Risk of failure A1 (CML) (P05;Mean;P95)</td><td rowspan="2">1</td><td colspan="2">Cost of failure for average consumer/year (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>50;200;400</td><td>20;80;190</td><td>0.44</td><td>0.05</td></tr>
</table>

* The reduced hydroelectric production is estimated to 3.7 MSEK year 3 with a linear relationship to 13.6 MSEK year 70.

# APPENDIX B: INPUT DATA FOR ALTERNATIVE 2

Estimated mean values and standard deviations (std) of lognormal probability distributions for the different cost and benefit items, as entered in Palisade's risk analysis software @Risk, are presented in the table below.

<table>
<tr><th>Main costs & benefits</th><th colspan="2">Description</th><th>Cost (-1) Benefit (1)</th><th>Mean (MSEK)</th><th>Std</th><th>Year</th></tr>
<tr><td rowspan="9">Water utility items</td><td colspan="2">Close down water treatment plants</td><td>-1</td><td>56</td><td>5</td><td>3</td></tr>
<tr><td colspan="2">Increase capacity pipe network GR</td><td>-1</td><td>2,340</td><td>500</td><td>1-3</td></tr>
<tr><td colspan="2">Increase capacity Gbg water utilities</td><td>-1</td><td>2,400</td><td>500</td><td>1-3</td></tr>
<tr><td colspan="2">Water protection area Göta älv</td><td>-1</td><td>5</td><td>1</td><td>1-2</td></tr>
<tr><td colspan="2">Initial regionalization set up costs</td><td>-1</td><td>59</td><td>5</td><td>1-2</td></tr>
<tr><td colspan="2">Capacity increase ref. pipe system</td><td>1</td><td>2340</td><td>500</td><td>29-39</td></tr>
<tr><td colspan="2">Capacity increase ref. water utilities</td><td>1</td><td>2400</td><td>500</td><td>29-39</td></tr>
<tr><td colspan="2">Changed O&M costs</td><td>1</td><td>42</td><td>5</td><td>3-70</td></tr>
<tr><td colspan="2">Initial maintenance costs due to higher ambition</td><td>-1</td><td>25.5</td><td>5</td><td>1-2</td></tr>
<tr><td rowspan="2">Effects on agriculture</td><td colspan="2">New restrictions water protection area at Göta älv</td><td>-1</td><td>1</td><td>0.4</td><td>2-70</td></tr>
<tr><td colspan="2">No restrictions in prior GR water protection areas</td><td>1</td><td>1</td><td>0.4</td><td>2-70</td></tr>
<tr><td rowspan="2">Health effects</td><td>Risk of infection Ref.alt.</td><td>Risk of infection A2</td><td rowspan="2">1</td><td colspan="2">Cost/ infection (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>2.97E-05</td><td>1.00E-06</td><td>14,305</td><td>1500</td></tr>
<tr><td rowspan="2">Water supply reliability</td><td>Risk of failure Ref.alt. (CML) (P05;Mean;P95)</td><td>Risk of failure A2 (CML) (P05;Mean;P95)</td><td>1</td><td colspan="2">Cost of delivery failure for average consumer/year (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>50;200;400</td><td>20;80;190</td><td>1</td><td>0.44</td><td>0.05</td></tr>
</table>

# APPENDIX C: INPUT DATA FOR ALTERNATIVE 3

Estimated mean values and standard deviations (std) of lognormal probability distributions for the different cost and benefit items, as entered in Palisade's risk analysis software @Risk, are presented in the table below.

| **Main costs & benefits** | **Description** | **Cost (-1) Benefit (1)** | **Mean (MSEK)** | **Std** | **Year** |
|---|---|---|---|---|---|
| Water utility items | Initial regionalization set up costs | -1 | 59 | 5 | 1-2 |
| | Changed O&M costs | 1 | 42 | 5 | 3-70 |
| | Initial maintenance costs due to higher ambition | -1 | 25.5 | 5 | 1-2 |

# APPENDIX D: INPUT DATA FOR ALTERNATIVE 4

Estimated mean values and standard deviations (std) of lognormal probability distributions for the different cost and benefit items, as entered in Palisade's risk analysis software @Risk, are presented in the table below.

<table>
<tr><th>Main costs & benefits</th><th colspan="2">Description</th><th>Cost (-1) Benefit (1)</th><th>Mean (MSEK)</th><th>Std</th><th>Year</th></tr>
<tr><td rowspan="5">Water utility items</td><td colspan="2">New treatment plants</td><td>-1</td><td>2200</td><td>400</td><td>1-3</td></tr>
<tr><td colspan="2">New pipe lines</td><td>-1</td><td>585</td><td>60</td><td>1-3</td></tr>
<tr><td colspan="2">New water protection areas</td><td>-1</td><td>3.5</td><td>0.5</td><td>1-2</td></tr>
<tr><td colspan="2">Capacity increase ref. pipe system</td><td>1</td><td>585</td><td>60</td><td>29-39</td></tr>
<tr><td colspan="2">Capacity increase ref. water utilities</td><td>1</td><td>2,200</td><td>500</td><td>29-39</td></tr>
<tr><td>Effects on agriculture</td><td colspan="2">New restrictions in new water protection areas</td><td>-1</td><td>0.032</td><td>0.01</td><td>2-70</td></tr>
<tr><td rowspan="2">Health effects</td><td>Risk of infection Ref.alt.</td><td>Risk of infection A4</td><td rowspan="2">1</td><td colspan="2">Cost/ infection (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>2.97E-05</td><td>1.0E-05</td><td>14,305</td><td>1500</td></tr>
<tr><td rowspan="2">Water supply delivery failure</td><td>Risk of failure Ref.alt. (P05;Mean;P95)</td><td>Risk of failure A4 (P05;Mean;P95)</td><td rowspan="2">1</td><td colspan="2">Cost of failure for average consumer/year (SEK)</td><td rowspan="2">3-39</td></tr>
<tr><td>50;200;400</td><td>20;80;190</td><td>0.44</td><td>0.05</td></tr>
</table>

# APPENDIX E: INPUT DATA FOR ALTERNATIVE 5

Estimated mean values and standard deviations (std) of lognormal probability distributions for the different cost and benefit items, as entered in Palisade’s risk analysis software @Risk, are presented in the table below.

| **Main costs & benefits** | **Description** | | **Cost (-1) Benefit (1)** | **Mean (MSEK)** | **Std** | **Year** |
|---|---|---|---|---|---|---|
| Water utility items | New water treatments plants | | -1 | 680 | 200 | 1-3 |
| | Pipe capacity increase | | -1 | 585 | 60 | 1-3 |
| | New water protection area | | -1 | 2 | 0,5 | 1-2 |
| | Capacity increase ref. pipe system | | 1 | 585 | 60 | 29-39 |
| | Capacity increase ref. water utilities | | 1 | 680 | 100 | 29-39 |
| Health effects | Risk of infection Ref.alt. | Risk of infection A5 | 1 | Cost/ infection (SEK) | | 3-39 |
| | 2.97E-05 | 1.8E-05 | | 14,305 | 1500 | |
| Water supply reliability | Risk of failure Ref.alt. (P05;Mean;P95) | Risk of failure A4 (P05;Mean;P95) | 1 | Cost of failure for average consumer/year (SEK) | | 3-39 |
| | 50;200;400 | 20;80;190 | | 0.44 | 0.05 | |