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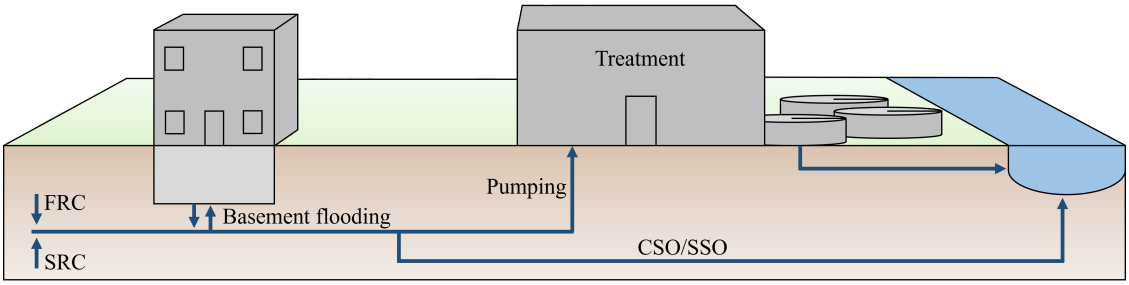

Assessing the Impacts of Infiltration and Inflow to wastewater systems

Evaluation of a Risk-based Model

Master's thesis Infrastructure and Environmental Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Overview of the boundaries for the applied model.

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Abstract

Our wastewater sewer systems are aging and with additional pressure from climate change and urbanisation, there is a growing need for better management. All the water, except sanitary sewage, within a wastewater system can be referred to as water from infiltration and inflow (I/I-water). In recent years, a renewed interest in I/I-water has started to grow as it has been identified as an area with potential for improvement. Removal of I/I-water can help the overall performance of the wastewater system but better tools to study and work with I/I-water is needed.

A risk-based model with the purpose to calculate the cost to society from I/I-water from a decision support perspective is developed within the PhD research project ”From hidden wastewater network to full access for smart decisions". The model calculates the cost of I/I-water from the four categories basement flooding, effects at the wastewater treatment plant (WWTP), sewer overflow (CSO/SSO), and pumping.

The aim of this Master’s thesis project is to evaluate the developed model with focus on data availability, uncertainties, and how different preconditions can affect the cost of I/I-water. This was done by implementing the model on three case study areas and a reference area. Input data were mainly collected through personal communication and expert knowledge elicitation workshops. Enough data could be collected to implement the model for all three case studies, but required additional simplifications and assumptions. Basement flooding was identified as an area in need of more studies to facilitate model application and to decrease the uncertainty of the calculated cost.

Restoration due to basement flooding and investment at the WWTP were shown to be the two included effects with the highest associated costs and the cost of CSO/SSO was shown to be negligible. Calculating performance indicators based on the model results were shown to have potential to contribute to valuable comparisons. Additionally, differences in cost of I/I-water between the studied areas could be identified but no general conclusions could be made as for the reasons behind the differences. Further studies including more case study areas are therefore recommended to be able to identify general patterns.

Keywords: infiltration and inflow, sewer system, decision support, risk analysis, uncertainty, cost to society

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Joacim Sundqvist, Gothenburg, May 2022

List of Acronyms

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

ALARP	As low as reasonably practicable
CCTV	Closed-circuit television
CSO	Combined system overflow
EAC	Equivalent annual cost
EKE	Expert Knowledge Elicitation
FRC	Fast response component
GWI	Groundwater infiltration
I/I-water	Infiltration and inflow water
MCA	Multi-criteria analysis
NPV	Net present value
PV	Present value
QoI	Quantity of interest
RDI	Rain-derived inflow
RII	Rain-induced infiltration
RIO	Rational impartial observer
SRC	Slow response component
SSO	Sanitary system overflow
WTP	Willingness to pay
WWTP	Wastewater treatment plant

Contents

1

Introduction

1.1 Background

Urbanisation and climate change are highly discussed subjects, and both can affect and alter the dynamics of water balances (Astaraie-Imani et al., 2012). The process of urbanisation typically entails introduction of impermeable surfaces into natural environments and increases pressure on water infrastructure. Climate change can lead to changing natural conditions, for example increased frequency and intensity of precipitation, causing further pressure on built and natural environments. Development and implementation of measures to decrease the adverse effects of urbanisation and climate change are, in addition to the potential future scenarios, also driven by stricter legislation. For example, according to article 4 in the EU Water Framework Directive (WFD), member states should take actions to restore and prevent deterioration of surface water and groundwater (Directive 2000/60/EC).

One of the affected infrastructures is the wastewater sewer system. If excluding the sanitary sewage within a wastewater system, the rest of the water can be referred to as water from infiltration and inflow (I/I-water) (Ohlin Saletti, 2020). The share of I/I-water varies between places due to different designs, conditions of the wastewater systems and rain intensity (Ohlin Saletti, 2020). A study done in Sweden by Clementson et al. (2020) showed that the share of I/I-water within the studied municipalities' sewer systems varied between 20-70%. Potential sources of I/I-water are groundwater, rainwater, and water from leaking pipes in the ground (Staufer et al., 2012). It can enter the sewer system through intentional or unintentional pipe connections (Ohlin Saletti, 2020). In addition, I/I-water can also infiltrate, normally due to damaged pipes or other damaged components.

Possible effects from I/I-water can be related to all three dimensions of sustainability: environmental, social, and economic (Sola et al., 2020). In addition to the potential effects from urbanisation and climate change, there is a growing need to better manage I/I-water due to aging pipe networks (Ohlin Saletti et al., 2021). Clementson et al. (2020) calls I/I-water one of the most pressing issues within the water and wastewater area in Sweden. Additionally, a lack of analysis before measures are taken to improve the situation was also identified by the authors, meaning that the long-term effects of investments can be unknown. Hence, there is a need for better tools and approaches to evaluate and work with I/I-water.

As part of the research program Mistra InfraMaint, a risk-based model has been developed within the PhD project entitled ”From hidden waste water network to full access for smart decisions” (Ohlin Saletti et al., 2022). The purpose of the model is to enable evaluation of the cost to society from I/I-water in wastewater systems with a risk-based decision support perspective.

1.2 Aim and Objectives

The aim of this project is to evaluate the model developed by Ohlin Saletti et al. (2022) by applying it at different locations. Special focus is put on availability of needed input data, effects of uncertainties, and the sensitivity of the results with respect to the input data.

Specific objectives of the project was to answer the following key questions:

- Can the required data be collected or is it necessary to make further model simplifications?
- Which model parameters are the results most sensitive to and thus most important to study further to obtain more accurate input data?
- How does different preconditions in the studied areas affect the results?

1.3 Limitations

The following limitations were identified for this project:

- Simplified methods were applied due to limited time and resources, for example the simplification of the SHELF-protocol to only include group judgments. This may have led to further uncertainties connected to the input data and calculated results.
- The number of case studies is not enough to make general conclusions but can give a first indication of the studied aspects.

2

Theory and Method Conceptualisation

2.1 Wastewater Systems

The wastewater system normally includes the pipes, pumping stations, and wastewater treatment plants (WWTPs) (Sola et al., 2020). For the components within the wastewater system, the terminology presented by Ohlin Saletti (2020) will be used in this project. This means that wastewater sewer system refers to the pipe network and can be built as either separate or combined. The flow in a combined sewer system is referred to as wastewater or combined sewage, generally consisting of both sanitary sewage and stormwater (Ohlin Saletti, 2020). Stormwater and sanitary sewage are separated in two pipe networks, stormwater sewer system and sanitary sewer system, in a separate sewer system. Ordinarily in the separated system, only the sanitary sewage is connected to a WWTP, whereas the stormwater sewer system has its own treatment or is discharged untreated directly to the recipient. An overview of the terminology is shown in Figure 2.1.

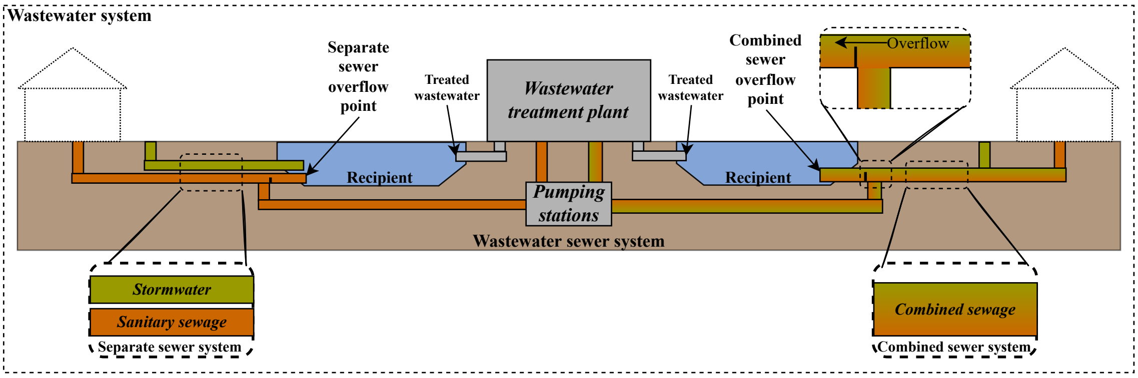

Figure 2.1: Overview of the terminology used in this project ragarding wastewater systems.

Underground sewer systems were constructed during the 19th century as a response to growing urbanisation and deteriorating sanitary conditions (Bäckman, 1985). Most of the systems were constructed as combined systems since urbanisation also increased the need to manage stormwater in urban areas. Problems that were discovered early on were the difference between flows during dry and wet weather and how that affected wastewater treatment (Field & Struzeski, 1972). Overflow points were therefore incorporated, where high flows could be discharged into receiving waters without treatment. This type of overflow is generally referred to as combined sewer overflow (CSO).

Protecting the environment became a new target when the negative environmental effects on the receiving waters were discovered halfway through the 20th century (Bäckman, 1985). Construction shifted as a result towards separate sewage systems. Most of the new systems are therefore separate systems but there are still combined systems in use as the cost of rebuilding all systems are often considered too high (Hey et al., 2016). Separate sewer overflow (SSO) is also of concern and usually happens due to infiltration or unauthorized inflows (Field & Struzeski, 1972).

2.2 Infiltration and Inflow Water

All the water in a wastewater sewer system, expect the sanitary sewage, can be considered as I/I-water and different ways of categorising I/I-water can be identified in the literature (Ohlin Saletti, 2020). It is common to divide I/I-water into categories based either on source or response time (Bäckman et al., 1993). A first distinction that depends on source can be made between direct rain dependent inflow and infiltration and drainage, where infiltration and drainage can be seen as either baseflow or indirect rain dependent. An example of this is shown in Figure 2.2.

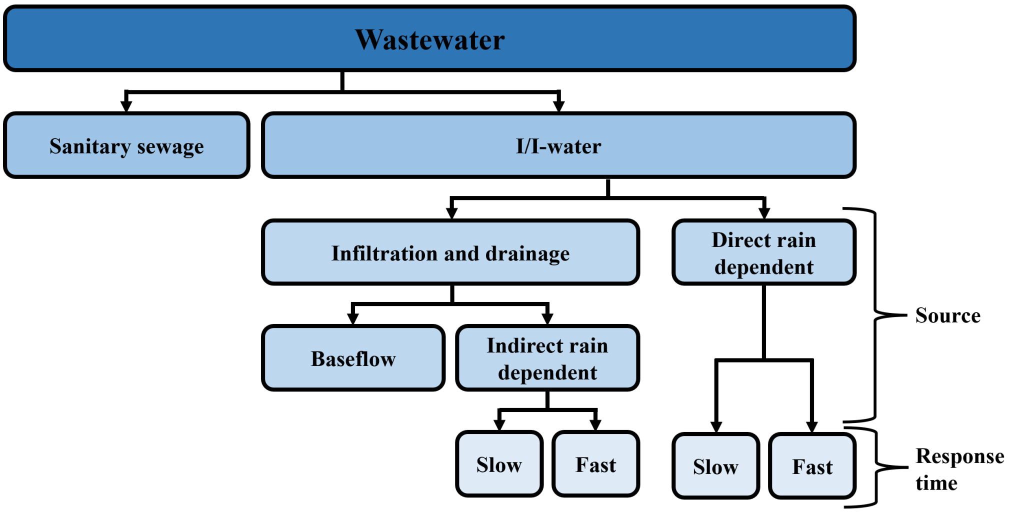

Figure 2.2: *Overview of wastewater and how I/I-water can be categorised based on source and time aspect (Bäckman et al., 1993; Ohlin Saletti, 2020).*

The direct rain dependent flows originate from surfaces which are directly connected to the sewer system. This can for example be stormwater drains, roof downpipes, and broken manhole covers connected to a combined sewer system (Nasrin et al., 2017). Some of these connection and cross-connections also exists in sanitary sewer systems illegally or are just old and forgotten.

As mentioned earlier, infiltration and drainage can be further divided into baseflow and indirect rain dependent flow. It can be difficult to strictly separate the two as some sources could belong to either. Examples of baseflows can be infiltration from surface waters, leaking drinking water pipes, and groundwater. This can continuously feed the sewer system and consequently create a higher continuous flow. Infiltration can also be indirect rain dependent, from leaking stormwater pipes and if precipitation raises the groundwater table over the sewer system (Ohlin Saletti, 2020).

Depending on what type of surface it is, direct rain dependent flows can have a fast or slow response time to a rain event (Bäckman et al., 1993). Faster response times usually imply impermeable surfaces, whereas slower response times can mean less impermeable surfaces or larger catchment area. As a result, it is sometimes expressed in terms of connected surface area. Indirect rain dependent flows can also have fast or slow response time to a rain event. It is therefore often difficult to differentiate between fast indirect rain dependent flows and slow direct rain dependent flows (Bäckman et al., 1993). Fast response component (FRC) and slow response component (SRC) can also be used to categorise I/I-water and focuses on the behaviour instead of source (Metelka et al., 1998). Hence, making it an appropriate classification to use for models or studies that base its observations on flow measurements.

Another approach to categorise I/I-water is described by Staufer et al. (2012) and consists of groundwater infiltration (GWI), rain-induced infiltration (RII), and rain-derived inflow (RDI). This is similar to the previous described approach since GWI could be seen as baseflow, while RII and RDI could be seen as indirect rain dependent and direct rain dependent, respectively.

2.2.1 Potential Effects

Sola et al. (2021) state that all three dimensions of sustainability (environmental, economic, and social) are relevant when discussing potential effects from I/I-water. It can also be useful to differentiate between effects originating from peak flows and continuous flows (Bäckman, 1985). One example from an environmental perspective is that I/I-water can lead to deteriorating water quality in receiving waters. This can be derived from continuous flows since it reduces the treatment efficiencies at WWTPs or from peak flows causing CSOs and SSOs (Sola et al., 2020; Bäckman, 1985). In addition, wastewater might have to bypass some of the treatment steps at the WWTP if maximum capacity is reached during peak flows. Higher continuous flows can lead to increased consumption of chemicals at the WWTP. It affects the environment with growing resource use, but can have economic impacts as well.

Further economic effects from higher continuous flows are increased costs for maintenance and electricity (Sola et al., 2020). Although, Dirckx et al. (2019) argue that the reduced electricity costs can be outweighed by rising costs from accelerated sludge production due to less diluted wastewater. Costs can moreover arise from peak flows as damages caused by overflows and basement flooding might require pay-outs (Sola et al., 2018).

Deteriorating water quality in natural waters can in addition to the environmental effects be linked to social sustainability. Sola et al. (2020) argue that availability to clean water can be included as a factor through ecosystem services. Examples that are given are the possibility for bathing and fishing with recreational purpose. The authors further note that human health can benefit from natural environments. Torgersen & Navrud (2018) bring up insecurity and phycological stress as crucial factors in terms of social sustainability regarding urban floods. Hence, it should be included when studying I/I-water and can be connected to basement flooding. Additionally, availability to clean natural waters can affect the cost and environmental strain from increased treatment need and required infrastructure in regards to drinking water production.

2.2.2 Finding and Reducing I/I

The first step in order to minimise or remove I/I-water is identification and quantification. There are various methods used for this, such as visual inspection, either in person or with closed-circuit television (CCTV) (Ohlin Saletti, 2020). Tracer methods can also be used where concentration differences in the sewer system are studied. It can be concentrations of substances that naturally occur in the system, or which are added just for this. Many different tracer methods have been tested and some examples are tracing the conductivity, turbidity, temperature, or stable isotopes (Guo et al., 2022; Heiderscheidt et al., 2022). Furthermore, flows can be used to study I/I-water. One key factor while doing this is to separate dry and wet weather flows since I/I-water can be both rain dependent and independent. Additional methods that Ohlin Saletti (2020) present in her review are based on modeling or in the category of digital water. Both rely on data collection and the advancements within online monitoring and data processing can improve the applicability.

Measures can be implemented with the purpose of limiting either the occurrence or the consequences of I/I-water (Ohlin Saletti et al., 2021). Rehabilitation of pipes and broken manholes can be used to reduce infiltration and inflow (Staufer et al., 2012; Sola et al., 2021). Additional measures that can affect the occurrence of I/I-water are to reduce the volume leaking from drinking water pipes and disconnecting stormwater flows (Ohlin Saletti et al., 2021; Ohlin Saletti, 2020). In some cases, improving the wastewater system's ability to operate with I/I-water might be more suitable. Examples of measures that can be implemented with this purpose are retention ponds or basins, improved capacity of the sewer system and WWTP, and flood resistant basements (Sola et al., 2021; Ohlin Saletti et al., 2021).

It is important to follow up with proper effectiveness assessment, as many of these measures can be expensive (Staufer et al., 2012). There can also be some challenges, in terms of ownership, when it comes to implementation of measures (Lundblad & Backö, 2014). This can often depend upon the cooperation between a municipal entity and property owners. The jurisdiction can in many cases be limited to remove unauthorised connections, for example disconnecting roof downpipes or drainage. Lundblad & Backö (2014) highlight that this type of measures can have a limited effect since removing the connection is the only thing that can be enforced. How the water is handled instead after the connection is removed is up to the property owner. Hence, even though the connection is removed, the water might still enter the sewer system for example through infiltration.

2.2.3 Decision Support Methods

The condition of the underground sewer systems and the volume of I/I-water have become important aspects within asset management for municipalities (Guo et al., 2022). Additionally, since the sewer system is only one of the municipalities' many assets in need of reinvestments and maintenance, prioritising measures is key for more optimised resource allocation (Ohlin Saletti, 2020). Having useful methods and tools to help with this prioritising process is therefore of importance and although various tools already exist today, further development is still needed.

An example of a tool is Future City Flow (DHI, n.d.-a). It is a simulation software that can be used to support planning, real-time control, and data analysis (DHI, n.d.-b). It builds upon hydraulic- and hydrologic models and enables the user to test different scenarios. Hence, future situations and the reduction of I/I-water following measures can be studied.

Sola et al. (2020) conducted a cost benefit analysis (CBA) with costs caused by I/I-water due to operation and phosphorus emissions, together with investment costs for various measures. The benefit included was from improved bathing water quality following the measures. After the evaluation, the study could conclude that there are measures available to reduce consequences from I/I-water in a socio-economically profitable way. They also highlighted that the reliability of the method would increase if some uncertainties could be reduced. Vallin (2016) came to a similar conclusion regarding uncertainties when testing a method which included multi-criteria analysis (MCA) and CBA. The purpose of the tested method was to identify areas where measures would give the most benefit, ultimately leading to more optimised resource allocation. Due to the uncertainties, the author recommended additional studies concerning sensitivity and that the method is used for decision support with supplementary evaluation.

A tool based on MCA with support for CBA is being developed by RISE and Swedish Water in a project aiming to develop strategic decision support regarding I/I-water (Svenskt Vatten, 2020). The tool originates from a Norwegian version and its purpose is to enable the user to create water balances, identify sources of I/I-water, and conduct a sustainability assessment. Additionally, the motivation behind the project is to reach something referred to as "sustainable level of inflow and infiltration (SELII)" (Svenskt Vatten, 2020). This means that there is not a clear goal of reducing I/I-water, but the focus is instead on reaching a sustainable situation.

2.3 Decision-Making and Risk Analysis

Decision-making is the process of reaching a decision regarding a problem and Aven (2012) described it as ”Decision-making is not just about making decisions, but about making good decisions”. It is difficult to objectively define what a good decision entails since it, among many factors, depends on the problem and the observer’s perspective. Hence, establishing a structured process is an effective way to increase transparency of the reasons behind a decision. A conceptualisation of the process Aven (2012) describes is presented in Figure 2.3.

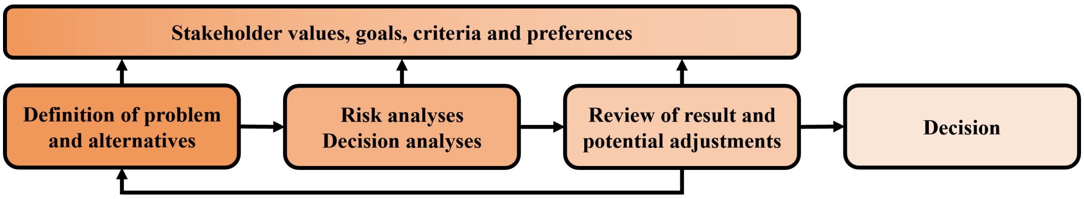

Figure 2.3: Conceptualisation of decision-making process inspired by Aven (2012).

The first step is to define the problem and the available alternatives to mitigate it (Aven, 2012). It is good to limit the number of alternatives at this point in the process to control the extent of the overall process. Continuing, the next step is then to conduct the necessary analyses, which can include risk assessment and decision analysis, for example cost benefit analysis (CBA). The purpose of the analyses is not to reach a decision, but to act as support in the process of reaching a decision (Aven, 2012). This means that the results need to be reviewed and discussed before any decision can be made. Throughout the process, stakeholders’ values, goals, criteria, and preferences should be considered. It should also be considered as an iterative process, and it might be necessary to go back to previous steps to adjust information.

2.3.1 Risk Assessment

As mentioned earlier, risk assessment can be a tool used in the decision-making process. Kaplan & Garrick (1981) summarised the purpose and necessity of good risk assessment when they wrote:

> *We are not able in life to avoid risk but only to choose between risks. Rational decision-making requires, therefore, a clear and quantitative way of expressing risk so that it can be properly weighed, along with all other costs and benefits, in the decision process.*

Kaplan & Garrick (1981) started defining risk by describing it with scenarios, the probability of the scenarios, and the consequences. The authors argued that risk could not be described with a number and instead established a risk curve where the whole curve represented the risk. Additionally, the authors argued that a curve was not enough either and discussed the possibility of including uncertainties if multiple risk curves were used. Their definitions and discussions regarding risk and the used risk analysis have since then had a large impact within the field.

The International Organization for Standardization (ISO, 2018) says that risk can usually be described with risk sources, potential events, consequences, and likelihood. It is further noted that even though the term ”likelihood” is often seen as ”probability”, an important distinction is that ”likelihood” can be used in a broader context and is not limited to a mathematical probability. Although, one of the most common usages of risk is through probability risk models (Aven, 2010). Within the probability models, risk is normally expressed as $Risk = (A, C, P)$ where A is the event, C is the consequence and P is the probability. This type of models were developed to enable the inclusion of both the probability and severity of a consequence. Aven (2010) argues that the use of probabilities is too narrow and suggests that uncertainties are used instead, giving $Risk = (A, C, U)$ where U is the uncertainty.

Uncertainties can be categorised as aleatory or epistemic (Hora, 1996). Aleatory uncertainties are caused by the natural randomness whereas epistemic uncertainties occur due to lacking knowledge. Hence, aleatory uncertainties cannot be reduced whereas epistemic uncertainties can be reduced with increased knowledge about the subject or model. There are various methods that can be used to include uncertainties in risk models. One alternative is to describe uncertainties by defining probability distributions (Aven, 2012). Risk can for example be described as $Risk = (A, C, U)$, where U aims to describe the uncertainties related to A and C. It can be implemented by assigning probability distributions or models for the parameters behind A and C. If historical data are not available to construct these distributions, a method that can be used to establish probability distributions is expert knowledge elicitation (EKE) and it is further described in section 2.4.

Probability distributions can result in quite complex calculations and Monte Carlo simulation is therefore frequently used (Aven, 2012). Monte Carlo simulation is a tool that automatically take random samples from the specified probability distributions during an iterative calculation process (Brooks, 1998). The iterative process results in probability distributions for the calculated values and consequently expresses uncertainties.

After the risk is calculated, it is typically evaluated according to three levels of risk acceptance (Aven, 2012). One where the risk is low enough to be treated as negligible, one where the risk is high enough to be unacceptable, and one in between where the risk must be reduced to be considered as low as reasonably practicable (ALARP).

2.3.2 Cost Benefit Analysis and Equivalent Annual Cost

A tool used as part of decision analysis is CBA and it is regularly used to support decisions aiming to reduce risks to the ALARP level (Aven, 2012). It balances benefits against costs and can be a fitting tool to use in wastewater planning as it allows aspect to be assigned monetary value (Sola et al., 2020). According to Aven (2012), a shortcoming with CBA can occur if factors are excluded due to the conversion into monetary values being too complicated. Willingness to pay (WTP) is one approach that can be used to estimate socio-economic cost for noneconomic factors (Sola et al., 2020). The WTP can be approximated, for example through questionnaires, where people are asked about how much they are willing to pay for certain policies and measures.

Net present value (NPV) is a performance measure utilised to compare alternatives when conducting CBAs (Aven, 2012). It is calculated according to Equation 2.1

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \tag{2.1}$$

where B_t is the benefit at year t, C_t is the cost at year t, T is the considered time in years and r is the discount rate. Discount rates can be used to give higher weight to the present costs and benefits compared to those in the future (Johansson & Kriström, 2018).

The calculated NPV can then be further used to calculate the equivalent annual cost (EAC) by using an annuity factor according to Equation 2.2 (Berggård, 2018). By using this method to calculate the yearly cost, taking both the discount rate and the length of the studied period into account, each year will have the same cost. Hence, it can allow comparisons of yearly costs even if different time periods are used.

$$EAC = Annuity\ factor \quad NPV = \frac{r}{1 - (1+r)^{-t}} \quad NPV \tag{2.2}$$

2.4 Expert Knowledge Elicitation

Expressing different points of interests with numbers can be helpful to create clarity and transparency within the decision-making process (Gosling, 2018). Obtaining the knowledge required for this can however be difficult in some cases. When measurements are either not possible or have unreasonable costs associated with it, EKE can be used to acquire data. Additionally, EKE is useful to be able to express uncertainties for variables providing decision-making support.

The goal of EKE is for uncertain quantities to be expressed with probability distributions based on experts' knowledge (O'Hagan, 2019). Even though EKE has several advantages and enables new types of analyses, it is very important to be aware of the disadvantages as well to produce as objective results as possible. The result will always have some subjectivity connected to it and it should therefore not be seen as absolute (O'Hagan, 2006). It is also important to have clear definitions for the relevant quantities to make the process easier and avoid misunderstandings.

Hoffman et al. (1995) describe that the personalities of the experts are one aspect that can affect the quality of the results. Extroverted experts were shown to have an easier time providing information and consequently gave more information during a short timeframe compared to introverted experts. Nevertheless, the authors also concluded that the introverted experts gave as much, and sometimes even more, information compared to the extroverted experts in the end. This highlights the need to understand the potential pitfalls and how to avoid them when using EKE.

Another aspect that can affect the quality of the results is different kinds of biases imposed by heuristics. Heuristics is a collective name for instinctive reasoning processes which are often used to make quick judgments (O'Hagan, 2019). This is usually achieved by not considering all the available information and aiming for satisfactory results instead of optimised results (Gigerenzer, 2008). It has had an important role throughout human history where quick decisions in everyday life were required, but it can easily influence more complex judgements as well. Some heuristics that are described by O'Hagan (2019) are anchoring, availability, range-frequency, overconfidence, and groupthink.

Anchoring is important to consider when making numerical judgements (O'Hagan, 2019). People tend to use a value they can easily remember as a starting point and adjust their judgment based on that. The starting value is referred to as the anchor and the judgment can easily be biased towards the anchor depending on how much the person adjust from their initial thought. It is therefore important to consider how information is provided and how questions are asked. Anchoring is similar to the availability heuristics in which people usually gives more weight to easily remembered information, potentially ignoring information from events that happened less recently (O'Hagan, 2006).

Cooke (1991) describes overconfidence as an important type of bias and notes that the effects from overconfidence can be even further enhanced by anchoring. How confident the experts are in their own ability to make the judgments can influence the size of their stated intervals. Overconfident experts might give too narrow intervals to appear knowledgeable while underconfident experts can give too broad intervals (O'Hagan, 2006).

It is normal that EKE is conducted with a group of experts and lead by a facilitator, with the goal of defining one probability distribution (O'Hagan, 2019). Depending on how the group of experts work together, some experts might become reluctant to suggest ideas that have the potential to be rejected by the group. This is what O'Hagan (2019) refers to as groupthink which can lead to some aspects not being considered in the judgements. In the end when there inevitably are multiple opinions on probability distributions, they can be combined either with a mathematical formula or by group discussions to reach consensus.

2.4.1 The Sheffield Elicitation Framework

Due to the possibility of having results influenced by the personalities of the experts, biases, and the experience of the facilitator, different protocols have been developed. The Sheffield Elicitation Framework (SHELF) is the protocol used in this project and it uses forms to guide the facilitator through different steps (Gosling, 2018). Material for using the SHELF-protocol is available as an open resource that has been developed by Tony O'Hagan and Jeremy Oakley with the aim of minimising biases throughout the elicitation process (O'Hagan, 2022). An overview of the process for an EKE workshop using the SHELF-protocol is shown in Figure 2.4.

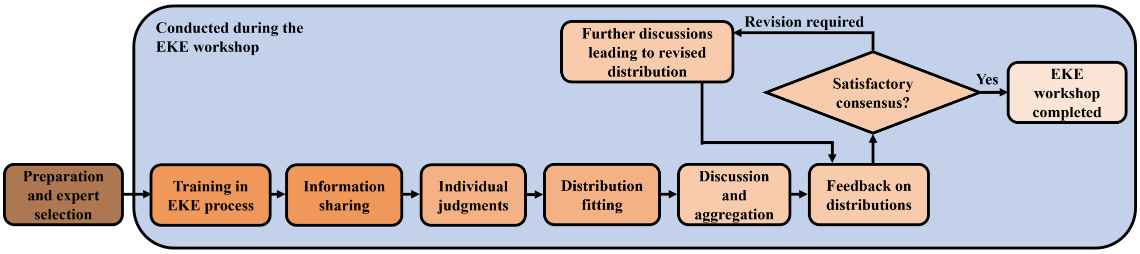

Figure 2.4: Workflow for a EKE workshop according to the SHELF protocol, inspired by Gosling (2018).

Preparation is an important part of the elicitation process that starts before the workshop and includes the recruitment of experts. O'Hagan (2019) recommends that around 4 to 8 experts are used to include a wide range of opinions while keeping the discussions at a reasonable length. Another important part of the preparation is preparation of the evidence dossier (O'Hagan, 2019). It should include the most relevant information about the quantities of interest (QoIs) that will be elicited to make sure that all the experts are aware of this key information. Hence, the evidence dossier plays a vital role in minimising the influence of the availability heuristic.

Training in the EKE process can be conducted both before the workshop and in the beginning of the workshop (O'Hagan, 2019). If all the experts can do it beforehand, more time can be spent discussing relevant matters during the workshop or reduce the required time. However, having the training in the beginning of the workshop can also have its benefits. It makes it easier for the facilitator to be confident in that all the experts have properly gone through training material and know the most important aspects. Additionally, questions can be directly addressed and can help limit confusion among the experts if they are inexperienced with the overall process or the SHELF protocol.

The individual judgments are the first of two judgment sections during the workshop. All the experts begin with privately writing down their plausible range for the QoI, referred to as X. This is done with a lower bound L and an upper bound U and should be defined in a way that the expert would be very surprised if the true value for X is outside their given range. O'Hagan (2019) mentions that the interval does not have to represent a specific percentile of probability, just that it is very unlikely for X to be outside. It is more important at this point to make the experts silently reason about the full range of X instead of making clear definitions, since the primary goal of this part is to minimise overconfidence. When all the experts have written down their range $[L, U]$, the facilitator challenges the judgements by saying that a true value for X have been reported and it is outside their given bounds. This is followed up with the facilitator giving the experts two alternative reactions to the statement. One where the expert objects and claims that something must be wrong with the reported value or the second one where the experts doubt their bounds and think the reported value is reasonable. All experts with the second reaction must adjust their bound(s) until all values outside $[L, U]$ are deemed unreasonable (O'Hagan, 2019).

When the bounds have been adjusted, if needed, the individual judgments can continue according to three different methods: quartile, tertile, or roulette (O'Hagan, 2019). Quartile is the method used throughout this project and it starts with the experts writing down their median value M. The value for M should represent the point where it is equally likely that the true value for X is below or above M. This is then challenged by the facilitator by asking the experts to imagine that there is a price to be won if they can guess if the true value is above or below M. Since M should represent the point where both options are equally likely, none of the experts should have a preference in the ideal case. Hence, all experts that have a preference must adjust their value for M (O'Hagan, 2019). It then continues with the experts specifying the quartiles $Q1$ and $Q3$, representing the 25^{th}- and 75^{th}-percentiles respectively. This can be challenged by the facilitator in a similar way to the value for M, meaning that there should not exist any preference between the intervals.

When all the experts have specified their values for L, $Q1$, M, $Q3$, and U, each individual judgment are fitted to a probability distribution. Everyone is allowed to see the results from the individual judgments at this point and each expert gets a chance to describe their thought process. This is the transition into group discussion and aggregation and since SHELF uses behavioural aggregation, the goal of the discussions is to reach consensus. The process is essentially the same for the group part as for the individual part of the workshop. O'Hagan (2019) recommends using a different method for the group judgment but in this project the quartile method was used for both mainly to limit the time required for training.

Since it is unlikely that everyone agrees with each other even after extensive discussions, it is recommended to introduce the concept of a rational impartial observer (RIO) perspective (O'Hagan, 2019). It is a theoretical perspective that should be used by the experts during the group judgment. An important aspect of introducing a RIO is that RIO does not completely agree one expert but can see advantages and disadvantages with every expert's arguments.

A crucial difference with the group judgment compared to the individual is that after the group have specified the five values and a probability distribution is fitted, they are allowed to adjust the distribution. This process should be repeated until the whole group agrees that the probability distribution represents RIO's judgment well. Some of the experts may think it is difficult to clearly understand the distribution by just looking at a graph and it can therefore be helpful to specify some percentiles and explain what those mean (Gosling, 2018). The tool provided by Oakley (2021) was used to fit distributions to the specified values throughout the project. In most cases the alternative ”best fitting” was used where the tool decides what type of distribution that is most suitable.

3

Model- and Case Study Description

3.1 General Model Description

The risk-based model used to calculate the cost of I/I-water is developed as part of the ongoing PhD research project with the title ”From hidden wastewater network to full access for smart decisions” and the submitted manuscript by Ohlin Saletti et al. (2022). It uses Microsoft Excel as its base and Monte Carlo simulations are used to consider uncertainties in input data and results. The calculations are done using Microsoft Excel and the add-in software @RISK.

The model includes effects, due to I/I-water, from basement flooding, CSOs/SSOs, pumping, and effects at the WWTP. This is conceptualised in Figure 3.1 and further described in the following sections.

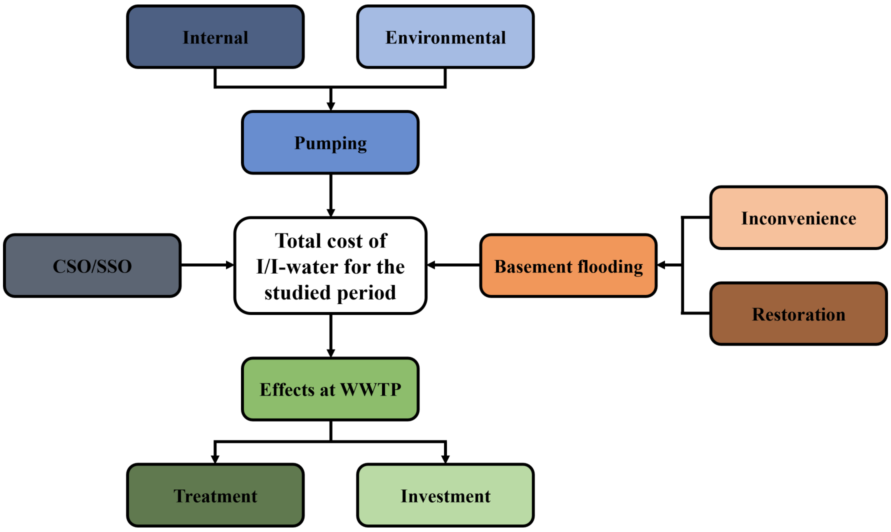

Figure 3.1: Overview of the effects due to I/I-water included in the model.

The included effects are defined as base effects or risks, where the base effects lead to continuous costs, while the risks cause costs that are calculated using events with corresponding consequences and probabilities (Ohlin Saletti et al., 2022). Costs at the WWTP and for pumping are seen as base effects and these costs are calculated according to Equation 3.1 and 3.2, respectively.

$$C_{WWTP} = V_{I/I} \quad c_{WWTP} \tag{3.1}$$

where C_{WWTP} is the cost at the WWTP, $V_{I/I}$ is the volume of I/I-water, and c_{WWTP} is the unit cost of I/I-water.

$$C_P = E_P \quad c_p \tag{3.2}$$

where C_P is the pumping cost, E_P is the energy used for pumping, and c_p is the cost for pumping which can include both financial costs and monetised environmental effects.

According to the earlier described definition, risk is defined as $Risk = (A, C, U)$, where uncertainties are included by assigning probability distributions for relevant variables. Basement flooding and CSO/SSO are defined as risks within the model and the risk costs are calculated as described in Equation 3.3 and 3.4.

$$R_{BF} = \int (c_{BF}) P_{BF} dP \tag{3.3}$$

where R_{BF} is the risk cost of basement flooding events caused by I/I-water, P_{BF} is the probability of basement flooding events, and c_{BF} is the cost of basement flooding events which can include both costs due to damaged properties and from psychological effects on affected people.

$$R_{CSO/SSO} = \int (c_{CSO/SSO}) P_{CSO/SSO} dP \tag{3.4}$$

where $R_{CSO/SSO}$ is the risk cost of CSO/SSO, $P_{CSO/SSO}$ is the probability of CSO/SSO, and $c_{CSO/SSO}$ is the cost CSO/SSO which can comparably to c_p include both financial costs and monetised environmental effects.

Discounting is used to calculate the present value (PV) for the costs to society associated with the base effects and risks, as the model is used to study longer time periods. The total PV of all included effects is calculated according to Equation 3.5.

$$PV_{tot} = \sum PV_{effect_n} \tag{3.5}$$

where PV_{effect_n} is the PV for effect n, calculated according to Equation 3.6

$$PV_{effect_n} = \sum_{t=0}^{T} \left(C_{n_t} \quad \frac{1}{(1+r)^t} \right) \tag{3.6}$$

where T is the length of the studied period including the years $t...T$, C_{n_t} is the cost of effect n in year t, and r is the social discount rate.

3.2 Model Implementation Götabergsgatan

Götabergsgatan is located in the central part of Gothenburg and is the case study area used by Ohlin Saletti et al. (2022) to apply the developed model. There are mixed types of buildings in the case study area including detached houses, apartment buildings, commercial buildings, and public buildings. The wastewater sewer system within the area is connected to Rya WWTP and is built as both separated and combined. Approximately 60% of the wastewater sewer system within the area is combined. Götabergsgatan is included in this project as a reference area and a more detailed description of how the four effects were implemented for the case study area follows.

3.2.1 Effects at the Wastewater Treatment Plant

The cost at the WWTP was calculated in two parts, treatment cost and investment cost (Ohlin Saletti et al., 2022). The PV for the cost of treating I/I-water for the whole studied period was calculated according to Equation 3.7.

$$PV_{WWTP_{tr}} = \sum_{t=0}^{T} V_{I/I_t} \quad (1 + yc_{I/I})^t \quad c_{tr} \quad (1 + yc_{tr})^t \quad \frac{1}{(1+r)^t} \tag{3.7}$$

where V_{I/I_t} is the volume of I/I-water to the WWTP from the case area during year t, $yc_{I/I}$ is the expected yearly change in volume calculated according to Equation 3.8, c_{tr} is the treatment cost per unit I/I-water at the WWTP, yc_{tr} is the expected yearly change in treatment cost calculated according to Equation 3.9.

$$yc_{I/I} = \left(\frac{1}{c_f}\right)^{\frac{1}{T}} - 1 \tag{3.8}$$

where c_f is a climate factor expressing the expected change due to climate change during T

$$yc_{tr} = \left(\frac{c_{tr}}{c_{tr} \quad inc_{tr}}\right)^{\frac{1}{T}} - 1 \tag{3.9}$$

where inc_{tr} is a factor expressing the expected change in treatment cost during T relative to today's monetary value.

The investment cost was calculated in two different ways that are referred to as the share of cost approach and the marginal cost approach (Ohlin Saletti et al., 2022). The marginal cost approach was only used as part of the sensitivity analyses within this Master's thesis project as it requires more input data compared to the share of cost approach.

3.2.1.1 Share of Cost Approach

When using the share of cost approach, the PV of investment is calculated according to Equation 3.10.

$$PV_{WWTP_i} = inv_{disc} \quad \frac{V_{I/I}}{V_{WWTP}} \tag{3.10}$$

where inv_{disc} is the discounted investment cost for the whole studied period calculated as described in Equation 3.11, V_{WWTP} is the total volume to Rya WWTP during T calculated according to Equation 3.12 and $V_{I/I}$ is the total volume I/I-water to the WWTP during T, calculated using the same approach as described in Equation 3.12.

$$inv_{disc} = \sum_{t}^{T} \frac{inv_t}{(1+r)^t} \tag{3.11}$$

where inv_t is the investment cost for year t.

$$V_{WWTP} = \sum_{t}^{T} V_{WWTP_t} \quad (1 + yc_{cf})^t \tag{3.12}$$

where V_{WWTP_t} is the volume during year t.

3.2.1.2 Marginal Cost Approach

The marginal cost approach builds upon earlier studies conducted by the city of Gothenburg (Ohlin Saletti et al., 2022). One aspect that was explored within these studies was that the WWTP must be built to handle high flows due to I/I-water even though those high flows rarely occur. This resulted in flow categories referring to different flow capacity requirements and the investment cost to achieve the capacity to reach each flow category was calculated within the model according to Equation 3.13.

$$c_f = \frac{inv_{disc} \quad s_f}{V_{WWTP} \quad s_{v_f}} \tag{3.13}$$

where s_f is the share of investment corresponding to flow category f and s_{v_f} is the share of the volume reaching Rya WWTP in flow category f.

Using a hydraulic model, the city of Gothenburg traced the volume of SRC and FRC from a selection of areas to study how these volumes affected the incoming wastewater to Rya WWTP (Ohlin Saletti et al., 2022). The result from this was used in the model to calculate an average cost for SRC and FRC according to Equation 3.14.

$$C_{SRC/FRC} = \frac{\sum_{a=1}^{A}(area_a \quad \sum_{f=1}^{F} c_f \quad s_{a_f})}{\sum_{a=1}^{A} area_a} \tag{3.14}$$

where A is the number of areas where SRC or FRC is monitored, $area_a$ is the area of area a, F is the number of flow intervals, and s_{a_f} is the share of volume in flow interval f reaching Rya WWTP from area a.

Lastly, the PV of investment regarding I/I-water was calculated according to Equation 3.15.

$$PV_{WWTP_i} = V_{I/I_t} \quad (V_{SRC_t} \quad c_{SRC} + V_{FRC_t} \quad c_{FRC}) \tag{3.15}$$

where V_{SRC_t} is the share of SRC from the case study area during year t, and V_{FRC_t} is the share of FRC from the case study area during year t.

3.2.2 Pumping

The cost of pumping was calculated as two different costs, internal financial cost and environmental cost (Ohlin Saletti et al., 2022). Equation 3.16 shows how the PV for the internal pumping cost was calculated.

$$PV_{P_{in}} = \sum_{t=0}^{T} V_{I/I_t} \quad (1 + yc_{cf})^t \quad E_p \quad c_{p_{in}} \quad \frac{1}{(1+r)^r} \tag{3.16}$$

where E_p is the energy consumption for pumping and $c_{p_{in}}$ is the internal energy cost.

The PV for the environmental cost of pumping for the studied period T was calculated according to Equation 3.17.

$$PV_{P_{env}} = \sum_{t=0}^{T} V_{I/I_t} \quad (1 + yc_{cf})^t \quad (E_p + E_{lift}) \quad c_{CO2_t} \quad yc_{CO2} \quad e_{CO2} \quad \frac{1}{(1+r)^t} \tag{3.17}$$

where E_{lift} is the energy needed to lift the I/I-water to the WWTP, c_{CO2} is the cost per carbon dioxide equivalent (CO_2-eq) for year t, yc_{CO2} is the expected yearly change in the cost of CO_2-eqs and e_{CO2} is CO_2-eqs per kWh.

3.2.3 Sewer Overflow

Equation 3.18 shows how the yearly risk cost of CSOs/SSOs was calculated and uses the volumes of CSOs/SSOs for a selection of studied return periods RP obtained using a hydraulic model (Ohlin Saletti et al., 2022).

$$R_{CSO/SSO_t} = \int \left(\frac{M_{CSO/SSO_{RP}}}{t_r} \quad WTP_{gs} \quad s_n \right) dP \tag{3.18}$$

where $M_{CSO/SSO_{RP}}$ is the mass of phosphorus and nitrogen in CSO/SSO for return period RP calculated according to Equation 3.19, t_r is the treatment requirement in recipients calculated according to Equation 3.20, WTP_{gs} is the WTP to reach good status in the recipients in the city of Gothenburg, and s_n is the share of the treatment requirement met by removing phosphorus and nitrogen.

$$M_{CSO/SSO_{RP}} = (V_{ss_{RP_{CSO/SSO}}} \quad P_{ss} + V_{sw_{RP_{CSO/SSO}}} \quad P_{sw}) \quad P_{PO_4eq} + \\ + (V_{ss_{RP_{CSO/SSO}}} \quad N_{ss} + V_{sw_{RP_{CSO/SSO}}} \quad N_{sw}) \quad N_{PO_4eq} \tag{3.19}$$

where $V_{ss_{RP_{CSO/SSO}}}$ is the volume of sanitary sewage in CSOs/SSOs for return period RP, P_{ss} is the concentration of phosphorus in sanitary sewage, $V_{sw_{RP_{CSO/SSO}}}$ is the volume of stormwater in CSOs/SSOs for return period RP, P_{sw} is the concentration of phosphorus in stormwater, P_{PO_4eq} is a conversion factor for phosphorus to PO_4-eq, N_{ss} is the concentration of nitrogen in sanitary sewage, N_{sw} is the concentration of nitrogen in stormwater, and N_{PO_4eq} is a conversion factor for nitrogen to PO_4-eq.

$$t_r = t_{r_P} \quad P_{PO_4eq} + t_{r_N} \quad N_{PO_4eq} \tag{3.20}$$

where t_{r_P} is the treatment requirement of phosphorus, and t_{r_N} is the treatment requirement of nitrogen.

Lastly, the PV of CSO/SSO for the whole studied period was then calculated according to Equation 3.21.

$$PV_{CSO/SSO} = \sum_{t=0}^{T} R_{CSO/SSO_t} \quad (1 + yc_{cf})^t \quad \frac{1}{(1+r)^t} \tag{3.21}$$

3.2.4 Basement Flooding

Cost of basement flooding was calculated as a risk cost for restoration and an inconvenience cost as a base effect (Ohlin Saletti et al., 2022). The restoration cost was calculated for a selection of return periods (RP_{BF}) according to Equation 3.22.

$$R_{BF} = \int S_{RP_{BF}} \quad U_{BF} \quad f_{U_{BF}} \quad s_{flood} \quad s_{base} \quad \sum_{b=1}^{B} cb_b \quad B_b dP \tag{3.22}$$

where $S_{RP_{BF}}$ is the share of basements being flooded during a rain with studied return period, s_{flood} is the share of buildings in the area where basement flooding could occur due to the sewer system, U_{BF} is the uncertainty of $s_{RP_{BF}}$, $f_{U_{BF}}$ is a factor to adjust the uncertainty depending on the return period, B is the number of building type b including $b...B$ with different restoration cost, s_{base} is the share of buildings with basement in the area where basement flooding events can occur, cb_b is the cost of basement flooding for building type b.

The PV for the restoration cost of basement flooding for T was calculated according to Equation 3.23.

$$PV_{R_{BF}} = \sum_{t=0}^{T} R_{BF} \quad (1 + yc_{cf})^t \quad \frac{1}{(1+r)^t} \tag{3.23}$$

The inconvenience cost represents an increasing WTP to avoid basement flooding in the future by people who live closer to at least one previous basement flooding.

Torgersen & Navrud (2018) describes three different zones, <100m, 100-1 000m, and >1 000m from previous flooding which were implemented for Götabergsgatan according to Equation 3.24.

$$PV_{BF_{in}} = \sum_{t=0}^{T} s_{base} \quad \sum_{z=1}^{Z} h_z \quad WTP_{BF_z} \quad \frac{1}{(1+r)^t} \tag{3.24}$$

where Z is the number of zones including $z...Z$ in different distance intervals from a previous basement flooding, h_z is the number of detached houses in zone z, WTP_{BF_z} is the WTP per household in detached houses to avoid basement flooding in zone z.

3.3 Case Study areas

To see how different preconditions affect the cost for I/I-water and test the availability of data, three case study areas were included in the project. This section will give a short description of the included case study areas and an overview of their locations is shown in Figure 3.2. The result for each case study area is presented in Chapter 5.

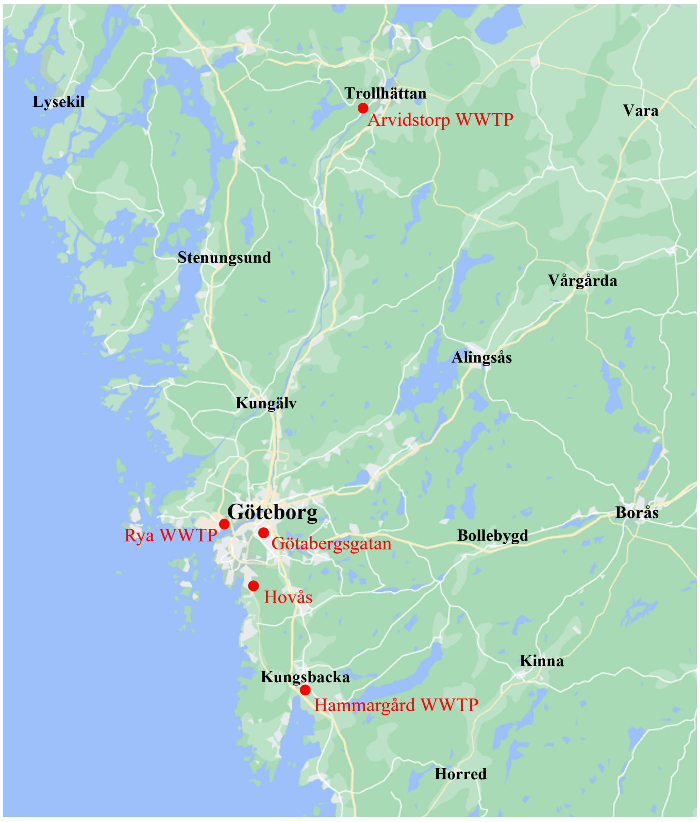

Figure 3.2: Overview of approximate locations of the included case study areas marked with red dots. Götabergsgatan is the reference area upon which the model is based and both Götabergsgatan and Hovås are connected to Rya WWTP. Mapdata @2022 Google

3.3.1 Hovås

The case study area in Hovås is located in the southwestern part of the city of Gothenburg. There are known problems with I/I-water within the area and the wastewater sewer system is built as a separate sewer system, where the sanitary sewage network is connected to Rya WWTP. The types of buildings are mainly detached houses but there are some larger buildings and a school within the area (City of Gothenburg, 2021).

3.3.2 Hammargård Wastewater Treatment Plant

Hammargård WWTP is located in Kungsbacka municipitality and is one of four WWTPs in the municipality (Kungsbacka municipality, 2021a). Its whole service area is included as a case study and it includes Kungsbacka, a part of Onsala, Fjärås, Hjälm, Anneberg, Älvåker, and Vallda (Kungsbacka municipality, 2021c). The sewer system is built as a separate system and the characteristics of connected buildings are mixed, including residential buildings, commercial buildings, schools, medical buildings, and some smaller industries. However, the connected industries have a small effect on the incoming wastewater to the WWTP. The share of I/I-water in the incoming wastewater to the WWTP is 45% on a 10-year average (Kungsbacka municipality, 2021b).

3.3.3 Arvidstorps Wastewater Treatment Plant

Arvidstorp WWTP is located in Trollhättan and its whole service area is included as a case study in this project. It includes Trollhättan, the northern part of Björke, Sjuntorp, Vetlanda, Åsaka, and Upphärad (Albertson, 2022). The wastewater sewer system is built as both separated and combined, consisting of approximately 20% combined. During the last fifteen years the share of I/I-water have varied between 60-70% (Albertson, 2022).

4

Model Implementation and Method Application

4.1 Model Implementation

This section describes how the model was implemented for each case study area with the implementation for Götabergsgatan as a reference area. Hence, the focus will be on the differences between the implementation for each case study area and Götabergsgatan. All data that were used for Götabergsgatan and the case studies are specified in detail in Appendix A-D.

As part of the sensitivity analysis, scenario analysis was used for the parameters that were not assigned probability distributions or were deemed to be particularly uncertain. The scenarios that were analysed in the same way for all case study areas are summarised in Table 4.1 and the scenarios that were adjusted based on the case study area are presented in each corresponding section.

Table 4.1: General scenarios analysed as part of the sensitivity analysis for all case study areas. Based on Ohlin Saletti et al. (2022).

Varying parameter	Standard value	Values for scenarios
Discount rate	0.035	0.015, 0.06
Climate factor	1.25	1.1, 1.4

The same process of running the model was used for Götabergsgatan and all case studies, including scenario analyses. It was done by running 10 simulations with 100 000 iterations each. Afterwards, the PV for the total cost of I/I-water was compiled and the standard deviation of the sample of 10 values was calculated using Microsoft Excel. This was then compared to the mean value of the sample and if the standard deviation was less than 1% of the mean value, the number of iterations were deemed to be enough. Thereafter, the result from simulation 1 was collected.

When the results from all four analyses were collected, yearly costs and performance indicators were calculated to enable comparisons. The yearly costs were calculated using Equation 2.2 and the performance indicators used were yearly cost per person, yearly cost per meter wastewater sewer system that transports sanitary sewage, and yearly cost per cubic meter I/I-water.

4.1.1 Hovås

Much of the model implementation for Götabergsgatan could be used for Hovås as the two areas are connected to the same WWTP. Hence, cost due to pumping, investment, and treatment could be implemented by only assigning the total I/I-water volume from Hovås case study area and the share of SRC or FRC. The total I/I-water volume and SRC or FRC were obtained from a hydraulic model for a normal year and a wet year, in respect to precipitation. A probability distribution was constructed for the total I/I-water flow by assuming a normal distribution where the wet year represented the 90^{th}-percentile and the 10^{th}-percentile was calculated according to Equation 4.1.

$$V_{10} = V_{normal} \quad \frac{V_{normal}}{V_{wet}} \tag{4.1}$$

where V_{10} is the 10^{th}-percentile of the total I/I-water volume, V_{normal} is the total I/I-water volume during a normal year, and V_{wet} is the total I/I-water volume during a wet year.

Regarding the cost related to basement flooding, the number of buildings were adjusted and the two parameters regarding the share of buildings with basement and the share of buildings where basement flooding can occur were combined into one parameter, share of houses vulnerable to basement flooding due to I/I-water. The information about share of basement flooding events for return period 1, 2, 5, 10, 20, 50, 100, 200 years was assumed to be the same as for Götabergsgatan. Furthermore, the number of zones for the inconvenience cost per unit were reduced to two from three, where the two closest zones (<100m and 100-1 000m from previous basement flooding) were combined into 1-1 000m from previous basement flooding. This zone was assigned the unit cost based on the previous zone 100-1 000m.

The cost from CSOs/SSOs was simplified to no longer have the discharged volume for return periods, but instead a yearly discharged volume. Discharged volumes were obtained for different discharge points for a normal year and a wet year. The discharged volume from each discharge point were combined for the normal year and wet year separately according to Equation 4.2 to estimate the total discharged volume.

$$V_{dtot} = V_{d1} + 0.2 \quad V_{d2} + 0.6 \quad V_{d3} \tag{4.2}$$

where V_{d1} is the discharged volume at the discharge points located within the Hovås case study area, V_{d2} is the discharged volume at the discharge points located furthest away from the Hovås case but that were still assumed to overflow due to I/I-water from the case study area, and V_{d3} is the discharged volume at the discharge points located in between the other described discharge points. The values 0.2 and 0.6 were chosen based on estimated contributions using a hydraulic model over the studied area.

In addition to the general scenarios presented in Table 4.1, two extra scenarios were analysed for Götabergsgatan and Hovås case study. One of the scenarios was when using the marginal cost approach instead of the share of cost approach. Hence, all results presented in Chapter 5 is calculated with the share of cost approach if the marginal cost approach is not specifically stated. The extra scenarios are summarised in Table 4.2.

Table 4.2: Overview of the scenarios used as part of the sensitivity analysis for Götabergsgatan and Hovås. DH = Detached houses, OB = other buildings (apartment/commercial and public), and higher cost means that the unit cost based on zone <100m from previous basement flooding was used.

Scenario	**Standard**	**Used for scenario**
Investment approach $^{/}$	Share of cost	Marginal cost
Included buildings	DH	DH + OB
Included buildings & cost	DH	DH + OB DH + higher cost DH + OB + higher cost

Conducted for Götabergsgatan
Conducted for Hovås

4.1.2 Hammargård and Arvidstorp Wastewater Treatment Plant

Most of the model was implemented for Hammargård WWTP and Arvidstorp WWTP in a similar manner. The total I/I-water volume from the case study areas was implemented using the same method as for Hovås, with flows for a normal year and a wet year. As only the share of cost approach was used for the cost of investment for Hammargård- and Arvidstorp WWTP, the share of FRC and SRC was not needed. The marginal cost approach is more suitable when studying sub-areas as the sum of all sub-areas within a service area, calculated according to the marginal cost approach, would result in a total cost higher than the estimated investment cost for the period. Furthermore, the marginal cost approach requires quite specific studies about how the volume FRC/SRC from different sub-areas affect the flow at the WWTP. Hence, the marginal cost approach was deemed unsuitable for Hammargård WWTP case study and Arvidstorp WWTP case study due to availability of data and the scope of this project.

The model for Arvidstorp WWTP required one additional parameter in the calculation of the cost associated with basement flooding. A total number of residential buildings were obtained instead of numbers of detached houses and apartment buildings separately. Hence, a parameter regarding the share of detached houses within residential buildings was added. The remaining share of residential buildings was assumed to be apartment buildings and was added to the number of commercial buildings to end up with the estimated number of apartment/commercial buildings.

One difference compared to the implementation of Hovås was how the WTP to reach good water status was estimated. Soutukorva & Wallström (2018) studied the WTP per household in Gothenburg and the lower and upper limits were therefore first recalculated to the WTP per person by assuming 2.1 persons per household in Gothenburg according to City of Gothenburg (n.d.). The two values were then multiplied by the number of persons connected to the system within Hammargård WWTP case study area and Arvidstorp WWTP case study area, respectively.

The usage of a different WTP led to lower benefits from removing PO_4-eq, 57 SEK/PO_4-eq and 91 SEK/PO_4-eq for Hammargård WWTP and Arvidstorp WWTP respectively. This was added as an scenario in the sensitivity analysis, where the benefit from removing PO_4-eq was assigned the value of 298 SEK/PO_4-eq based on Gothenburg instead of calculating it from WTP to see how it affected the cost of CSO/SSO. Additionally, Equation 3.19 was adjusted for Hammargård WWTP according to Equation 4.3 due to the use of a dilution factor.

$$M_{CSO_{RP}} = \frac{V_{ss_{RP}} \quad P_{ss}}{d_f} \quad P_{PO_4eq} + \frac{V_{ss_{RP}} \quad N_{ss}}{d_f} \quad N_{PO_4eq} \tag{4.3}$$

where d_f is the dilution factor of CSOs/SSOs compared to sanitary sewage.

An adjustment was made to the "Included buildings & cost" scenario as well. The information about the number of buildings within the zones 1-1 000m and 1 000m+ from previous basement flooding had large uncertainties connected to it for Arvidstorp WWTP case study area and the same information could not be obtained for Hammargård WWTP case study area. Hence, the inconvenience cost was calculated with the assumption that 100% of the buildings were within the closer zone in addition to the first assumption that it was 50% within both zones. An overview of the of the scenarios analysed for Hammargård WWTP case study and Arvidstorp case study, in addition to the general scenarios in Table 4.1, is presented in Table 4.3.

Table 4.3: Overview of the scenarios used as part of the sensitivity analysis for Hammargård- and Arvidstorp WWTP. A = benefit based on WTP used, B = benefit from Gothenburg used, DH = Detached houses, OB = other buildings (apartment/commercial and public), and higher cost means that the unit cost based on zone <100m from previous basement flooding was used.

Scenario	**Standard**	**Used for scenario**
Benefit from removing PO_4-eq	Based on WTP	Benefit from Gothenburg
Included buildings & cost (A)	DH	DH + OB DH + higher cost DH + OB + higher cost
Included buildings & cost (B)	DH	DH + OB DH + higher cost DH + OB + higher cost

4.2 Data Collection

4.2.1 Götabergsgatan

Within the PhD research project ”From hidden waste water network to full access for smart decisions”, four EKE workshops were conducted to collect data for Götabergsgatan (Ohlin Saletti et al., 2022). Data and valuable reflections were collected for this master's thesis as well by participation and note-taking during the workshops. These workshops will therefore be briefly described in this report.

The first EKE workshop was conducted on 2022-02-10. During the 2.5 hour long workshop, the QoIs discussed was energy use, CO_2 emissions, economic valuation of CO_2-equivalents, and WTP to reach good water status in recipients. It was conducted with participants from the project group and the process was adopted to focus more on discussions, rather than individual judgments.

Treatment cost of I/I-water and reinvestment cost for 3 different time intervals (year 1-10, year 11-50, and year 51-100) with year 2021 as the starting point were QoIs addressed during the second EKE workshop. It was conducted on 2022-02-11 and was 3 hours long. In total, 4 experts, the facilitator, and 2 additional persons were present during the workshop. The workshop followed the procedure described in section 2.4.1 without any adjustment. As the time during the workshop was limited, the division into flow-intervals was specified via emails between the participating experts and the facilitator afterwards.

In similar fashion, the third EKE workshop was completed according to the description in section 2.4.1. It was conducted on 2022-02-22 with 3 experts, the facilitator and 1 additional person for administrative tasks. Treatment requirement of phosphorus and nitrogen in recipients and the share of the treatment requirement that will be fulfilled by removing phosphorus and nitrogen were QoIs in focus during the 3 hours long workshop. The judgments of phosphorus and nitrogen concentrations in sanitary sewage and stormwater were elicited via email after the workshop.

The fourth and last EKE workshop regarding Götebergsgatan was held on 2022-03-01. Apart from the facilitator and 1 person for note-taking, 3 experts participated. The share of combined system within the area and the share of basements connected to combined system were the two QoIs addressed during the workshop. This workshop was conducted according to section 2.4.1 but was finished early to discuss some elements identified during the group discussions.

4.2.2 Hovås

Since most of the parameters in need of a probability distributions that were specified for Götabergsgatan could be used for Hovås as well, no EKE workshops were conducted specifically for Hovås. However, one elicitation was conducted via email with two experts from the workshop on 2022-03-01 regarding the share of buildings vulnerable to basement flooding. The rest of the data was collected from hydraulic models and systems with help from the Department of Sustainable

Waste and Water, City of Gothenburg, apart from the number of buildings which was manually counted and categorised using Google Maps and Street View.

4.2.3 Hammargård Wastewater Treatment Plant

One EKE workshop regarding Hammargård WWTP was conducted on 2022-03-22 with 4 persons from Kungsbacka municipality, with mixed backgrounds and knowledge, acting as experts. In addition to the experts, the facilitator and 1 person for administrative tasks were present during the workshop. A simplified version of the SHELF protocol was used to limit the required time for each judgment and to better fit the composition of the group of experts. An overview of the QoIs discussed during the workshop is presented in Table 4.4.

Table 4.4: QoIs addressed during the workshop regarding Hammargård WWTP.

QoI	Description	Unit
QoI 1	Investment costs year 1-10	SEK
QoI 2	Investment costs year 11-50	SEK
QoI 3	Investment costs year 51-100	SEK
QoI 4	Share of houses vulnerable to basement flooding due to I/I-water	-
QoI 5	Treatment costs for I/I-water	kWh/m^3
QoI 6	Energy use for pumping	SEK/m^3
QoI 7	Energy cost	SEK/kWh
QoI 8	Treatment of phosphorus needed in recipients	kg P/year
QoI 9	Treatment of nitrogen needed in recipients	kg N/year

Selection of experts was done by one representative from Kungsbacka municipality, based on a brief description about what topics would be discussed during the workshop. The aim for the composition of the group of experts was to include mixed knowledge and backgrounds, as there were quite varied topics covered within the QoIs. Additionally, the preparation of the evidence dossier also differed compared to the description in section 2.4.1. The accessibility to relevant information was higher for the experts, compared to the organiser, in this case as they were employed within the municipality. Hence, the evidence dossier focused more on giving a description of the QoIs instead of providing relevant values. A short description of the steps used when following the quartile method within the SHELF protocol was included as well in the evidence dossier that was sent out to the participants 1.5 weeks prior to the EKE workshop.

A simplified version of the quartile methods within the SHELF protocol was used during the EKE workshop. The initial training elicitation was done as individual judgments to ensure that each expert understood the process. Following the training, all judgments regarding the QoIs were elicited using group judgments only, excluding the individual judgment section of the SHELF protocol. This simplification was done mainly to limit the required time to a single 3-hour long session, but also due to the composition of the group of experts. The level of knowledge of the experts within the group varied between different topics and it was therefore assumed that some experts would find it difficult to make individual judgments. Hence, allowing group discussions directly was determined to be the appropriate approach. Each step to estimate L, U, M, $Q1$, and $Q3$ was still thoroughly followed, and the experts were allowed to adjust the fitted distribution at the end of each judgment.

For the data where no probability distribution was needed, for example data regarding volumes, Kungsbacka municipality (2021c) and Kungsbacka municipality (2021b) were used together with complementing information from Kungsbacka municipality via email. As information about number of buildings could not be obtained, it was estimated by manually counting with the help of Google Maps and Street View.

4.2.4 Arvidstorp Wastewater Treatment Plant

Regarding Arvidstorp WWTP, one EKE workshop was conducted on 2022-04-26 with 6 persons from Trollhättan Energi AB as experts. The workshop was conducted using the same simplified version of the SHELF-method described for Hammargård WWTP in section 4.2.3. Prior to the workshop, the data in no need of probability distributions were collected via email and one meeting with Trollhättan Energi AB. The QoIs for the EKE workshop were also discussed during a meeting prior to the workshop as preparation.

All QoIs could not be addressed during the 3 hour long workshop and some judgments were therefore conducted via email after the workshop. This was deemed to be the most appropriate approach, as the time and availability was limited, and every participant felt like they fully understood all necessary steps of the judgments. Table 4.5 shows how the judgement for each QoI was conducted.

Table 4.5: QoIs addressed during and after the workshop regarding Arvidstorp WWTP.

QoI	**Description**	**Unit**
QoI 1	Investment costs year 1-10	SEK
QoI 2	Investment costs year 11-50	SEK
QoI 3	Investment costs year 51-100	SEK
QoI 4	Share of houses vulnerable to basement flooding due to I/I-water	-
QoI 5	Treatment costs for I/I-water	kWh/m^3
QoI 6	Energy use for pumping	SEK/m^3
QoI 7	Energy cost	SEK/kWh
QoI 8	Treatment of phosphorus needed in recipients	kg P/year
QoI 9	Treatment of nitrogen needed in recipients	kg N/year

Discussed during the workshop and complemented afterwards via email
Judgment conducted after the workshop via email

5

Results & Discussion

5.1 Götabergsgatan

The PV for the total cost of I/I-water from Götabergsgatan is presented in Figure 5.1. It shows that the median value is around 450 million SEK with the 10^{th}-percentile (P10) about 17% lower at 380 million SEK. Further, the 90^{th}-percentile (P90) is 20% higher than the median at roughly 540 million SEK.

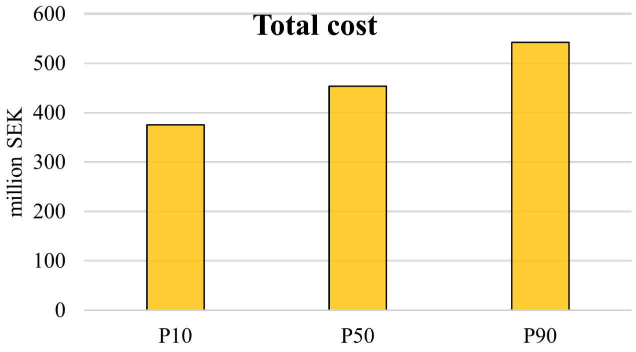

Figure 5.1: PV for the total cost of I/I-water from the Götabergsgatan area. Presented as P10, P50, and P90.

A more detailed view of the result is presented in Figure 5.2, where each effect included in the model are shown separately. Inconvenience related to basement flooding, CSO/SSO, and internal pumping are the effects associated with the smallest costs. Their median values range from 1 million SEK to 5 million SEK, but all three effects have P90 values that are at least 150% higher than their median.

Restoration cost connected to basement flooding is the effect associated with the highest cost with a median value of 250 million SEK. The value for P90 is 26% higher than the median at 310 million SEK and P10 is about 24% lower compared to the median. Investment cost have the second highest median, followed by the treatment at almost 100 million SEK and 70 million SEK respectively.

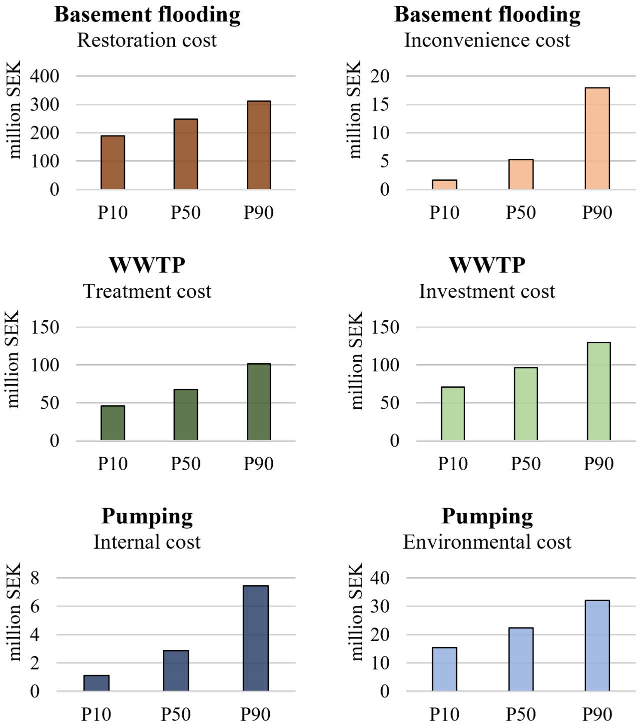

Figure 5.2: PV for the cost of I/I-water for each included effect in the model for Götabergsgatan.

5.1.1 Sensitivity Analysis

Figure 5.3 shows the Spearman rank correlation coefficients for the PV of the total cost of I/I-water. The parameter with the highest positive correlation coefficient is the total I/I-water volume from the area but is closely followed by two parameters related to basement flooding. This means that the cost increases with increasing I/I-water volume. Additionally, it is noteworthy that four of the seven highest correlation coefficients are connected to basement flooding.

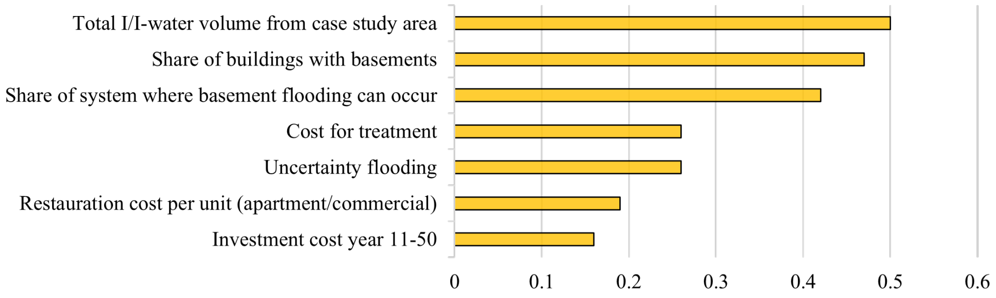

Figure 5.3: Spearman rank correlation coefficients for the PV of the total cost of I/I-water from Götabergsgatan.

How different discount rates and climate factors affected the result is presented for the PV of the total cost in Figure 5.4. It is evident that the choice of climate factor is not as important as for the discount rate. Using a discount rate of 0.015 instead of 0.035 resulted in 93% higher values for the presented percentiles, while a discount rate of 0.06 gave about 41% lower values.

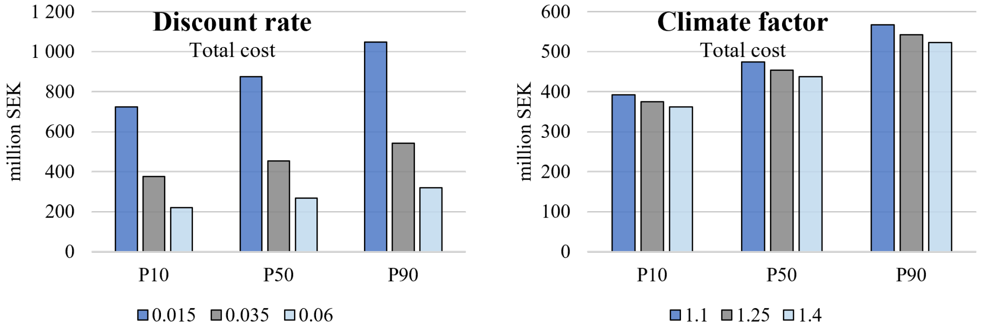

Figure 5.4: PV for the total cost of I/I-water from Götabergsgatan for varied discount rate to the left and varied climate factor to the right.

Both the marginal cost approach and the share of cost approach were implemented for Götabergsgatan and Figure 5.5 shows the result for both. The investment cost differs depending on the used approach with the share of cost approach resulting in a 70% lower median value of around 100 million SEK compared to 320 million SEK. In addition, the P10 and P90 is about 50% and 90% lower for the share of cost approach, respectively. It was described earlier that investment was associated with the second highest cost since share of cost is the approach mainly used in this project. However, the cost associated with investment would instead be the highest cost if the marginal cost approach was used. The P90 for the PV of the total cost would be 1.5 billion SEK instead of 130 million SEK in this case.

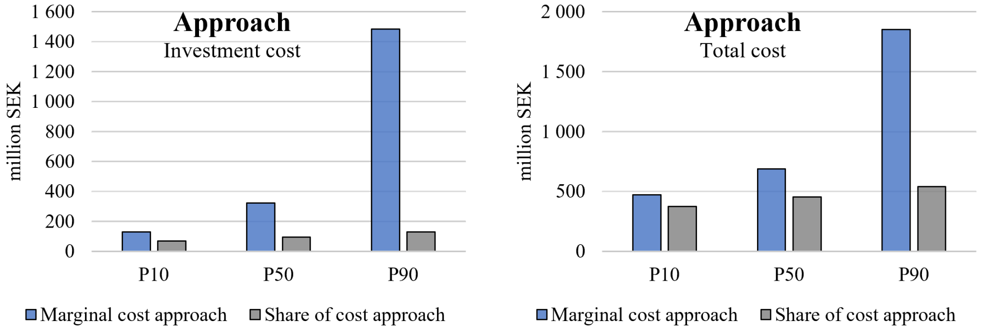

Figure 5.5: PV for the investment cost due to I/I-water from Götabergsgatan to the left and PV for the total cost of I/I-water to the right, depending on what investment approach was used.

Figure 5.6 shows the result from the scenario analysis where the apartment/commercial building and public building categories were assigned inconvenience costs similar to detached houses. Including those categories would increase the inconvenience cost with more than 1 000% with the median cost increasing from 5 million SEK to 60 million SEK. Although, it only affects the median value of the PV for the total cost with about 15% since the inconvenience cost is an overall relatively small cost.

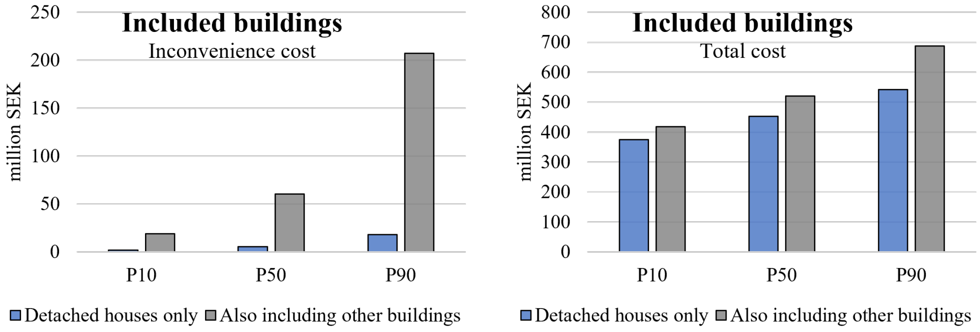

Figure 5.6: PV for the inconvenience cost caused by I/I-water within Götabergsgatan to the left and the PV for the total cost of I/I-water to the right.

5.2 Hovås

Figure 5.7 presents the PV of the total cost of I/I-water for Hovås case study area. The median cost is 39 million SEK and P90 is 49% higher at 58 million SEK. Additionally, P10 is 28 million SEK which is around 28% lower.

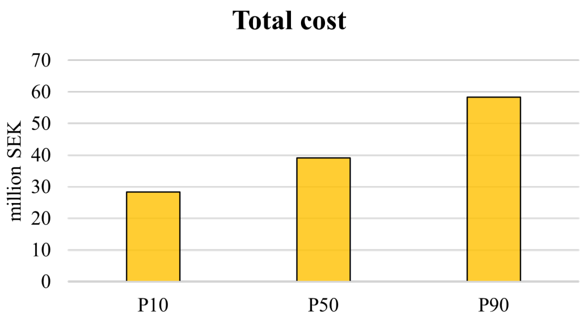

Figure 5.7: PV for total cost of I/I-water from Hovås case study area for the studied period of 100 years

By studying the more detailed view of the result for Hovås in Figure 5.8 it becomes evident that the cost associated with CSO/SSO and internal pumping is the lowest for Hovås similarly to Götabergsgatan. The inconvenience cost has a relatively low median value as well but ranges from 0.4 million SEK to 11 million SEK since P10 and P90 is 80% lower and 415% higher, respectively. Restoration resulting from basement flooding is still associated with the highest cost followed by investment.

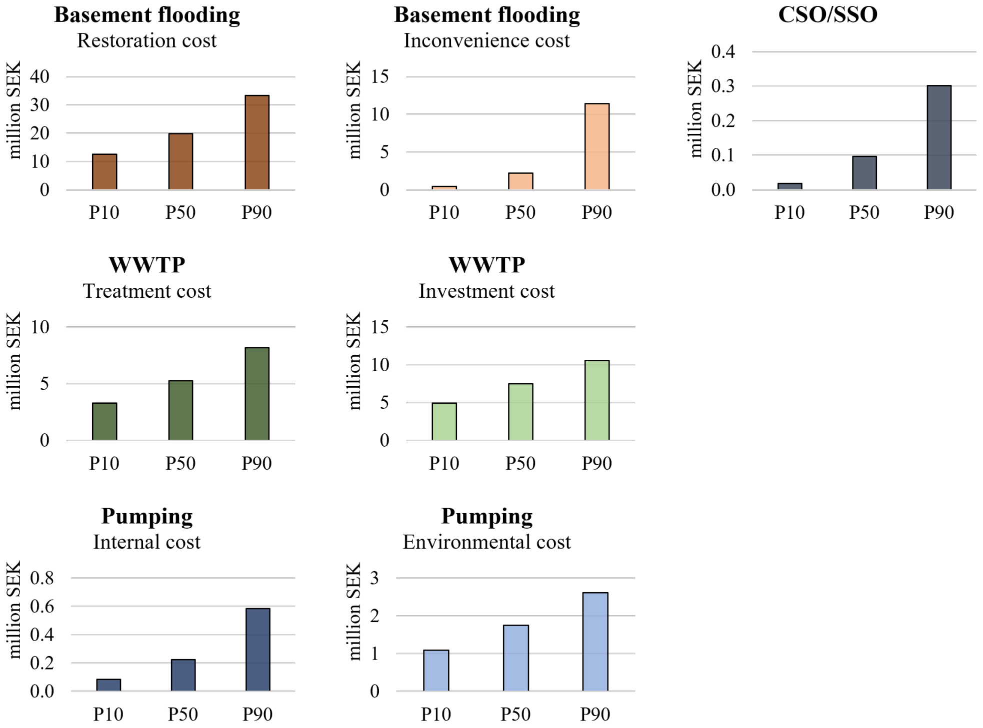

Figure 5.8: PV for the cost of I/I-water for each included effect in the model for Hovås case study area.

5.2.1 Sensitivity Analysis

The Spearman rank correlation coefficients for the PV of the total cost of I/I-water from Hovås is presented in Figure 5.9. It shows a quite similar result compared to Götabergsgatan but it is apparent that the two areas have different building characteristics. The result from Hovås indicates that the PV is more dependent on the number of detached houses whereas the result from Götabergsgatan is more dependent on the number of apartment/commercial buildings. It is also noteworthy that the inconvenience cost for the zone of detached houses within 1 000m meter of previous basement flooding has the second highest Spearman rank correlation coefficient.

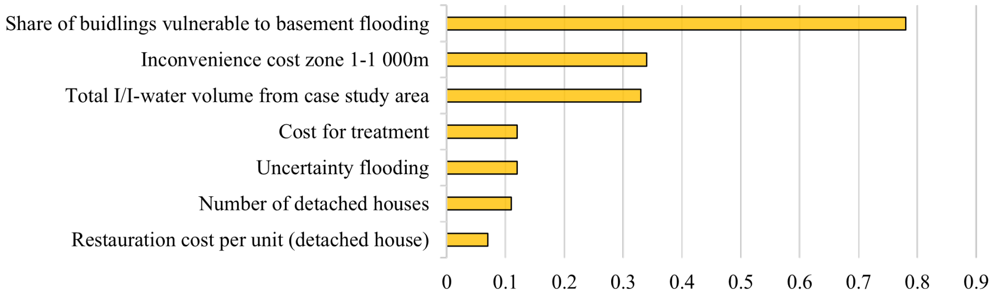

Figure 5.9: Spearman rank correlation coefficients for the total cost of I/I-water from Hovås case study area.

From the scenario analysis of the PV of the total cost of I/I-water from Hovås with varying discount rate and climate factor, presented in Figure 5.10, the same conclusion can be drawn in that varying the discount rate affects the result more than varying the climate factor.

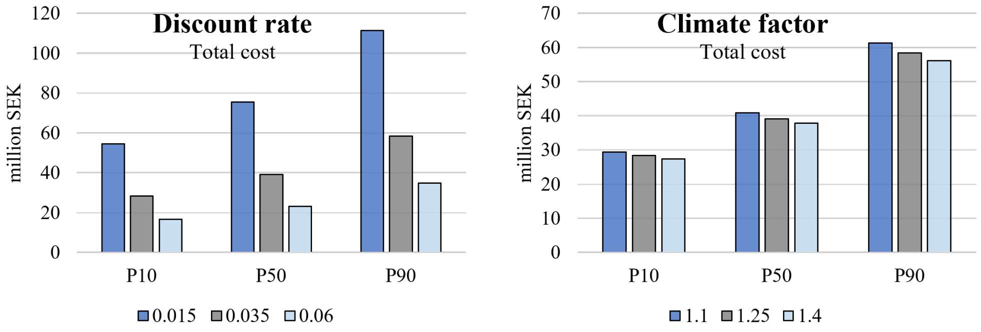

Figure 5.10: PV for the total cost of I/I-water from Hovås case study area for varied discount rate to the left and varied climate factor to the right.

Both the share of cost approach and the marginal cost approach were used for Hovås as well. The comparison of the results from both approaches are shown in Figure 5.11 and the marginal cost approach results in higher cost in this case too. Although, the differences between the two approaches are smaller for Hovås compared to Götabergsgatan. Using the share of cost approach yields a median for the investment cost that is 48% lower than for the marginal cost approach, whereas Götabergsgatan resulted in a 70% lower median. This can also be seen for P90 for the total cost.

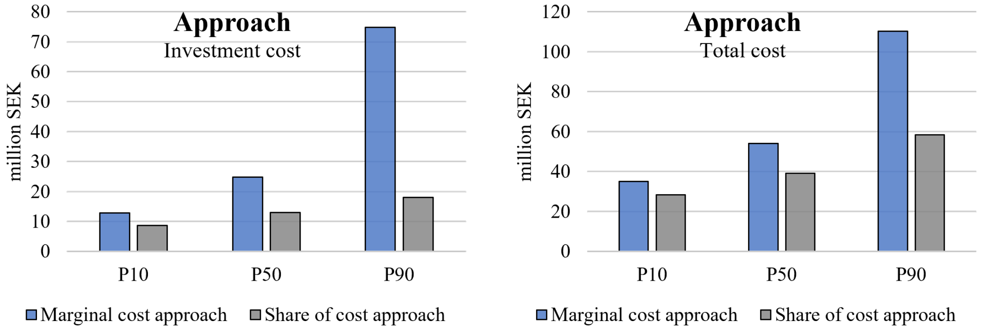

Figure 5.11: PV for the investment cost due to I/I-water from Hovås case study area to the left and the PV for the total cost of I/I-water to the right, depending on what investment approach was used.

Since two zones (1-1 000m and 1 000m+) were used instead of three (1-100m, 100-1 000m, and 1 000m+) for the calculation of inconvenience cost, the inconvenience cost per unit was varied in addition to the inclusion of other buildings. The result from these scenarios is presented in Figure 5.12. It becomes clear that these factors affect the inconvenience cost as the median and P90 varies between 2 to 5 million SEK and 11-23 million SEK, respectively. This mostly affect P90 of the PV of the total cost of I/I-water from Hovås where the difference between the lowest and highest value is 15%.

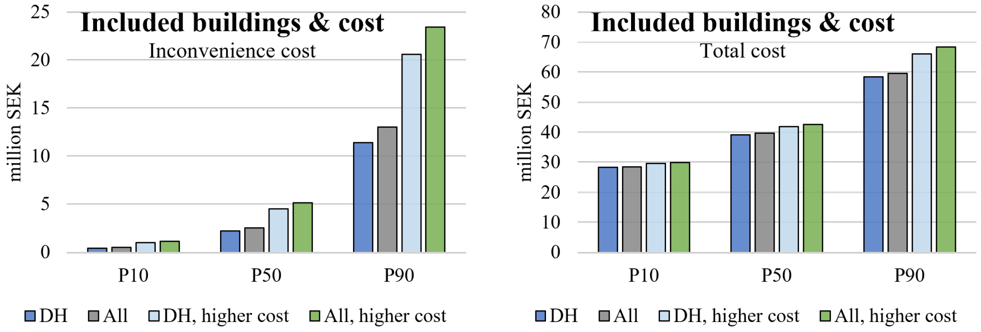

Figure 5.12: PV for the inconvenience cost caused by I/I-water within Hovås case study area to the left and the PV for the total cost of I/I-water to the right. DH = detached house only, All = including other buildings as well, and higher cost = cost for zone 1-100m instead of 100-1 000m was used.

5.3 Hammargård Wastewater Treatment Plant

Figure 5.13 presents the PV for the total cost of I/I-water for Hammargård WWTP case study area. The median cost is 1.3 billion SEK with P90 being 33% higher at almost 1.8 billion SEK. Additionally, P10 is 980 million SEK which is 26% lower than the median.

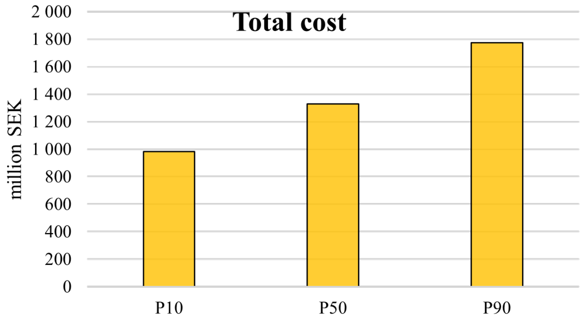

Figure 5.13: PV for total cost of I/I-water within Hammargård WWTP case study area for the studied period of 100 years

The more detailed view of the total cost of I/I-water within Hammargård WWTP case study area is shown in Figure 5.14. Costs associated with inconvenience from basement flooding and CSO/SSO are the lowest ones, similarly to Götabergsgatan and Hovås. Furthermore, the inconvenience cost carries large uncertainty as for Hovås. The P90 value for the inconvenience cost is 383% higher than the median and P10 is 79% lower.

Investment at the WWTP is the effect resulting in the highest cost with a median cost of 880 million SEK and P90 of 1.3 billion SEK. In addition, P10 is 33% lower at 590 million SEK.

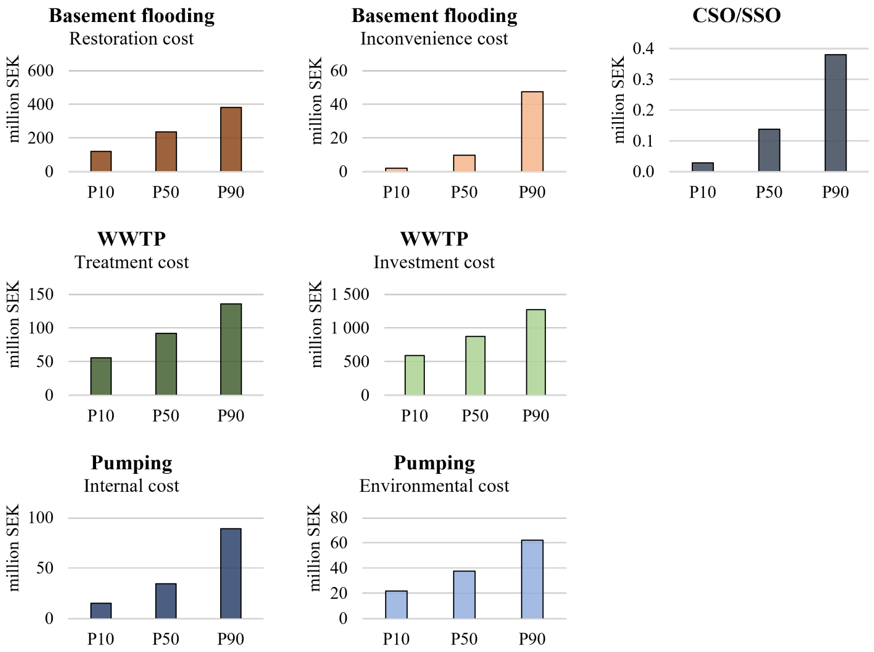

Figure 5.14: PV for the cost of I/I-water for each included effect in the model for Hammargård WWTP case study area.

5.3.1 Sensitivity Analysis

As for Götabergsgatan, the total I/I-water volume is the variable with the highest Spearman rank correlation coefficient. This can be seen in Figure 5.15. The share of buildings vulnerable to basement flooding have the third highest correlation coefficient even though the variables are more related to investment for this case study area, compared to Hovås and Götabergsgatan. Furthermore, the total wastewater volume to the WWTP shows a higher correlation coefficient than for the previous cases with a value of -0.25.

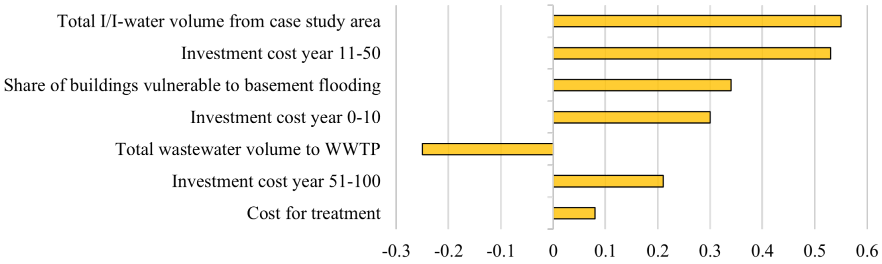

Figure 5.15: Spearman rank correlation coefficients for the total cost of I/I-water within Hammargård WWTP case study area.

When looking at the PV for the total cost of I/I-water with varying discount rate and climate factor, shown in Figure 5.16, the same trend continues where the discount rate affects the result more than the climate factor.

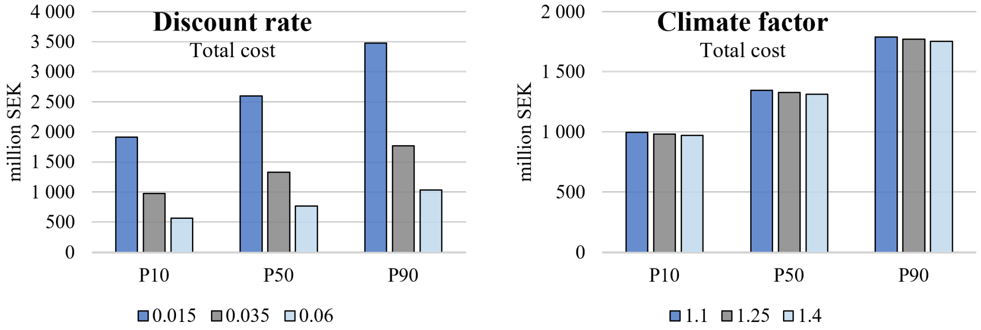

Figure 5.16: PV for the total cost of I/I-water within Hammargård WWTP case study area for varying discount rate to the left and varying climate factor to the right.

The results from the analyses of the PV for the inconvenience cost from basement flooding and the PV for the total cost of I/I-water, depending on included buildings, share of buildings within zone 1-1 000m from previous basement flooding, and inconvenience cost per unit, are presented in Figure 5.17. It is evident that all these parameters affect the PV for the inconvenience cost in a considerable manner but not for the PV for the total cost of I/I-water. Although, there are slight differences when assuming 100% of the buildings are within 1 000m of a previous basement flooding instead of 50%.

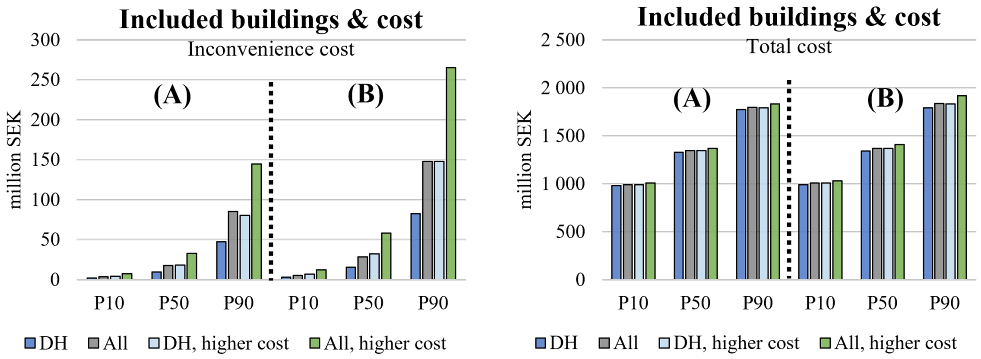

Figure 5.17: PV for the inconvenience cost caused by I/I-water within Hammargård WWTP case study area to the left and the PV for the total cost of I/I-water to the right. DH = detached house only, All = including other buildings as well, and higher cost = cost for zone 1-100m instead of 100-1 000m was used. Case A uses the assigned probability distribution for share of buildings within 1 - 1 000m from previous basement flooding and case B is a scenario where that share instead is 100%.

Figure 5.18 presents the result from the analysis using benefit from removing PO_4-equivalents based on WTP per person and an assigned benefit from

Gothenburg. The higher benefit from Gothenburg yields about 300-500% higher costs for CSO/SSO for the reported percentiles but it is still a relatively small cost. Hence, there is not a noticeable affect on the PV for the total cost of I/I-water.

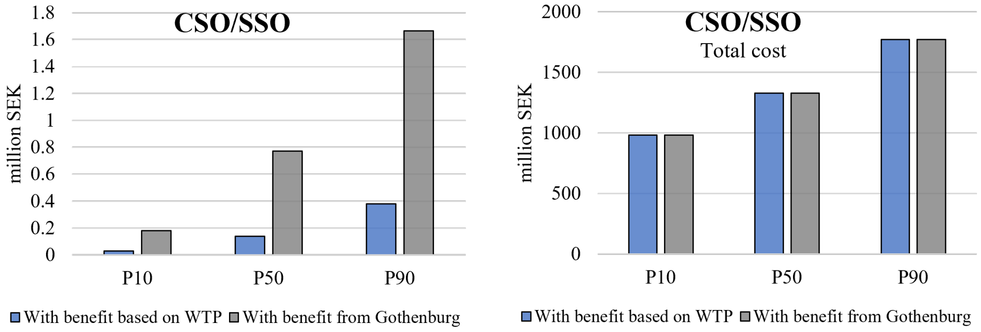

Figure 5.18: PV for the cost of CSO/SSO to the left and PV for the total cost of I/I-water, with varied benefit from removal of PO_4-equivalents.

5.4 Arvidstorp Wastewater Treatment Plant

The PV for the total cost of I/I-water within Arvidstorp WWTP case study area is presented in Figure 5.19. It ranges from about 1.6 billion SEK to 2.4 billion SEK for P10 and P90 with a median cost of 1.9 billion SEK.

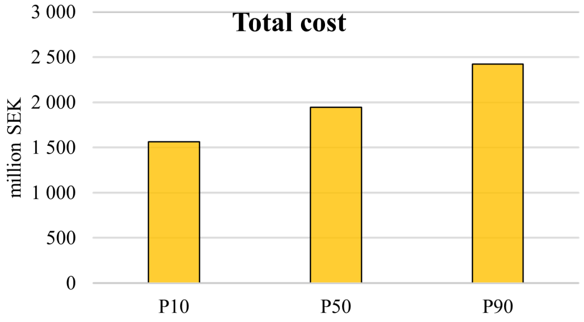

Figure 5.19: PV for total cost of I/I-water [million SEK] within Arvidstorp WWTP case study area for the studied period of 100 years

From the more detailed view of the total cost of I/I-water, shown in Figure 5.20, it can be concluded that the costs related to inconvenience from basement flooding and CSO/SSO are the lowest ones. This is consistent with the result from the other case studies. The highest cost is associated with investment at the WWTP as the median value is 770 million SEK in addition to P10 and P90 at 530 million SEK and 1.1 billion SEK. Further, the second highest cost is associated with restoration due to basement flooding. This cost shows a relatively smaller uncertainty with a 16% lower P10 and 18% higher P90 compared to the median cost of 600 million SEK.

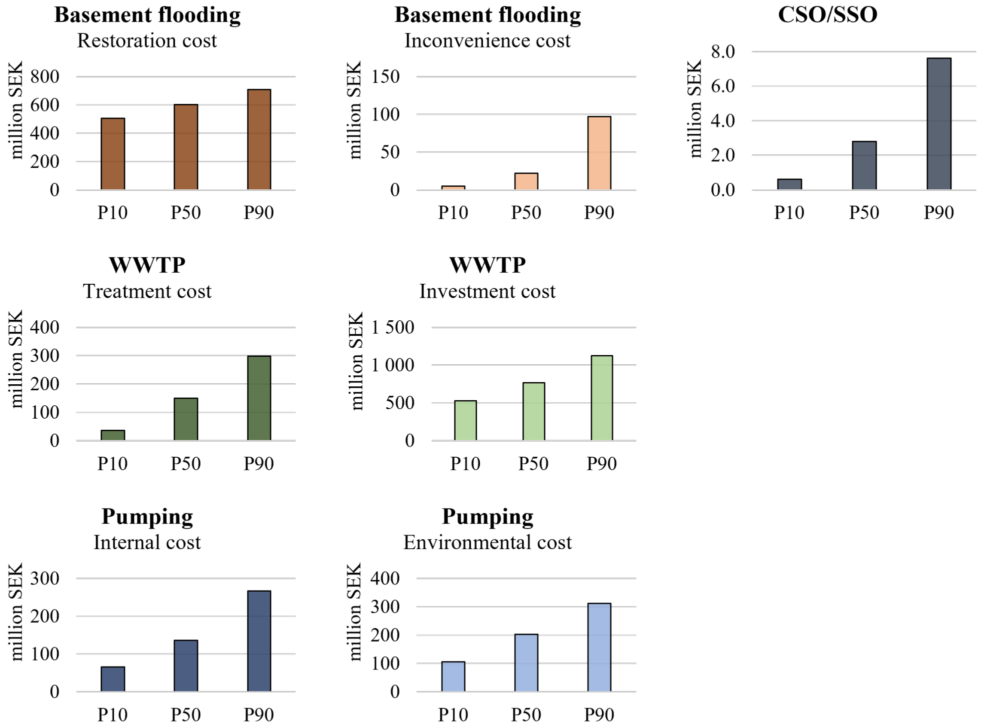

Figure 5.20: PV for the cost of I/I-water for each included effect in the model for Arvidstorp WWTP case study area.

5.4.1 Sensitivity Analysis

Figure 5.21 shows the Spearman rank correlation coefficients for the PV for the total cost of I/I-water within Arvidstorp WWTP case study area. Total I/I-water volume is the variable with the highest correlation coefficient, like for Hammargård WWTP and Götabergsgatan. Additionally, it is noteworthy that none of the variable are directly connected to basement flooding which have been the case for the other case studies.

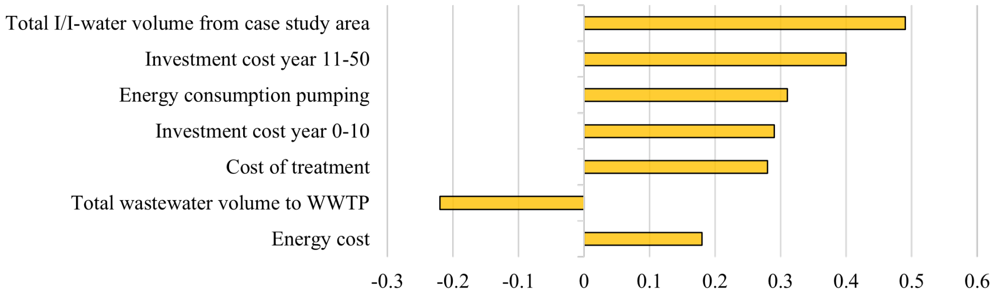

Figure 5.21: Spearman rank correlation coefficients for the total cost of I/I-water within Arvidstorp WWTP case study area.

The results from the analyses with varying discount rate and climate factor is presented in Figure 5.22. As for the previous case studies, the discount rate has a larger impact on the total cost than the climate factor. Lowering the discount rate to 0.015 instead of 0.035 results in about 87% higher values and increasing it to 0.06 results in 39% lower values. Whereas varying the climate factor between 1.1 and 1.4 only affects the result with around 2%.

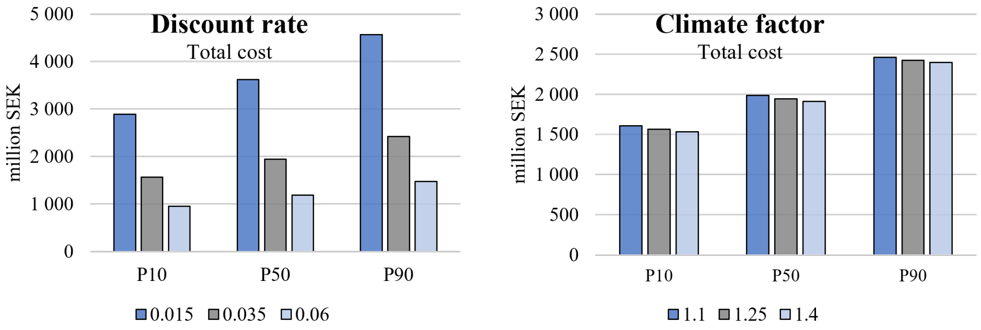

Figure 5.22: PV for the total cost of I/I-water within Arvidstorp WWTP case study area for varied discount rate to the left and varied climate factor to the right.

As for Hammargård WWTP case study, analyses of inconvenience cost from basement flooding and how it affects the PV for the total cost of I/I-water was conducted by varying the same parameters. Figure 5.23 shows the results and the same conclusions can be made. The inconvenience cost per unit, included building categories, and share within the zone 1-1 000m from previous flooding are all factors that affect the PV for the inconvenience cost. Furthermore, the inconvenience cost is relatively small and therefore does not affect the PV for the total cost if I/I-water in a significant manner.

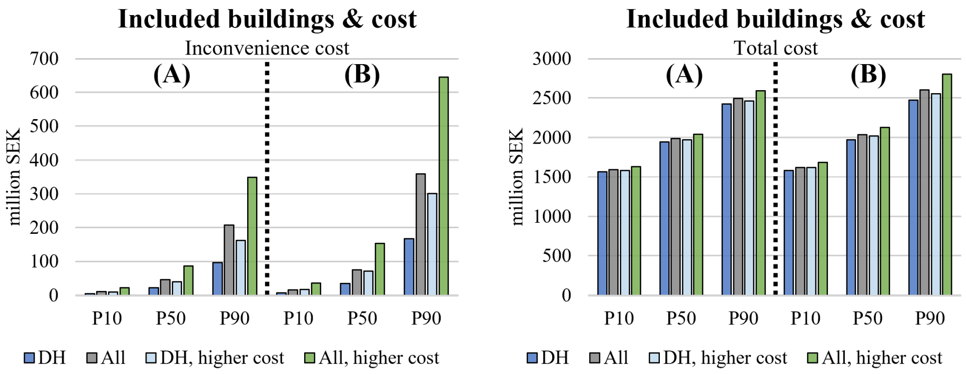

Figure 5.23: PV for the inconvenience cost caused by I/I-water within Arvidstorp WWTP case study area to the left and the PV for the total cost of I/I-water to the right. DH = detached house only, All = including other buildings as well, and higher cost = cost for zone 1-100m instead of 100-1 000m was used. Case A uses the assigned probability distribution for share of buildings within 1 - 1 000m from previous basement flooding and case B is a scenario where that share instead is 100%.

From the analysis of varying benefits from removing PO_4-equivalents, presented in Figure 5.24, the same conclusion can be made for Arvidstorp WWTP case study as for Hammargård WWTP case study. Although, the difference between the two approaches is a bit smaller in this case with the benefit from Gothenburg yielding 180-280% higher values for the reported percentiles.

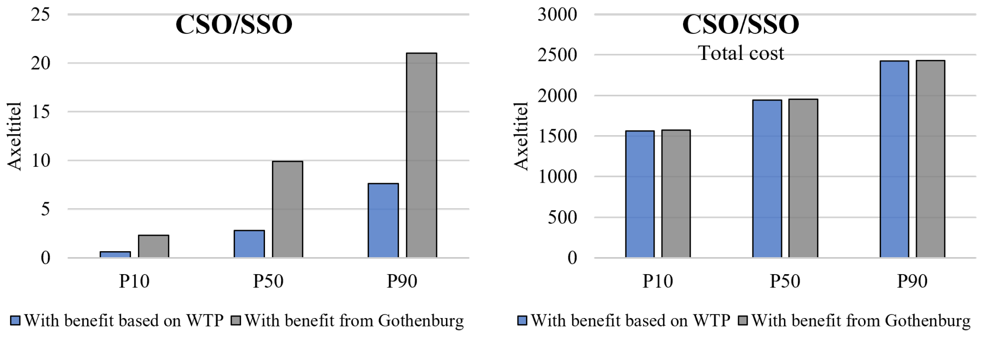

Figure 5.24: PV for the cost of CSO/SSO to the left and PV for the total cost of I/I-water, with varied benefit from removal of PO_4-equivalents.

5.5 Comparison and Performance Indicators

All the results regarding median costs from the detailed views for each case study were put together and the shares of the included effects are presented in Figure 5.25. By comparing the results for Götabergsgatan and Hovås with Hammargård WWTP and Arvidstorp WWTP, it becomes evident that there are differences. The cost from basement flooding makes up a major part of the total cost for Götabergsgatan and Hovås at about 60%, whereas it makes up 19% and 33% for Hammargård WWTP and Arvidstorp WWTP, respectively.

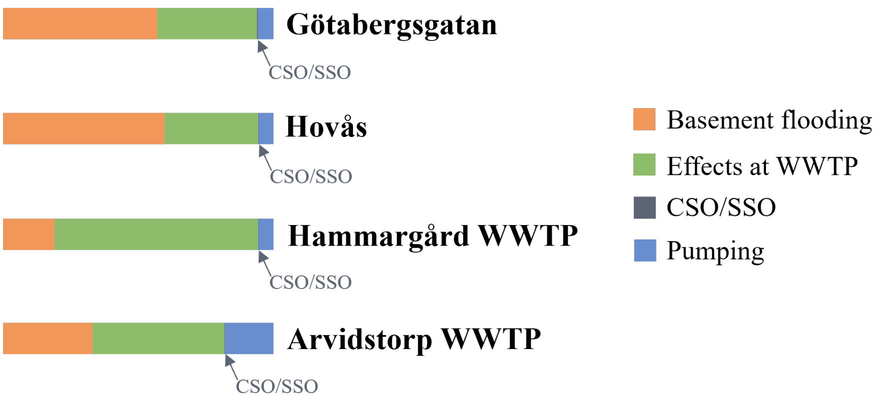

Figure 5.25: Share of each effect for all four case study areas.

The costs from effects at the WWTP differs in both the share it makes up out of the total cost and the distribution between treatment and investment cost, shown in Figure 5.26. Hammargård WWTP has the highest costs from effects at the WWTP, making up 75% of the total cost, followed by Arvidstorp WWTP at 49%. Further, Götabergsgatan and Hovås have a more even distribution between investment and treatment cost compared to Hammargård WWTP and Arvidstorp WWTP, where Hammargård WWTP has the PV that relies most of the investment cost with about 90% investment cost and 10% treatment cost.

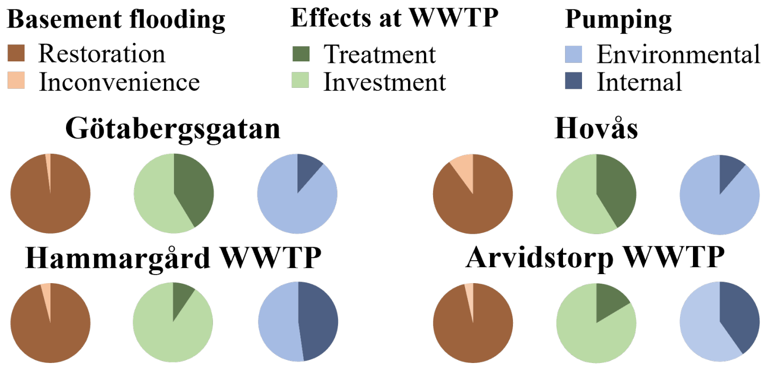

Figure 5.26: Share of each sub-category related to basement flooding, effects at WWTP and pumping for all four case study areas.

Götabergsgatan, Hovås, and Hammargård WWTP are quite similar when it comes to the share of the total cost made up from pumping. Though Hammargård WWTP have a more even distribution between environmental cost and internal cost compared to the other two. Arvidstorp WWTP have a bit higher share associated with pumping at 18% of the total cost and a somewhat even distribution between environmental cost and internal cost at 40% and 60%, respectively.

One additional observation that is consistent for all case studies is that the cost from CSO/SSO is negligible when studying the total cost of I/I-water. A separate comparison is therefore shown in Figure 5.27 where the yearly cost of CSO/SSO, calculated according to Equation 2.2, is presented.

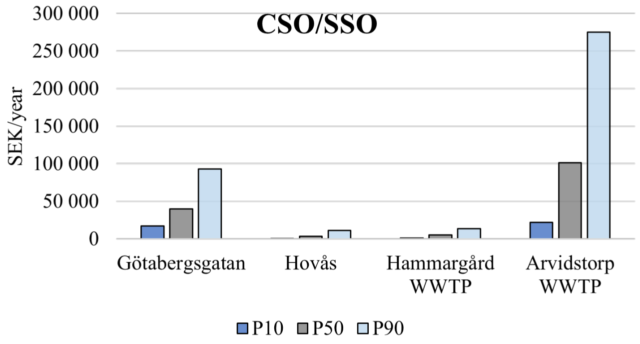

Figure 5.27: Yearly cost from CSO/SSO.

It is evident that there are differences regarding the cost of CSO/SSO between the case study areas even though all show negligible effect on the total cost. Götabergsgatan ranges between 17 327 and 93 081 SEK/year for the reported percentiles and Arvidstorp WWTP ranges between 22 225 and 275 341 SEK/year. Meanwhile, Hovås and Hammargård WWTP yielded lower costs between 675 and 10 904 SEK/year and between 1 073 and 13 769 SEK/year, respectively.

An additional observation can be made from Figure 5.25 in that the share of cost approach yields the same distribution between the treatment cost and investment cost for both Götabergsgatan and Hovås, 41% treatment cost and 59% investment cost. To further study this, a comparison between the calculated costs using the share of cost approach and the marginal cost approach, used in the sensitivity analyses, is presented in Figure 5.28.

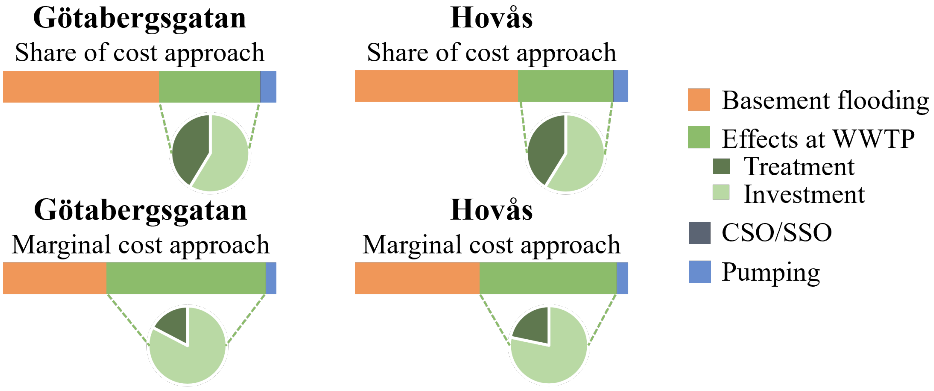

Figure 5.28: Comparison of results when using the share of cost approach and the marginal cost approach for Götabergsgatan and Hovås.

This comparison shows that the marginal cost approach yields higher investment costs at the WWTPs for both Götabergsgatan and Hovås. In contrast to the share of cost approach, the marginal cost approach does not yield the same distribution between investment and treatment when comparing the two case study areas. It can be explained by the fact that both the treatment cost and the investment cost are directly correlated with the total I/I-water volume when using the share of cost approach. Hence, the distribution between these two effects ends up correlating with the shared parameters regarding the WWTP. This means that all sub-areas which are connected to the same WWTP will always yield the same distribution between investment and treatment when the share of cost approach is used.

Another method to compare the case studies is to use performance indicators. The total cost of I/I-water was therefore used, after being recalculated to a yearly cost with Equation 2.2, to calculate three different performance indicators. Although, it is important to note that it is not a strict measure of how well a system performs due to the uncertainties involved.

One performance indicator is to look at the cost per person and the result for this is presented in Figure 5.29. The yearly cost per person is lowest for Götabergsgatan with a median cost of 520 SEK/year/person, followed by Hovås with 702 SEK/year/person as the median cost. Hammargård WWTP and Arvidstorp WWTP have a bit higher median cost at 1 077 SEK/year/person and 1 279 SEK/year/person, respectively.

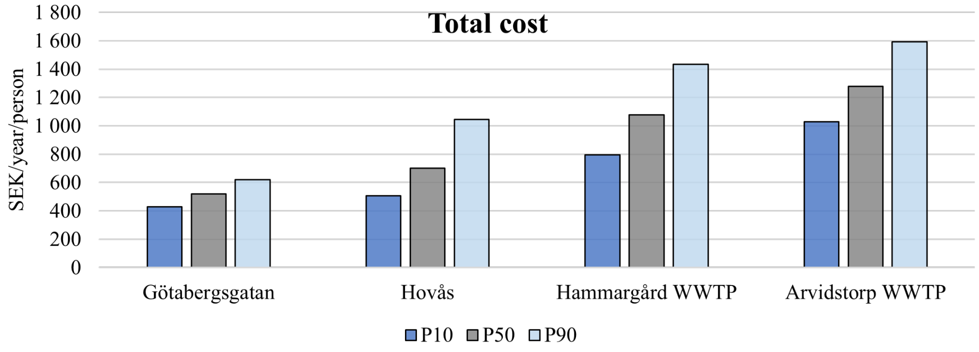

Figure 5.29: Yearly cost per person for the total cost of I/I-water.

Population density can be a factor that at least partly explains this. Götabergsgatan is located in the central part of the city of Gothenburg and have more apartment/commercial buildings than detached houses. Hence, it is the area with the highest population density compared to the other studied areas. Hovås is instead located in the outskirts of the city of Gothenburg with predominant share of detached houses. Furthermore, Hammargård WWTP case study area and Arvidstorp WWTP case study area have mostly detached houses as well but also include more sparse areas, such as farms. It therefore seems likely that this affects the cost per person as one would expect Götebergsgatan to have the lowest, followed by Hovås and then the last two.

A more detailed view with the yearly cost per person from each sub-category is shown in Figure 5.30. An interesting observation is that Götabergsgatan shows a higher yearly cost per person from CSO/SSO even though the cost from CSO/SSO have been negligible when studying the total cost in the previous figures. Apart from CSO/SSO and inconvenience, Götabergsgatan have comparatively low costs though.

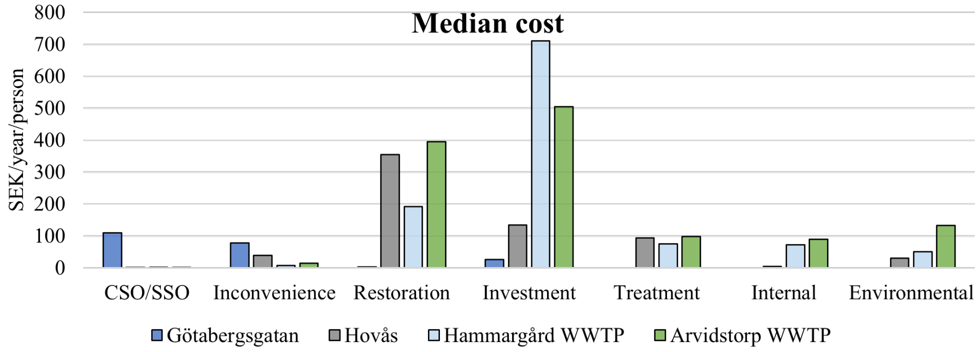

Figure 5.30: Yearly cost per person for each included effect.

The yearly treatment cost per person is quite similar between Hovås, Hammargård WWTP, and Arvidstorp WWTP but differences can be seen for the other costs. Hovås and Arvidstorp WWTP have higher costs associated with restoration. Hammargård WWTP have instead the highest cost in terms of investment costs at the WWTP where Hovås have a relatively low cost.

The second performance indicator analysed is the cost per meter wastewater sewer system that transports sanitary sewage. An overview of the result is shown in Figure 5.31 together with the share of combined system. Götabergsgatan yields the highest yearly cost with 421 SEK/year/meter as the median cost, followed by Arvidstorp WWTP at 242 SEK/year/meter. Further, the median yearly cost for Hovås is the lowest of the four at 102 SEK/year/meter and Hammargård WWTP yields a bit higher yearly cost at 155 SEK/year/meter.

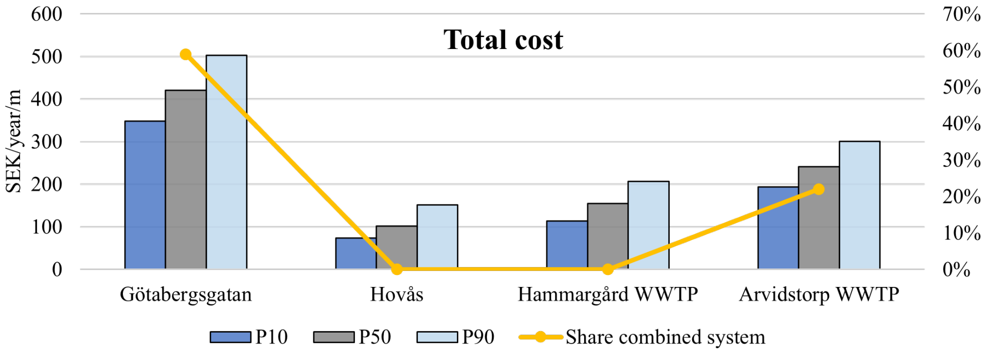

Figure 5.31: Yearly cost per meter wastewater sewer system that transports sanitary sewage for the total cost of I/I-water as bars and share of combined system as a yellow line on the secondary axis.

Population density can have an affect on this performance indicator as well. If two systems have the same capacity but one is sparser, it seems logical that the sparser system would require a longer pipe network even though the same volume is handled. Hence the cost per meter wastewater sewer system that transports sanitary sewage is lowered. One can also argue that a longer pipe network would inevitably lead to more I/I-water within the system if the same quality is assumed for pipes and connections. Considering that, the cost has the possibility to increase for the sparser system and it is difficult to say which effect would increase/decrease the cost per meter wastewater system that transports sanitary sewage the most.

The share combined system was added to Figure 5.31 as it was considered another factor that could affect the cost per meter wastewater system that transports sanitary sewage. One would expect that the addition of stormwater as direct inflow within combined systems would lead to more I/I-water compared to separated systems, assuming the same length and quality. From Figure 5.31 it seems like a correlation between higher share combined system and higher cost per meter wastewater system that transports sanitary sewage can exist. It is difficult to say with certainty, due to the uncertainties and small sample size, but Götabergsgatan has both the highest cost and highest share combined system.

Additionally, Arvidstorp WWTP have the second highest cost and second highest share combined system whereas Hovås and Hammargård WWTP both have 0% combined system and yields the lowest costs out of the four.

If the yearly cost per meter wastewater sewer system that transports sanitary sewage is studied for each sub-category, presented in Figure 5.32, it becomes evident that much of the total cost for Götabergsgatan comes from restoration. Furthermore, Götabergsgatan have in general higher costs in relation to the other case study areas, compared to the performance indicator per person. Hammargård WWTP still have the highest cost associated with investment but is quite similar to Götabergsgatan and Arvidstorp WWTP.

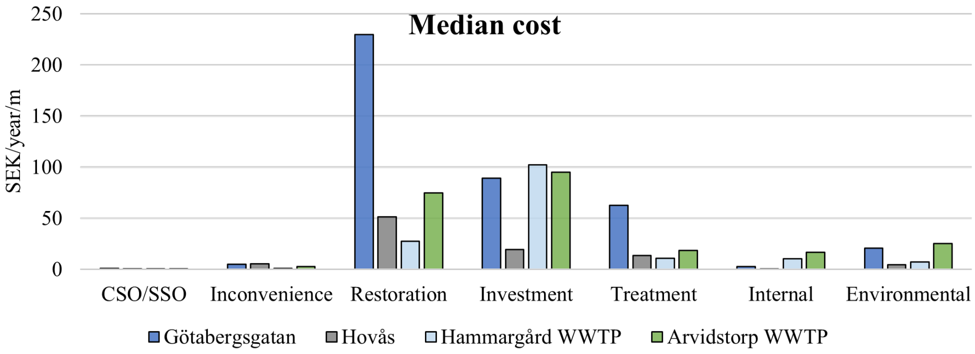

Figure 5.32: Yearly cost per meter wastewater sewer system that transports sanitary sewage for each included effect.

The third and final performance indicator that was analysed is the yearly cost per cubic meter I/I-water and the result is presented in Figure 5.33. Götabergsgatan and Arvidstorp WWTP show quite similar costs while Hovås yield slightly higher cost. Furthermore, Hammargård WWTP show significantly higher cost with a median cost of 26 SEK/year/m^3 compared to Hovås with the second highest median cost at 8 SEK/year/m^3.

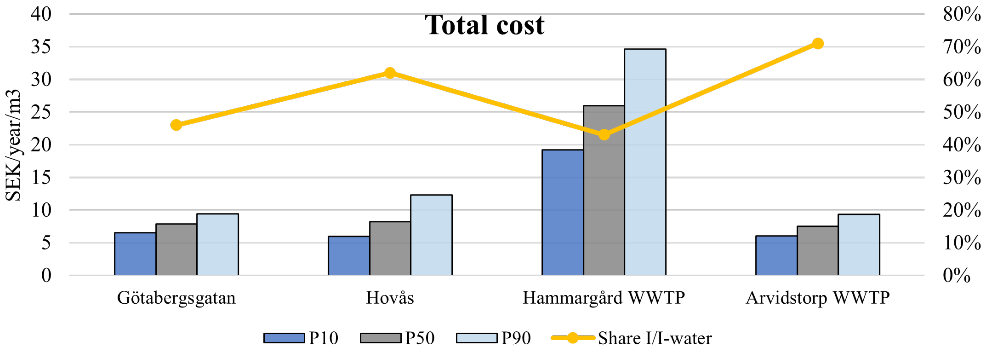

Figure 5.33: Yearly cost per cubic meter I/I-water for the total cost of I/I-water as bars and share of I/I-water as a yellow line on the secondary axis.

Share of I/I-water was added to the secondary axis in Figure 5.33 since it could be a factor that affects the yearly cost per cubic meter I/I-water. There is no clear correlation between the cost per cubic meter and share of I/I-water, and the share of I/I-water have the potential to both increase and decrease the cost per cubic meter I/I-water. If the volume of I/I-water were to increase one would expect the costs due to I/I-water to increase. At the same time, increasing I/I-water volume have the potential to decrease the cost per cubic meter I/I-water depending on how the cost rises per increased cubic meter I/I-water. This was briefly analysed by increasing the share of I/I-water for Hovås, Hammargård WWTP, and Arvidstorp WWTP by only changing the total volume of I/I-water. It may not be an entirely fair comparison as some of the other parameters most likely would be affected by increased I/I-water volume as well. However, it showed that the yearly cost per cubic meter I/I-water increased for all three case studies with decreasing share of I/I-water (or decreasing total I/I-water volume). It can therefore be interesting to further study this aspect to gain more knowledge about this performance indicator.

The yearly cost per cubic meter I/I-water for each sub-category are presented in Figure 5.34. It shows clearly that most of the difference between Hammargård WWTP and the others are related to investment. Other than that, the costs seem to be quite similar with some smaller differences.

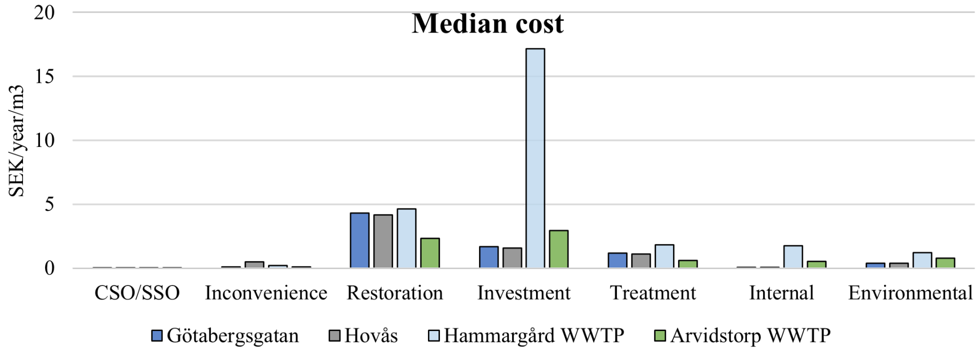

Figure 5.34: Yearly cost per cubic meter I/I-water for each included effect.

5.6 Model Implementation and Data Availability

The calculations for all case study areas were based on the application of the model on Götabergsgatan, but some further simplifications and assumptions were needed. For example, the information regarding share of basement flooding events connected to return periods of rain was used as standard values for all case studies. Even though the variable was represented with a probability distribution, the information of which it is based on is probably not general enough for it to be fully representative. It was still deemed to be the best approach since it is something that have not been widely studied and the data availability is therefore limited. Generating new data regarding the share of flooded basements requires extensive hydraulic modelling. Hence, further studies within this area can be useful to better understand how different characteristics of an area can influence basement flooding.

Another aspect regarding basement flooding mentioned before is that the share of buildings with basements and the share of buildings where basement flooding can occur were combined into one parameter, share of houses vulnerable to basement flooding due to I/I-water. The reasons behind this were to reduce the number of parameters in need of elicitation and it felt more appropriate to combine the two as some experts expressed, during an elicitation, that both were quite difficult to estimate. However, this may have affected the inconvenience cost as the combined parameter expressing the share of houses vulnerable to basement flooding due to I/I-water also determined the number of household included in the calculation of the inconvenience cost. The initial assumption, before the combination, that only households with a basement would worry about basement flooding in the future seems valid. Although, after the combination it also includes the aspect of where basement flooding is possible. This assumes that the households have a quite deep understanding of the wastewater sewer system. It therefore likely leads to an underestimation of the inconvenience cost as it would probably be fair to assume that there exist households with basements that worries about future basement flooding even though characteristics of the system makes it very unlikely.

One cost that was calculated differently compared to Götabergsgatan, due to data availability, was CSO/SSO. None of the case studies had data regarding discharged volume connected to rain events with specific return periods. Hence, yearly discharged volumes were assigned with probability distributions based on a wet year and a normal year. This difference in implementation changes CSO/SSO more towards a base effect instead of a risk, as described earlier. It is difficult to say how this affects the result, but it was a simplification necessary to base the calculation on reliable data without requiring additional studies or models. Doing the calculation in this way might therefore be necessary if the model is going to be widely used.

Information about the number of buildings within different building categories and the distance from buildings to previous basement flooding was shown to have somewhat limited availability. For Hovås case study and Hammargård WWTP case study, the number of buildings were manually counted and categorised. It introduces human error, the latest information might not have been used, and the processes of counting can become quite time consuming when the size of the case study area increases. Furthermore, the information about the distance to other buildings from previous basement flooding events could be retrieved for Hovås using the GIS system that the Department of Sustainable Waste and Water, City of Gothenburg uses. This information was however unavailable for Hammargård WWTP case study and the estimation provided within Arvidstorp WWTP case study area was expressed to have large uncertainties.

With the described assumptions and uncertainties regarding basement flooding, it can be identified as an area in need of more studies. In addition, parameters regarding basement flooding had at least one of the eight highest Spearman rank correlation coefficients for Götabergsgatan, Hovås, and Hammargård WWTP. This further strengthens the need to better understand the underlying factors regarding basement flooding.

Some of the difficulty with data availability is decreased with the use of EKE. Even though EKE and the SHELF-protocol was new concepts to most of the participants in the workshops within this project, the response afterwards was generally positive. It was an appreciated method as it introduced a structured way to discuss and evaluate, and furthermore made the participants consider new aspects of different topics. The simplified version of the SHELF-protocol used within this project skips some of the steps designed to reduce biases. Biases can therefore have had a more significant effect on the results than it would if the full protocol was used. That was a trade-off deemed worth doing based on the scope of the project. One can further argue that a less time-consuming approach makes the applicability higher as projects can usually be restricted by time and budget. Furthermore, the SHELF-protocol was used within the context of estimating parameters for model implementation to provide decision support. The experts were in addition the people who would normally create material for decision support or make decisions regarding these topics, meaning that their personal biases could have an influence either way. Hence, having the structure provided by the SHELF-protocol, even if simplified, can still give value to the overall process.

All QoIs addressed during the EKE workshops were not easy for the participating experts to make judgments on. Two that were combined into one regarding basement flooding have already been mentioned and it was also expressed that how recently the participants had worked with permits could heavily influence the knowledge about certain topics, for example treatment requirements. In addition, the size of the municipality can influence the amount of available resources to use for studies and consequently creating further knowledge gaps. It could therefore be interesting to conduct further case studies connected to municipalities with varying sizes. Investment costs for the future periods were also identified as challenging to elicitate. Developing additional details about the investment cost with more specified categories could potentially help guide the judgments, compared to the more open ended judgment used within this project.

5.7 Model Evaluation

It was previously mentioned that the results and comparisons should not be seen as exact representations of the studied systems but rather be used as decision support. Still, the comparisons combined with the use of performance indicators highlights the strengths of having a tool such as the model used in this project. For example, Götabergsgatan shows higher yearly cost per meter sewer system that transports sanitary sewage whereas Hammargård WWTP shows higher yearly investment cost per cubic meter I/I-water, compared to the other case study areas. It is difficult to say with certainty if this is due to underlying factors representative of reality, overestimation or underestimation during the data collection process, or a combination of both. Although it still provides insights about the systems and can help identify areas in need of more investigations. Furthermore, the sample size is small as the model is new, but with more studied cases to compare with and with better understanding of the differences in analysing a sub-area and a whole service area, more knowledge about different systems can be gained.

The model, in combination with elicitation, can provide value within this field in addition to the value of the results. It has already been mentioned that elicitation, the SHELF-protocol in particular, gave an appreciated structure for discussion whilst the model provides the topics that needs to be discussed. In addition to quantification/monetisation of parameters, some of the workshop participants expressed that it started further discussions on related topics. This is a positive effect that is important for the decision-making process but might not be visible by only studying the results produced with the model.

As with most models, the model used within this project is not a perfect representation of reality. Difficulties concerning what to include and what to exclude can arise and it is not always just about the willingness to include specific factors but rather finding a balance regarding complexity. One example is CSO/SSO where the benefit from removing PO_4-eqs to reach good water status was used to calculate the cost. More effects can potentially be added to also include for example pathogens. Pathogens can affect the availability of drinking water by polluting drinking water sources or increase the treatment cost for drinking water production. Additionally, societal- and healthcare costs can occur from people getting ill from polluted drinking water or when bathing in polluted natural waters. Not including effects like this can be one of the reasons why the cost of CSO/SSO was negligible in comparison to the total cost of I/I-water.

In addition, even more effects could be included but the concerns regarding complexity is not only connected to the complexities of monetising or mathematically describe these effects appropriately. It is also important to consider how easy the model is to use. Complex descriptions can require quite specific and detailed data which reduces a wider applicability. Additionally, increased complexity puts higher demands on the abilities of the user. That too lowers a wider applicability and must therefore be weighed against the purpose. Furthermore, the broader societal perspective that the model utilises can provide development in the right direction. It becomes more difficult to drive sustainable development forward, especially in terms of resource allocation, if all stakeholders only analyses from their own perspectives. Having a tool to analyse from a more general and overall perspective can therefore help to organise and allocate resources with multiple stakeholders' involvement.

6

Conclusion

The main conclusions based on the model implementation in the four case study areas are:

- The model was successfully applied on all four case study areas, but required in some cases extra simplifications and assumptions. For example, detailed data connected to certain return periods, both in regard to basement flooding and CSO/SSO, could not be obtained for all of the case study areas. Yearly volumes discharged as CSOs/SSOs were therefore used instead and this might be a more appropriate approach for more generic applicability.
- Basement flooding was identified as an area in need of further studies based on the assumptions and simplifications needed in combination with how it can affect the total cost of I/I-water. Furthermore, investment costs at the WWTP were shown to be important variables and challenging to assess during expert elicitations. More detailed definition of what to include as investment cost can improve the elicitation process.
- Restoration due to basement flooding and investment at the WWTP was the two effects with the highest costs associated with it. Costs from CSO/SSO was on the other hand shown to have negligible effect on the total cost of I/I-water.
- Expert knowledge elicitation provided valuable input to the model applications in terms of parameter quantifications and discussions. It was also an appreciated method by the participants, who considered it to be a method applicable also in other types of projects.
- Differences in the costs of I/I-water could be identified between the case study areas. A major part of the total cost of I/I-water was associated with basement flooding for Götabergsgatan and Hovås, whereas it was associated with effects at the WWTP for Hammargård WWTP and Arvidstorp WWTP. However, due to the limited number of case study areas in this project, it is difficult to conclude the reasons as to why these differences could be identified. It would therefore be beneficial to apply the model on additional case study areas to identify if such differences can be traced to different preconditions.
- The model provided results that enabled assessments of I/I-water. Furthermore, using performance indicators can put the calculated costs into perspective and provide valuable comparisons.

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A

Data used for Götabergsgatan

Table A.1: General data used in the analysis of Götabergsgatan.

Parameter	**Unit**	**Value**
Discount rate	-	0.035
Climate factor	-	1.25
Length of the studied period	years	100
Length of wastewater sewer system within the case study area	m	38 988
Number of connected people	#	31 542

Table A.2: Data used to calculate effects at Rya WWTP for Götabergsgatan.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Volume I/I-water from case study area to WWTP	m^3/year	(1 940 512, 2 171 696, 2 441 090)	Pearson (Q1, M, Q3)	Hydraulic model
Total volume to WWTP	m^3/year	(128 933 990, 137 792 219, 147 480 697)	Pearson (Q1, M, Q3)	Hydraulic model
Share SRC from case study area	-	(0.13, 0.22, 0.24, 0.33)	Beta (L, Q1, Q3, U)	Hydraulic model
Share FRC from case study area	-	(0.67, 0.76, 0.78, 0.87)	Beta (L, Q1, Q3, U)	Hydraulic model
Treatment cost	SEK/m^3	(0.5, 0.8, 1.0, 1.35, 2.0)	Lognormal (L, Q1, M, Q3, U)	Workshop 2022-02-11
Factor for increasing treatment cost	-	1.5	Point value	Workshop 2022-02-11
Share of investment 0-1.99 m^3/s	-	(0.39, 0.53)	Beta (M, Q3)	Workshop 2022-02-11
Share of investment 2-3.99 m^3/s	-	(0.19, 0.30)	Beta (M, Q3)	Workshop 2022-02-11
Share of investment 4-6.99 m^3/s	-	(0.22, 0.32)	Beta (M, Q3)	Workshop 2022-02-11
Share of investment 7-9.99 m^3/s	-	(0.09, 0.14)	Beta (M, Q3)	Workshop 2022-02-11
Share of investment 10-16 m^3/s	-	(0.11, 0.15)	Beta (M, Q3)	Workshop 2022-02-11
Share of flow 0-1.99 m^3/s	-	(0.36, 0.42, 0.49, 0.56)	Beta (L, Q1, Q3, U)	Hydraulic model
Share of flow 2-3.99 m^3/s	-	(0.24, 0.34, 0.35, 0.44)	Beta (L, Q1, Q3, U)	Hydraulic model
Share of flow 4-6.99 m^3/s	-	(0.04, 0.12, 0.16, 0.24)	Beta (L, Q1, Q3, U)	Hydraulic model
Share of flow 7-9.99 m^3/s	-	(0, 0.03, 0.05, 0.14)	Beta (L, Q1, Q3, U)	Hydraulic model
Share of flow 10-16 m^3/s	-	(0, 0.01, 0.02, 0.12)	Beta (L, Q1, Q3, U)	Hydraulic model
Investment WWTP year 0-10	Million SEK	(500, 800, 1 000, 1 200, 1 500)	Normal (L, Q1, M, Q3, U)	Workshop 2022-02-11
Investment WWTP year 11-50	Million SEK	(5 000, 9 500, 11 000, 12 000, 14 000)	Beta (L, Q1, M, Q3, U)	Workshop 2022-02-11
Investment WWTP year 51-100	Million SEK	(5 000, 10 000, 12 000, 16 000, 22 000)	Beta (L, Q1, M, Q3, U)	Workshop 2022-02-11
Area of area where FRC/SRC is monitored	m^2	Table A.6 and A.7		
Share of flow interval from area	-	Table A.6 and A.7		

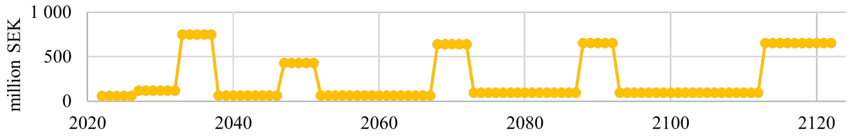

Figure A.1: Investment distribution at Rya WWTP for Götabergsgatan (Workshop 2022-02-11).

Table A.3: Data used to calculate effects from pumping for Götabergsgatan.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Energy consumption	kWh/m^3	(0.1, 0.12, 0.13, 0.14, 0.15)	Normal (L, Q1, M, Q3, U)	Workshop 2022-02-10
Pumping cost	SEK/kWh	(0.7, 1.25, 1.5, 2.0, 4)	Lognormal (L, Q1, M, Q3, U)	Workshop 2022-02-10
Energy lift	kWh/m^3	0.065	Point value	Calculated value
Cost per CO2-eq year 2021, 2031	SEK/CO$_2$-eq	0.80, 6.31	Point values	Ohlin Saletti et al. (2022) based on *Carbon pricing* (2022); Isacs et al. (2016)
CO$_2$-eq per kWh	CO$_2$-eq/kWh	(0, 0.26, 0.35, 0.44, 1)	Normal (L, Q1, M, Q3, U)	Workshop 2022-02-10
Yearly change in cost of CO$_2$-eq 2021-2030	-	0.17	Uniform	Workshop 2022-02-10
Yearly change in cost of CO$_2$-eq 2031-2121	-	(-0.02, 0, 0.004)	Beta pert (L, P50, P90)	Workshop 2022-02-10

Table A.4: Data used to calculate effects from CSOs/SSOs for Götabergsgatan.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
WTP to reach good water status	Million SEK/year	(50, 156, 169.5, 183, 300)	Normal (L, Q1, M, Q3, U)	Workshop 2022-02-10
Share of requirement fulfilled with P and N	-	(0.05, 0.15, 0.2, 0.25, 0.35)	Beta (L, Q1, M, Q3, U)	Workshop 2022-02-22
Volume sanitary sewage in CSO/SSO for return period 0.02, 0.08, 0.5, 1, 2, 5, 10, 20 years	m^3	(155/245, 189/293, 252/383, 282/420, 313/457, 403/574, 493/678, 581/793)	Uniform (L/U)	Hydraulic model
Volume stormwater in CSO/SSO for return period 0.02, 0.08, 0.5, 1, 2, 5, 10, 20 years	m^3	(871/1 112, 1 452/1 815, 3 791/4 635, 5 635/6 735, 8 127/9 491, 13 057/14 891, 18 343/20 418, 25 392/27 569)	Uniform (L/U)	Hydraulic model
phosphorus concentration in sanitary sewage	kg P/m^3	(2.0, 4.9, 6.0, 7.0, 9.0)	Beta (L, Q1, M, Q3, U)	Workshop 2022-02-22
phosphorus concentration in stormwater	kg P/m^3	(0.04, 0.15, 0.19, 0.25, 0.65)	Lognormal (L, Q1, M, Q3, U)	Workshop 2022-02-22
Nitrogen concentration in sanitary sewage	kg N/m^3	(17.5, 22.5, 29.0, 34.5, 42.5)	Gumbel type II (L, Q1, M, Q3, U)	Workshop 2022-02-22
Nitrogen concentration in stormwater	kg N/m^3	(0.70, 1.55, 1.85, 2.20, 4.25)	Gamma (L, Q1, M, Q3, U)	Workshop 2022-02-22
Conversion factor phosphorus	kg PO$_4$-eq/m^3	3.07	Point value	Söderqvist et al. (2022)
Conversion factor nitrogen	kg PO$_4$-eq/m^3	0.42	Point value	Söderqvist et al. (2022)
Treatment requirement phosphorus	kg P/year	(1 000, 3 000, 4 000, 5 000, 6 000)	Normal (L, Q1, M, Q3, U)	Workshop 2022-02-22
Treatment requirement nitrogen	kg N/year	(25 000, 160 000, 240 000, 310 000, 500 000)	Weibull (L, Q1, M, Q3, U)	Workshop 2022-02-22

Table A.5: Data used to calculate effects from basement flooding for Götabergsgatan.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Share of basement flooding events for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0, 0, 0.5, 0.2, 0.4, 0.7, 0.85, 0.9	Point values	Rosén & Nimmermark (2018)
Uncertainty distribution share of flooding	-	(0.8, 0.85, 0.95, 1)	Beta (P05, P25, P75, P95)	Workshop 2022-02-10
Factor for uncertainty of share of flooding for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0.06, 0.22, 0.44, 0.78, 0.94, 1	Point values	Workshop 2022-02-10
Share of buildings where basement flooding can occur	-	(0.55, 0.70, 0.78, 0.83, 0.95)	Beta (L, Q1, M, Q3, U)	Workshop 2022-03-01
Share of buildings that have basements	-	(0.65, 0.73, 0.80, 0.85, 0.92)	Weibull (L, Q1, M, Q3, U)	Workshop 2022-03-01
Cost basement flooding detached house	SEK/flooding event	(54 896, 2 609)	Log normal (μ, ω)	Ohlin Saletti et al. (2022) based on Rosén & Nimmermark (2018)
Cost basement flooding apartment/commercial building	SEK/flooding event	(221 917, 17 537)	Log normal (μ, ω)	Ohlin Saletti et al. (2022) based on Rosén & Nimmermark (2018)
Cost basement flooding public building	SEK/flooding event	(210 238, 17 771)	Log normal (μ, ω)	Ohlin Saletti et al. (2022) based on Rosén & Nimmermark (2018)
Number of detached houses	#	(396, 400, 404)	Beta pert (L, M, U)	Workshop 2022-03-01
Number of apartment/commercial buildings	#	(684, 760, 836)	Beta pert (L, M, U)	Workshop 2022-03-01
Number of public buildings	#	(287, 290, 293)	Beta pert (L, M, U)	Workshop 2022-03-01
Number of detached houses in zone 0-99.99, 100-1000, 1000+ meter from previous flooding	#	(73, 327, 0)	Point values	City of Gothenburg
WTP per household in detached houses to avoid flooding 0-99.99 meter (also used for higher cost scenario)	SEK/year	(1 500, 2 366)	Lognormal (μ, ω)	Ohlin Saletti et al. (2022) based on Torgersen & Navrud (2018)
WTP per household in detached houses to avoid flooding 100-1000 meter	SEK/year	(828, 1 524)	Lognormal (μ, ω)	Ohlin Saletti et al. (2022) based on Torgersen & Navrud (2018)
WTP per household in detached houses to avoid flooding 1000+ meter	SEK/year	(151, 1 351)	Lognormal (μ, ω)	Ohlin Saletti et al. (2022) based on Torgersen & Navrud (2018)

Table A.6: Area of areas and share of flow of SRC where SRC was monitored (Ohlin Saletti et al., 2022).

	Flow [m3/s]					**Area**
	0-1.99	**2-3.99**	**4-6.99**	**7-9.99**	**10-**	
SRC 1	0%	25%	44%	18%	13%	665 m2
SRC 2	0%	25%	46%	17%	11%	742 m2
SRC 3	0%	28%	48%	15%	9%	328 m2
SRC 4	0%	28%	47%	16%	9%	176 m2
SRC 5	0%	28%	48%	15%	9%	665 m2
SRC 6	0%	25%	44%	18%	13%	651 m2
SRC 7	0%	22%	45%	20%	13%	390 m2
SRC 8	0%	32%	32%	26%	10%	494 m2
SRC 9	0%	26%	45%	18%	11%	500 m2
SRC 10	0%	36%	41%	15%	8%	2682 m2
SRC 11	0%	23%	46%	19%	12%	559 m2
SRC 12	0%	28%	48%	15%	9%	761 m2

Table A.7: Area of areas and share of flow of FRC where FRC was monitored (Ohlin Saletti et al., 2022).

	Flow [m3/s]					**Area**
	0-1.99	**2-3.99**	**4-6.99**	**7-9.99**	**10-**	
FRC 1	0%	14%	36%	24%	26%	60 m2
FRC 2	0%	9%	40%	25%	26%	44 m2
FRC 3	0%	9%	38%	23%	31%	58 m2
FRC 4	0%	9%	40%	23%	29%	213 m2
FRC 5	0%	11%	43%	27%	19%	144 m2
FRC 6	0%	20%	36%	21%	23%	50 m2
FRC 7	0%	11%	34%	26%	29%	405 m2
FRC 8	0%	15%	46%	20%	18%	95 m2
FRC 9	0%	9%	39%	28%	24%	158 m2
FRC 10	0%	13%	46%	22%	19%	220 m2
FRC 11	0%	8%	35%	28%	29%	88 m2

B

Data used for Hovås

Table B.1: General data used in the analysis of Hovås case study area.

Parameter	**Unit**	**Valus**
Discount rate	-	0.035
Climate factor	-	1.25
Length of the studied period	years	100
Length of wastewater sewer system within the case study area	m	13 895
Number of connected people	#	2 020

Table B.2: Data used to calculate effects at Rya WWTP for Hovås case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Volume I/I-water from case study area to WWTP	m^3/year	(119 653, 224 271)	Normal (P10, P90)	Hydraulic model
Total volume to WWTP	m^3/year	(128 933 990, 137 792 219, 147 480 697)	Pearson (Q1, M, Q3)	Götabergsgatan
Share SRC from case study area	m^3/year	(0.871, 0.899, 0.785, 0.985)	Beta (P25, P75, Min, Max)	Hydraulic model
Share FRC from case study area	m^3/year	(0.108, 0.121, 0.015, 0.215)	Beta (P25, P75, Min, Max)	Hydraulic model
Treatment cost	SEK/m^3	(0.5, 0.8, 1.0, 1.35, 2.0)	Lognormal (L, Q1, M, Q3, U)	Workshop 2022-02-11
Factor for increasing treatment cost	-	1.5	Point value	Götabergsgatan
Share of investment 0-1.99 m^3/s	-	(0.39, 0.53)	Beta (M, Q3)	Götabergsgatan
Share of investment 2-3.99 m^3/s	-	(0.19, 0.30)	Beta (M, Q3)	Götabergsgatan
Share of investment 4-6.99 m^3/s	-	(0.22, 0.32)	Beta (M, Q3)	Götabergsgatan
Share of investment 7-9.99 m^3/s	-	(0.09, 0.14)	Beta (M, Q3)	Götabergsgatan
Share of investment 10-16 m^3/s	-	(0.11, 0.15)	Beta (M, Q3)	Götabergsgatan
Share of flow 0-1.99 m^3/s	-	(0.36, 0.42, 0.49, 0.56)	Beta (L, Q1, Q3, U)	Götabergsgatan
Share of flow 2-3.99 m^3/s	-	(0.24, 0.34, 0.35, 0.44)	Beta (L, Q1, Q3, U)	Götabergsgatan
Share of flow 4-6.99 m^3/s	-	(0.04, 0.12, 0.16, 0.24)	Beta (L, Q1, Q3, U)	Götabergsgatan
Share of flow 7-9.99 m^3/s	-	(0, 0.03, 0.05, 0.14)	Beta (L, Q1, Q3, U)	Götabergsgatan
Share of flow 10-16 m^3/s	-	(0, 0.01, 0.02, 0.12)	Beta (L, Q1, Q3, U)	Götabergsgatan
Investment WWTP year 0-10	Million SEK	(500, 800, 1 000, 1 200, 1 500)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Investment WWTP year 11-50	Million SEK	(5 000, 9 500, 11 000, 12 000, 14 000)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Investment WWTP year 51-100	Million SEK	(5 000, 10 000, 12 000, 16 000, 22 000)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Area of area where FRC/SRC is monitored	m^2	Table A.6 and A.7		
Share of flow interval from area	-	Table A.6 and A.7		

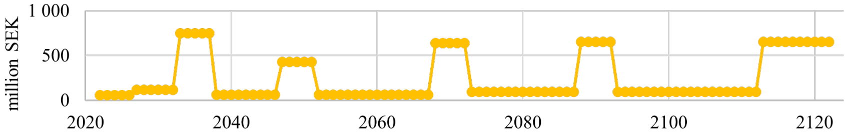

Figure B.1: Investment distribution at Rya WWTP for Hovås (Workshop 2022-02-11).

Table B.3: Data used to calculate effects from pumping for Hovås case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Energy consumption	kWh/m^3	(0.1, 0.12, 0.13, 0.14, 0.15)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Pumping cost	SEK/kWh	(0.7, 1.25, 1.5, 2.0, 4)	Lognormal (L, Q1, M, Q3, U)	Götabergsgatan
Energy lift	kWh/m^3	0.065	Point value	Götabergsgatan
Cost per CO2-eq year 2021, 2031	SEK/CO$_2$-eq	0.80, 6.31	Point values	Götabergsgatan
CO$_2$-eq per kWh	CO$_2$-eq/kWh	(0, 0.26, 0.35, 0.44, 1)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Yearly change in cost of CO$_2$-eq 2021-2030	-	0.17	Uniform	Götabergsgatan
Yearly change in cost of CO$_2$-eq 2031-2121	-	(-0.02, 0, 0.004)	Beta pert (L, P50, P90)	Götabergsgatan

Table B.4: Data used to calculate effects from CSOs/SSOs for Hovås case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
WTP to reach good water status	Million SEK/year	(50, 156, 169.5, 183, 300)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Share of requirement fulfilled with P and N	-	(0.05, 0.15, 0.2, 0.25, 0.35)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Volume CSO/SSO	m^3/year	(569, 1 780, 0)	Normal (P50, P90, Trunc min)	Hydraulic model
Share sanitary sewage in CSOs/SSOs	-	(0.35, 0.43)	Uniform (min, max)	Hydraulic model
phosphorus concentration in sanitary sewage	kg P/m^3	(2.0, 4.9, 6.0, 7.0, 9.0)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
phosphorus concentration in stormwater	kg P/m^3	(0.04, 0.15, 0.19, 0.25, 0.65)	Lognormal (L, Q1, M, Q3, U)	Götabergsgatan
Nitrogen concentration in sanitary sewage	kg N/m^3	(17.5, 22.5, 29.0, 34.5, 42.5)	Gumbel type II (L, Q1, M, Q3, U)	Götabergsgatan
Nitrogen concentration in stormwater	kg N/m^3	(0.70, 1.55, 1.85, 2.20, 4.25)	Gamma (L, Q1, M, Q3, U)	Götabergsgatan
Conversion factor phosphorus	kg PO$_4$-eq/m^3	3.07	Point value	Götabergsgatan
Conversion factor nitrogen	kg PO$_4$-eq/m^3	0.42	Point value	Götabergsgatan
Treatment requirement phosphorus	kg P/year	(1 000, 3 000, 4 000, 5 000, 6 000)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Treatment requirement nitrogen	kg N/year	(25 000, 160 000, 240 000, 310 000, 500 000)	Weibull (L, Q1, M, Q3, U)	Götabergsgatan

Table B.5: Data used to calculate effects from basement flooding for Hovås case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Share of basement flooding events for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0, 0, 0.5, 0.2, 0.4, 0.7, 0.85, 0.9	Point values	Götabergsgatan
Uncertainty distribution share of flooding	-	(0.8, 0.85, 0.95, 1)	Beta (P05, P25, P75, P95)	Götabergsgatan
Factor for uncertainty of share of flooding for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0.06, 0.22, 0.44, 0.78, 0.94, 1	Point values	Götabergsgatan
Share of houses vulnerable to basement flooding due to I/I-water	-	(0.17, 0.265, 0.44)	Gamma (P10, P50, P90)	Email elicitation
Cost basement flooding detached house	SEK/flooding event	(54 896, 2 609)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding apartment/commercial building	SEK/flooding event	(221 917, 17 537)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding public building	SEK/flooding event	(210 238, 17 771)	Log normal (μ, ω)	Götabergsgatan
Number of detached houses	#	(730, 803)	Normal (P50, P90)	Manually counted
Number of apartment/commercial buildings	#	(20, 22)	Normal (P50, P90)	Manually counted
Number of public buildings	#	(5, 6)	Normal (P50, P90)	Manually counted
Number of detached houses in zone (1-1000, 1000+ meter from previous flooding)	#	(730, 0)		City of Gothenburg
WTP per household in detached houses to avoid flooding 1-1000 meter	SEK/year	(828, 1 524)	Lognormal (μ, ω)	Götabergsgatan
WTP per household in detached houses to avoid flooding 1000+ meter	SEK/year	(151, 1 351)	Lognormal (μ, ω)	Götabergsgatan

C

Data used for Hammargård WWTP

Table C.1: General data used in the analysis of Hammargård WWTP case study area.

Parameter	**Unit**	**Valus**
Discount rate	-	0.035
Climate factor	-	1.25
Length of the studied period	years	100
Length of wastewater sewer system within the case study area	m	310 000
Number of connected people	#	44 630

Table C.2: Data used to calculate effects from pumping for Hammargård WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Volume I/I-water from case study area to WWTP	m^3/year	(1 810 410, 2 230 471)	Normal (P50, P90)	Kungsbacka municipality (2021c)
Energy consumption	kWh/m^3	(0.38, 0.145)	Normal (μ,ω)	Workshop 2022-03-22
Pumping cost	SEK/kWh	(0.73, 1.7, 5.41)	Lognormal (P05, P50, P90)	Workshop 2022-03-22
Cost per CO2-eq year 2021, 2031	SEK/CO$_2$-eq	0.80, 6.31	Point values	Götabergsgatan
CO$_2$-eq per kWh	CO$_2$-eq/kWh	(0, 0.26, 0.35, 0.44, 1)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Yearly change in cost of CO$_2$-eq 2021-2030	-	0.17	Uniform	Götabergsgatan
Yearly change in cost of CO$_2$-eq 2031-2121	-	(-0.02, 0, 0.004)	Beta pert (L, P50, P90)	Götabergsgatan

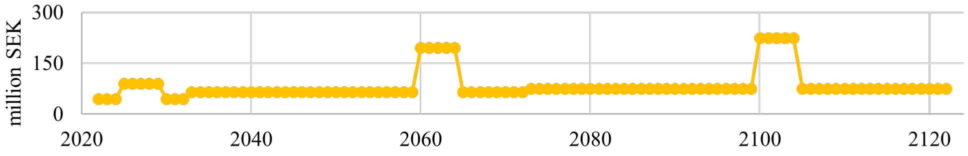

Figure C.1: Investment distribution for Hammargård WWTP case study area (Workshop 2022-03-22).

Table C.3: Data used to calculate effects from CSOs/SSOs for Hammargård WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
WTP to reach good water status	Million SEK/year	(13, 15)	Normal (P05, P95)	
Share of requirement fulfilled with P and N	-	(0.05, 0.15, 0.2, 0.25, 0.35)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Volume CSO/SSO	m^3/year	(11 221, 29 001)	Normal (P50, P90)	Kungsbacka municipality (2021c)
phosphorus concentration in sanitary sewage	kg P/m^3	(2.0, 4.9, 6.0, 7.0, 9.0)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Nitrogen concentration in sanitary sewage	kg N/m^3	(17.5, 22.5, 29.0, 34.5, 42.5)	Gumbel type II (L, Q1, M, Q3, U)	Götabergsgatan
Conversion factor phosphorus	kg PO_4-eq/m^3	3.07	Point value	Götabergsgatan
Conversion factor nitrogen	kg PO_4-eq/m^3	0.42	Point value	Götabergsgatan
Treatment requirement phosphorus	kg P/year	(4 000, 2 220)	Normal (μ,ω)	Workshop 2022-03-22
Treatment requirement nitrogen	kg N/year	(30 000, 130 000)	ExtvalueMinAlt(P10, P90)	Workshop 2022-03-22
Dilution factor of CSOs	-	5.2	Point value	Kungsbacka municipality

Table C.4: Data used to calculate effects from basement flooding for Hammargård WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Share of basement flooding events for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0, 0, 0.5, 0.2, 0.4, 0.7, 0.85, 0.9	Point values	Götabergsgatan
Uncertainty distribution share of flooding	-	(0.8, 0.85, 0.95, 1)	Beta (P05, P25, P75, P95)	Götabergsgatan
Factor for uncertainty of share of flooding for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0.06, 0.22, 0.44, 0.78, 0.94, 1	Point values	Götabergsgatan
Share of houses vulnerable to basement flooding due to I/I-water	-	(0.14, 0.0741)	Normal (μ,ω)	Workshop 2022-03-22
Cost basement flooding detached house	SEK/flooding event	(54 896, 2 609)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding apartment/commercial building	SEK/flooding event	(221 917, 17 537)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding public building	SEK/flooding event	(210 238, 17 771)	Log normal (μ, ω)	Götabergsgatan
Number of detached houses	#	(9 782, 10 760)	Normal (P50, P95)	Manually counted
Number of apartment/commercial buildings	#	(1 754, 1 929)	Normal (P50, P95)	Manually counted
Number of public buildings	#	(170, 187)	Normal (P50, P95)	Manually counted
Share of detached houses in zone 1-1000 meter from previous basement flooding	-	(0.5, 0.05, 0.4, 0.6)	Normal (μ, ω, Trunc min, Trunc max)	
WTP per household in detached houses to avoid flooding 1-1000 meter	SEK/year	(828, 1 524)	Lognormal (μ, ω)	Götabergsgatan
WTP per household in detached houses to avoid flooding 1000+ meter	SEK/year	(151, 1 351)	Lognormal (μ, ω)	Götabergsgatan

Table C.5: Data used to calculate effects at WWTP for Hammargård WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Volume I/I-water from case study area to WWTP	m^3/year	(1 469 458, 2 230 471)	Normal (P10, P90)	Kungsbacka municipality (2021c)
Total volume to WWTP	m^3/year	(3 831 921, 4 848 850)	Normal (P10, P90)	Kungsbacka municipality (2021c)
Treatment cost	SEK/m^3	(1.49, 0.445)	Normal (μ,ω)	Workshop 2022-03-22
Factor for increasing treatment cost	-	1.5	Point value	Götabergsgatan
Investment WWTP year 1-10	Million SEK	(500, 670, 900)	Lognormal (P25, P50, P75)	Workshop 2022-03-22
Investment WWTP year 11-50	Million SEK	(1 754, 3 260, 7 280)	Lognormal (P05, P50, P95)	Workshop 2022-03-22
Investment WWTP year 51-100	Million SEK	(2 110, 4 250, 9 000)	Lognormal (P05, P50, P90)	Workshop 2022-03-22

D

Data used for Arvidstorp WWTP

Table D.1: General data used in the analysis of Arvidstorp WWTP case study area.

Parameter	**Unit**	**Valus**
Discount rate	-	0.035
Climate factor	-	1.25
Length of the studied period	years	100
Length of wastewater sewer system within the case study area	m	290 840
Number of connected people	#	54 998

Table D.2: Data used to calculate effects at WWTP for Arvidstorp WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
Volume I/I-water from case study area to WWTP	m^3/year	(7 841 684, 10 964 176)	Normal (P10, P90)	Trollhättan Energi AB
Total volume to WWTP	m^3/year	(11 654 343, 14 953 459)	Normal (P10, P90)	Trollhättan Energi AB
Treatment cost	SEK/m^3	(0.03, 1.11, 0, 1.2)	Normal (P20, P95, Trunc min, Trunc max)	Workshop 2022-04-26
Factor for increasing treatment cost	-	1.5	Point value	Götabergsgatan
Investment WWTP year 1-10	Million SEK	(305, 520, 1 060, 1 000)	Lognormal (P05, P50, P95, Trunc max)	Workshop 2022-04-26
Investment WWTP year 11-50	Million SEK	(808, 1 240, 3 450, 4 200)	Lognormal (P05, P50, P95, Trunc max)	Workshop 2022-04-26
Investment WWTP year 51-100	Million SEK	(648, 1 500, 8 170, 6 000)	Lognormal (P05, P50, P95, Trunc max)	Workshop 2022-04-26

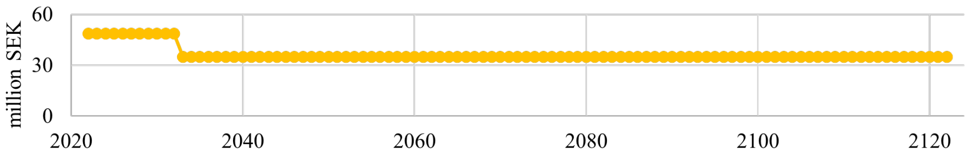

Figure D.1: Investment distribution for Arvidstorp WWTP case study area (Workshop 2022-04-26).

Table D.3: Data used to calculate effects from CSOs/SSOs for Arvidstorp WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	**Unit**	**Value**	**Distribution**	**Source**
WTP to reach good water status	Million SEK/year	(16, 18)	Normal (P05, P95)	
Share of requirement fulfilled with P and N	-	(0.05, 0.15, 0.2, 0.25, 0.35)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
Volume CSO/SSO	m^3/year	(252 861, 643 697)	Normal (P50, P90)	Trollhättan Energi AB
phosphorus concentration in sanitary sewage	kg P/m^3	(2.0, 4.9, 6.0, 7.0, 9.0)	Beta (L, Q1, M, Q3, U)	Götabergsgatan
phosphorus concentration in stormwater	kg P/m^3	(0.04, 0.15, 0.19, 0.25, 0.65)	Lognormal (L, Q1, M, Q3, U)	Götabergsgatan
Nitrogen concentration in sanitary sewage	kg N/m^3	(17.5, 22.5, 29.0, 34.5, 42.5)	Gumbel type II (L, Q1, M, Q3, U)	Götabergsgatan
Nitrogen concentration in stormwater	kg N/m^3	(0.70, 1.55, 1.85, 2.20, 4.25)	Gamma (L, Q1, M, Q3, U)	Götabergsgatan
Conversion factor phosphorus	kg PO_4-eq/m^3	3.07	Point value	Götabergsgatan
Conversion factor nitrogen	kg PO_4-eq/m^3	0.42	Point value	Götabergsgatan
Treatment requirement phosphorus	kg P/year	(1 180, 11 000, 0, 11 000)	ExtvalueMin (P05, P95, Trunc min, Trunc max)	Workshop 2022-04-26
Treatment requirement nitrogen	kg N/year	(7 270, 61 100, 14 200, 85 460)	Normal (P05, P95, Trunc min, Trunc max)	Workshop 2022-04-26
Share of sanitary sewage in CSOs	-	(6.4, 6.7)	Normal (P50, P90)	Trollhättan Energi AB

Table D.4: Data used to calculate effects from pumping for Arvidstorp WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	Unit	Value	Distribution	Source
Energy consumption	kWh/m^3	(0.17, 0.57)	ExtvalueMin (P05, P95)	Workshop 2022-04-26
Pumping cost	SEK/kWh	(0.67, 1.19, 2.47)	Gamma (P05, P50, P95)	Workshop 2022-04-26
Cost per CO2-eq year 2021, 2031	SEK/CO_2-eq	0.80, 6.31	Point values	Götabergsgatan
CO_2-eq per kWh	CO_2-eq/kWh	(0, 0.26, 0.35, 0.44, 1)	Normal (L, Q1, M, Q3, U)	Götabergsgatan
Yearly change in cost of CO_2-eq 2021-2030	-	0.17	Uniform	Götabergsgatan
Yearly change in cost of CO_2-eq 2031-2121	-	(-0.02, 0, 0.004)	Beta pert (L, P50, P90)	Götabergsgatan

Table D.5: Data used to calculate effects from basement flooding for Arvidstorp WWTP case study area. Götabergsgatan as source indicates that the same data was used and the original source can be found in Appendix A.

Parameter	Unit	Value	Distribution	Source
Share of basement flooding events for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0, 0, 0.5, 0.2, 0.4, 0.7, 0.85, 0.9	Point values	Götabergsgatan
Uncertainty distribution share of flooding	-	(0.8, 0.85, 0.95, 1)	Beta (P05, P25, P75, P95)	Götabergsgatan
Factor for uncertainty of share of flooding for return period 1, 2, 5, 10, 20, 50, 100, 200 years	-	0.06, 0.22, 0.44, 0.78, 0.94, 1	Point values	Götabergsgatan
Share of houses vulnerable to basement flooding due to I/I-water	-	(0.19, 0.25, 0.41, 0.4)	Lognormal (P05, P50, P95, Trunc max)	Workshop 2022-04-26
Cost basement flooding detached house	SEK/flooding event	(54 896, 2 609)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding apartment/commercial building	SEK/flooding event	(221 917, 17 537)	Log normal (μ, ω)	Götabergsgatan
Cost basement flooding public building	SEK/flooding event	(210 238, 17 771)	Log normal (μ, ω)	Götabergsgatan
Number of residential buildings	#	16 609	Point value	Trollhättan Energi AB
Number of commercial buildings	#	1 572	Point value	Trollhättan Energi AB
Number of public buildings	#	469	Point value	Trollhättan Energi AB
Share of detached houses within the residential building category	-	(0.85, 0.9)	Uniform (L, U)	QGIS 3.22 and Geofabrik (2022)
Share of detached houses in zone 1-1000 meter from previous flooding	%	(0.5, 0.05, 0.4, 0.6)	Normal (μ, ω, min trunc, max trunc)	Trollhättan Energi AB
WTP per household in detached houses to avoid flooding 1-1000 meter	SEK/year	(828, 1 524)	Lognormal (μ, ω)	Götabergsgatan
WTP per household in detached houses to avoid flooding 1000+ meter	SEK/year	(151, 1 351)	Lognormal (μ, ω)	Götabergsgatan

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