CHALMERS

Risk Assessment for Scenarios of Increased Water Levels

Problem Forecast and Management for Technical Facilities within the Municipality of Gothenburg

Master of Science Thesis in the Master Degree Programme, Infrastructure and Environmental Engineering

Johan Emanuelsson
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: River outlet of the river Göta älv (Kulturbåtarna, 2014)

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ABSTRACT

In a future scenario, sea levels are expected to increase and precipitation is likely to be intensified due to the ongoing progress of climate change. This thesis has been dedicated to assess the present and future flood risk of technical facilities that manage water, wastewater and waste (e.g. pumping stations, recycling centres, raw water facilities) that is owned and/or governed by the municipality of Gothenburg, Sweden. A proposition for ensuring that essential facilities is sufficiently elevated to withstand an increased water level of **+ 3.80 m** has been put forward by the local authorities. This level is set with respect to three aspects; the present highest high water of **+ 1.80 m** from average sea level, an expected increase in sea level up to **1.0 m** and an additional safety margin of **1.0 m.** The work consisted in the development of risk cost estimations using present value (PV) calculations over the discount periods: **20**, **50** and **90 years**. The objective was also to establish a clearer insight in the chains of events that encompasses flood scenarios and furthermore to elaborate regarding possible countermeasures.

The results from PV calculations in this work showed that the studied drinking water pumping stations have insignificant risk costs and does not require any immediate countermeasures. The reserve raw water pumping station was attached to the most significant risk costs but there are no comprehensive small scale solutions available to flood proof the facility. The analysed sewage pumping station did also show a comparably high PV but further studies including cost-benefit analysis is suggested before implementing any countermeasures.

Great scale solutions such as flood gates could probably mitigate the flood risk attached to many of the facilities, but the effects must be further examined in a comprehensive profitability study. In order to achieve a more holistic description of the risk costs, further effort is needed in estimating the probable costs linked to, for example, basement flooding in various scenarios. Another recommendation consists in the development of an analysis method which comprises pluvial contributions together with terrain and structure elevation data.

Key words: Risk Assessment, Flooding, Technical Facilities, PV, Increased Sea Level

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SAMMANFATTNING

I framtiden förväntas havsnivåerna att stiga och mängden nederbörd att öka till följd av pågående klimatförändringar. Detta arbete är genomfört för att titta närmare på nuvarande och framtida risker på anläggningar som används för hantering av vatten, avlopp och avfall (t.ex. pumpstationer, återvinningscentraler, råvattenanläggningar) och som ägs och sköts av avdelningen *Kretslopp och vatten* på Göteborg Stad. En proposition för att säkra samhällsviktiga anläggningar mot vattennivåer upp till **+ 3,80 m** har lagts fram av de lokala myndigheterna. Nivån är satt med hänsyn taget till det befintliga högsta vattenståndet av **+ 1,80 m,** en förväntad havsnivåhöjning av **+ 1,0 m** och en ytterligare säkerhetsmariginal av **+ 1,0 m**. Arbetet har analyserat de olika anläggningarna med hjälp av nuvärdesberäkningar med diskonteringsperioderna **20**, **50** och **90 år**. Målet var att skapa en tydligare bild av händelseförlopp i samband med översvämningar och samtidigt föra en diskussion gällande möjliga lösningar på problemen.

Resultatet av nuvärdesberäkningarna visade att de studerade dricksvattenpumpstationerna hade låga riskkostnader och därför inte är i behov av några direkta motåtgärder. Reservråvattenstationen hade den högsta riskkostnaden, men det finns i dagsläget inga småskaliga, effektiva motåtgärder för att säkra anläggningen mot översvämning. Den analyserade spillvattenpumpstationen visade också en jämförelsevis hög riskkostnad i nuvärdesberäkningar, men ytterligare studier såsom kostnads-nyttoanalys rekommenderas innan införande av åtgärder.

Storskaliga lösningar såsom skyddsportar kan komma att minska risken för översvämning för flera anläggningar, men ytterligare lönsamhetsanalys rekommenderas för att slå fast de faktiska effekterna av sådana lösningar. För att uppnå en mer övergripande bild av riskkostnaderna så krävs ytterligare arbete med att slå fast kostnader relaterade till exempelvis källaröversvämningar vid olika översvämningshändelser. Ytterligare en rekommendation innefattar utveckling av en analysmodell som tar hänsyn till pluviala flöden samt topografiska aspekter såsom höjddata.

Nyckelord: Risk hantering, översvämning, tekniska anläggningar, nuvärde, höjda vattennivåer

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PREFACE

This thesis has provided us with a unique opportunity to work with flood assessment in reality, something which has been both exciting and educative. The assessment was carried out as a task appointed by the municipality of Gothenburg and this thesis is to be seen as one of the steps in outlining risks for technical facilities in the municipality. We want to thank all involved staff on the Dept. of Sustainable Water and Waste for the help with information and answers to the many questions that we encountered throughout this semester. Special thanks go to our supervisor Annika Malm, Fredrik Torstensson, Roger Grundell, Jakob Ljungquist and Håkan Strandner at *Kretslopp och vatten* and to Andreas Lindhe at *Chalmers*, who helped us in achieving the risk analysis carried out in this work.

Gothenburg, June 2014

Johan Emanuelsson & Victor Jansson

LIST OF ABBREVATIONS

CBA	*Cost Benefit Analysis*
CSO	*Combined Sewer Overflow*
DWPS	*Drinking Water Pumping Station*
DWTP	*Drinking Water Treatment Plant*
LPL	*Lowest Pressure Level*
NPV	*Net Present Value*
PV	*Present Value*
RRWPS	*Reserve Raw Water Pumping Station*
RWI	*Raw Water Intake*
SEK	*Swedish Krona*
SPS	*Sewage Pumping Station*
SSO	*Separate Sewer Overflow*
STA	*Swedish Traffic Administration*
WWTP	*Waste Water Treatment Plant*

1. INTRODUCTION

A future increase in sea level is forecasted by several scientific institutes around the world (Bergström, 2012) and by year **2100** it is anticipated that the average precipitation within the Gothenburg area will reach an increase between **10-30 %** (SMHI, 2011). Hence, various problems related to flooding needs to be evaluated and one of them is associated to damages on technical devises that are essential for maintaining the function of municipal water distribution and waste water management (e.g. pumping stations and motorized valves). Another risk that arises is that recycling stations and recycling centres could become flooded, with contamination of the surrounding environment as a potential result. The *Department of Sustainable Water and Waste* within the *City of Gothenburg*; in Swedish referred to as *Kretslopp och vatten*, are in charge of these facilities and are interested in acquiring a better overview of the described problem.

A municipal proposition for ensuring the function of essential facilities within the city was introduced in **2009** (City of Gothenburg, 2010). The prospect of the proposition is to ensure that the elevation of such facilities is sufficient to withstand an increased water level of **3.80 m**. This level is set with respect to three aspects; the present highest high water of **+ 1.80 m** from average sea level, an expected increase in sea level up to **1.0 m** and an additional safety margin of **1.0 m** (Ibid).

1.1 Aim

The main purpose of the project is to identify facilities and devices, important for maintaining function within the municipality of Gothenburg, which are at risk of becoming affected due to extreme weather and climate conditions. The works consists in establishing a risk analysis for facilities and devices within the drinking water, raw water, wastewater and solid waste management in the municipality. The intention is to determine the actual risk cost associated to the different objects and, if possible, discuss and elaborate regarding suitable countermeasures to decrease the present and future risks.

1.2 Objective

The objectives of the project can be summarized in the following bullet points:

- Identify facilities and devices at risk together with corresponding critical elevations
- Determine risk costs for the different facilities and devices, using various discount periods
- Identify the consequences due to flooding for the different facilities and devices
- Provide support in present and future decision making
- Discuss and elaborate regarding pros and cons for possible countermeasures

1.3 Scope

The project intends to identify risks for facilities that are owned and/or managed by *Kretslopp och vatten*. The project is limited to include facilities located in the city centre, suburban regions as well as in the archipelago within the municipality, see Figure 1. The facilities included in the study are limited to: pumping stations for drinking water and sewage, raw water facilities, motorized valves**,** recycling stations and recycling centres. The main cause for flooding evaluated in this work will be limited to high water levels in the surrounding water bodies (e.g. the river Göta älv and the sea). Pluvial (e.g. precipitation) contributions will only be discussed briefly and not included in the analysis. The objects that are evaluated in this work are located on elevations of **+ 3.80 m** or less, which is in accordance to the described proposition for securing essential facilities during events of extreme water levels within the municipality.

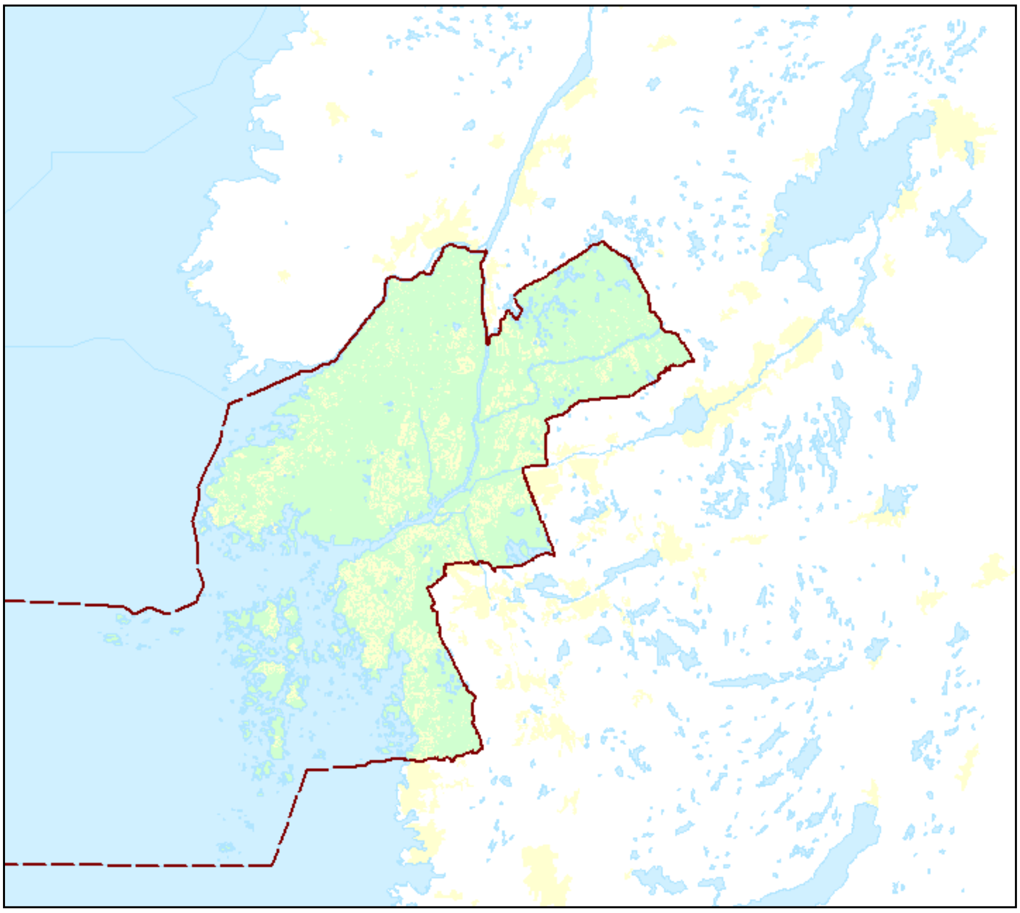

Figure 1 Map illustrating the geographical span of the project

1.4 Method

The structure of this work follows the conceptual model for decision making processes as presented by (Aven, 2003) with focus on the first two parts, see Figure 2. The work should be seen as the initiating step in achieving proper decision support.

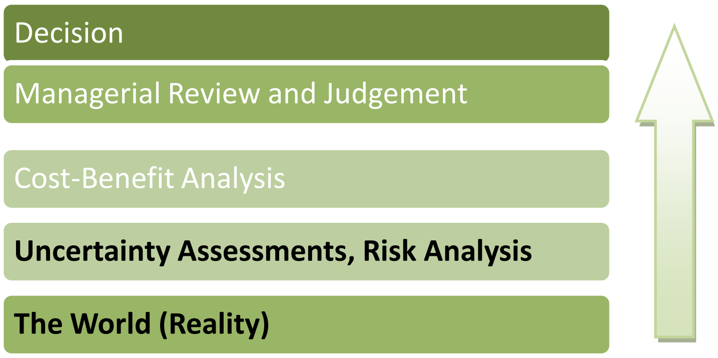

Figure 2 Schematic structure for decision making processes **(Aven, 2003)**

The first step of the work consists in gathering information such as elevation data for the facilities of interest. It is essential to use proper data in order to get valid results from later analysis. The risk analysis that is used involves summarization of the risks over a finite span of water level return periods and calculations over a predefined time horizon using present value (PV). Furthermore, risk tree assessment is used for establishing a logic system overview for certain facilities, where connections between different events are identified. There will not be any strict cost-benefit analysis (CBA) carried out in this work since there are too much uncertainties and a lack of information linked to the costs for countermeasures. However, a discussion regarding pros and cons for different measures will be put forward in the analysis for the different facilities and devices. The last step consists in reviewing the actual outcome from the analysis and is mainly limited to discussion and elaboration regarding the validity of the work as well as interpretation of all gathered output information.

The work of identifying objects of interest for analysis is made with respect to the elevations on each location, together with present barriers and safety devices (e.g. backwater valves and high water hatches). The identification process can be described by the flow chart in Figure 3. For example, objects located on low elevations can still have safety devices which suggest that there is a lower risk for water intrusion through any rear entry. Some objects are not included in the PV calculations due to features such as mobility (i.e. easily moveable objects) and/or issues in obtaining actual costs for scenarios of inundation.

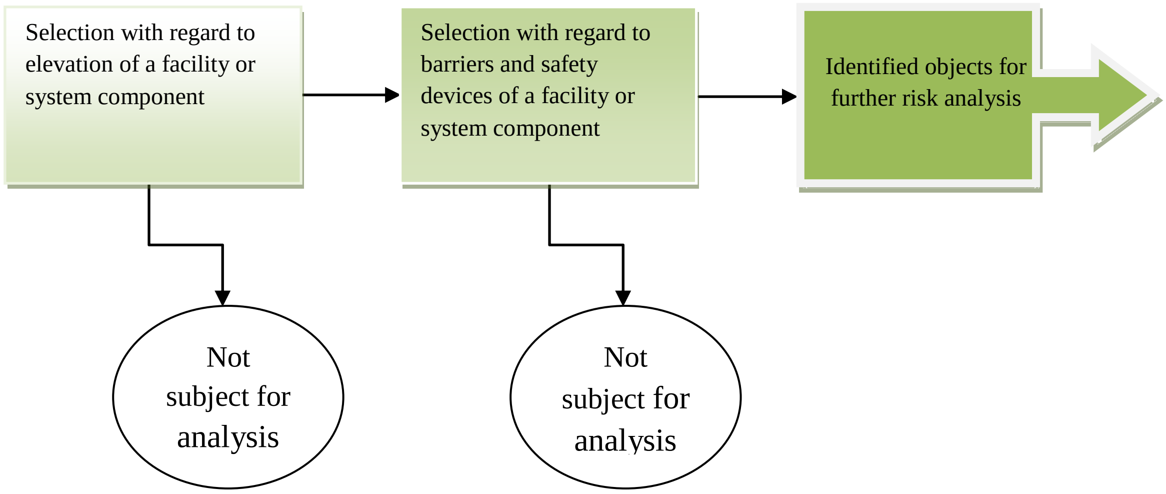

Figure 3 Flow chart describing the selection process for facilities and system components

The methods for identifying the risk of flooding involves present applications within the field of geographical information systems (GIS) in combination with study visits at some locations. In particular cases the project used GIS applications and results from previous simulations for visualization of scenarios with altered water stands. In order to make topography readings at locations of interest, the municipal GIS tool referred to as *Solen X* was used together with present maps and listed information at *Kretslopp och vatten*. The prior was also used for identifying the various facilities and components that are present in the municipal system.

2. LITERATURE STUDY

The following section will provide useful information regarding the facilities and devices of interest for this work and describe the purpose and function of hatches and valves in the system. Furthermore it will give an overview of the software products mentioned in chapter **1.4** and describe the different types of flooding. The subsections in the literature study will serve as input and facilitate for understanding the upcoming chapters which contain results, analysis and discussion.

2.1 Flooding

The definition of flooding can be stated as any event where water of any ocean, river, creek, lake or similar, cover land areas above the natural shoreline or seaside (MSB (a), 2011). This section will provide information on the three main types of flooding; **(1)** flooding induced by high water stands in the sea called coastal flooding, **(2)** flooding caused by lake, stream or river overflow referred to as fluvial flooding and **(3)** flooding caused by precipitation called pluvial flooding, see Table 1 (Zevenbergen, et al., 2011). In coastal areas with river outlets to the sea, such as Gothenburg, all three flood types can occur separately or in combination. In this case the risk of fluvial flooding is evident since the river Göta Älv flows through the very city centre. According to a report from the Swedish Civil Contingencies Agency, Gothenburg is identified as an area with substantial risk for flooding. The report presented five selection methods for identification of risk areas and notable is that Gothenburg fell out as a risk zone in every one of them (MSB (a), 2011). The identification was made with respect to the amount of people directly affected (i.e. residents and employees) during extreme flows (i.e. 100-years return period), together with the predicted impact on economic activity, human health, environment and cultural heritage.

Table 1 Different flood types and their causes **(Zevenbergen, et al., 2011)**

Flood type	**Caused by**
Costal	Increased Sea Level
Fluvial	River/Stream/Lake Overflow
Pluvial	Precipitation

The return period for any sea level or water flow means that such an event is occurring or is surpassed in average one time over the defined period (Ivarsson, et al., 2011). The probability of any rain event or flow to occur at any year can be described by Equation 1:

$$p = \frac{1}{T} \qquad (1)$$

p = Annual probability of occurrence
T= Return period for the event

With this relationship it is possible to calculate probabilities for events that ultimately lead to flood related problems. Table 2 shows the probability for events with variable return period to occur at least one time during different time periods. The figure series has been calculated beforehand and was obtained by the use of a statistical distribution called Gumbel distribution (SMHI, 2011). The series is determined by the use of Equation 2 (City of Gothenburg, 2006):

$$P_n = 1 - (1 - p)^n \qquad (2)$$

P_n= Probability of occurrence during time period
p= Annual probability of occurrence
n= Amount of years within the time period

Table 2 Relationship between return period and probability of occurrence over different time periods **(Ivarsson, et al., 2011)**

Return Period	Probability during 20 years [%]	Probability during 50 years [%]	Probability during 100 years [%]
25 years	56	87	98
50 years	33	64	87
100 years	18	39	63

The work of mapping out possible implications from flood events is of course very important. Nevertheless, it is of importance to make reasonable assumptions regarding actual probabilities for various extreme events. It is for example most unlikely for Gothenburg to experience an extreme rain event in combination with the highest high water in sea and river (City Planning Office, 2014).

Due to the previous presence of continental ice, there is a successive ongoing uplift of the land in Sweden and for the Gothenburg area it amounts to about **3 mm/year** (Sweco (a), 2014). The uplift has a counter effect to the increase in sea level and a prognosis made by the Swedish Meteorological and Hydrological Institute (SMHI) predicts a net increase in sea level of **0.70 m** between **1990-2100**, see Figure 4 (SMHI, 2011).

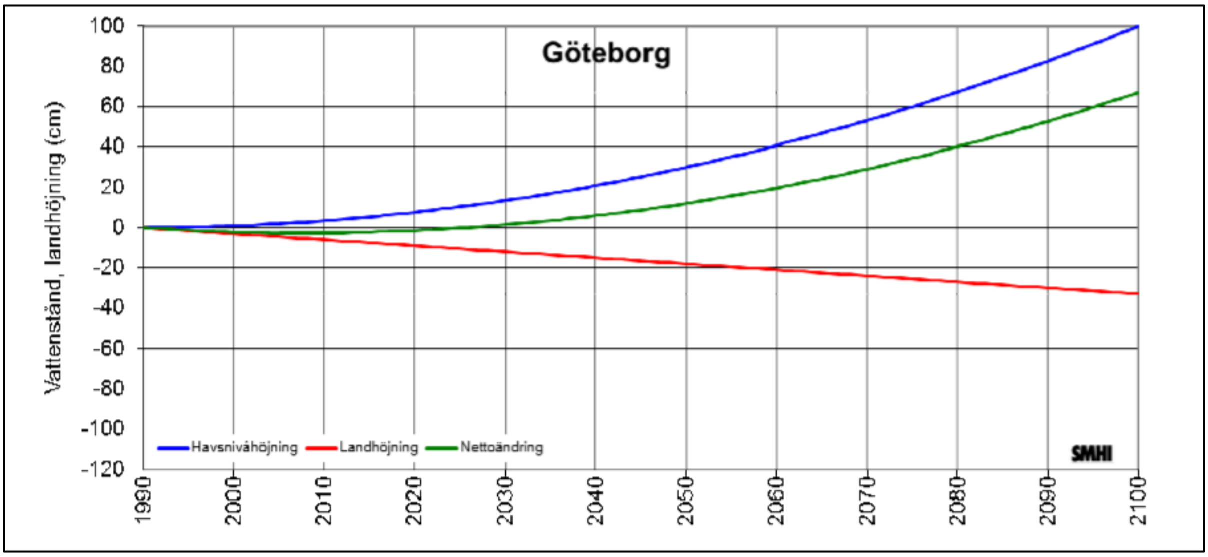

Figure 4 Graph showing the sea level increase (blue), the uplift (red) and the net change in sea level (green) between 1990-2100 **(SMHI, 2011)**

2.1.1 Coastal Flooding

Coastal flood events do usually occur due to depressions in air pressure or heavy winds during storms, where the highest water levels can be expected a few hours after the peak intensity of a storm event (County Administration (b), 2012). The high water levels do usually take place during a few hours and do rarely exceed a day (City Planning Office, 2014). As for Gothenburg, which has a flood outlet to the Western Sea, there is a funnel effect which increases the water levels toward the city centre and the continuing river line. Coastal flooding is identified as the main flood issue for Gothenburg. Nevertheless, fluvial and pluvial contributions present significant sources of influence in the flood management[1].

In areas located at coastal sites, there is a present risk for coastal flooding and the expected increase in sea level will further increases the threat (County Administration (a), 2013). The probabilities for present water levels together with forecasted levels and probabilities, past year **2100,** can be extracted from Figure 5. (SMHI, 2011). It should be noted that the probabilities presented in the diagrams describe probability of occurrence or exceedance for the corresponding events.

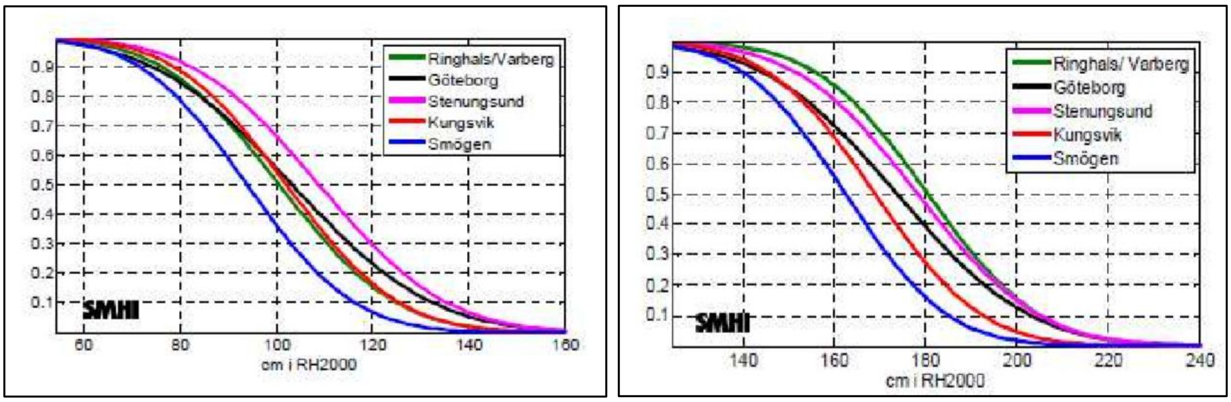

Figure 5 Graph showing probabilities for different water levels for the coastal zone of Gothenburg (black lines).To the left: 2010 and to the right: 2100 (SMHI, 2011)

Table 3 compiles some of the presented levels and their corresponding return periods (County Administration (a), 2013). It is of importance to recall coastal flooding as not only a result from high sea levels, but also from contributing effects connected to rainfall in association to the coastal catchment in question (Zevenbergen, et al., 2011).

Table 3 Compilation of some water levels and their corresponding probabilities for the coastal zone of Gothenburg **(County Administration (a), 2013)**

Time period	**Return period [years]**			
	2	**10**	**100**	**200**
1974 - 2010	1.03 m	1.33 m	1.65 m	1.73 m
After 2100	1.75 m	2.03 m	2.36 m	2.43 m

[1] Håkan Strandner, Specialist - projects within wastewater, Kretlopp och Vatten, Interview 2 April 2014

2.1.2 Fluvial Flooding

A common type of flooding within Sweden is fluvial flooding, which refers to flooding induced by lake, river or stream overflow (MSB (a), 2011). The typical reasons for this flood type are snowmelt and periods with heavy precipitation. It is also possible for fluvial flooding to occur due to flow interruptions caused by ice plugs. Gothenburg is connected to the lake Vänern via the river Göta älv and the water level in connection to the city is determined by the lake outflow and the runoff entering throughout the watercourse (County Administration (a), 2013). The lake is regulated at its outlet toward the river and future predictions suggest that the outlet volume, more often than today, will reach the maximum limit set by the authorities. This since greater fluctuations in the runoff is expected especially during winter season (City of Gothenburg, 2006). Furthermore, long lasting rain events with high summarized precipitation quantities can in general result in severe flooding of rivers draining a catchment, where the most persistent floods are expected in larger river basins (Zevenbergen, et al., 2011). Nevertheless, the most significant impact, for the Gothenburg area, comes from the present sea level at the river outlet and it is a reasonable assumption that the river level in close connection to the outlet is equal to the sea level[2].

2.1.3 Pluvial Flooding

Flooding due to rainfall does typically have effect on local level and the events are present only for a short time period (Chen, et al., 2010). Such events take place when the function of local drainage systems is lost and infiltration into the ground is insufficient (Houston, et al., 2011). In urban areas, the ground is to a large share covered with impervious pavement such as asphalt, which decreases the possibility of natural infiltration and percolation (Yang & Li, 2010). The result becomes both increased runoff volumes and velocities which leads to less resilient drainage systems. Pluvial flooding is typically induced by intense rain events which last during relatively short time periods (Zevenbergen, et al., 2011). According to (Houston, et al., 2011), it is possible for certain areas to have pluvial flooding in combinaion with both coastal- and fluvial flooding, which ultimatley lead to a more complex and difficult management issue.

Modelling of flooding induced by precipitation has become more addressed in recent years and understanding of runoff pathways has proven to be an important knowledge for predicting and solving problems related to pluvial flooding. One example is the recent initiative for development of a hydro model covering the city centre of Gothenburg, where runoff paths and volumes are identified (Ramböll, 2013). Damages related to downpour have had serious economic consequences in Sweden over history. For example the heavy rains over the island Orust at the west coast, had an accumulated cost of about **123 million SEK** (MSB (b), 2013). This single event of downpour lead to the highest societal expenses of all registered rain related events in Sweden, but the costs could probably have been much higher if the affected area had been one with more dense population and a greater degree of urbanisation.

[2] Håkan Strandner, Specialist - projects within wastewater, Kretlopp och Vatten, Interview 2 April 2014

2.2 Essential Facilities

A regional political proposition regarding an extended protection for essential facilities in the society was announced in **2009** (City of Gothenburg, 2010). The Traffic office in Gothenburg identifies these facilities by a number of criteria. Such facilities have a vital function within the society; a long technical lifespan; high investment costs and are impossible, or at least not easily, relocated (Traffic Office , 2008). Another definition criterion for essential facilities state that the society is heavily disfavoured by the damage or malfunction of the facilities. The facilities are exemplified as tunnels, bridges, and greater electrical installations (City Planning Office, 2014).

Not all facilities managed or owned by *Kretslopp och vatten* are reckoned as essential facilities. Nevertheless, all objects covered in this work are analysed with regards to the recommended safety margin for the essential facilities. The practical implement of this margin comes when the different object are identified and classified with regards to risk elevation. The objects located below **+ 3.80 m** are targets for analysis while the rest are assorted as objects located at adequate altitude. Notable is that the recommended level for the objects vary with regard to the location within the study area (City Planning Office, 2014). Objects in the city centre are associated with the mentioned level of **+ 3.80 m**, whilst objects located upstream, north of the Marieholm Bridge, are suggested a level of **+ 4.0 m** and objects located toward the stream outlet, past the Älvsborg Brige, a level of **+ 3.50 m**, see Figure 6. As mentioned before, this project is performed under the simplified assumption that all parts of the study area adopt the recommendations used for the central area.

Figure 6 Location of the bridges which define the boarders for the three suggested safety elevation zones.

2.3 Control and Safety Devices

There are some devices that are essential for securing the function of the wastewater system. In this chapter there will be an introduction to combined sewer overflows (CSOs) and emergency discharges. Furthermore, a description of hatch devices which prevent unwanted intrusion of water to the system is made.

2.3.1 CSOs, SSOs and Emergency Discharges

A combined sewer overflow (CSO) is a simple installation to ensure that the amount of storm water within a combined sewer system is kept at an acceptable level (NYDEC, 2014). This is crucial for avoiding street flooding and that extreme (i.e. not manageable) flows reaches the linked wastewater treatment plant (WWTP). The CSO is composed by a pipe outlet covered by a board with suitable height as schematically illustrated in Figure 7. Water flows past the outlet during normal weather conditions and is allowed to overflow during extreme weather events. The excess water is thereby discharged directly into the recipient.

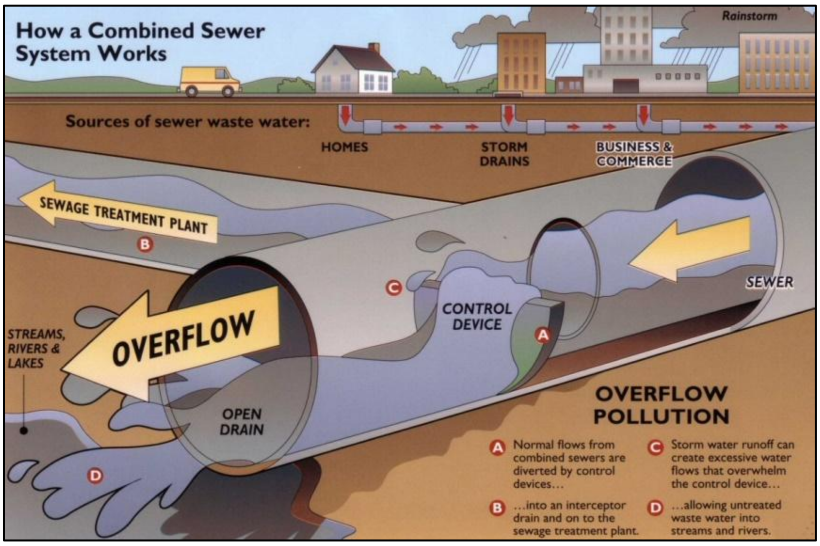

Figure 7 Schematic description of a typical CSO **(NYDEC, 2014)**

In Gothenburg, there are many CSO events occurring each year since approximately **25 %** of the city is founded on combined sewers[3]. There are similar installations for separate sewers called separate sewer overflows (SSOs), which discharges either sewage from the sewage system or storm water from storm water system.

An emergency discharge is another important security component of the wastewater system used as protection during malfunction or clogging in the system. The function of emergency discharges is basically the same as for CSOs, but this kind of installation is often used in sewage pumping stations and within the actual pipe system[4]. An emergency discharge is used to lead away excess water once a critical level is reached inside a pipe or facility. Notable is that emergency discharges are only used during extraordinary events and not during normal operating conditions in the system.

2.3.2 High Water Hatches and Backwater Valves

One essential part of the wastewater pipe network is composed by different hatch devices. In order to prevent intrusion of water from the outlet points of the system during events of high water stands, it is common to use high water hatches[4]. This devise is basically composed by a hatch attached to a counterweight. During normal water levels there is equilibrium between hatch and counterweight but as the water level rises, the balance is shifted and the hatch

[3] Annika Malm, Head of unit – Strategic coordination, Kretslopp och vatten, Interview 25 April 2014
[4] Fredrik Torstensson, Head of Unit – Sewage Pipe Network, Kretslopp och vatten, Interview 13 March 2014

closes. High water hatches are present in combined sewers, sewage pipes as well as in storm water pipes. When installed in combined sewers and sewage pipes, the intent is to protect the system and its components (e.g. pumping stations), while installations in storm water pipes have the purpose to protect from upstream ground level flooding. The high water hatches are usually placed in connection to CSOs or emergency discharges. Another common component in the sewage system is backwater valves which are used in order to stop the flow from going in the wrong direction in a pipe system, for example during an impoundment[1]. The valves are placed in connection to emergency discharges, preventing back flow of storm water in to the sewage pipes. They are also used on service pipes in order to prevent basement flooding.

In chapter **3.2** there has been a selection of objects with respect to the present protection installations. SPSs secured by succeeding high water hatches or backwater valves is assorted as objects not at risk of backwater intrusion and the same goes for stations with discharge linked to the sewage pipe network. However, even though there are no problems related to backwater, certain objects are still at risk of flooding due to presence of water at ground level.

2.4 Software Products

The different software products used throughout the work is presented in the following sections. The products use the elevation system called *RH2000*, which is nowadays the system used broadly over Sweden and which serves as the official reference system (City of Gothenburg , 2013) . Gothenburg City used an older system called *GH88* until **2013** before switching to the present one. *GH88* had the zero-plane approximately **10 m** below sea level so that all elevations should have a positive value. *RH2000*, on the other hand, uses the mean sea level as zero-plane, meaning that objects located below sea level are provided with negative values. All elevations mentioned in this report refer to the *RH2000* system (Ibid).

2.4.1 Solen X

In order to obtain the geographical positions of the different municipal facilities, the software product referred to as *Solen X* was used. The program is a geographical information system (GIS) which can be used to make searches and gather information regarding attributes that are attached to different objects. The program presents various layers, including main- and private pipes for sewage, storm water and drinking water. It is also possible to visualize the position of various components such as pumping stations, hatch devices and valves. Another useful layer within the software show elevation curves, a function that was used for estimating the elevation of any facility which lacked precise elevation data. Notable is that *Solen X* is functional as “peephole”, meaning that it is solely a tool for observation of the municipal system and cannot be used to alter or introduce new data to the present GIS.

2.4.2 City Planner

City Planner is a web-based tool used for hydro modelling within Gothenburg city, including some but not all suburban areas. The goal is to finish the model in **2014** and the main purpose is to enable decision support within the city planning management (Agency9, 2014). Notable is that the software shows the predicted water level without considering present flood barriers (e.g. walls and embankments) or other barriers (e.g. ridges, banks and structures) (City of Gothenburg (a), 2014). However, *City Planner* is used in order to give a coarse illustration of the risk areas and a glimpse of how flooding would appear at some locations. The software can be used for illustrating various water levels including the critical level of **+ 3.80 m** used in this work. Figure 8 illustrates two screenshots induced by *City Planner* which shows the *Frihamnen* area in central Gothenburg during normal conditions as well as with the described increase in water level. In fact, when observing the latter scenario, it is evident that a large share of the city area is located at critical elevation.

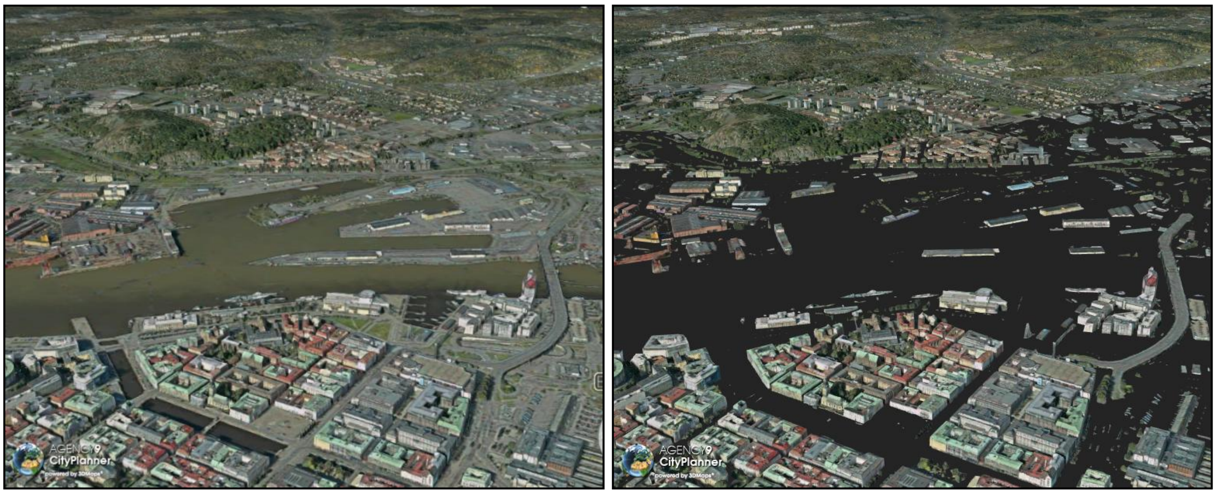

Figure 8The Frihamnen area in central Gothenburg: to the left normal water conditions at + 0 m and to the right extreme water level conditions at + 3.80 m **(Agency9, 2014)**

2.5 Different Types of Facilities

The upcoming sections describe the facilities of interest for the study. The elevation level used for limiting the number of objects for analysis is **+ 3.80 m** and further motivation for the choice of elevation limit is presented in chapter **1.3**.

Since pumping stations, valves and pipes are considered as objects of particular importance for the society, these objects have been anonymized throughout the work. Instead of location labels, objects are referred to as numbered objects such as DWPS4; drinking water pumping station with consecutive number four or SPS2; sewage pumping station with consecutive number two.

In general, installations present in technical facilities such as SPSs, DWPSs or such, are revised within a time span of about **20-30 years**. There are however exceptions for greater facilities, where the revision regarding technical installations is done less frequently[5]. The revision is made in order to secure the functionality of different system components by observing the depletion in mechanical and electrical function. Furthermore there is often a need to exchange the equipment in order to secure the possibility of providing spare parts needed for mechanical and electrical service and reparation.

[5] Roger Grundell, Chief Security Officer, Kretslopp och vatten, Interview 21 February 2014

2.5.1 Drinking Water Pumping Stations

Drinking water pumping stations (DWPSs) contain electrical equipment, which is the main reason to why they are sensitive to events of flooding. The appearance varies among the facilities but the general schematics for DWPS's are illustrated in Figure 9.

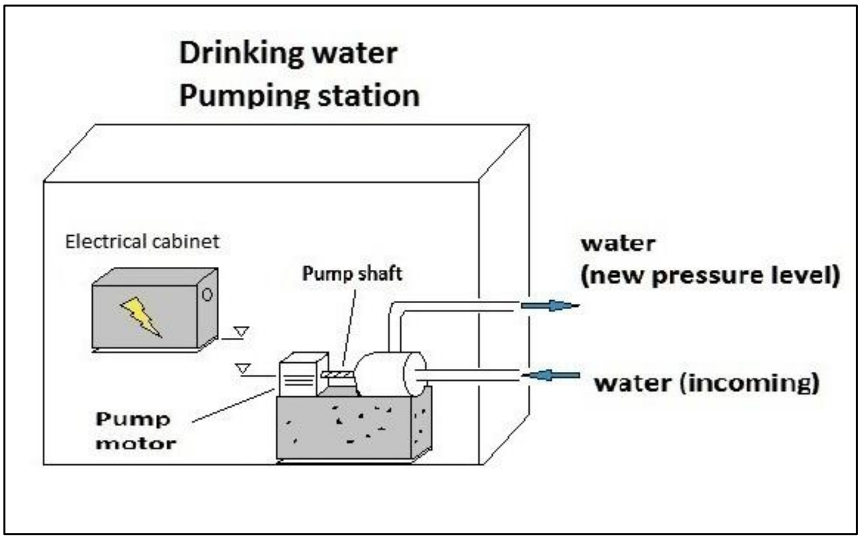

Figure 9 Schematics for drinking water pumping stations with the electrical cabinet located above the pump shaft

In general there is an electrical cabinet inside the pumping station and the elevation of this cabinet represents a critical level during possible events of flooding. This since water would severely damage the installed components inside the cabinet. In DWPSs, the electrical cabinet is generally located above the pump shaft that is attached to the pump motor[6]. If the pump motor becomes flooded it is likely that the pumping function is disturbed or terminated. Hence, the motor itself composes a crucial elevation level in a flooding scenario. Furthermore, it is common that a non-submersible security power switch is installed at approximately the same height as the shaft and motor[7], see Figure 10. Water from DWPSs is assorted as a viand. In order to reduce risk of contamination and sabotage, DWPS's are therefore always located inside buildings[4].

Figure 10 To the left; pumping shaft on a drinking water pump and to the right; security power switch

[6] Roger Grundell, Chief Security Officer, Kretslopp och vatten, Interview 21 February 2014
[7] Sven Särnbratt, Specialist -Electricity and Safety, Kretslopp och vatten, Study Visit 4 April 2014

The elevations linked to drinking water pumping stations were retrieved from data in a key map at *Kretslopp och vatten*. The map included 64 pumping stations with their correlating elevations, from which all stations below **+ 3.80 m** were identified. Table 4 describes the critical levels in DWPSs and the actual levels are presented in chapter 3.1.

Table 4 Elevations of interest for drinking water pumping stations

Drinking Water Pumping Stations
Floor level
Pump shaft level
Electrical cabinet (installation) level

2.5.2 Sewage Pumping Stations

In sewage pumping stations (SPSs), the electrical cabinet is normally placed over the lid of the pumping chamber[8]. There is an additional level of interest in SPSs associated with installed emergency discharges. The level must be identified since there is a possibility of water, within the pipe system or from linked water bodies (e.g. sea and river), to dam up inside the pump chamber during events of high water stands and/or heavy precipitation. However the actual rise of water inside the chamber is limited by the present water level of the linked water source, see Figure 11. Therefore it is unlikely for any SPS with emergency discharge to experience flooding due to damming of water in the chamber. Nevertheless, intrusion of water through the emergency discharge may lead to both higher stresses on system parts lying prior to the pumping station, as well as basement flooding at certain low elevated properties upstream in the pipe system[9].

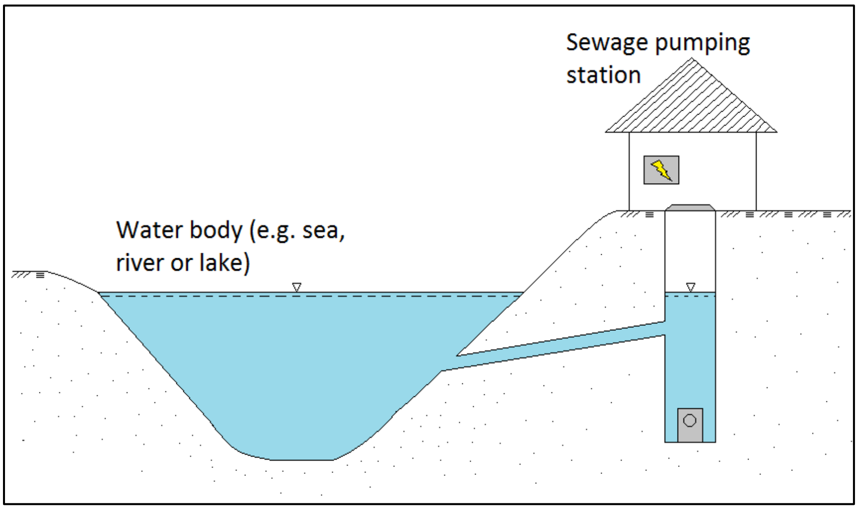

Figure 11 The level to which the water rise in the chamber is limited by the water level of any connected water source

[8] Roger Grundell, Chief Security Officer, Kretslopp och vatten, Interview 21 February 2014
[9] Fredrik Torstensson, Head of Unit – Sewage Pipe Network, Kretslopp och vatten, Interview 15 May 2014

The appearance among SPSs varies but the general schematics are illustrated in Figure 12.

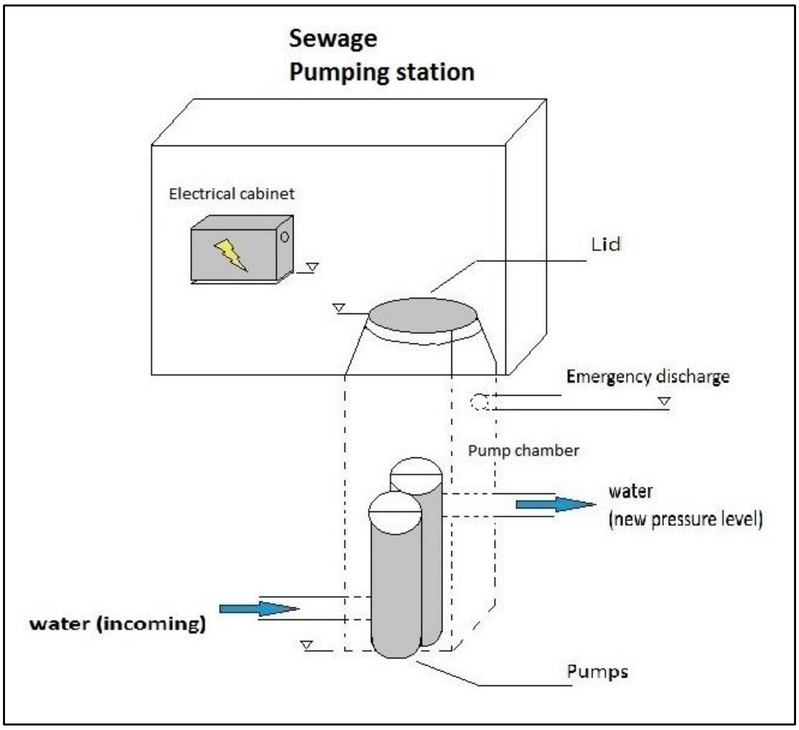

Figure 12 Schematics for sewage pumping stations with the electrical cabinet located above the lid of the pumping chamber

Most sewage pumps are located below ground level in pump chambers, either inside a building or outside. Such pumps are working in submerged conditions and are usually covered with hatches, see Figure 13.

Figure 13 Example of a covered outdoor pumping chamber with submerged pumps. The power cord connection are marked with the yellow circle in the image to the right

The submerged pumps are not subjects of concern during a flood scenario but there is generally power cord connections located at the top of the chamber. These connections are not particularly sensitive to fresh water[10]. However, the function is threatened if the connections are inundated for a longer time period. Sea water would affect the function within a much

[10] Michael Angelin, Workshop Manager, Kretslopp och vatten, Interview 16 May 2014

shorter time of exposure, due to the greater conduction ability of the media. The pump function is terminated if the connections are short circuited. The analysis does however only consider the components inside electrical cabinets as installations composing crucial elevation levels. Hence connections inside the chamber are not included in the analysis for SPSs.

Alternately, indoor dry pumps can be used for pumping from a separate sewage basin, see Figure 14. These pumps are often non-submersible and therefore sensitive to flooding.

Figure 14 To the left; dry sewage pumps and to the right; separate sewage basin

Information regarding elevations connected to the pumping stations managing sewage was obtained from an internal list, handed from staff at *Kretslopp och vatten*. In particular, the list showed elevations for emergency discharge, floor and lid, for **226** sewage pumping stations. In this case, all stations with emergency discharge below **+ 3.80 m** were considered as objects for further analysis. The critical levels of interest for SPSs are described in Table 5 and the actual levels are presented in chapter 3.2.

Table 5 Elevations of interest for sewage pumping stations

Sewage Pumping Stations
Emergency discharge
Floor (or ground) level
Lid level
Pump motor (i.e. dry pumps)
Electrical cabinet (installation) level

2.4.2 Raw Water Facilities

Urban raw water intakes are facilities which are crucial for the function of society since they regulate the supply of water as a viand and asset. The normal procedure consists in raw water (i.e. surface water or groundwater) extraction from the raw water source through some kind of grid or screen (Jones, 2008). The water is eventually lead to treatment at a drinking water treatment plant (DWTP), where it undergoes a variety of purification processes before it is distributed to users. The flow of raw water is enhanced by the use of raw water pumping stations. The municipality of Gothenburg extracts raw water from the river Göta älv and the present constellation enables for closing of the intake during occasions when there is a risk for extraction of raw water with unsatisfying water quality[11]. During such periods, the supply is dependent on the reserve water sources which consist in the Delsjö lakes and lake Rådasjön.

2.5.3 Recycling Centres

The purpose of recycling centres is to enable disposal of all kinds of bulky waste, electronic devices, hazardous waste and various packaging materials (Renova, 2014). There are **5** recycling centres within the study area, namely: *Bulycke Recycling Centre*, *Högsbo Recycling Centre*, *Sävenäs Recycling Centre*, *Tagene Recycling Centre* and *Alelyckan Recycling Centre*. The elevations for the different centres were obtained in *Solen X* by reading of the elevation curves at each specific location. Figure 15 shows the recycling centre at Alelyckan. An outdated definition of the term waste can be stated as "a movable object which has no direct use, and is discarded permanently" (Albanna, 2012). Sweden is moving toward a vision of a future totally free from waste where recycling and reuse together with preventive initiatives against waste generation is encouraged (Avfall Sverige , 2014). The goal however, is not achieved in present time and the path towards it is challenging. Present waste handling at recycling centres includes a number of environmental protective measures which reduces spread of hazardous substances into the surroundings[12].

Figure 15 To the left; recycling containers for combustible waste and to the right containers for hazardous waste at Alelyckan recycling centre

The issues that have been evaluated for each recycling centre at risk are summarized in the following questions:

- Is there a present risk for discharge of hazardous substances in to the surroundings in a flood scenario?
    - What are the consequences of a discharge?
- What protective installations are required?
    - Are the present installations sufficient?
    - Is it possible to adopt further/other actions and installations?
- What is the expected lifespan of the recycling centre?
- Are there other problems which contribute to additional risk?

[11] Hans Fransson, Drinking Water Production - Electrical Department, Kretslopp och vatten, Interview 21 May 2014

[12] Sanna Göransson, Head of Unit – Recycling and Reuse, Kretslopp och vatten, Interview 24 April 2014

2.5.4 Recycling Stations

There are more than **300** recycling stations deployed around the city of Gothenburg (City of Gothenburg (b), 2014). The stations are used for sorting papers, metals, glass, batteries, containerboards and plastics. Figure 16 illustrates the typical appearance of containers at recycling stations. The recycling stations located at critical levels were obtained by consulting staff at the GIS- department at *Kretslopp och vatten*. The selection procedure for the stations was performed by the use of GIS software supporting structured quarry language (SQL). Any recycling station missing information regarding its elevation had to be checked manually in *Solen X* in the same manner as described in chapter **2.4.3**.

Figure 16 To the left; overview of a local recycling station and to the right; recycling container for plastics

2.5.5 Motorized Valves

Valves are installations which are used to regulate flows within a pipe system and in order to facilitate the effort of operating, motors are often used. Motorized valves are often installed in pipes with great diameter and the operation is commonly executed remotely at a control centre[13]. One of the appearing drawbacks regarding motorized valves lies with the possible moist sensitivity of electrical equipment linked to the power supply and the remote regulating. Hence, such valves are subject to certain risk during possible events of flooding. The general assumption regarding valve elevation within the municipality of Gothenburg is that they are located about **1.5 m** below ground level[14] and the ground elevation was mapped out using *Solen X*.

2.6 Flood Related Costs

There are many damages related to events of flooding. However, the damage evaluation often distinguishes two main damage types which consist in tangible and intangible damages. Tangible damage refers to destruction or harm to property and/or material goods which can be designated with an estimated monetary cost (Lekuthai & Vongvisessomjai, 2001). Intangible damage instead refers to other kind of damage which is not easily quantified in terms of money. Such damage could be for example inconvenience, loss of life and/or various types of

[13] Roger Grundell, Chief Security Officer, Kretslopp och vatten, Interview 25 April 2014
[14] Annika Malm, Head of Unit – Strategic Coordination, Kretslopp och vatten, Interview 6 March 2014

disruptions (Zevenbergen, et al., 2011). Furthermore damage can often be grouped as direct and indirect, which refer either to damage directly from contact with flood water (e.g. wetting of equipment and structure parts) in the actual flood event, or to damage due to disturbance of different economic or social networks in society, respectively (Ibid). Figure 17 illustrates the possible types of damage constellation. The costs that are presented in this chapter are mainly estimates made by staff at *Kretslopp och vatten* which implies that these figures should be seen as guidance values rather than exact cost.

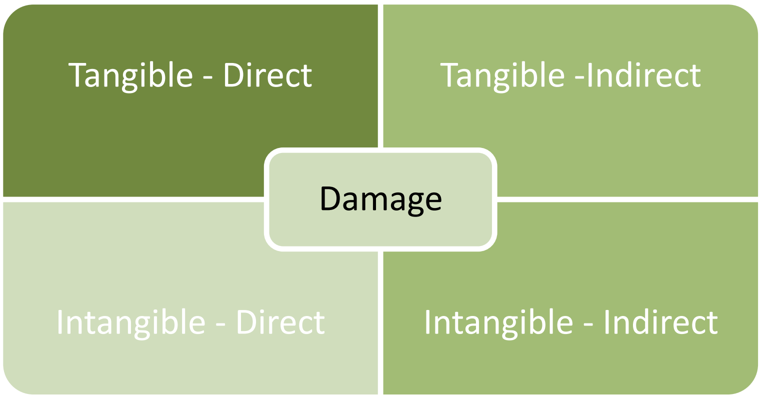

Figure 17 The four main groups of damage used in analysis of flood events

When it comes to DWPSs, one of the immediate costs that arise due to pump failure is linked to the need of emergency water. Emergency water is in some cases distributed by water lorries but the regular procedure consists in establishing temporary stations for water withdrawal from appropriate fire hydrants[15], see Figure 18. It is possible make assumptions regarding the amount of households that will be affected in case of ceased pump function. Such estimates are based upon the lowest pressure level (LPL) for any DWPS, which specifies the actual pressure level obtained without any pumping support. The anticipated emergency water cost per temporary station is about **6 000 Swedish kronor** (SEK).

Figure 18 Temporary station for drinking water distribution from fire hydrant

[15] Michael Angelin, Workshop Manager, Kretslopp och vatten, Interview 23 April 2014

Other expenses related to DWPSs are material costs for any destroyed or damaged equipment during the flood progress. Table 6 presents estimated costs for pumping of any water on the floor and costs for replacement of pump motor and electrical cabinets. It should be noted that some stations have greater and more expensive electrical installations than others.

Table 6 Estimated costs for regular equipment and service for drinking water pumping stations

Equipment	Costs [SEK]
Floor (i.e. pumping of excess water)	5,000
Pump Motor (i.e. for dry pumps)	30,000
Minor Electrical Cabinet	50,000
Major Electrical Cabinet	150,000

In similarity to DWPSs there are some general material costs associated with flooding of SPSs. Table 7 lists estimated costs for pumping of any water on the floor and costs for replacement of pump motor and electrical cabinets. Notable is that some stations have several pumps which raises possible repair and service costs. Furthermore, some stations will acquire a much more extensive pumping cost due to basements included in the structure.

Table 7 Estimated costs for regular equipment and service for sewage pumping stations

Equipment	Costs [SEK]
Floor (i.e. pumping of excess water)	5,000
Pump Motor (i.e. for dry pumps)	40,000
Minor Electrical Cabinet	50,000
Major Electrical Cabinet	150,000

Function disturbance or termination of SPSs does sometime involve costs linked to flooding of basements. This work does only cover costs which directly encumber *Kretslopp och vatten* and the main focus is therefore deductibles paid from the organisation to the main insurer. This delimitation has some drawbacks which are further discussed in chapter 5. The mean deductible for **2013**, based upon **67** flooded basements where *Kretslopp och vatten* has compensate the affected, was **111,366 SEK**[16]. The cost varies from **10,000 SEK** (i.e. basic sanitation) up to **1,000,000 SEK** (i.e. expensive basements with a lot of chattels). Most of the damages resulted in a lower cost than the mean value but a few was much higher, which forces the mean value to such a high level. There is nevertheless much uncertainty regarding how many households that are possible subjects for basement flooding in a scenario of system overload.

The costs associated with the raw water intake are listed in Table 8 while costs associated with raw water pumping stations are presented in Table 9. The sanitation costs that are linked

[16] Annika Wenzel, Claim Adjuster, Kretslopp och vatten, Interview 28 May 2014

to the raw water intake are uncertain but the costs in the worst case scenario is estimated to figures over **10 million SEK**.

Table 8 Estimated costs for regular equipment and service for raw water intake

Equipment	Costs [SEK]
Floor (i.e. pumping of excess water)	5,000
Electrical Equipment	1,000,000
Sanitation Measures for Intake Basin	>10,000,000

Table 9 Estimated costs for regular equipment and service for raw water pumping station

Equipment	Costs [SEK]
Floor (i.e. pumping of excess water)	5,000
Electrical Equipment	6-7,000,000

2.7 Probabilistic Calculations

Net present value (NPV) calculations enable for estimations regarding the present monetary value stemming from investment benefits and investment costs generated over a time period in a specific investment scenario (Ayyub , 2014). Equation 3 describes how the NPV is calculated.

$$NPV = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \times (B - C) \qquad (3)$$

NPV= Net present value
T= Time horizon in years
t= Time step
r= Discount rate
B= Associated Benefits
C= Associated Costs

In order to assess the risk costs which develop over a time period, it is possible to simplify the expression in Equation 3. The total annual risk cost, which arises due to a certain probability of occurrence and a predicted cost consequence for an event, can be used instead of the expression within brackets (Sweco (a), 2014). This leads to a new expression, shown in Equation 4. Notable is that this equation describes present value (PV) instead of net present value (NPV) since the investments is not considered. The PV will be used for estimating actual costs over a decided time period and in this particular case, **20**, **50** and **90 years** will be used as discount periods.

$$PV = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \times R_{total} \qquad (4)$$

PV= Present value
T= Time horizon in years
t= Amount of years

r= Discount rate
R_{total}= Total annual risk cost

Equation 5 describes how the total annual risk cost is calculated.

$$R_{total} = \sum_{t}^{T} P \times C \qquad (5)$$

R_{total}= Total annual risk cost
P= Annual probability for any event of interest
C= Associated cost.

Figure 19 describes the total annual risk cost in a schematic manner. It is represented by the summarized area containing the probabilities and costs of interest. It is crucial to ensure elimination of any double count in the calculation of the total area. For example; A3 is calculated as the product of P3 and C3 subtracted by the product of P3 and C2. This must be done since the area composed by the factors P3 and C2 already has been included in preceding risk scenarios.

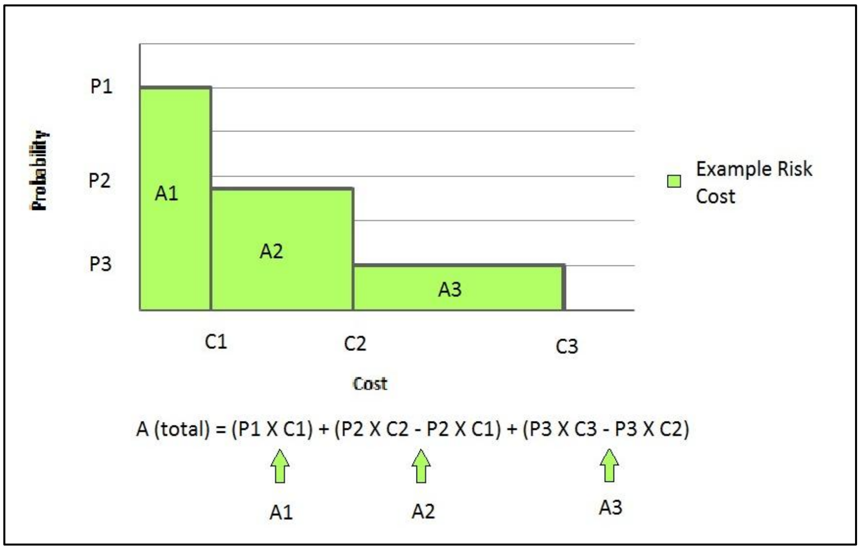

Figure 19 Scematic illustration describing the total annual risk cost as the area of the rectangles A1, A2 and A3

Discount rates are frequently used in socioeconomic projects in order to estimate present values of costs and benefits since they often arise at different occasions in a defined period or lifespan (Söderqvist, 2006). There are various discount rates available and amongst them are discount rates which originate from the *Stern Review*. The review encouraged low discount rates based upon subjective high values for securing wellbeing in future generations and taking early actions against climate change (Shah, 2002). In a report on cost- benefit analysis for flooding countermeasures in Gothenburg, two different discount rates were adopted for calculations and analysis (Sweco (a), 2014). The first rate, which was based upon the *Stern Review*, amounts to **1.4 %** and the second one, which was proposed by the *Swedish Transport Administration*, amounts to **3.5 %**. However, *Kretslopp och vatten* uses a discount rate of

3%[17]. This since it is an administration within the Gothenburg municipality and therefore has to borrow funds for their investments from the municipality, which decides what discount rate to be used. The municipal discount rate will be used throughout the work and the other two rates will be used for sensitivity analysis.

The fact that the annual risk is not constant over time implies that the calculation for PV is more difficult than what is suggested by Equation 4. In reality the probability for any water level will be much higher in the future (Sweco (a), 2014). For example, by the year **2100** a water level in the central river basin with present return period of **100 years** can be expected every **1.5 years**. To account for the risk development it is reasonable to attach some kind of upsurge to the annual risk costs[18].

Forecasts regarding water levels for the river Göta älv have been performed for year **2100**. However, the development between present time and year **2100** is not presented in previous work, which makes it more difficult to make proper assumptions regarding the growth pattern for the related probabilities (County Administration (a), 2013). One of the easier ways to interpolate between two known points is to assume linear development and such an assumption makes it easy to calculate the annual upsurge of the risk cost. The annual upsurge is determined by subtracting the total annual risk cost for present time from the total annual risk cost for the future scenario and then dividing by the actual number of years between the two occasions, see Equation 6. The difference between the two total annual risk costs is illustrated by the example in Figure 20.

$$\beta = \frac{R_{total,f} - R_{total,p}}{t} \qquad (6)$$

β= *The annual upsurge in risk cost*
$R_{total,f}$= *Total annual future risk cost*
$R_{total,p}$= *Total annual present risk cost*
t= time in years between present time and future scenario

[17] Lena de Woul, Financial Coordinator, Kretslopp och vatten, Interview 14 May 2014
[18] Lars Rosén, Professor: Civil and Environmental Engineering, Chalmers University of Technology Meeting 19 February 2014

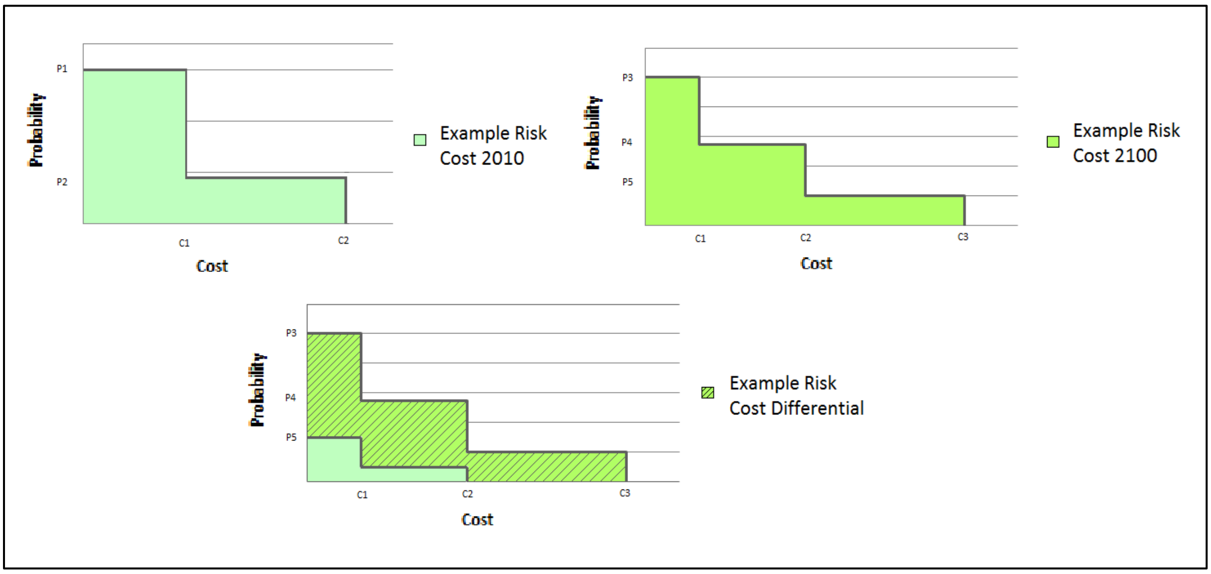

Figure 20 Comparison between total annual risk costs for year 2010 and 2100, with the increase in risk cost illustrated by the hatched area in the lowermost diagram

Since the PV is the summarized value in Equation 4 for each year between the present and future time, the corresponding risk cost for each year is obtained by subtracting the annual upsurge from the risk cost of the subsequent year.

In order to get a better system overview it is a good idea to implement event tree analysis. Event trees start with an initial event and typically unfold to various outcomes through sequences of terminal nodes (Rausand & Høyland, 2004). The terminal nodes sate a query which distinguishes a true and a false outcome as illustrated in Figure 21.

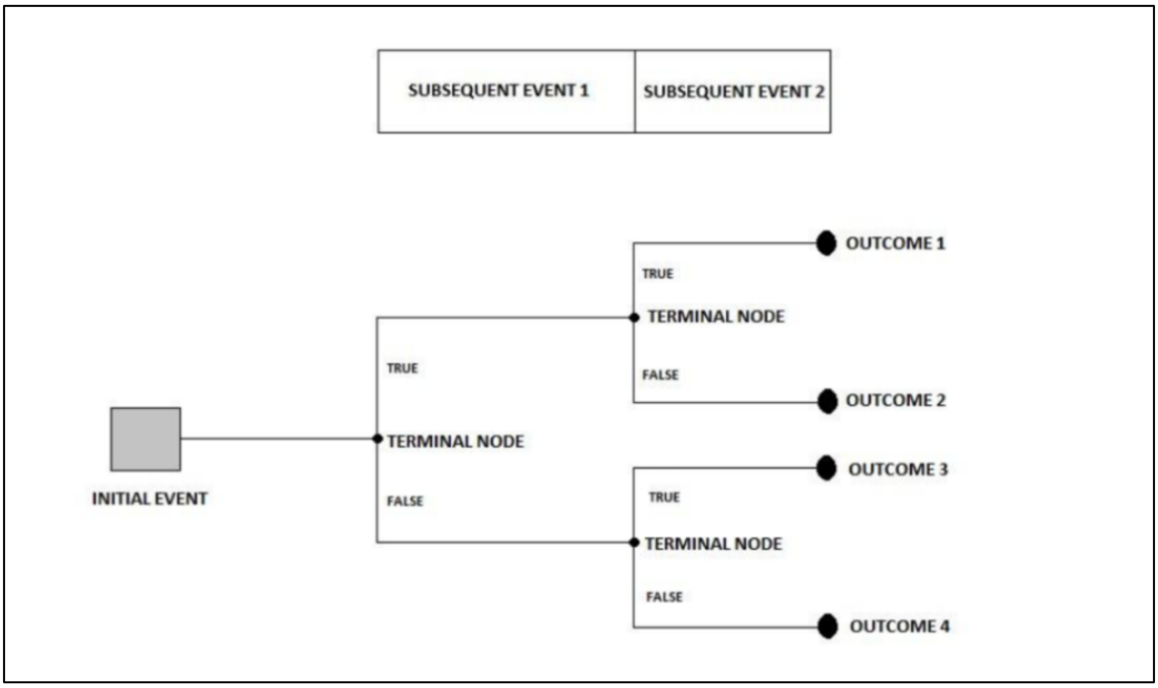

Figure 21 Structure of an event tree with its typical components.

The reason for using event tree analysis in this work is rather to understand and pinpoint crucial steps in the event sequences than to achieve exact probabilistic figures for the various events and outcomes. The total probability for each branch sums up to 100 %. For example; if the probability for a true outcome, P (T), is **30 %**, then the probability for a false outcome, P (F), must be 1-P (1) which in this case is **70 %** (Blomqvist , 2010). Although, since the different events

2.8 Uncertainty Considerations & Facilitations in the Analysis

There is a wide range of uncertainties linked to most modelling and analysis methods and this work is no exception. Uncertainties can be coped with in different ways but one of the common ways includes sensitivity analysis of any discount rate used in the calculations of present value figures (Mishan & Quah, 2007). For this reason this report uses **3** different rates in the calculations concerning PV. Other ways of coping with uncertainties involves estimates regarding upper and lower limits regarding what values that can be expected for costs and probabilities.

Other uncertainties lie within the assumption that the probabilities has a linear annual upsurge, this coarse assumption is likely to have a significant impact on the final result in calculations for the PV. Nevertheless, the lack of any previous estimates regarding return period patterns between present time and year **2100** makes this assumption necessary in order to come up with a first prediction in risk cost calculations.

The studied facilities have been evaluated with regard to their relative elevation and objects have been assorted as risk objects if the associated elevation is below the selection criteria. It is however much uncertain whether an inundation of the river bank or coastal area would affect a specific object, since appearance of terrain and present barriers have not been emphasised in the analysis. There are however, as mentioned in chapter **2.7.1**, work currently being carried out in order to simulate flow paths for pluvial contributions. Those patterns could possibly partially apply to scenarios of riverbank or coastal overflows and thereby contribute to the development of a more comprehensive future urban flood management.

The costs that are included in the study come mainly from estimations made by staff at *Kretslopp och vatten.* The figures should be appreciated as guidance values rather than precise costs and this is an important consideration when observing the analysis outcome. It is of course possible to apply various tampering of the costs to observe changes in outcome, but since there already is a high variability among the construction appearance for different objects with regard to for example the number of pumps and proportions of electrical cabinets, this has not been performed.

Previous studies has shown that wind impact have a non-negligible impact on water levels. For example it is anticipated that the levels can be increased by **0.20-0.30 m** for the part of the river Göta älv passing through the city centre of Gothenburg (SMHI, 2011). However, such levels are only expected during occasions of extreme wind speeds. Wind impact is also governed by depth and length of the water course segment in question. Nevertheless, in order to facilitate analysis, wind influence is not included as a parameter in this work.

2.9 Flood Management

There are two different types of countermeasures that needs to be considered, measures that reduce the probability for flooding and measures that reduces the consequences once an area becomes flooded (County Administration (a), 2013). This chapter provides information on the possibilities for the flood management process both in a short term and a long term perspective. Countermeasures are presented both for specific objects of importance but also for the area as a whole.

According to (Zevenbergen, et al., 2011), the strategy for implementing countermeasures should consider the uncertainty of external drivers such as climate change. In a scenario where such drivers are recognized and the attached uncertainties are comparably low, it might be possible to adopt single investment solutions which may sustain function over a long time span, see Figure 22. The system performance is decreasing due to a combination of external drivers and a natural drop in function performance of the installation. The figure shows how a change in the external drivers may intensify the decline in system performance (Ibid).

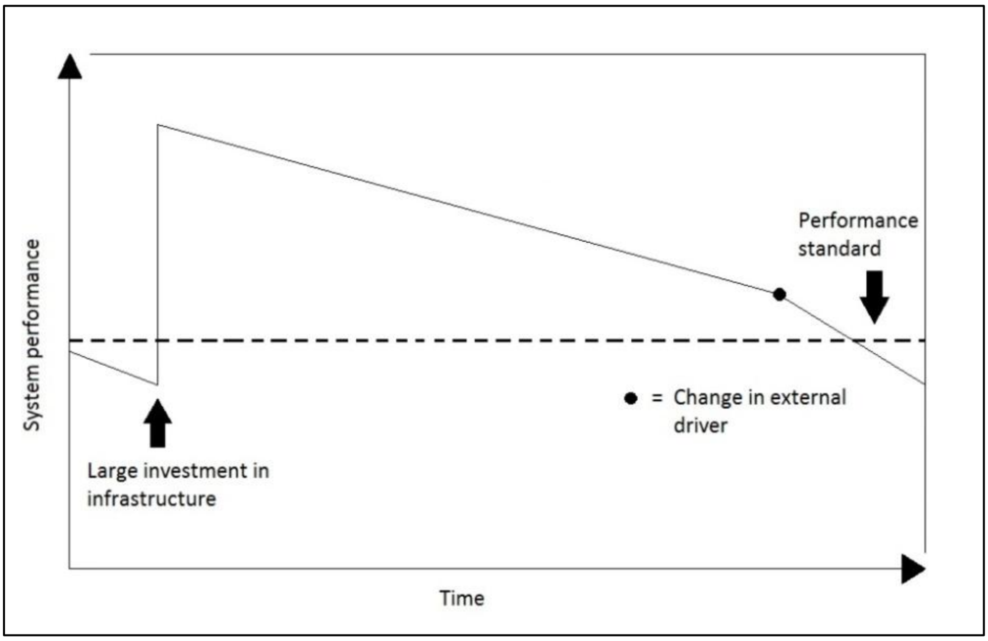

Figure 22 Large single investment in infrastructure, which is reasonable when external drivers are known and has low uncertainties **(Zevenbergen, et al., 2011)**

If instead, the external drivers are more loosely identified and their corresponding uncertainties are not easily quantified, adaptable measures might be more suitable option (Zevenbergen, et al., 2011). The adaptable approach suggests that responses to flood risk are made with regard to an expected increase in knowledge regarding climate change. The responses are implemented and are expected to last over shorter time period. The idea is to assess the uncertainties by including the increased knowledge in upcoming responses and hence, achieve a more effective response strategy, see Figure 23.

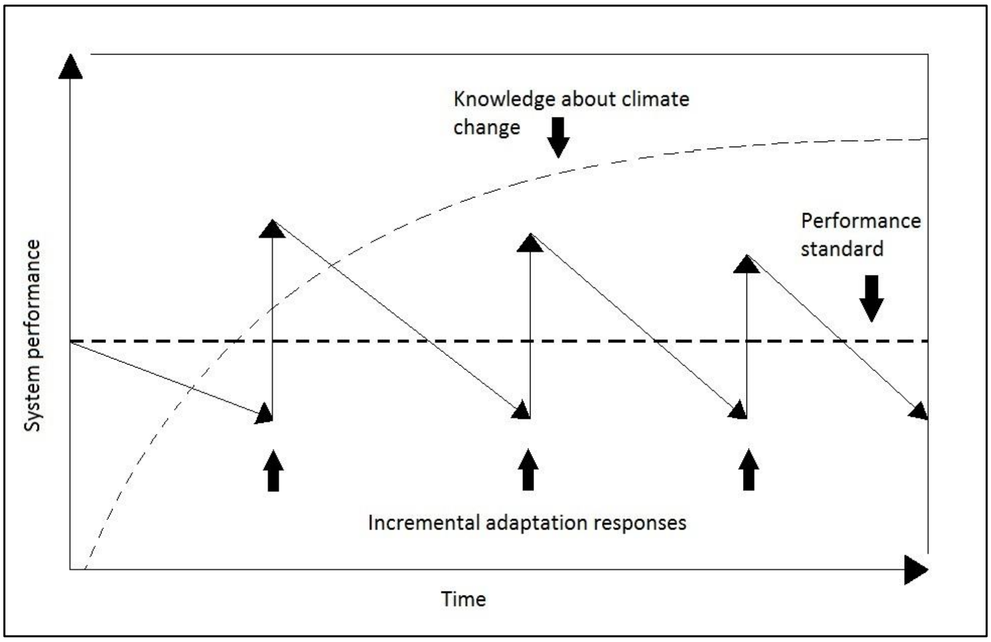

Figure 23 Incremental adaption responses, which is reasonable when external drivers are not fully known and has high uncertainty **(Zevenbergen, et al., 2011)**

2.9.1 Previous Studies

A recent study has been carried out in order to evaluate the possibility to implement flood gates and barriers at some central connections to the river Göta älv (Sweco (b), 2013). The study uses present solutions from abroad (e.g. the Netherlands) to exemplify possible measures. In particular, barriers are suggested for the connections associated to Stora Hamnkanalen and Vallgraven. Furthermore, possible barriers in the creek Säveån has been identified and briefly evaluated together with a barrier for the creek Kvillebäcken, see Figure 24. These solutions are intended to protect the inner city against flooding during periods of high sea and river water levels (Ibid).

Figure 24 Small scale barriers for the described connections to the river Göta älv **(Sweco (b), 2013)**

An alternative solution is also considered, which consists in application of greater barriers (i.e. gates) (Sweco (b), 2013). It is suggested to place one gate at the outlet of the river Göta älv, past the Älvsborg Bridge, in combination with one or two gates upstream towards Kungälv, see Figure 25. This option presents a great scale solution to future flood problems in the Gothenburg area which makes it possible to strongly limit the water level in the river basin associated with the inner city.

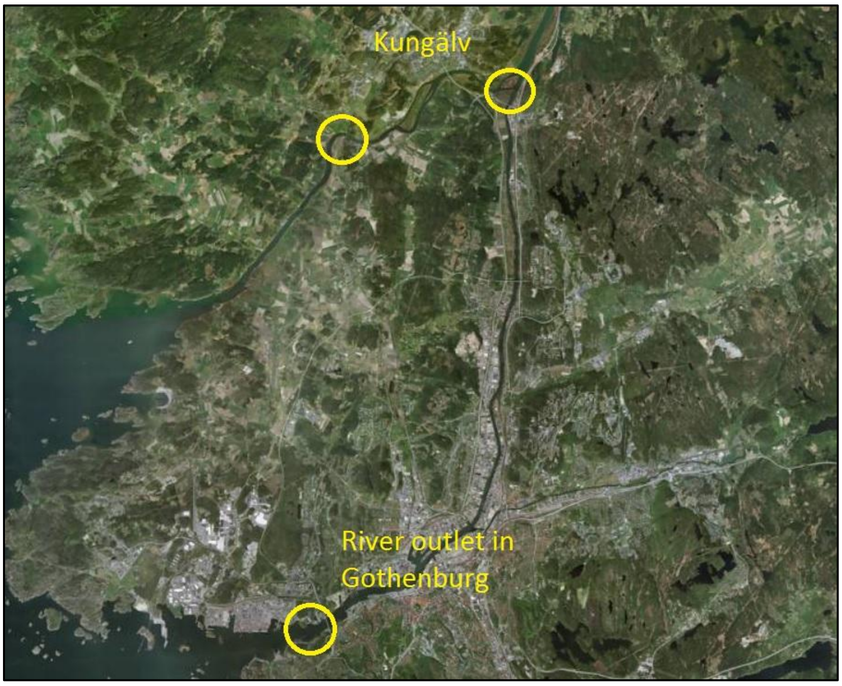

Figure 25 Great scale barriers for the Gothenburg area **(Sweco (b), 2013)**

Even though pluvial flooding is not considered in this work, there is a hydrological model under development, used to anticipate surface runoff in scenarios with extreme precipitation and altering water levels for central parts of Gothenburg. The model is developed partly in MIKE zero and partly in MIKE Flood. The work was first conducted by staff on the city planning office in Gothenburg and was then handed on, with the objective to achieve further improvements in the model and to increase its geographical coverage. One of the main improvements of the model was to ensure that all permanent barriers (e.g. concrete walls and various embankments) were included in the elevation model (Ramböll, 2013). In performed simulations, a rain with **100-years** in return period was used in combination with two different water levels. The first scenario was simulated with a water level of **+ 0.15 m** (i.e. normal fluctuation in water level) and the second scenario with a water level of **+ 1.85 m** (i.e. present extreme water level). Figure 25 illustrates the first scenario and Figure 26 the latter one. Notable is that the simulations only cover the inner city of Gothenburg so far.

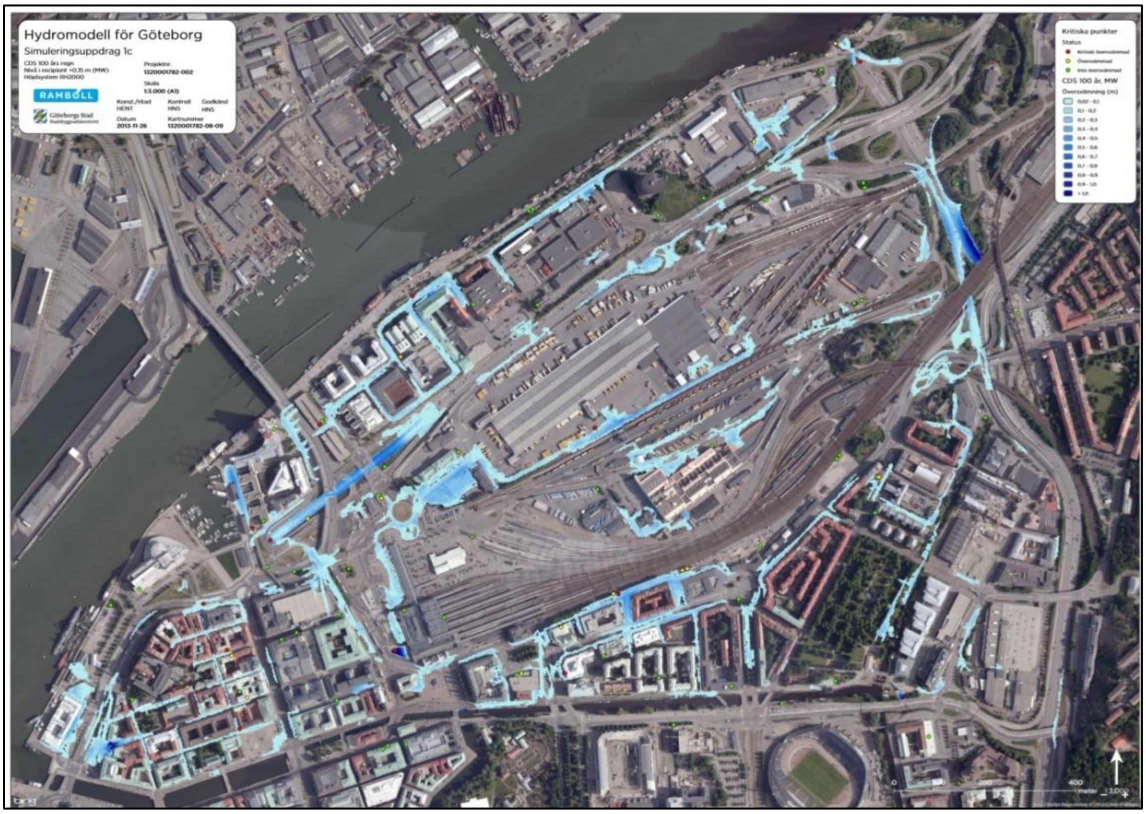

Figure 26 Simulation result with + 0.15 m water level in combination with a rain event with 100-years in return period **(Ramböll, 2013)**

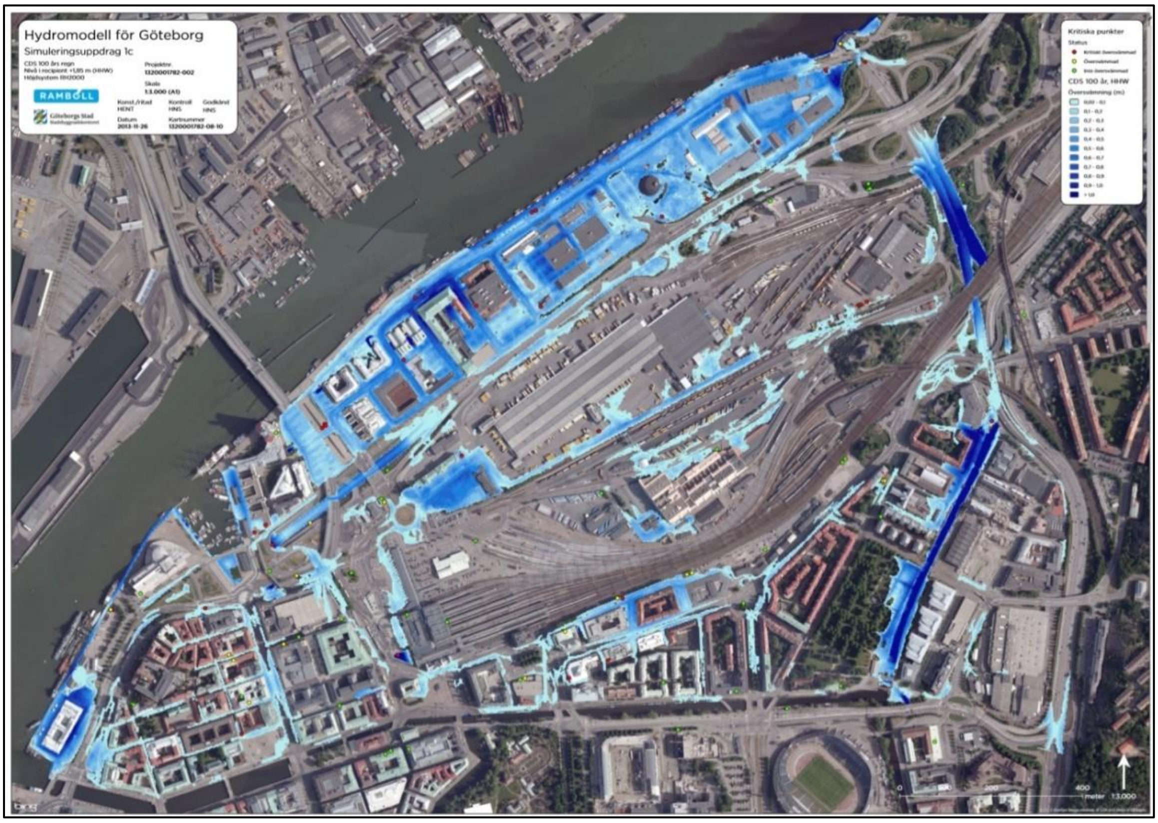

Figure 27 Simulation result with + 1.85 m water level in combination with a rain event with 100-years in return period **(Ramböll, 2013)**

2.9.2 Flood Proofing of Facilities

It is possible to implement some risk reducing measures at the very local level as well. For example, it is in some cases possible to increase the elevation of sensitive equipment above the expected level of flooding (Zevenbergen, et al., 2011). This measure together with sealing of gaps in structure surfaces and implementation of permanent physical barriers in connection to structures is denoted as passive flood proofing. In contrast to passive measures, active measures such as implementation of temporary barriers (e.g. sandbags or mobile walls). In Gothenburg, a particular crisis plan has been developed in order to prepare for extreme conditions, including flood scenarios (SRA, 2012). The plan is mainly developed to organise implementation of temporary flood barriers consisting in mobile concrete blocks in combination with rubber clothing, with the main objective to prevent inflow of water to the tunnel openings of Tingstadstunneln and Götatunneln. Such barriers could possibly prove useful in the flood proofing of certain important facilities which are identified as vulnerable objects in flood scenarios.

An important consideration when it comes to flood proofing of any type of structure is that it must be capable to cope with any hydrostatic forces acting on the surface of the structure (FEMA & FIA, 1993). The force is dependent on the actual water level. It is also vital to remember to assign saturated soil pressures to calculations related to loads below ground level. Furthermore, the structure must be protected from vertical forces which could result in floatation.

Another simple approach consists in elevating the entire structure and thereby eliminating the risk of direct contact between structure and flood water (Zevenbergen, et al., 2011). This approach could be an option for certain facilities but it should be noted that implementation of this measure could be complicated and the expenses can be expected to be high. For example in pumping stations, this alternative would require additional efforts in linking present pipe network with new pipe sections.

2.9.3 Integrated Flood Management

A more modern long term approach includes implementation of integrated flood-risk management where floods are considered as a natural part of the urban environment during certain time periods (Ivarsson, et al., 2011). This does not mean that flood disasters are accepted as phenomena but rather that the urban area is built in a robust and flood resilient manner, meaning that floods can take place without damaging the function or properties of the society. Measures that are related to the integrated approach include flood parks, flood resilient structures, elevated paths for traffic and pedestrians etc.

3. RESULTS

This section describes the obtained results for the different facilities and system components with the support of tables and figures. The lion's share of the objects was anonymised in order to meet the privacy agreements set by the municipality.

3.1 Drinking Water Pumping Stations

There are **64** pumping stations for drinking water within the municipality of Gothenburg, of which **3** stations are considered to be located at elevations low enough to be at risk of flooding (i.e. under + 3.80 m). The pumping stations are referred to as DWPS1-DWPS3**,** see Table 10. Notable is that in DWPS2, the electrical cabinet is located **300 mm** below the pump shaft[8], making this the first level of concern in a flood scenario.

Table 10 Drinking water pumping stations below + 3.8 m and their correlating elevations

Pumping Station	Floor [m]	Pump shaft [m]	Electrical cabinet [m]
DWPS1	+ 2.0	+ 2.5	+ 2.57
DWPS2	+ 3.0	+ 3.4	+ 3.1
DWPS3	+ 3.0	+ 3.4	+ 3.5

3.2 Sewage Pumping Stations

There are in total **226** pumping stations for sewage within the study area. Figure 28 illustrates the screening of the station stack. It can be seen that out of the total share, 125 SPSs have an elevation of less than **+ 3.80 m** to the lowest critical level, generally composed by an emergency discharge. Out of the 125 SPSs, 9 have either a high water hatch or a backwater valve installed where the next critical level is above **+3.8 m**, hence they are considered safe. This gives a total of 116 SPSs that are assorted as risk objects. The stations in this selection are referred to as SPS1-SPS116 and are listed with correlating elevations in Appendix 1.

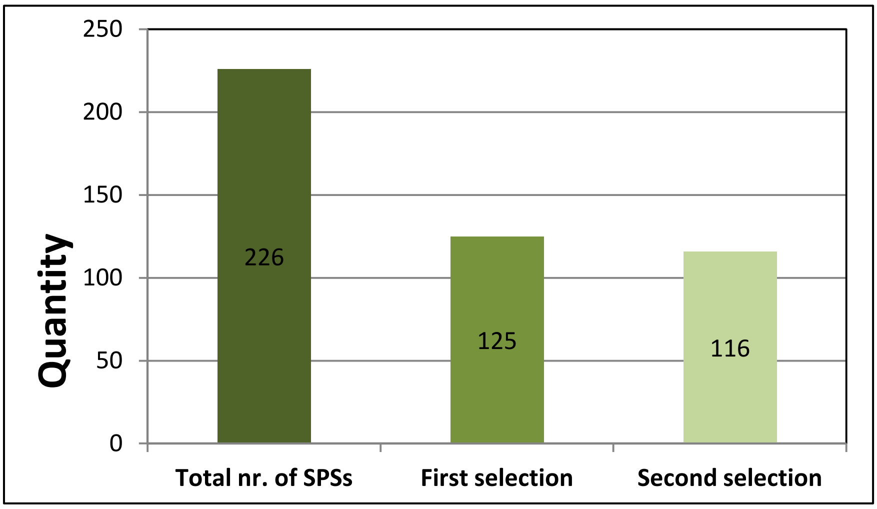

Figure 28 Diagram showing the outcome from the selection process concerning SPSs

3.3 Raw Water Facilities

The raw water intake is located at the eastern riverbank of the river Göta Älv and the intake building is located at an elevation of **+ 2.30 m**. If the intake building gets flooded and the water rises about **30 - 40 cm** above the floor, there will be severe damage of electrical equipment.[19]. Another crucial part is the intake basin, which is separated from the river Göta älv by a pier, elevated just below **+ 2.30 m**, see Figure 29. There is also a laboratory inside the building that would be affected (i.e. equipment gets damaged) if the water rises **50 cm** above the floor level. Although, no costs estimations has been obtained for a case concerning inundation of the laboratory equipment.

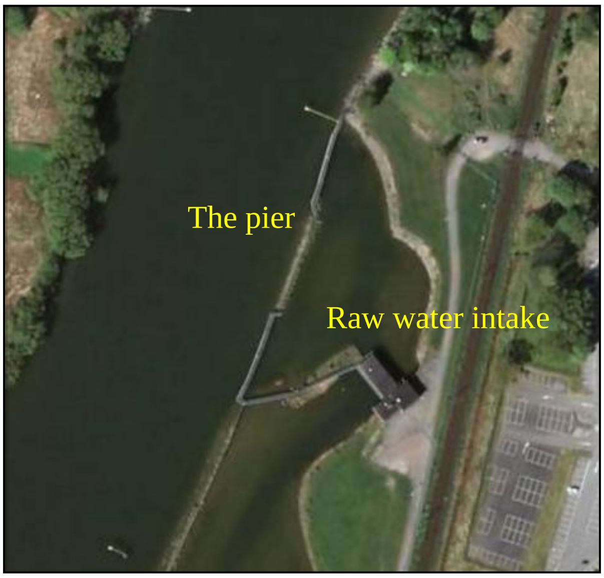

Figure 29 The raw water intake and the pier separating the basin and the river Göta älv

The raw water pumping station turned out to be safe with regards to flooding from high water stands[20]. Even though it is located at a low level and enclosed by the surrounding, with regards to storm water runoff, the pumps inside the building is submersible and all the sensitive electrical equipment has been moved to a higher level (i.e. above +3.80 m). Since it is classified as safe, no cost was obtained and no further analysis will be made. There is however a reserve raw water pumping station that, on the other hand, is sensitive to high water stands. The floor in the pumping station is located at **+2.10 m** and if the water reaches just **10 cm** above the floor, the electrical equipment (i.e. transformers and high voltage devices) will become damaged.

[19] Hans Fransson, Drinking Water Production - Electrical Department, Kretslopp och vatten, Interview 21 May 2014
[20] Lisa Ahnoff, Head of Unit - Water Plant Projects, Kretslopp och vatten, Interview 14 April 2014

3.4 Recycling centres

The recycling centres with their corresponding elevations are presented in Appendix 2. It could be seen that Alelyckan recycling centre was the only centre located below the critical elevation. Figure 30 shows a screenshot from City Planner which illustrates the recycling centre during normal water stand as well as critical water stand and Figure 31 illustrates the topographic features of the area. By observing the latter, it is evident that the main part of the area is located well below **+ 3.80 m**. There is however, another railroad bank located to the west of the one illustrated in Figure 30, which could serve as a minor barrier in case of a flooding of the river Göta Älv.

Figure 30 Aerial view over Alelyckan recycling centre; to the left: normal water stand and to the right: water stand of + 3.80 m **(Agency9, 2014)**

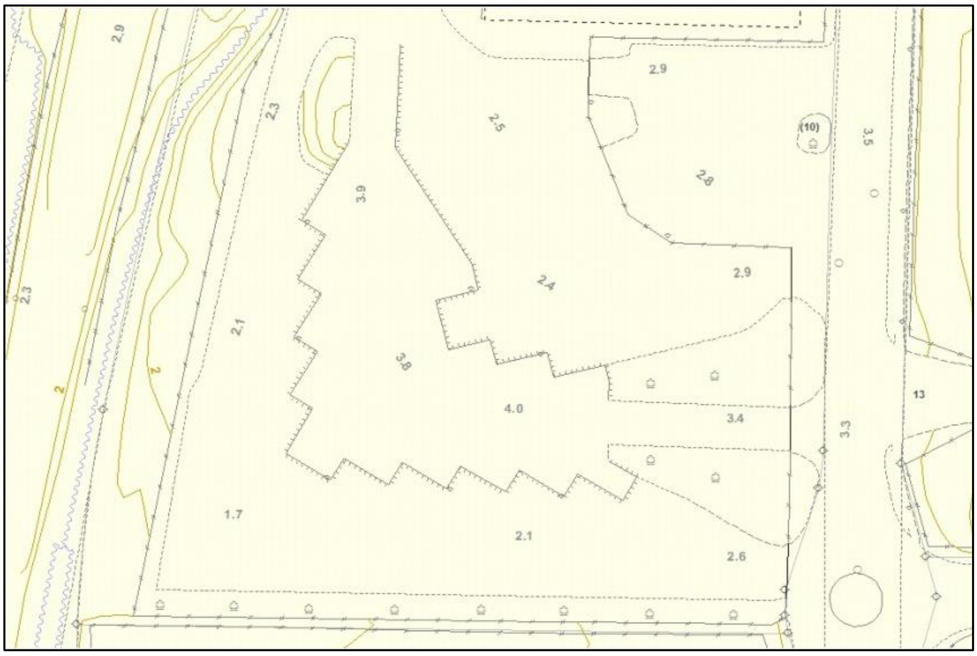

Figure 31Topography at the location for Alelyckan recycling centre

Alelyckan recycling centre uses immersed oil separators for treatment of storm water and oil spill[21]. This installation serves as a protection measure for the surrounding environment during normal conditions. However, during a flood scenario it is possible to flood the chamber and thereby release contaminated water in to the surroundings. Since Alelyckan recycling centre is located in close relation to the river Göta älv there is also a risk of contaminated water to reach the municipal raw water intake. It should be noted that in order for contaminated water to reach the environment there is an additional chamber that also has to become flooded. Furthermore, during normal conditions (i.e. without a leakage of oil) the amount of oil contained in the separating chamber is not substantial. Other protective measures that are present at Alelyckan recycling centre consists in sealable containers for different kind of hazardous waste and mobile passerines for drain covers in case of excessive rainfall.

The centre was established in **2007** and the expected lifespan is at present time not clearly decided. The recycling centre is located at marshy piece of land and is under incessant settlement which contributes to a more critical future elevation relative to the river Göta älv[19]. Due to the properties of the soil at the site, an increased elevation for containers is not seen as a future option in case of an increased water level in the river. An implication that is linked to Alelyckan recycling centre is drainage problems during heavy rain, which sometimes lead to flooding of certain parts the centre. The problems have been occurring since the founding of the centre and the back lying reasons have not yet been fully mapped out. However, the ground flooding is rather a problem linked to accessibility than a risk for the surrounding environment.

3.5 Recycling stations

It is essential to map out stations in need of possible future removal or replacement and the location of such facilities is therefore identified and documented in this work. The stations below **+ 3.80 m** were sorted out by the GIS-department at *Kretslopp och vatten* and a few stations lacked elevation data and therefore had to be checked manually in *Solen X*. Table 11 lists the recycling stations together with information regarding elevation and Figure 32 show the location of each station.

Table 11 The recycling stations and their correlating elevations.

Location	Elevation [m]	Location	Elevation [m]
1. Kvillegatan	+ 1.52	**7.** Lärjeågatan	+ 2.91
2. Tandkullegatan	+ 2.06	**8.** Hagkroksvägen	+ 3.18
3. Saltholmsgatan	+ 2.06	**9.** Sörhallstorget	+ 3.18
4. Södra Särövägen	+ 2.17	**10.** Gamla Flygplatsvägen	+ 3.50
5. Odinsplatsen	+ 2.17	**11.** Miraallén	+ 3.57
6. Backaplan, Södra Deltavägen	+ 2.52	**12.** Brännekullavägen	+ 3.71

[21] Sanna Göransson, Head of unit – Recycling and reuse, Kretslopp och vatten, interview 24 April 2014

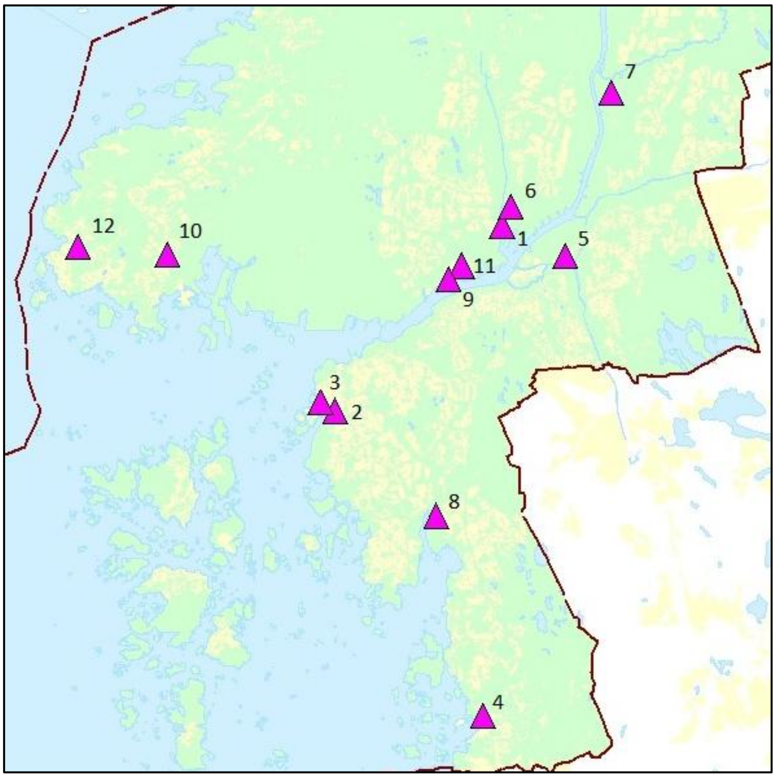

Figure 32 Map over recycling stations located at critical elevations

3.6 Motorized valves

There are **7** valves that are managed by motor within the study area and in this report they are referred to as MV1-MV7. By interpretation of the elevation curves in *Solen X,* it was noted that one of the valves, MV2, is located at the critical elevation of **+ 3.30 m** (i.e. + 4.80 m at ground level), see Figure 33. All valves and their correlating elevations are presented in Appendix 3.

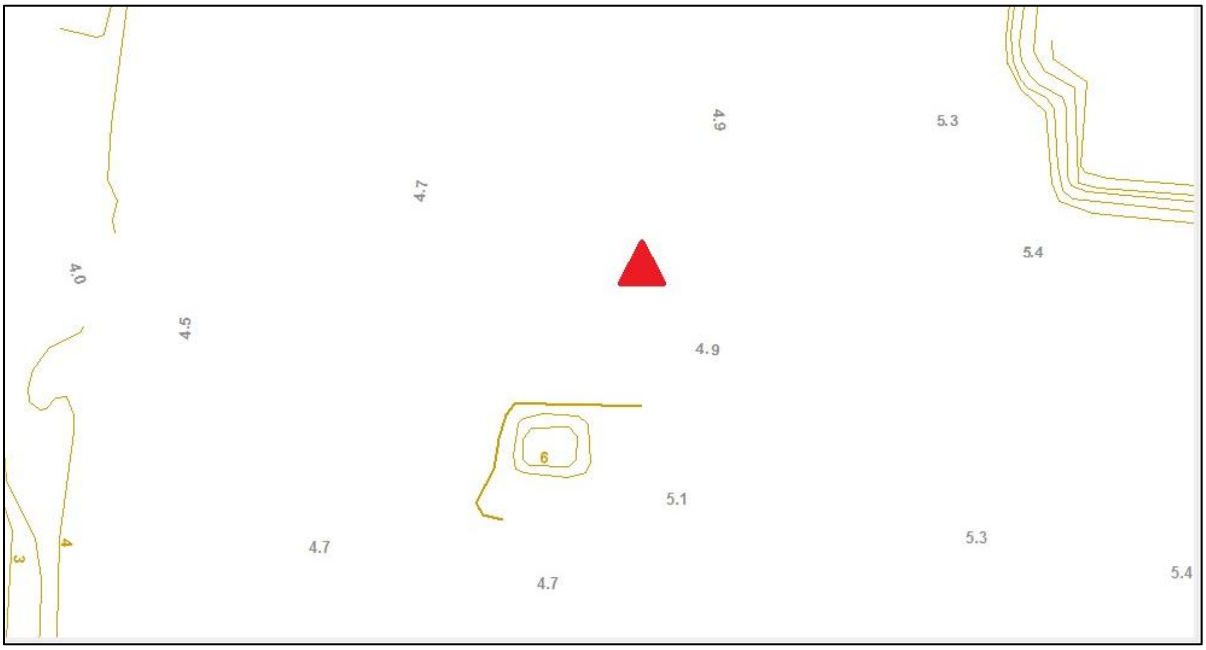

Figure 33 The topography at the location of MV2, with the valve visualized as the red triangle

4. ANALYSIS

This chapter presents the performed analysis of the obtained results for each type of facility. The DWPSs and SPSs as well as some of the raw water facilities are included for calculations of present value (PV). The recycling stations are evaluated by the use of event tree analysis for oil discharge whilst the recycling stations and the motorized valves are only briefly studied and not analysed in practice. The reason for this is also explained further in the following sections.

4.1 Drinking Water Pumping Stations

The drinking water pumping stations with low elevations associated with any of the levels; floor, pump shaft or electrical cabinet, were presented in chapter **3.1**. In order to make a cost benefit analysis, three different scenarios were constructed; (**A**) Floor becomes flooded, (**B**) Pump shaft becomes flooded and (**C**) Electrical cabinet becomes flooded. For DWPS1 and DWPS3 it is only possible to flood the electrical cabinet if the floor and the pump shaft is already flooded. However, in DWPS2, the electrical cabinet becomes flooded before the pump shaft.

By applying PV calculations, see Appendix 4, for the different DWPSs, the total risk cost during specific time periods were obtained and they turned out to be insignificant or none existing, see Table 12-14. The low values indicate that it is not worth investing a lot of money in securing the pumping stations from the evaluated flood scenarios. However, the PV calculations did not contain cost for any possible supply of emergency water since it is difficult to estimate the affected number of households without further calculations based upon the LPL for each DWPS. The discount rates affect the result of the PV calculations to some extent, but it is hard to draw any particular conclusions from such comparison.

Table 12 PV for the DWPSs for three different discount periods with a discount rate of 3 %

Discount Period	PV DWPS1 [SEK]	PV DWPS2 [SEK]	PV DWPS3 [SEK]
2010-2030	1,000	0	0
2010-2050	2,800	0	0
2010-2100	6,200	0	0

Table 13 PV for the DWPSs for three different discount periods with a discount rate of 1.4 %

Discount Period	PV DWPS1 [SEK]	PV DWPS2 [SEK]	PV DWPS3 [SEK]
2010-2030	1,300	0	0
2010-2050	4,100	0	0
2010-2100	13,400	0	0

Table 14 PV for the DWPSs for three different discount periods with a discount rate of 3.5 %

Discount Period	PV DWPS1 [SEK]	PV DWPS2 [SEK]	PV DWPS3 [SEK]
2010-2030	1,000	0	0
2010-2050	2,500	0	0
2010-2100	4,986	0	0

4.2 Sewage Pumping Stations

For analysis regarding sewage pumping stations with low elevations associated with any of the crucial levels for installations, four different scenarios were created; (**A**) Emergency discharge becomes flooded, (**B**) Floor becomes flooded, (**C**) Pump motor (i.e. dry pump) becomes flooded and (**D**) Electrical cabinet becomes flooded. Due to the function of high water hatches and backwater valves, it is not necessarily a problem to have the emergency discharges of sewage pumping stations at elevations of low altitude. Chapter **3.1** revealed how many SPSs that had emergency discharges but lacked safety devices for high water stands and/or problems related to capacity overflow. Scenario **(A)** is generally not attached to any cost in the analysis due to problems in estimating the actual damages that stem from intrusion of water through emergency discharges. Nevertheless, it should once again be noted that excessive flows to the pump chamber from an emergency discharge, can have severe consequences on the system parts located downstream as well as upstream of the SPS (e.g. basement flooding). This section provides information on the risk costs associated with SPSs. Due to the large amount of stations at risk; the analysis method is exemplified by considering only one object. The object selected to undergo analysis was SPS21, which has three pumps located at the basement level in the station building. The PV for the three different discount periods attached to **SPS21** is presented in Table 15-17.

Table 15 PV for SPS21 for three different discount periods with a discount rate of 3 %

Discount Period	PV SPS21 [SEK]
2010-2030	78,700
2010-2050	213,800
2010-2100	474,800

Table 16 PV for SPS21 for three different discount periods with a discount rate of 1.4 %

Discount Period	PV SPS21 [SEK]
2010-2030	96,700
2010-2050	315,800
2010-2100	1,029,800

Table 17 PV for SPS21 for three different discount periods with a discount rate of 3.5 %

Discount Period	PV SPS21 [SEK]
2010-2030	73,900
2010-2050	190,500
2010-2100	383,600

The calculations, see Appendix 5, is based upon the assumption that the basement level of the SPS becomes inundated in a scenario with **+1.80 m** water level, which in this case correspond to the ground level surrounding the station. The electrical cabinet will not become flooded since the water level is not expected to reach **+2.60 m** in any scenario. When comparing results in PV calculations it is evident that the discount rate is of great significance. For example by using a discount rate of **1.4 %** instead of the default **3 %**, the PV over **90 years** becomes more than twice as high. The choice of discount rate is evidently very important for future analysis such as CBA. The results from calculations with all three discount rates may suggest that it could be profitable to implement countermeasures. However it is difficult to make any proper suggestions before a more detailed study has been made for different alternatives and a CBA has been put forward. This example shows a comparably high risk cost to what is anticipated for the other critical SPSs, but it is crucial to perform similar analysis to the other objects in order to obtain a more justifying picture regarding benefits from great scale solutions such as flood gates.

4.3 Raw Water Facilities

The reserve raw water pumping station is at a great risk of getting flooded in the future, although, the facility is not that crucial as it once was. Due to a duplication of the main raw water pipe feeding system, the supply security is increased due to the optional path for raw water pumping[22]. Hence, the raw water supply is not as dependant on the reserve pumping station as it previously was. However, if there is a breakdown on the main raw water pumping station, then it is of great importance that the reserve pumping station is up and running. The system is said to be triple redundant since there are three separate installations which enable for raw water supplying.

If the raw water intake gets flooded and the electrical equipment gets damaged, then it will not be possible to manoeuvre the intake[19]. This means that water from the river Göta älv will enter the basin since the connection between the basin and river cannot be closed. In case the river gets contaminated or there is an oil leakage during a malfunction of the intake, the basin needs to be sanitised.

There are today not any particular countermeasures that with ease can be implemented on either the reserve raw water pumping station or the raw water intake[19]. The facilities cannot be completely waterproof due to all the pipes penetrating the building envelope and electrical equipment is already placed as high as possible and cannot be moved to a higher elevation with regard to the present construction appearance. The most likely countermeasure to be implemented is to protect the building with embankments or other flood proof walls that prevent the water from reaching the facilities and the related critical levels.

The PV values for the intake and reserve raw water pumping station is shown in Table 18-20 and the calculations can be seen in Appendix 6 and Appendix 7 respectively. The variability of the results with regard to the discount rate, suggests that the choice of rate is essential for any profitability analysis regarding implementation of countermeasures.

[22] Hans Fransson, Drinking Water Production - Electrical Department, Kretslopp och vatten, Interview 21 May 2014

Table 18 PV for the reserve raw water pumping station and raw water intake with a discount rate of 3%

Discount Period	PV RRWPS [SEK]	PV RWI [SEK]
2010-2030	205,000	100
2010-2050	556,800	300
2010-2100	1,236,400	700

Table 19 PV for the reserve raw water pumping station and raw water intake with a discount rate of 1.4 %

Discount Period	PV RRWPS [SEK]	PV RWI [SEK]
2010-2030	251,800	100
2010-2050	822,400	400
2010-2100	2,681,600	1,400

Table 20 PV for the reserve raw water pumping station and raw water intake with a discount rate of 3.5 %

Discount Period	PV RRWPS [SEK]	PV RWI [SEK]
2010-2030	192,600	100
2010-2050	496,000	300
2010-2100	998,800	500

The PV for the raw water intake is very low but if the water just could rise another **20 cm** by **2100** it would knock out the electrical equipment and a big cost would be added to the calculations. Regarding risk associated to the basin, costs can arise if certain events occur. If the water in the river Göta älv becomes contaminated (e.g. oil or pathogens) and the possibility of closing the intake is lost, or if the water level rises above the pier and enters the basin, the outcome would most likely be very costly due to the possible need of thorough sanitation measures.

4.4 Recycling Centres

Alelyckan recycling centre is located just east of the creek Säveån and the centre is therefore to be considered as more vulnerable to events of fluvial as well as coastal flooding. The main concern is thought to be the possible risk of oil discharge from the present oil separator to the environment during a heavy flood[23]. Noteworthy is that the oil content of the oil separator is not believed to be of great volume during normal conditions. However, there is a potential risk of spread of oil contaminated water to the municipal raw water intake, which significantly increases the severity of such an event. There are no estimated possibilities for such event, but the progress can be described by the construction of an event tree, see Figure 34. The progress has been divided into a number of succeeding events which ultimately lead toward **4** different outcomes with correlating damages to the society. The risk tree can be seen as a hazard flow chart which explains the progress leading to the outcomes. However, estimates for the

[23] Sanna Göransson, Head of unit – Recycling and reuse, Kretslopp och vatten, interview 24 April 2014

probabilities in the chart; P (1), P (2), P (3) and/or their corresponding complements are needed in order to obtain a predicted total risk for each outcome. It can be seen that the most serious outcome culminates in the need of closing the present raw water intake together with remediation of both land and water surroundings. In this tree one additional event is implemented, which questions whether the intake is closed before a possible discharge reaches the location or not. For example it could be interesting to include the risk for an oil discharge to enter the raw water intake before termination of the actual pumping of raw water has occurred. The presented risk tree can be seen as a first step in identifying risks for the recycling centres but should be complemented by additional information on probabilities and costs related to each outcome. Moreover it is suitable to estimate the errors linked to both probabilities and costs in order to achieve a more comprehensive analysis. Moreover, suggestions concerning implementation of countermeasures are not reasonable before a more extensive analysis has been performed.

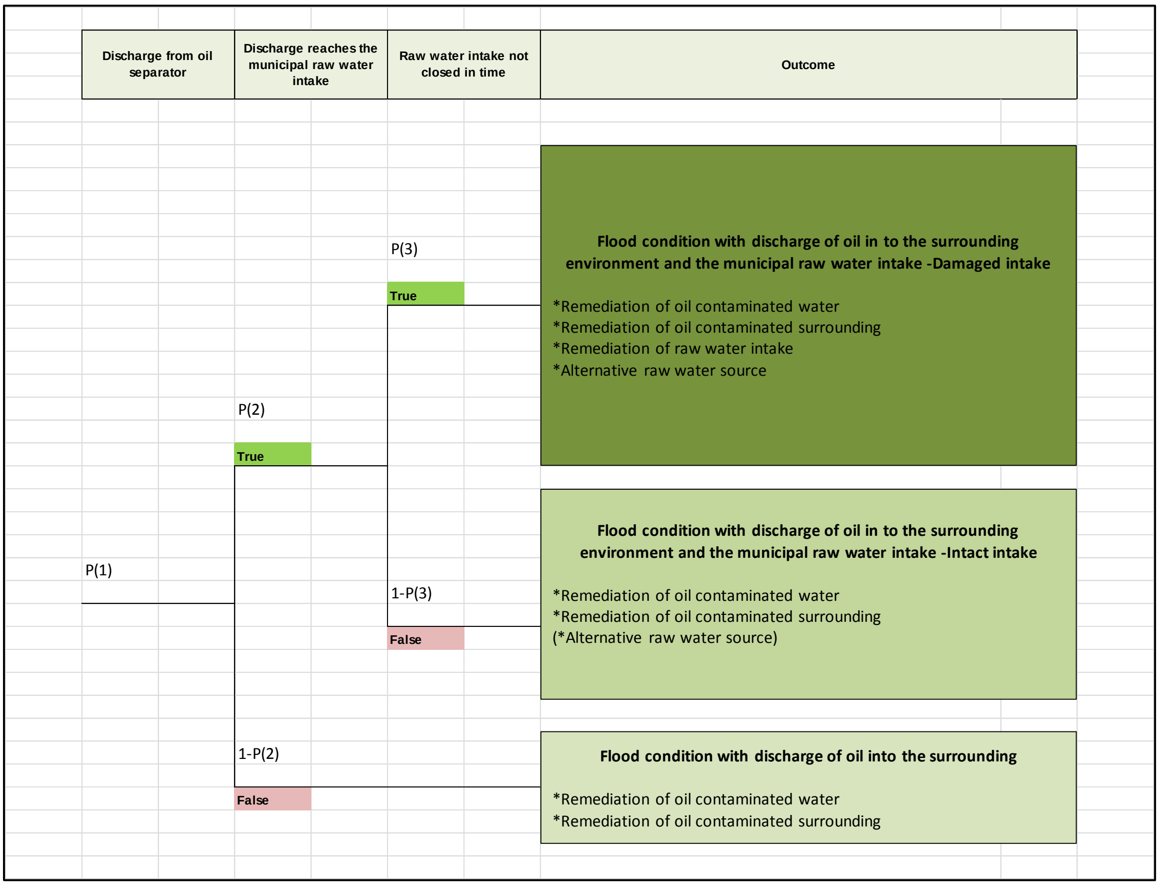

Figure 34 Event tree for the oil separator at Alelyckan recycling centre

4.5 Recycling Stations

In a scenario with a water level of **+ 3.80 m**, it is likely that management for relocation of any recycling stations at low elevations have been carried out well in beforehand. Furthermore, the intended content of recycling stations does not compose a substantial risk for spreading of any hazardous substances into the environment during possible flooding of the containers. For this reason there will not be any particular analysis carried out regarding risk costs for recycling stations at low altitudes.

4.6 Motorized Valves

If the function of a motorized valve fails due to short circuiting, it will not be possible to control it from the control centre and hence someone has to go and manoeuvre the valve manually at the valve location[24]. If the valves are correctly installed they are supposed to withstand inundation, but as the time progresses, the sensitivity to water tend to increase and the valve could therefore become damaged in a flood scenario. If there is a rupture on the raw water pipe network and the raw water gets contaminated (e.g. from pathogens in leaking sewage pipes or other substances embedded in the ground) then it is crucial that the valves are working and can be closed as soon as possible (i.e. remotely). What could happen otherwise is that contaminated water reaches the drinking water treatment plant, which ultimately could lead to substantial costs which is hard to fully anticipate.

[24] Roger Grundell, Chief Security Officer, Kretslopp och vatten, Interview 28 May 2014

5. DISCUSSION

There are a number of uncertainties which impact the results in this work. When it comes to the prognosis for future water levels within the river basin, the lack of data between year **2010** and **2100** makes it difficult to make assumptions regarding the appearance of the development. Furthermore there are of course uncertainties linked to the estimations presented in previous work. The assumption to use linear interpolation between the two occasions was however a necessity in order to come up with a simple risk cost analysis for some of the facility types.

It would be interesting to perform some kind of sensitivity analysis linked to the cost estimates for flood sensitive equipment. Still, fact remains that the costs presented in this study mainly originates from rough estimations made by staff at *Kretslopp och vatten*. It does therefore seem unlikely that analysis with for example minimum or maximum percentiles for cost estimates would result in a more credible result. Future work in accruing more exact figures or cost intervals is therefore engorged.

It should be noted that some information regarding elevations for various facilities was inadequate. Some of the pumping stations for instance lacked information regarding their emergency discharge elevations and/or whether they actually had any installed emergency discharge at all. The reason for this is thought to be insufficient data at the occasion when objects first where introduced in *Solen X* or listed in other forms. The mapping is however steadily ongoing in order to reduce information gaps in the attribute files concerning different objects. However, information regarding emergency discharges had little significance for the results of this study since backwater intrusion was not included as an event linked to any costs in the PV calculations.

In the scope of this report it is stated that objects located under the level **+ 3.80 m** are considered as objects at risk of flooding. It could be discussed whether this is an appropriate level for future city planning or not. The risk reduction potential must be further evaluated in terms of cost and benefit in order to find out if it is feasible to use this new high level of security. Furthermore it should be noted that the municipal proposition suggest this level only for objects of great importance for the societal function, something which does not apply in practice for all facilities included in this work. Nevertheless this level is only used as a limit for the selection process regarding what objects to include in the study.

This work does mainly cover material costs linked to inundation of different equipment and installations and the analysis does not implement values that arise due to basement flooding of households and other structures. Thus it should be noted that some results stemming from the risk cost evaluation in this work are indeed underestimated, and that further data and forecasts are needed in order to grasp a more accurate risk cost image. The possibilities of achieving a reliable analysis regarding basement flooding and other subsequent societal damages that comes due to pump failure in SPSs are however doubtful, since high uncertainties can be expected regarding the amount of households affected in each specific scenario.

The fact that the work does only cover cost figures encumbering *Kretslopp och vatten* can be questioned since the administration is part of the municipal organisation. Damages associated with property owned by the *City of Gothenburg* are compensated by the municipal insurer *Göta Lejon*. Hence, many of the flood related costs on public property does encumber the municipality seen as a whole unit. Nevertheless, *Kretslopp och vatten* has its function founded almost exclusively on various fees together with water rates, which is why it can be seen as a separate unit of the municipal organisation. This is one of the reasons to why various societal costs have been excluded from the analysis in this report. Furthermore a wider analysis would involve many uncertainties which would be hard to anticipate in a justifying manner with present information input. With sufficient information, it would be interesting to include intangible costs in future studies, in order to make a more inclusive analysis which also holds damages which are not easily valued in monetary terms (e.g. discomforts from water shortage and trauma from basement inundation).

The fact that the study excludes impacts from wind in made calculations and analysis must be noted. Since the methods for analysis can be considered as rather simplified it does not seem justifying to include wind as a variable parameter. It is of course possible to apply an additional height (i.e. 0.20-0.30 m) to the present water stand. This procedure could serve as a sensitivity analysis but it is doubtful if the addition of wind would give a more accurate result. If the wind is to be applied as an actual parameter, it is therefore desirable to develop a more detailed analysis method.

The lifespan of the different facilities is worth mentioning as a subject for discussion. If for example, the appearance and location of a pumping station is revised every **30** or **40 years**, it is more difficult to apply a long term risk cost elaboration for the object. However, long term risk cost estimates (i.e. PV-calculations) could provide useful information for revisions even in a shorter time perspective. If the analysis proves that the location of an object is threatened in a long term perspective or if there is a need of excessive enhancements it is maybe better to relocate the object in beforehand. There is however complications related to repositioning of facilities such as SPSs or DWPSs, since the pipes network both upstream and downstream often are planned with respect to the location of such services. The freedom to relocate facilities is therefore limited in several cases.

The future work in providing more comprehensive decision support is governed by a more accurate and diverse input of data to the analysis. A more holistic approach is probably to develop a model which considers both probabilities for river overflow of facilities together with input from GIS analysis such as the developing hydrological model. The flow patterns in urban areas should be included in order to grasp the actual probabilities for inundation of specific areas. The problem today however, seem to be that the finalised hydrological model is only thought to cover certain areas of the study area, this since it is expensive and time demanding to develop an accurate elevation model for the entire municipality.

A future accomplishment of a risk cost estimate for the entire stash of facilities within the municipality could possibly serve as another guidance instrument in the question regarding future implementation of great scale flood proofing (i.e. gates) of the inner city. The estimation would give a hint of the total risk costs for the studied objects. This together with additional risk cost estimates for other objects (e.g. buildings, properties and recreational areas) could be used as input in a CBA for the presented solutions. The assessment of the total risk cost for all studied facilities would also make it possible to apply a feasibility comparison between flood proofing of facilities, small scale solutions and great scale solutions presented throughout this thesis. It is however possible that a decision regarding implementation of some of the latter alternatives will be achieved in the upcoming years, resulting in a different situation regarding PVs for the studied facilities.

Integrated flood management has not been presented as a single solution to the flood risk issues of the municipality. Nevertheless, it seems important to implement such solutions as a part in achieving a long term sustainable solution, even if such solutions could prove more difficult to evaluate in terms of risk cost reduction or monetary savings.

The choice of a proper discount rate is crucial for obtaining an accurate result for input in future decision support analysis such as CBA. It is evident that the choice of discount rate becomes even more important when the risk costs are high. Therefore it must be discussed whether the default discount rate of **3 %**, at *Kretslopp och vatten*, is the “correct” one to use. In this study the most important consideration should be not to greatly overestimate or underestimate the risk costs produced in the PV calculations.

6. CONCLUSIONS

The aim of this project was to identify technical facilities and devices located below elevations of **+ 3.80 m** and to come up with a proper methodology for analysing risk costs which arise due to flooding of such objects.

The largest risk costs were associated with the reserve raw water pumping station. The high risk costs are mainly due to extremely high consequential costs in case of damaged equipment. The studied sewage pumping station, **SPS21** did also display relatively high risk cost figures. The drinking water pumping stations were not attached to any particularly high risk cost and implementation of countermeasures does therefore seem inessential.

Alelyckan recycling centre was identified as the only recycling centre located at critical elevation. The main risk associated to the recycling centre was identified as a possible discharge from the present oil separator. The worst case scenario consists in contamination reaching the municipal raw water intake. However, much more thorough gathering of data is required to enable for a justifying analysis in the matter. The recycling stations are not thought to compose any particular threat in case of a flood scenario due to the absence of environmentally harmful substances and the mobility of the containers composing the recycling station.

The countermeasures that could be encompassed for the facilities differ in magnitude and the level of monetary and technical effort required is variable as well. The possible great scale solutions that have been put forward are likely to alleviate the risk situation for many of the objects included in this thesis. The decision for implementation of such measures is however not solely dependent on the risk level associated to technical facilities and devices, but rather on the risk level for the society as a whole. Risk alleviation for some facilities can be achieved by smaller measures such as increased elevation of sensitive equipment or implementation of permanent flood barriers (e.g. walls) in connection to the structure. The recommendation is nevertheless to await possible decisions or further profitability studies regarding great scale solutions before considering any customized small scale solutions.

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Appendix 1 – Sewage Pumping Stations

(green)	=	back water valve or high water hatch connected
(red)	=	no back water valve or high water hatch connected
-9,95	=	unknown elevation or non existing

Name	Lid Level	Floor Level	Edge Level	Emergency Discharge Level
SPS1	3,05	-9,95	-9,95	1,57
SPS2	3,62	-9,95	-9,95	1,49
SPS3	2,71	-9,95	2,67	0,56
SPS4	-9,95	-9,95	1,92	0,12
SPS5	-9,95	-9,95	1,74	No emergency discharge
SPS6	2,89	-9,95	-9,95	1,97
SPS7	-9,95	-9,95	2,08	0,99
SPS8	-9,95	3,08	-9,95	2,50
SPS9	-9,95	2,53	-9,95	0,55
SPS10	-9,95	-9,95	1,57	0,56
SPS11	2,52	-9,95	-9,95	0,47
SPS12	3,55	-9,95	-9,95	1,24
SPS13	1,93	-9,95	-9,95	1,77
SPS14	-9,95	2,33	-9,95	0,85
SPS15	-9,95	-9,95	2,27	1,37
SPS16	4,02	-9,95	-9,95	2,42
SPS17	-9,95	-9,95	5,97	3,43
SPS18	-9,95	3,63	-9,95	1,49
SPS19	3,66	-9,95	-9,95	2,55
SPS20	-9,95	-9,95	-9,95	1,50
SPS21	-9,95	-1,28	-9,95	-9,95
SPS22	-9,95	2,32	-9,95	1,45
SPS23	2,95	-9,95	-9,95	1,68

SPS24	-9,95	-9,95	2,57	0,75
SPS25	-9,95	-9,95	2,68	0,40
SPS26	-9,95	-9,95	3,52	1,05
SPS27	4,14	-9,95	-9,95	1,65
SPS28	-9,95	-9,95	1,72	1,24
SPS29	-9,95	-9,95	-9,95	1,50
SPS30	-9,95	-9,95	2,51	1,51
SPS31	-9,95	-9,95	2,81	1,76
SPS32	1,69	-9,95	-9,95	0,15
SPS33	1,93	-9,95	-9,95	0,45
SPS34	4,30	-9,95	-9,95	3,47
SPS35	-9,95	-9,95	2,98	-0,16
SPS36	2,67	-9,95	-9,95	0,40
SPS37	-9,95	2,10	-9,95	0,97
SPS38	4,94	-9,95	-9,95	2,72
SPS39	-9,95	-9,95	2,17	-1,44
SPS40	-9,95	-9,95	1,61	-9,95
SPS41	3,20	-9,95	-9,95	2,09
SPS42	-9,95	2,02	-9,95	1,24
SPS43	-9,95	-9,95	4,87	3,00
SPS44	-9,95	-9,95	-9,95	-9,95
SPS45	2,57	-9,95	-9,95	0,87
SPS46	-9,95	-9,95	-9,95	1,01
SPS47	-9,95	2,00	-9,95	1,01
SPS48	-9,95	2,21	-9,95	1,37
SPS49	2,06	-9,95	-9,95	-0,53
SPS50	-9,95	-9,95	2,00	No emergency discharge
SPS51	2,64	-9,95	-9,95	0,38
SPS52	-9,95	-9,95	1,85	1,50

SPS53	-9,95	-9,95	3,55	1,07
SPS54	-9,95	2,45	-9,95	0,65
SPS55	-9,95	-9,95	1,72	0,37
SPS56	-9,95	-9,95	2,34	0,21
SPS57	-9,95	-9,95	2,44	1,65
SPS58	-9,95	3,35	-9,95	2,58
SPS59	-9,95	-9,95	-9,95	-9,95
SPS60	3,78	-9,95	-9,95	1,88
SPS61	2,07	-9,95	2,07	0,66
SPS62	1,70	-9,95	-9,95	-2,21
SPS63	-9,95	-9,95	-9,95	-9,95
SPS64	1,10	-9,95	-9,95	-9,95
SPS65	3,34	-9,95	3,34	2,51
SPS66	4,20	-9,95	4,20	2,10
SPS67	2,49	-9,95	-9,95	0,44
SPS68	-9,95	-9,95	2,28	1,05
SPS69	-9,95	-9,95	2,36	1,21
SPS70	-9,95	-9,95	1,94	1,29
SPS71	4,40	-9,95	-9,95	2,44
SPS72	-9,95	-9,95	4,68	2,93
SPS73	-9,95	-9,95	1,91	-9,95
SPS74	-9,95	-9,95	-9,95	-9,95
SPS75	-9,95	-9,95	1,90	-9,95
SPS76	-9,95	1,77	-9,95	1,45
SPS77	-9,95	-9,95	2,19	1,29
SPS78	-9,95	-9,95	2,66	1,59
SPS79	-9,95	-9,95	2,57	1,52
SPS80	2,84	-9,95	-9,95	1,80
SPS81	-9,95	-9,95	2,86	2,06

SPS82	-9,95	-9,95	2,72	1,64
SPS83	5,86	-9,95	5,86	3,28
SPS84	2,68	-9,95	-9,95	1,85
SPS85	-9,95	2,99	-9,95	1,41
SPS86	2,74	2,74	-9,95	1,20
SPS87	4,88	-9,95	-9,95	3,59
SPS88	-9,95	2,23	-9,95	1,44
SPS89	-9,95	-9,95	2,49	1,15
SPS90	4,51	-9,95	-9,95	1,89
SPS91	-9,95	1,85	-9,95	1,42
SPS92	2,16	-9,95	-9,95	1,40
SPS93	4,05	-9,95	-9,95	2,72
SPS94	-9,95	-9,95	2,65	1,77
SPS95	-9,95	-9,95	4,88	2,91
SPS96	4,44	-9,95	-9,95	3,11
SPS97	-9,95	-9,95	4,96	0,90
SPS98	2,88	-9,95	-9,95	1,78
SPS99	-9,95	2,74	-9,95	1,41
SPS100	2,43	-9,95	-9,95	1,17
SPS101	-9,95	2,13	-9,95	0,86
SPS102	-9,95	2,53	-9,95	1,57
SPS103	-9,95	-9,95	2,57	1,67
SPS104	3,65	-9,95	-9,95	0,35
SPS105	2,37	-9,95	-9,95	0,96
SPS106	-9,95	2,19	-9,95	1,16
SPS107	-9,95	-9,95	4,85	2,07
SPS108	-9,95	-9,95	-9,95	1,39
SPS109	2,05	-9,95	-9,95	1,08
SPS110	-9,95	-9,95	-9,95	1,09

SPS111	-9,95	-9,95	2,04	0,75
SPS112	-9,95	1,73	-9,95	0,65
SPS113	-9,95	-9,95	3,46	1,85
SPS114	-9,95	1,90	-9,95	0,79
SPS115	-9,95	-9,95	1,85	0,05
SPS116	-9,95	-9,95	-9,95	-9,95

Appendix 2 – Recycling Centres

Recycling Centre	Elevation Span (Solen X – Elevation curves) [m]
Bulycke Recycling Centre	4.7 - 7.0
Högsbo Recycling Centre	24.0 - 28.3
Sävenäs Recycling Centre	5.7 - 8.1
Tagene Recycling Centre	34.2 - 36.3
Alelyckan Recycling Centre	1.7 - 4.0

Appendix 3 – Motorized Valves

Motorized Valve	Ground Elevation [m]	Valve Elevation [m]	Structure at Ground level	Comment
MV1	+ 10.6	9.1	Yes	-
MV2	+ 4.8	3.3	Yes	Concerning
MV3	+ 55	53.5	No	-
MV4	+ 55	53.5	No	-
MV5	+ 55	53.5	No	-
MV6	+ 55	53.5	No	-
MV7	+ 10.6	9.1	Yes	-

Appendix 4 – Drinking Water Pumping Station

DWPS1

Critical Level [cm]	**Probability 2010**	**Probability 2100**	**Costs 2010[SEK]**	**Costs 2100 [SEK]**
2	0.00%	13.00%	5000	
2.5	0.00%	0.00%	30000	
2.57	0.00%	0.00%	50000	

Risk Cost 2010	**Risk Cost 2100**
0	650

Amount of years	**Annual Upsurge [SEK]**	**Annual Risk Cost [SEK]**	**Year**	**2010-2100**		**Year**	**2010-2050**		**Year**	**2010-2030**	
90	7.22	650.00	2100	45.45		2050	88.56		2030	79.98	
89		642.78	2099	46.30		2049	88.94		2029	78.26	
88		635.56	2098	47.15		2048	89.26		2028	76.36	
87		628.33	2097	48.01		2047	89.51		2027	74.28	
86		621.11	2096	48.88		2046	89.71		2026	72.01	
85		613.89	2095	49.77		2045	89.83		2025	69.54	
84		606.67	2094	50.66		2044	89.88		2024	66.85	
83		599.44	2093	51.55		2043	89.86		2023	63.93	
82		592.22	2092	52.46		2042	89.75		2022	60.79	
81		585.00	2091	53.38		2041	89.55		2021	57.39	
80		577.78	2090	54.30		2040	89.26		2020	53.74	
79		570.56	2089	55.23		2039	88.88		2019	49.82	
78		563.33	2088	56.16		2038	88.39		2018	45.61	
77		556.11	2087	57.11		2037	87.79		2017	41.11	
76		548.89	2086	58.06		2036	87.07		2016	36.29	
75		541.67	2085	59.01		2035	86.23		2015	31.15	
74		534.44	2084	59.97		2034	85.27		2014	25.67	
73		527.22	2083	60.94		2033	84.17		2013	19.83	
72		520.00	2082	61.90		2032	82.92		2012	13.62	
71		512.78	2081	62.88		2031	81.53		2011	7.01	
70		505.56	2080	63.85		2030	79.98		2010	0.00	
69		498.33	2079	64.83		2029	78.26				
68		491.11	2078	65.80		2028	76.36		**NPV**	**1023**	**SEK**
67		483.89	2077	66.78		2027	74.28		NPV (Stern)	1257	SEK
66		476.67	2076	67.76		2026	72.01		NPV (STA)	961	SEK
65		469.44	2075	68.73		2025	69.54				
64		462.22	2074	69.71		2024	66.85				
63		455.00	2073	70.68		2023	63.93				
62		447.78	2072	71.64		2022	60.79				
61		440.56	2071	72.60		2021	57.39				
60		433.33	2070	73.55		2020	53.74				
59		426.11	2069	74.49		2019	49.82				
58		418.89	2068	75.43		2018	45.61				
57		411.67	2067	76.35		2017	41.11				
56		404.44	2066	77.26		2016	36.29				
55		397.22	2065	78.16		2015	31.15				
54		390.00	2064	79.04		2014	25.67				
53		382.78	2063	79.90		2013	19.83				
52		375.56	2062	80.75		2012	13.62				
51		368.33	2061	81.57		2011	7.01				
50		361.11	2060	82.37		2010	0.00				
49		353.89	2059	83.15							
48		346.67	2058	83.89		**NPV**	**2780**	**SEK**			
47		339.44	2057	84.61		NPV (Stern)	4106	SEK			
46		332.22	2056	85.29		NPV (STA)	2476	SEK			
45		325.00	2055	85.94							
44		317.78	2054	86.55							
43		310.56	2053	87.12							
42		303.33	2052	87.65							
41		296.11	2051	88.13							
40		288.89	2050	88.56							
39		281.67	2049	88.94							
38		274.44	2048	89.26							
37		267.22	2047	89.51							
36		260.00	2046	89.71							
35		252.78	2045	89.83							
34		245.56	2044	89.88							
33		238.33	2043	89.86							
32		231.11	2042	89.75							
31		223.89	2041	89.55							
30		216.67	2040	89.26							
29		209.44	2039	88.88							
28		202.22	2038	88.39							
27		195.00	2037	87.79							
26		187.78	2036	87.07							
25		180.56	2035	86.23							
24		173.33	2034	85.27							
23		166.11	2033	84.17							
22		158.89	2032	82.92							
21		151.67	2031	81.53							
20		144.44	2030	79.98							
19		137.22	2029	78.26							
18		130.00	2028	76.36							
17		122.78	2027	74.28							
16		115.56	2026	72.01							
15		108.33	2025	69.54							
14		101.11	2024	66.85							
13		93.89	2023	63.93							
12		86.67	2022	60.79							
11		79.44	2021	57.39							
10		72.22	2020	53.74							
9		65.00	2019	49.82							
8		57.78	2018	45.61							
7		50.56	2017	41.11							
6		43.33	2016	36.29							
5		36.11	2015	31.15							
4		28.89	2014	25.67							
3		21.67	2013	19.83							
2		14.44	2012	13.62							
1		7.22	2011	7.01							
0		0.00	2010	0.00							
			NPV	**6172**	**SEK**						
			NPV (Stern)	13387	SEK						
			NPV (STA)	4986	SEK						

Appendix 5 – Sewage Pumping Station

SPS21

Critical Level [cm]	**Probability 2010**	**Probability 2100**	**Costs [SEK]**
1.8	0.00%	40.00%	125000
2.6	0.00%	0.00%	50000

Risk Cost 2010	**Risk Cost 2100**
0	50000

Amount of years	**Annual Upsurge [SEK]**	**Annual Risk Cost [SEK]**	**Year**	**2010-2100**	
90	555.56	50000.00	2100	3496.39	
89		49444.44	2099	3561.27	
88		48888.89	2098	3626.89	
87		48333.33	2097	3693.25	
86		47777.78	2096	3760.32	
85		47222.22	2095	3828.09	
84		46666.67	2094	3896.55	
83		46111.11	2093	3965.66	
82		45555.56	2092	4035.42	
81		45000.00	2091	4105.80	
80		44444.44	2090	4176.76	
79		43888.89	2089	4248.29	
78		43333.33	2088	4320.35	
77		42777.78	2087	4392.91	
76		42222.22	2086	4465.93	
75		41666.67	2085	4539.38	
74		41111.11	2084	4613.22	
73		40555.56	2083	4687.41	
72		40000.00	2082	4761.89	
71		39444.44	2081	4836.63	
70		38888.89	2080	4911.56	
69		38333.33	2079	4986.64	
68		37777.78	2078	5061.80	
67		37222.22	2077	5136.98	
66		36666.67	2076	5212.12	
65		36111.11	2075	5287.15	
64		35555.56	2074	5361.98	
63		35000.00	2073	5436.54	
62		34444.44	2072	5510.76	
61		33888.89	2071	5584.53	
60		33333.33	2070	5657.77	
59		32777.78	2069	5730.38	
58		32222.22	2068	5802.25	
57		31666.67	2067	5873.28	
56		31111.11	2066	5943.34	
55		30555.56	2065	6012.33	
54		30000.00	2064	6080.11	
53		29444.44	2063	6146.54	
52		28888.89	2062	6211.48	
51		28333.33	2061	6274.79	
50		27777.78	2060	6336.31	
49		27222.22	2059	6395.87	
48		26666.67	2058	6453.30	
47		26111.11	2057	6508.42	
46		25555.56	2056	6561.04	
45		25000.00	2055	6610.97	
44		24444.44	2054	6657.98	
43		23888.89	2053	6701.86	
42		23333.33	2052	6742.38	
41		22777.78	2051	6779.30	
40		22222.22	2050	6812.37	
39		21666.67	2049	6841.33	
38		21111.11	2048	6865.89	
37		20555.56	2047	6885.76	
36		20000.00	2046	6900.65	
35		19444.44	2045	6910.23	
34		18888.89	2044	6914.18	
33		18333.33	2043	6912.15	
32		17777.78	2042	6903.77	
31		17222.22	2041	6888.67	
30		16666.67	2040	6866.45	
29		16111.11	2039	6836.69	
28		15555.56	2038	6798.97	
27		15000.00	2037	6752.84	
26		14444.44	2036	6697.81	
25		13888.89	2035	6633.41	
24		13333.33	2034	6559.12	
23		12777.78	2033	6474.39	
22		12222.22	2032	6378.69	
21		11666.67	2031	6271.41	
20		11111.11	2030	6151.95	
19		10555.56	2029	6019.69	
18		10000.00	2028	5873.95	
17		9444.44	2027	5714.04	
16		8888.89	2026	5539.26	
15		8333.33	2025	5348.85	
14		7777.78	2024	5142.03	
13		7222.22	2023	4917.98	
12		6666.67	2022	4675.87	
11		6111.11	2021	4414.80	
10		5555.56	2020	4133.86	
9		5000.00	2019	3832.08	
8		4444.44	2018	3508.49	
7		3888.89	2017	3162.02	
6		3333.33	2016	2791.61	
5		2777.78	2015	2396.14	
4		2222.22	2014	1974.42	
3		1666.67	2013	1525.24	
2		1111.11	2012	1047.33	
1		555.56	2011	539.37	
0		0.00	2010	0.00	
			NPV	**474796**	**SEK**
			NPV (Stern)	1029789	SEK
			NPV (STA)	383555	SEK

Year	**2010-2050**	
2050	6812.37	
2049	6841.33	
2048	6865.89	
2047	6885.76	
2046	6900.65	
2045	6910.23	
2044	6914.18	
2043	6912.15	
2042	6903.77	
2041	6888.67	
2040	6866.45	
2039	6836.69	
2038	6798.97	
2037	6752.84	
2036	6697.81	
2035	6633.41	
2034	6559.12	
2033	6474.39	
2032	6378.69	
2031	6271.41	
2030	6151.95	
2029	6019.69	
2028	5873.95	
2027	5714.04	
2026	5539.26	
2025	5348.85	
2024	5142.03	
2023	4917.98	
2022	4675.87	
2021	4414.80	
2020	4133.86	
2019	3832.08	
2018	3508.49	
2017	3162.02	
2016	2791.61	
2015	2396.14	
2014	1974.42	
2013	1525.24	
2012	1047.33	
2011	539.37	
2010	0.00	
NPV	**213814**	**SEK**
NPV (Stern)	315811	SEK
NPV (STA)	190470	SEK

Year	**2010-2030**	
2030	6151.95	
2029	6019.69	
2028	5873.95	
2027	5714.04	
2026	5539.26	
2025	5348.85	
2024	5142.03	
2023	4917.98	
2022	4675.87	
2021	4414.80	
2020	4133.86	
2019	3832.08	
2018	3508.49	
2017	3162.02	
2016	2791.61	
2015	2396.14	
2014	1974.42	
2013	1525.24	
2012	1047.33	
2011	539.37	
2010	0.00	
NPV	**78709**	**SEK**
NPV (Stern)	96697	SEK
NPV (STA)	73942	SEK

Appendix 6 - Raw Water Intake

Intake											
Critical Level [cm]	**Probability 2010**	**Probability 2100**	**Cost [SEK]**								
230	0.00%	1.40%	5000								
265	0.00%	0.00%	1000000								
Risk Cost 2010	**Risk Cost 2100**										
0	70										
Amount of Years	**Annual Upsurge [SEK]**	**Annual Risk Cost [SEK]**	**Year**	**2010-2100**		**Year**	**2010-2050**		**Year**	**2010-2030**	
90	0.78	70.00	2100	4.89		2050	9.54		2030	8.61	
89		69.22	2099	4.99		2049	9.58		2029	8.43	
88		68.44	2098	5.08		2048	9.61		2028	8.22	
87		67.67	2097	5.17		2047	9.64		2027	8.00	
86		66.89	2096	5.26		2046	9.66		2026	7.75	
85		66.11	2095	5.36		2045	9.67		2025	7.49	
84		65.33	2094	5.46		2044	9.68		2024	7.20	
83		64.56	2093	5.55		2043	9.68		2023	6.89	
82		63.78	2092	5.65		2042	9.67		2022	6.55	
81		63.00	2091	5.75		2041	9.64		2021	6.18	
80		62.22	2090	5.85		2040	9.61		2020	5.79	
79		61.44	2089	5.95		2039	9.57		2019	5.36	
78		60.67	2088	6.05		2038	9.52		2018	4.91	
77		59.89	2087	6.15		2037	9.45		2017	4.43	
76		59.11	2086	6.25		2036	9.38		2016	3.91	
75		58.33	2085	6.36		2035	9.29		2015	3.35	
74		57.56	2084	6.46		2034	9.18		2014	2.76	
73		56.78	2083	6.56		2033	9.06		2013	2.14	
72		56.00	2082	6.67		2032	8.93		2012	1.47	
71		55.22	2081	6.77		2031	8.78		2011	0.76	
70		54.44	2080	6.88		2030	8.61		2010	0.00	
69		53.67	2079	6.98		2029	8.43				
68		52.89	2078	7.09		2028	8.22		**NPV**	**110**	**SEK**
67		52.11	2077	7.19		2027	8.00		NPV (Stern)	135	SEK
66		51.33	2076	7.30		2026	7.75		NPV (STA)	104	SEK
65		50.56	2075	7.40		2025	7.49				
64		49.78	2074	7.51		2024	7.20				
63		49.00	2073	7.61		2023	6.89				
62		48.22	2072	7.72		2022	6.55				
61		47.44	2071	7.82		2021	6.18				
60		46.67	2070	7.92		2020	5.79				
59		45.89	2069	8.02		2019	5.36				
58		45.11	2068	8.12		2018	4.91				
57		44.33	2067	8.22		2017	4.43				
56		43.56	2066	8.32		2016	3.91				
55		42.78	2065	8.42		2015	3.35				
54		42.00	2064	8.51		2014	2.76				
53		41.22	2063	8.61		2013	2.14				
52		40.44	2062	8.70		2012	1.47				
51		39.67	2061	8.78		2011	0.76				
50		38.89	2060	8.87		2010	0.00				
49		38.11	2059	8.95							
48		37.33	2058	9.03		**NPV**	**299**	**SEK**			
47		36.56	2057	9.11		NPV (Stern)	442	SEK			
46		35.78	2056	9.19		NPV (STA)	267	SEK			
45		35.00	2055	9.26							
44		34.22	2054	9.32							
43		33.44	2053	9.38							
42		32.67	2052	9.44							
41		31.89	2051	9.49							
40		31.11	2050	9.54							
39		30.33	2049	9.58							
38		29.56	2048	9.61							
37		28.78	2047	9.64							
36		28.00	2046	9.66							
35		27.22	2045	9.67							
34		26.44	2044	9.68							
33		25.67	2043	9.68							
32		24.89	2042	9.67							
31		24.11	2041	9.64							
30		23.33	2040	9.61							
29		22.56	2039	9.57							
28		21.78	2038	9.52							
27		21.00	2037	9.45							
26		20.22	2036	9.38							
25		19.44	2035	9.29							
24		18.67	2034	9.18							
23		17.89	2033	9.06							
22		17.11	2032	8.93							
21		16.33	2031	8.78							
20		15.56	2030	8.61							
19		14.78	2029	8.43							
18		14.00	2028	8.22							
17		13.22	2027	8.00							
16		12.44	2026	7.75							
15		11.67	2025	7.49							
14		10.89	2024	7.20							
13		10.11	2023	6.89							
12		9.33	2022	6.55							
11		8.56	2021	6.18							
10		7.78	2020	5.79							
9		7.00	2019	5.36							
8		6.22	2018	4.91							
7		5.44	2017	4.43							
6		4.67	2016	3.91							
5		3.89	2015	3.35							
4		3.11	2014	2.76							
3		2.33	2013	2.14							
2		1.56	2012	1.47							
1		0.78	2011	0.76							
0		0.00	2010	0.00							
			NPV	**665**	**SEK**						
			NPV (Stern)	1442	SEK						
			NPV (STA)	537	SEK						

Appendix - 7 Reserve Raw Water Pumping Station

RRWPS											
Critical Level [cm]	**Probability 2010**	**Probability 2100**	**Costs [SEK]**								
210	0.00%	6.00%	5000								
220	0.00%	2.00%	6500000								
Risk Cost 2010	**Risk Cost 2100**										
0	130200										
Amount of Years	**Annual Upsurge [SEK]**	**Annual Risk Cost [SEK]**	**Year**	**2010-2100**		**Year**	**2010-2050**		**Year**	**2010-2030**	
90	1446.67	130200.00	2100	9104.60		2050	17739.42		2030	16019.69	
89		128753.33	2099	9273.54		2049	17814.82		2029	15675.26	
88		127306.67	2098	9444.42		2048	17878.77		2028	15295.76	
87		125860.00	2097	9617.21		2047	17930.52		2027	14879.37	
86		124413.33	2096	9791.87		2046	17969.29		2026	14424.24	
85		122966.67	2095	9968.35		2045	17994.25		2025	13928.40	
84		121520.00	2094	10146.61		2044	18004.53		2024	13389.84	
83		120073.33	2093	10326.59		2043	17999.23		2023	12806.42	
82		118626.67	2092	10508.24		2042	17977.42		2022	12175.95	
81		117180.00	2091	10691.49		2041	17938.09		2021	11496.13	
80		115733.33	2090	10876.28		2040	17880.23		2020	10764.56	
79		114286.67	2089	11062.54		2039	17802.74		2019	9978.75	
78		112840.00	2088	11250.18		2038	17704.52		2018	9136.10	
77		111393.33	2087	11439.13		2037	17584.38		2017	8233.91	
76		109946.67	2086	11629.28		2036	17441.10		2016	7269.36	
75		108500.00	2085	11820.56		2035	17273.40		2015	6239.54	
74		107053.33	2084	12012.84		2034	17079.94		2014	5141.38	
73		105606.67	2083	12206.02		2033	16859.32		2013	3971.71	
72		104160.00	2082	12399.97		2032	16610.10		2012	2727.24	
71		102713.33	2081	12594.59		2031	16330.75		2011	1404.53	
70		101266.67	2080	12789.71		2030	16019.69		2010	0.00	
69		99820.00	2079	12985.21		2029	15675.26				
68		98373.33	2078	13180.93		2028	15295.76		**NPV**	**204958**	**SEK**
67		96926.67	2077	13376.71		2027	14879.37		NPV (Stern)	251800	SEK
66		95480.00	2076	13572.37		2026	14424.24		NPV (STA)	192552	SEK
65		94033.33	2075	13767.73		2025	13928.40				
64		92586.67	2074	13962.59		2024	13389.84				
63		91140.00	2073	14156.76		2023	12806.42				
62		89693.33	2072	14350.01		2022	12175.95				
61		88246.67	2071	14542.12		2021	11496.13				
60		86800.00	2070	14732.83		2020	10764.56				
59		85353.33	2069	14921.90		2019	9978.75				
58		83906.67	2068	15109.06		2018	9136.10				
57		82460.00	2067	15294.02		2017	8233.91				
56		81013.33	2066	15476.47		2016	7269.36				
55		79566.67	2065	15656.11		2015	6239.54				
54		78120.00	2064	15832.59		2014	5141.38				
53		76673.33	2063	16005.58		2013	3971.71				
52		75226.67	2062	16174.70		2012	2727.24				
51		73780.00	2061	16339.55		2011	1404.53				
50		72333.33	2060	16499.75		2010	0.00				
49		70886.67	2059	16654.84							
48		69440.00	2058	16804.40		**NPV**	**556771**	**SEK**			
47		67993.33	2057	16947.93		NPV (Stern)	822373	SEK			
46		66546.67	2056	17084.96		NPV (STA)	495984	SEK			
45		65100.00	2055	17214.95							
44		63653.33	2054	17337.37							
43		62206.67	2053	17451.64							
42		60760.00	2052	17557.16							
41		59313.33	2051	17653.31							
40		57866.67	2050	17739.42							
39		56420.00	2049	17814.82							
38		54973.33	2048	17878.77							
37		53526.67	2047	17930.52							
36		52080.00	2046	17969.29							
35		50633.33	2045	17994.25							
34		49186.67	2044	18004.53							
33		47740.00	2043	17999.23							
32		46293.33	2042	17977.42							
31		44846.67	2041	17938.09							
30		43400.00	2040	17880.23							
29		41953.33	2039	17802.74							
28		40506.67	2038	17704.52							
27		39060.00	2037	17584.38							
26		37613.33	2036	17441.10							
25		36166.67	2035	17273.40							
24		34720.00	2034	17079.94							
23		33273.33	2033	16859.32							
22		31826.67	2032	16610.10							
21		30380.00	2031	16330.75							
20		28933.33	2030	16019.69							
19		27486.67	2029	15675.26							
18		26040.00	2028	15295.76							
17		24593.33	2027	14879.37							
16		23146.67	2026	14424.24							
15		21700.00	2025	13928.40							
14		20253.33	2024	13389.84							
13		18806.67	2023	12806.42							
12		17360.00	2022	12175.95							
11		15913.33	2021	11496.13							
10		14466.67	2020	10764.56							
9		13020.00	2019	9978.75							
8		11573.33	2018	9136.10							
7		10126.67	2017	8233.91							
6		8680.00	2016	7269.36							
5		7233.33	2015	6239.54							
4		5786.67	2014	5141.38							
3		4340.00	2013	3971.71							
2		2893.33	2012	2727.24							
1		1446.67	2011	1404.53							
0		0.00	2010	0.00							
			NPV	**1236369**	**SEK**						
			NPV (Stern)	2681570	SEK						
			NPV (STA)	998776	SEK						