Modelling climate change effects on Kodammarna wastewater pumping station

A case study in Gothenburg

Master's Thesis in the Master degree program of Geo and Water Engineering

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ABSTRACT

In 2007, IPCC released its fourth assessment report, stating that global warming will cause climate change all over the world. Increased precipitation amounts and changes in precipitation patterns will have large impacts on the urban drainage system and receiving waters close to urban areas will experience larger pollution loads as a result of more combined sewage overflow (CSO) discharges. An assessment of how future precipitation will affect Kodammarna wastewater pumping station, located in Gullbergsvass area in Göteborg, is made in this master thesis project at the Master program of Geo and Water Engineering at Chalmers University of Technology in Göteborg, Sweden. The objectives of the project has been to assess the consequences the increased volume of water will have on Kodammarna pumping station, how much contaminants that will be released into the river through the combined sewage overflow and how the pumping pattern should be managed to mitigate the sewage overflow discharges. Observed five-year rainfall series are transformed to future rainfall series with the delta change method and simulated in a pipe network model of the drainage area in the software Mike Urban Collection Systems. Pollution loads on receiving waters are calculated with Microsoft Excel and standard values for contamination in wastewater from Gothenburg Water, the municipally owned company responsible for the sewage network. The results show that the maximum incoming flow to the pumping station under normal circumstances is 9.99 m^3/s, which is below the station capacity at 11 m^3/s. However, for extreme precipitation events, such as a 100-year return period rain, the station is less prepared and can experience trouble handling all the incoming water. The total inflow to the station is expected to rise with 18%, while the rise in sewage overflow is above 150%. The water quality assessment results show that the contamination load on the recipient will increase with more than 100% for all contaminants considered. The conclusions from the thesis work is that the station is at no immediate danger because of the climate change, but a more detailed study of how the network responds to an extreme rain storm event is recommended to find measures to secure the station in case of flood threats. In view of the large increase in pollutant load on the receiving water, additional discussions amongst politicians, the municipality and the inhabitants is encouraged. The pollutants are toxic to the aquatic environment, but to have them in the sewage sludge at the wastewater treatment plant will interfere with plans to sell the sludge for commercial use. An increased public awareness about the sewage network and the treatment processes will help improve management practices for the pumping station and create a more sustainable future.

Key words: Climate change, Kodammarna wastewater pumping station, delta change method, pollution load, future precipitation

Modellering av klimatförändringens effekter på Kodammarnas avloppspumpstation
En fallstudie i Göteborg
Examensarbete inom Masterprogrammet för Mark, vatten och anläggning
EMELIE ALENIUS
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SAMMANFATTNING

När IPCC år 2007 släppte sin fjärde rapport över hur den globala uppvärmningen kommer att påverka klimatet, påbörjades i många svenska kommuner studier över vilka hot och möjligheter som klimatförändringarna kan utsätta oss för i framtiden. En av de parametrar som påverkar samhällets infrastruktur mest är nederbörden, då en stads avloppsnät och dess kapacitet är avgörande för att förhindra översvämningar i urbana miljöer i händelse av kraftiga regn. Detta projekt har varit ett examensarbete i Masterprogrammet för Mark, Vatten och Anläggning (Geo and Water Engineering) på Chalmers Tekniska Högskola i Göteborg och syftar till att utvärdera Kodammarnas avloppspumpstations sårbarhet för framtida förändringar i inkommande vattenflöden orsakade av ökade nederbördsmängder som en följd av den globala uppvärmningen. Rapportens syfte är att besvara frågeställningar om hur mycket vatten som kan förväntas inkomma till stationen, hur mycket som kommer att bräddas till recipient, hur föroreningsmängden i bräddvattnet påverkas, samt om pumpstyrningen på stationen bör justeras för att förhindra för mycket föroreningsspridning. Observerade nederbördsserier har gjorts om till framtida nederbördsserier med hjälp av delta change-metoden och simulerats i en nätverksmodell av avloppsnätet. Dataprogrammet Mike Urban har använts och resultatet i form av inkommande flöden till Kodammarnas pumpstation har utvärderats. Resultatet visar att det högsta förväntade inflödet i framtiden är 9.99 m^3/s, vilket är under pumpstationens maxkapacitet som är 11 m^3/s. För extrema väderhändelser, som ett framtida 100-års regn, har stationen inte tillräcklig kapacitet utan skulle då översvämmas av det inkommande vattnet. Resultaten visar också att bräddmängden skulle öka med över 150%, trots att den totala ökningen i inkommande flöde endast är 18%. Utsläppen av föroreningar till recipient skulle även dessa öka kraftigt med mer än 100% till år 2071, för samtliga undersökta ämnen. Slutsatserna av projektet är att stationen inte är i någon omedelbar fara på grund av klimatförändringarna, men extrema regntillfällen i slutet av seklet skulle kunna skapa problem. Därför är rekommendationen att göra en översyn av det omgivande avloppsnätets svaga punkter för att identifiera åtgärder som i en händelse av ett kraftigt regn kan användas för att skydda stationen från översvämning. En övrig rekommendation är att uppmuntra en politisk diskussion om utsläpp av orenat vatten och var slam av förorenat dagvatten bäst tas om hand. En publik diskussion om detta ämne skulle också öka samhällets insikt i hur avloppsnätet fungerar en ökad förståelse för reningsprocessen, vilket skulle vara ett steg i rätt riktning mot ett mer hållbart samhälle.

Nyckelord: klimatförändring, delta change-metoden, Kodammarna, bräddvattenföroreningar, framtida nederbörd

Contents

Preface

This project has been carried out as a master thesis project at the division for Water Environment Technology (WET) at Chalmers University of Technology in Gothenburg, Sweden.

Our project is partly connected to a national project carried out by several parties including Linköping University and the Swedish Geotechnical Institute (SGI). The national project aims to create a facile and user-friendly way to assess the sensitivity and risks to cities as well as research society's ability to adapt to these in view of the climate change. The three main focuses of the national project is: Integrated sensitivity assessment, Creation of a useful toolbox and Co-operation between users and researchers.

To start the process of making the integrated sensitivity assessment, two municipalities in western Sweden were chosen as representative cities. One of them is Gothenburg. The assessment is intended to show strengths and weaknesses of the city to the threats posed by climate change and also how well people of the community will react and adapt to new conditions. (Jonsson, 2009)

The local water company in Gothenburg, Gothenburg Water, is responsible for production and distribution of drinking water, but also for the sewage network. The wastewater treatment plant is managed by a separate, although municipality owned, company. To make a sensitivity assessment of the drinking water and wastewater system is a priority, as the consequences of being taken by surprise by changing weather conditions could be catastrophic.

This master thesis project is a part of the integrated sensitivity analysis for Gothenburg wastewater system and its ability to cope with the expected increase in stormwater volume as a result of global warming.

The authors would like to thank Håkan Strandner at DHI Sweden and Jonas Olsson at SMHI for their help and support without which this thesis would never have been written. Thank you also to our supervisors Per-Arne Malmqvist and Annika Malm. Additional support was given by Claes Hernebring, DHI Sweden which is gratefully acknowledged.

Notations and abbreviations

CSO	Combined Sewer Overflow
MU	Mike Urban
DC	Delta change factor
GCM	Global Circulation Models
RCM	Regional Circulation models
IPCC	Intergovernmental Panel on Climate Change
SRES	Special Report on Emission Scenarios (published by IPCC)
AR4	Fourth assessment report (from IPCC)
RDI	Rainfall Dependent Infiltration

Roman upper case letters

M^{tot}	Total mass of the contaminant released untreated through weir discharge
Q_{storm}^{weir}	Stormwater volume of untreated wastewater released trough weir discharge
C_{storm}	Standard values concentration for substance in stormwater
Q_{sewage}^{weir}	Sewage volume of untreated wastewater released through weir discharge
C_{sewage}	Standard values concentration for substance in sewage water

1 Introduction

The Kodammarna pumping station (hereafter named Kodammarna) is a key wastewater pumping station in the Gothenburg sewage network. Kodammarna discharges wastewater from approximately 178 000 person equivalents. In addition, urban runoff from large areas is connected.

Today the wastewater is pumped to Ryaverket Wastewater Treatment Plant (hereafter named Ryaverket) for treatment. During heavy rainfall events large volumes of water flow through the pumping station where some of the water is discharged as combined sewage overflow (CSO) directly into Gullbergsån, in close proximity to Göta Älv river. At present, the "first flush" flow during a rain storm event after a dry period is pumped to Ryaverket for treatment, but after a given time, less water is pumped to Ryaverket and more is discharged without treatment. This is named "quality control".

Following the IPCC report on climate change, precipitation is expected to increase in the future (IPCC, 2007). Since a large portion of the sewage network connected to Kodammarna is a combined sewage network, this means the stormwater inflow to the pumping station will rise.

1.1 Background

Climate Change has been discussed for a long time and anticipations about a future climate has been made. Our population increases and technology constantly moves forward which will most likely cause temperature to continue to rise worldwide (IPCC, 2007). The result will be more frequent rain periods and higher rain intensities in the future which implies that flooding will become more common.

The city of Gothenburg distributes one fourth of its sewage water through Kodammarna which pumps the water to Ryaverket (SWECO VIAK, 2006). As Kodammarna is located in a low lying area and has a limited pumping capacity it is even more important to consider flooding as a future problem for the pumping station. Another concern is that higher inflow to the pumping station will result in more direct discharge of wastewater to Göta Älv thus increasing the contaminant load on the river. Anticipations about how the climate change will affect Gothenburg in general in the future have been made by Gothenburg municipality (Göteborgs Stad, 2009). However, no previous studies have shown how the future climate is going to affect Kodammarna.

1.2 Objective

When precipitation patterns change and the water inflow increases, the pumping patterns at Kodammarna will have to change in order to adapt to the new conditions. What consequences will the increased volume of water have for the pumping station? What situations may arise and what can we do about it? How much contaminants will be released into the river in the future? Should the pumping pattern be changed to mitigate combined sewer overflow discharges to the river?

1.3 Delimitations

- The sea water level has not been taken into account when assessing impacts on Kodammarna. The pumping station is located in a low-lying area close to Göta Älv, but it is protected from high water levels by levees.
- An existing calibrated model of the network was used and was not further developed or analyzed.
- Results are analyzed for the pumping station only, impacts on the network have not been assessed.
- No additional measurements have been made in this project; all data are taken from existing available sources.

1.4 Working process for the thesis project

The first part of the thesis work was a literature study where the geographical area, previous studies about the pumping station, literature regarding climate change and literature regarding climate modelling theory were examined. This formed a crucial foundation for continuing development of the thesis. Some time was also spent on learning how to use the simulation program, Mike Urban/Mouse by DHI, and how to extract and analyze results.

Early in the thesis project, a simplified network model was used for simulations. This model was replaced by the network model described in chapter three halfway through the project, and the simulations that had been done with the early model were remade. This was done to increase reliability and obtain more accurate results.

Finding relevant input data with optimum resolution for simulations was a challenge and an ongoing process for the entire project period. Basic data from the Swedish Institute of Meteorology (SMHI) displayed faults and was eventually manipulated by the authors to better suit the purpose of this project. The basic data used was 10-minute tipping bucket gauge rain series from Barlastplatsen in Gothenburg transformed to expected future precipitation with the delta change method described in chapter two.

Rainfall was simulated for three different future time periods and the incoming water volumes to Kodammarna obtained was then analyzed and compared. An extreme precipitation event in the future was also simulated to assess the maximum capacity at the pumping station.

The last part of the thesis project was to make a water quality assessment on stormwater discharges from the weir overflow at Kodammarna. Standard values were used to calculate the annual release of contaminants to the recipient from the pumping station.

2 Modelling future precipitation

The first attempts to make a computer model of planet Earth's climate system were made around 1990 (Rummukainen, 2004). Since then both the models and the knowledge about how the system works have improved, but still the models fail to emulate reality to the full extent. Models in general can never mimic reality completely and contemplating the complexity of global climate systems, the hardships of climate modellers can easily be understood. At present, a number of models depicting the global climate are available and used, but these are not sufficient for usage on a regional or local scale. Many nations has therefore chosen to proceed and develop models that are more adapted to a specific region and have a better ability to make more accurate interpretations of the local climate (Jones, 2004).

Global

The global models are referred to as Global Circulation Models (GCM) and the two that are used as input for the Regional Circulation Models (RCM) in Sweden are the ECHAM and HadCM models. (Persson, 2007)

The ECHAM model was developed at the Max Planck Institute of Meteorology in Hamburg where it was built on a previous operational forecast model named ECMWF (from where the EC in the name is taken), and a parameterisation package developed in Hamburg (hence the HAM) that allowed the model to be used for climate experiments (Roeckner, 2003). ECHAM is an atmospheric model, and only calculates processes taking place above ground. Because of this it is coupled with an oceanic model that calculates impacts made by the oceans when used to make predictions for future climate changes.

The HadCM model was developed at Hadley Centre for Climate Prediction and Research in Great Britain. It is also a coupled model that contains both an atmospheric and an oceanic model. The two GCMs share similar factors like the grid net used to divide the planet into smaller pieces for simulation and they also have a similar time step for simulation. The name HadCM simply means HADley centre Circulation Model. (Johns, 1997)

Regional

GCMs usually have a spatial resolution of 200-400 km per grid box. Since weather can be very local, this coarse resolution does not give good enough predictions on the local scale. Instead a RCM, with a spatial resolution of between 20-50 km over a certain region, is incorporated into the GCM. (Jones, 2004)

In Sweden, such a RCM has been developed at Rossby Centre which is the department for climate research at the Swedish Institute of Meteorology (SMHI). The model is called RCAO (Rossby Centre Atmospheric and Oceanic model) and is a grid point, hydrostatic model. Since Rossby Centre has not developed any GCM of their own, their RCM shows some differences in the physics of the model compared to the GCM that set the boundary conditions. While this will cause some noise in the boundary simulations, it also gives the freedom of choosing better approaches for parameterisation techniques within the model. (Jones, 2004) Results in this project are based on simulations from the latest run of the regional model and is therefore output from atmospheric part of the model (RCA3) only (SMHI, 2009), (Kjellström, 2005), (Olsson, 2009b).

Since regional models use the global models as boundary input data, the results from the regional model will depend on the global model used. To obtain a wider range of possible outcomes, climate researchers often use more than one (SOU, 2007). In this project however, the results used have been modelled with boundary conditions from ECHAM4 only (Kjellström, 2005).

2.1 Precipitation Modelling

Precipitation is one of many parameters considered when recording weather conditions, but it is nonetheless one of the most important. Floods have severe impacts on urban society, cost a lot of money and when it comes to sewage floods the consequences can also be an issue of human health. Precipitation is measured at selected point locations using a rain gauge of some kind. For climate modelling purposes, verification is often done with a tipping bucket gauge. When the collected rain measures 0.2 mm, the bucket tips and a registration of the time is made in a computer (Butler, et al., 2004). An example of a recorded tipping bucket rain series can be seen in Table 1.

A common problem with rain measurements is that rain gauges are not fully accurate. They consistently underestimate the amount of precipitation because of wind movements; some of the rain drops that otherwise would go into the measurement instrument end up beside it. (CTH, 1978)

Since precipitation can be formed on a very local level, there are also difficulties when trying to model precipitation levels in a regional area. Jones, et al. (2004) showed that the RCA model used in Sweden has a realistic representation of the mean annual precipitation cycle. However, even the high resolution grids used in RCMs are too coarse to make accurate predictions for urban drainage purposes and when used for wastewater modelling, the output data from the RCM are used to quantify the percental change between modelled present day and future time. This method is referred to as the delta change (dc) method and is the most commonly used one today. (Olsson, 2009)

Table 1. Example of rain series recorded with a tipping bucket gauge. The data is recorded from the 14th of August until the 19th of August 2008. As there are no values from the 15th, 16th, 17th and 18th of August, the conclusion is that it did not rain on these days. On the 14th of August it rained during the night, but most importantly it rained between ten and eleven o'clock the 19th of August. Data from Gothenburg Water.

Date and time	Value
2008-08-14 01:02	0.2
2008-08-14 01:09	0.2
2008-08-19 09:45	0
2008-08-19 10:15	0.2
2008-08-19 10:21	0.2
2008-08-19 10:25	0.2
2008-08-19 10:26	0.2
2008-08-19 10:27	0.2
2008-08-19 10:44	0.2
2008-08-19 10:46	0.2
2008-08-19 10:47	0.2
2008-08-19 10:49	0.2
2008-08-19 11:01	0.2
2008-08-19 11:03	0.2
2008-08-19 11:06	0.2
2008-08-19 11:07	0.2
2008-08-19 11:08	0.2
2008-08-19 11:09	0.2
2008-08-19 11:15	0.2

2.2 Scenarios for future climate

In 2007 the Intergovernmental Panel on Climate Change (IPCC) published its fourth assessment report, known as the AR4. This report is a suite of the third assessment report (TAR) which was published in 2001, and contains observed changes in global climate, possible causes for this change and most importantly: future projections on how the climate changes will develop and how this might impact our planet. These future projections are much discussed worldwide and has inspired many governments and multinational corporations to take action and become aware of the environment, intensify environmental research and develop methods to create a more sustainable future.

When predicting the future, the uncertainties of the results are both substantial and difficult to overcome. The technical aspects of the atmospheric models at the basis for the predictions improve continuously, but still the input data are subjective judgments made by the world's climate experts and researchers. Also, since all experts have their own beliefs and views of how the world will develop in terms of population, economic structure and technical improvements, there are as many scenarios of how the future will turn out as there are scientists who predict it.

In 2001, IPCC published a Special Report on Emission Scenarios (SRES). This report contains 40 different scenarios for how the CO_2 levels in the atmosphere may develop in the future. To make the report and the scenarios more user-friendly, these 40 scenarios are grouped into scenario families where each family group share key driving forces for the climate change. The scenario families are denoted A1, A2, B1 and B2. They are described without any judgment as to which is more probable or possible than the others. For each family, a representative scenario was also chosen to make it easier for policymakers and researchers on a regional base. (Nakicenovic, 2000)

2.2.1 Scenario descriptions

The storylines are shortly described here, for more detailed description of each storyline, see the IPCC SRES which can be found on the IPCC website.

The A1 and A2 storylines describe a world where economic gain is the driving force for change, whereas in the B1 and B2 storyline the incentive for change is environmental awareness and concern as illustrated in figure 1. Similarly, in the A1 and B1 storylines the different economical regions of the world converge and generate global solutions to environmental problems whereas in the A2 and B2 storylines solutions and development are kept at a local or regional level instead.

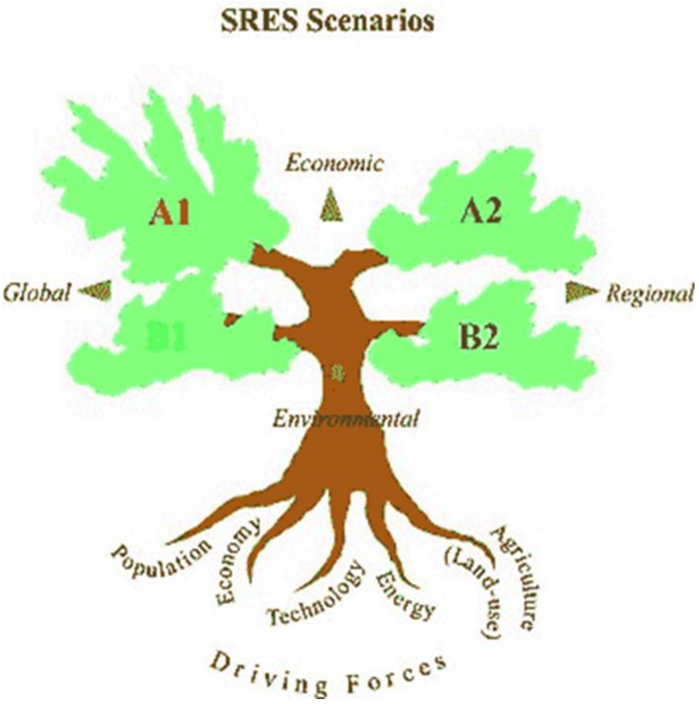


Figure 1 The scenario storylines differ as described above. Scenarios belonging to the A1 and A2 family are driven by economic forces while in the B1 and B2 world environmental concern play a big part of the incentive for change. The scenarios also differ in the sense that the A1 and B1 scenarios describe a world where global solutions are found and applied whereas in the A2 and B2 scenarios the economic regions of the world becomes even stronger and solutions are applied on a national or local level. Figure from IPCC AR4.

2.2.1.1 A1 Storyline

In the A1 storyline the world experiences a rapid economic growth, slow population growth and rapid introduction of new technologies resulting in high emission levels in the future.

The economic growth in this storyline is global and such that the differences in average income worldwide will finally dissolve. The regions in the world that are poor today will become more affluent and the world will become more equal.

Since the population growth in a country is closely linked to its economic situation, the exponential increase in human beings on planet earth will ease out and eventually go into reverse as the countries that are poor at present become more affluent. Average life expectancy will increase as will average age.

The successful economic development is enabled and partly driven by a rapid technological progress, where new and efficient technologies reduce the need for resource input and increase the level of output. After an initial increase in energy use, the energy consumption per capita will decrease when the new technologies are introduced in more and more countries. This will also eventually release resources that are now bound to human usage.

The scenarios within the A1 family differ somewhat when it comes to which source of energy will be the most dominating during the 21st century. Some scenarios describe a continuous carbon-intensive energy use, while others put across natural gas, renewable energy sources, nuclear power or a mix between all of them as the most probable energy source. (Nakicenovic, 2000)

2.2.1.2 A2 Storyline

The A2 scenario family is characterized by regional differences in economic growth, high population growth and slow technical progress. This scenario causes medium to high emission levels in the future (Butler, 2004).

In the scenarios belonging to the A2 family, the world divides into self-relying regions. Influences, ideas and impacts are kept within the regions causing new technologies, economic growth and social and cultural developments to spread very slowly in the global context. The present differences in average income between industrialized and developing countries will remain, and a social focus on family and community will keep the population growth rapid.

Since each region strives to become self-sufficient, the energy source used will reflect the resources available in the region. Resource-rich regions will continue to use fossil fuel as their primary energy source, whereas resource-poor regions will shift to new energy technologies. (Nakicenovic, 2000)

2.2.1.3 B1 Storyline

In the B1 storyline environmental consciousness and concern together with a globally interacting society will create a world with low population growth, rapid changes in economic structure and introduction of new clean technologies resulting in medium to low emission levels.

Driven by environmental awareness and a desire for sustainability the economical structure of the world will rapidly change into a more information and service-based approach in the B1 scenarios. The economical growth will be balanced and deliberately aimed towards an equal living standard for all humans. Problems connected to environment, pollution and resource-use will be solved on an international scale and firmly established in the national and local context.

The environmental concern will also be part of the reason for the slow population growth and the shift towards new clean and resource-efficient technologies. These technologies will diffuse easily between regions in the world and help create a sustainable future despite lack of climate policies. (Nakicenovic, 2000)

2.2.1.4 B2 Storyline

In the world of the B2 storyline, the regional difference in development is significant. Environmental concern and awareness is a crucial driving force, but kept on a local and national level. Regions will develop in line with their economic ability to pursue a more sustainable society thus creating scenarios with overall moderate economic development and population growth. Strong regional values will hinder a rapid technological diffusion and create a wider range of available technologies. This scenario results in low emission levels in the future (Butler, 2004).

The energy source used will depend on the resource availability in the region concerned, thus forcing some societies to develop new technologies for energy extraction, while others will remain in a fossil-fuel intensive state. The only thing uniting the regions is consciousness of the need for globally sustainable societies, thus enabling solutions for transboundary environmental problems, such as atmospheric and oceanic pollution. (Nakicenovic, 2000)

2.2.2 Regional use of scenarios

The scenarios described above are used in the GCM to obtain numerical values of how the climate may change in the future. The results from these simulations can be found in the Fourth assessment report (AR4) from IPCC, available at the IPCC webpage (IPCC, 2009). At the same time as IPCC has prepared AR4, different regions in the world have run scenarios in their RCM to acquire results that apply to their local conditions. At Rossby Centre, two out of the four SRES scenarios were chosen and used for simulations in the regional model.

In Sweden, the storylines A2 and B2 were chosen for simulations. The selection of these two scenarios was made on basis of the emission levels; no weight was given to the socio-economical aspects of the scenarios. The representative scenario was chosen from both scenario families. (SOU, 2007) Choosing only two scenarios also means leaving two other equally possible scenarios out, but the two chosen ones cover a big part of the range of possible future emission levels of CO_2 and the probability of finding the true levels of future emission within these two options is high.

2.3 Delta change method

The RCMs give precipitation output in 30-minute time steps. In an urban drainage context, much can happen in a sewage system during this time. Therefore, a higher time resolution is preferred when doing simulations for urban drainage studies. Also, the resolution grids in the RCMs are too coarse to make accurate predictions for locally occurring weather phenomena, and when doing simulations on spatially limited sewage systems a method for describing precipitation in a specific point is needed. The delta change method (hereafter named dc method) is such a method and the theory is described below.

The dc method transforms observed rainfall series into future rainfall series and can be applied to series of any time resolution. It is built on a comparison between outputs from different time periods in the RCM runs. The simulation data is divided into four time periods and given specific names, the reference period TC (1961-1990), near future time period FC1 (2011-2040), intermediate future time period FC2 (2041-2070) and distant future time period FC3 (2071-2100). Furthermore, the series from each time period is grouped according to season. The winter season is December to February, spring is March to May, summer is June to August and autumn is September to November.

Each group are then ranked according to intensity level. The lowest intensity is given number 1 and the highest recorded intensity is given the highest ranking number. There are as many ranking numbers as there are time steps with recorded rainfall. An example of a ranking can be seen in figure 2, where the ranking numbers have been exchanged for percentiles. The difference in intensity that can be seen in the figure indicates that low intensity rains will further decrease in intensity, whereas high intensity rain will increase in intensity between the reference period (TC) and distant future time (FC3). (Olsson, 2009)

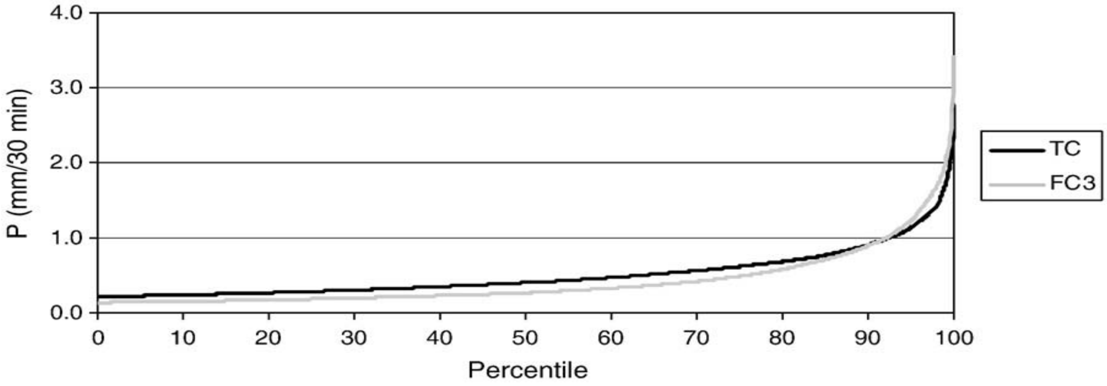


Figure 2. The time periods FC3, 2071-2100, and TC, 1961-1990, are ranked according to summer season precipitation and intensity level, emission scenario A2 in Kalmar. (Olsson, 2009)

From this ranking, a percental difference is derived, one for each percentile, season and time period. It is obtained by dividing the future time period value with the reference time period value and the output is called the dc factor:

$$FC3/_{TC} = dc\ factor$$

When this division has been made for each percentile and season in the time period, the result can be plotted in a diagram. An example of how this diagram can be is shown in figure 3. In this figure, dc factors for all three time periods are shown in the same figure. (Olsson, 2009)

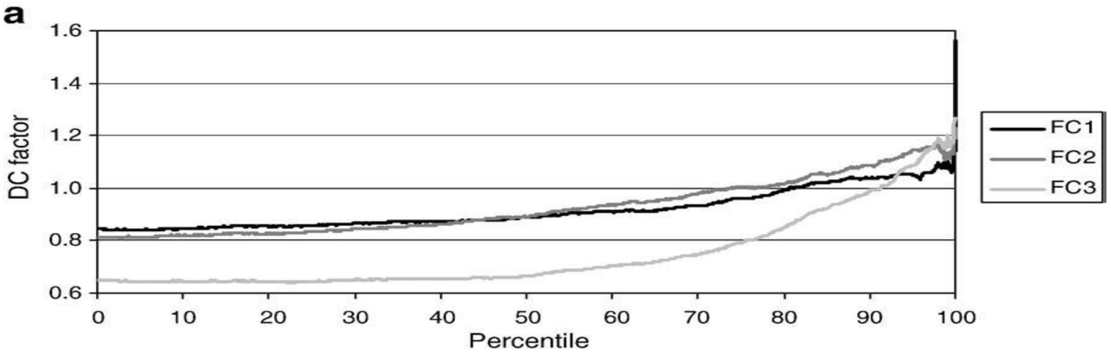


Figure 3 (Olsson, 2009). The future time periods each shows the summer dc factor distribution, emission scenario A2 in Kalmar. (Olsson, 2009)

The dc factors obtained can then be used on an observed rainfall time series of any resolution. The observed rainfall series is ranked after intensity level the same way as the modelled series, and after that, each time step of the observed series is multiplied with the dc factor that corresponds to that particular percentile of intensity and season. This means that high and low intensity rains will have different dc factors and changes in both average precipitation and extreme rain storm events is thus taken into account. (Olsson, 2009)

Every emission scenario simulated in the RCM gives different precipitation output, and the dc factors will for this reason be different for each scenario. Also, the RCM gives output for every grid box simulated, and it is important to use results from a grid box that is close to the point location from which the observed rainfall series is taken. (Olsson, 2009) In this project, data from emission scenarios A2 and B2 were used, and the dc factors were derived from the grid box covering the central parts of Gothenburg. The dc factors used are plotted in diagrams and can be seen in appendix A.

While this method gives future time series with high enough resolution for urban drainage studies, some noise or errors can be expected to occur in the process. One significant difficulty when using this method is transferring spatially coarse data to point locations. The output value from the regional model represents the average value for the entire grid box, while the annual precipitation volume in reality can differ between locations within it. Many rain storm events are formed by convective forces and can be confined to a small area. On a long term scale, these differences will converge and since the dc-factors in this project are built on statistics over 30-year period (Olsson, 2009), no further adjustments have been made.

The dc factors used in this project are created by Jonas Olsson at SMHI. For further reading: (Olsson, 2009)

3 Description of the model

3.1 The modelled area

The focus of this project is the drainage areas in Gothenburg that channel their wastewater through Kodammarna. The entire zone is 3145 ha, of which 609 ha, or 19%, are impermeable surfaces (Göteborg Vatten, 2007). A map over the drainage area can be found in appendix B and list of all subzones can be seen in Appendix C. The population in the area is 178 000 person equivalents (pe).

Close to 60 % of the area has a combined sewer system (Karlsson, 1997), where wastewater and stormwater run together in the same pipe. At selected points, CSOs are installed to keep the system from flooding in case of intense rain. The rest of the system is separate, although the sewage from these areas is led through the combined system and is there mixed with stormwater. Stormwater from the separate system is discharged directly into receiving water.

In general, areas close to receiving waters have separate system since stormwater can be discharged easily, whereas areas further from a watercourse are built with a combined sewage system.

Because of the large portion of combined areas, the inflow to Kodammarna differs substantially and is of course weather related. For 2005-2006, measured inflow volumes vary between 0.1 - 8.7 m^3/s, according to H. Strandner, DHI (Personal correspondence 2009-02-05).

At Kodammarna, six wastewater pumps are installed. All pumps can be operated simultaneously if needed. At maximum four pumps can discharge water into receiving water through a pressured outlet pipe, while all six can pump water to the treatment plant. (Karlsson, 1997) Under normal conditions, no more than two pumps are needed to operate the system. The average inflow (2004-2008) is 1.1 m^3/s. The six pumps have a total maximum capacity of 11 m^3/s. (SWECO VIAK, 2006)

3.2 MIKE Urban

The simulations in this project are done with a software called MIKE Urban (MU). The program is developed by DHI and is a GIS based product. MU models both wastewater and drinking water systems and is a part of the MIKE family, which contains applications for all kinds of water systems modelling. This project is a wastewater project, and therefore MU CS (Collection Systems) has been used.

MU CS is used for planning, analysing and assessing sewage systems, and can manage both separate and combined systems. It is made up of 5 modules: Pipeflow, Rainfall-Runoff, Control, Pollution Transport and Biological Process.

The Pipeflow and Rainfall-Runoff modules, which make up the core of the software, are built on a MOUSE engine and use ESRI's GIS software for presentation and layout. (DHI Group, 2009)

3.3 Network model

Model simplifications have been made in order to decrease the data volume and the simulation time. The pipe network connected to Kodammarna consists of approximately 15000 pipes and 59 weir discharges (Karlsson, 1997). The model has been simplified to consist of 58 pipes instead of 15000. These pipes receive water from 13 catchment areas and have eight weir discharges distributed on the areas, the remaining drainage areas are connected to the pipes directly. The network model is seen in figure 4.

Further downstream, the pipes gather in the same node, the pumping station node, to either distribute water to the treatment plant or through the combined sewage overflow. Further, no consideration has been taken to the quality control management and thus incoming water exceeding 2.1 m^3/s will be distributed through the combined sewage overflow.

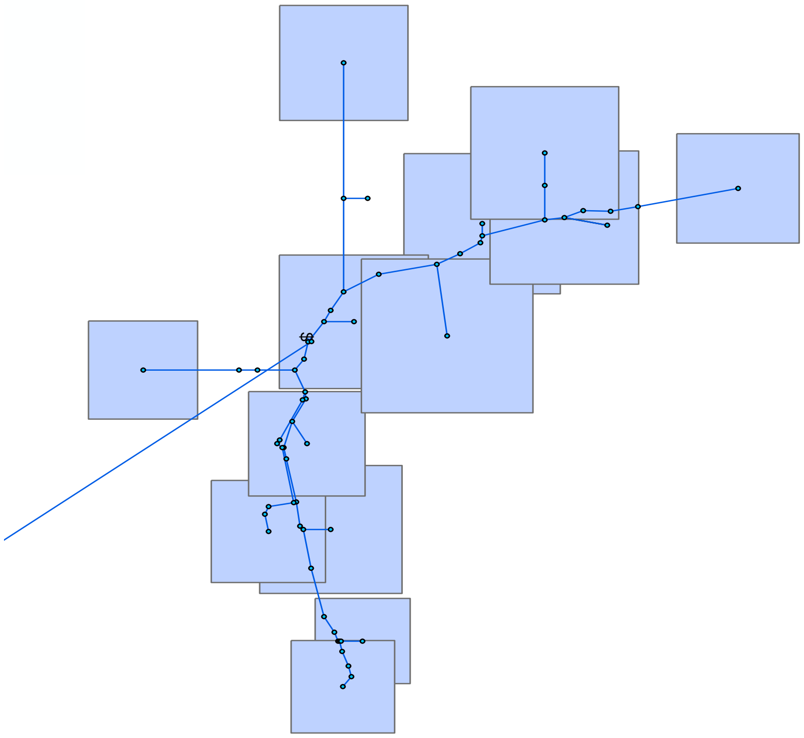


Figure 4 The network model used for simulations

The water inflow to Kodammarna depends on several parameters such as total drainage area and the extent of impervious area. The parameter settings do not equal actual values since it takes less time to transport water through 58 pipes than 15000. DHI calibrated the impervious parameter to 16 percent, three percent lower than the actual value.

Moreover, settings for continuous runoff in MU can be modelled two ways, either as a constant additional flow or as a rainfall dependent infiltration (RDI) computation. In an urban drainage system the transportation time to reach the pumping station depends on the material to be transported through. By applying RDI, movement variations such as surface runoff, snow melting, unsaturated zone and groundwater flows can be taken into account. RDI provides more detailed and accurate modelling than constant additional flow and therefore used in this project. (DHI, 2008)

3.4 Calibration

Before running the simulations the model was calibrated. Simulated inflow to the pumping station for the years 2004-2008 was compared to measured inflow for the same period. The computational settings that gave the result closest to the measured values were chosen for simulations in the project.

Data concerning population and dry weather flow were adjusted to today's situation. The population in the area has risen and is now calculated to 178 000 person equivalents.

The dry weather flow at Kodammarna is calculated by Gothenburg Water to 512 l/s (Göteborg Vatten, 2007). This value is based on records of drinking water usage in the area and wastewater generation per person in the model has therefore been adjusted so that the total amount corresponds to the official value.

During the calibration period (2004-2008) a known leakage of 100 l/s at a specific pipe added to the inflow volume at Kodammarna, and is therefore included in the model. Although this leakage is now repaired no alteration was made when the simulations began. Instead this was perceived as drainage water, and no further addition of water leakage into the pipes was made.

The result is presented in figure 5 and table 2 as the maximum inflow, total inflow, total flow towards Ryaverket, total amount of water discharged over the overflow weir and percentage of total inflow discharged over the weir.

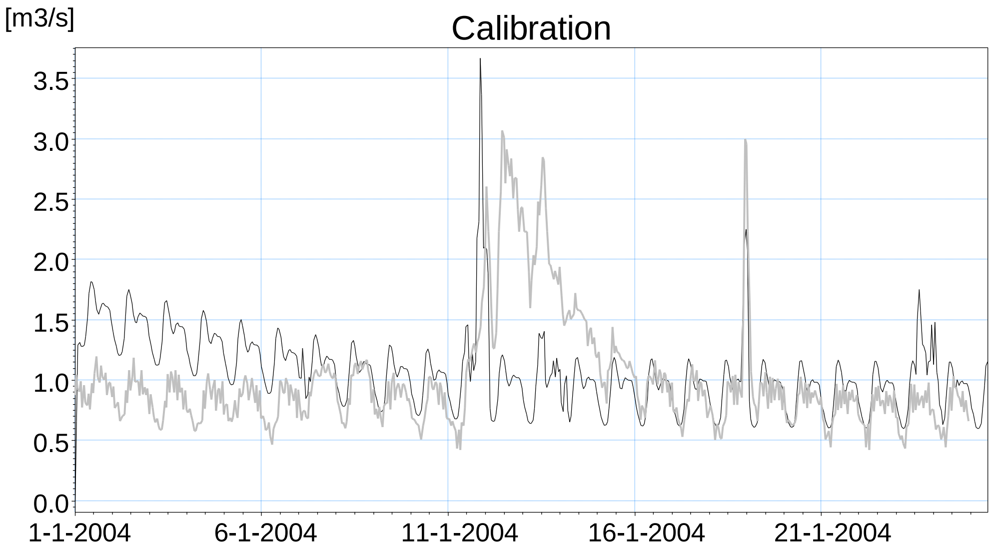


Figure 5 The model is calibrated and the result is compared to measured values. Modelled inflow to Kodammarna is shown in black and the measured inflow in grey.

As shown in figure 5 and table 2, there is a consistency between measured and modelled results. Models in general fail to mimic reality to the full extent and therefore are a margin of error up to 20 % acceptable. (Strandner, Personal correspondence 2009-02-05). The result from the calibration shows that the total inflow and the further distribution are underestimated with approximately 10%.

The model does not take the first flush into account and the amount of water discharged over the weir is therefore assumed to be overestimated in the model. Although more water is assumed to be transported through the overflow pipe and less to Ryaverket, no proof of this can be seen in the actual results. A possible explanation to this can be that fewer pipes decrease the water transportation time into the station which increases the peak flow and hence the CSO discharge. Concerning the underestimated inflow to the station, no explanations were found.

Table 2 Comparison between modelled and measured mean annual weir overflow

Mean annual incoming flow and water distribution					
	$Q_{maximum}$	$Q_{total\ inflow}$	Q_{rya}	$Q_{weir,\ total}$	Q_{weir}
	[m3/s]	**[m3]**	**[m3]**	**[m3]**	**[%]**
Measured	8.5	179 756 200	169 712 537	10 043 663	5.59
Modelled	9.5	164 711 413	155 414 503	9 296 910	5.64
Difference	9.5 %	-9 %	-9 %	-8 %	-

4 Simulation setup

Before running simulations two precipitation series were extracted and transformed into future precipitation. The future rain series was simulated in the network model hence the capacity of managing future precipitation was determined for Kodammarna.

The rain series were transformed into future precipitation by the aid of dc diagrams. The diagrams were provided by Jonas Olsson at SMHI and used in this project. The diagrams are describing the variations in dc factors for Gothenburg region. The variations in dc factors are due to different intensity levels which are taken into account. Since the dc factors also varies between seasons and emission scenarios eight different diagrams has been used, appendix A.

The diagrams indicates that extreme and average precipitation over the year will increase in the future. The dc factors are mostly above 1, except in the summer months where the dc factors are below 1, both for emission scenario B2 and A2. This indicates that the average rainfall will decrease during future summer months and increase during the rest of the year.

The dc factors for maximum intensity vary both between the different seasons and the two emission scenarios. As can be seen appendix A, the highest dc factors will appear in winter and spring while less significant changes will appear in summer and autumn. However, the worst precipitation events will probably occur during future summer periods. The past is also proving that the heaviest rains have been during warm summers (Lindahl, 2006).

4.1 Long time simulation

The precipitation series were extracted from a continuous five-year period and transformed into future precipitation. The series were simulated and Kodammarna capacity of managing average precipitation in the future was analysed.

The five-year rainfall series represents four time periods, observed period TC (2000-2004), near future time period FC1 (2011-2040), intermediate future time period FC2 (2041-2070) and distant future time period FC3 (2071-2100). TC is going to be the base point for further simulations and compared with future precipitation

4.2 Simulation extreme rain event

The second precipitation series is an extreme rain event provided to evaluate if Kodammarna is going to be able to manage extremely high precipitation in the future.

Claes Hernebring at DHI has constructed one extreme rain event with 100-year return period with 24 hour duration. In this project, the extreme rain event is transformed into future precipitation by applying the highest possible dc factor on the entire series.

The highest dc factor is taken from emission scenario A2, December-February. The future extreme rain event is incorporated into already existing rain series to represent one dry period and one wet period. The difference between the future rain series is the amount of rain appearing one month before the future extreme rain event takes place.

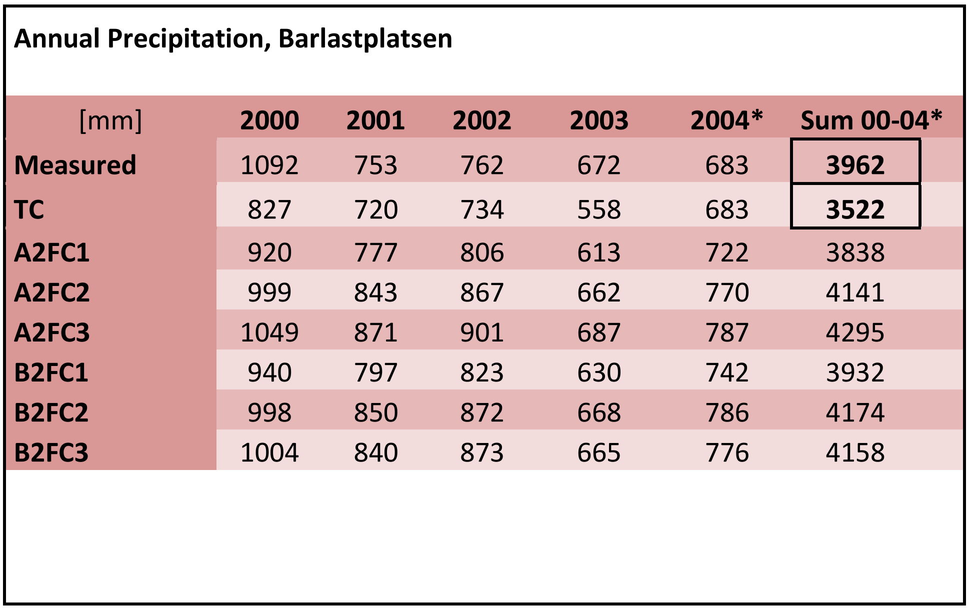
The wet rain event is characterised by a rainy month while the dry rain event is identified by a dry month i.e. no rain. The extreme rain events are both followed by two days rain. A random rain series from 2000-01-05 to 2000-02-10 has been selected and used to represent the wet period while the dry period are represented by a dry period.

4.3 Input Data

The input data used in this project are based on precipitation measurements from a tipping bucket gauge in central Gothenburg. The Swedish Institute of Meteorology, (SMHI) has been given data from this gauge when making rain series for future time periods in Gothenburg. These rain series are derived directly from Gothenburg Water's database which can give data in any resolution. To obtain 10-minute values, the program simply adds the tipping bucket registrations into 10-minute periods and gives the value obtained as output. However, after verifying accumulated 10-minute values against accumulated 1-minute output values, it was found that the 10-minute series underestimate the accumulated annual amount as can be seen in table 4. It is believed that this is caused by the extraction program that uses an incorrect method for round off. It was also discovered upon additional inspection, that specific dates where the gauge had been out of order had simply been left out of the series.

These two faults in data extraction result in precipitation series for Gothenburg that underestimate the amount of precipitation during the model period. As a consequence, the prediction for rain patterns and precipitation amount for FC3 (2071-2100) equals the measurements made for 2004-2008 in Gothenburg.

Table 4. Annual precipitation at Barlastplatsen, Gothenburg. Measured values are taken directly from Gothenburg Water, and scenario values are compiled from each rain series. As can be seen in the last column, the difference between measured values and the base scenario (TC) is over 400 mm when it should have been roughly the same. *until October 30th .

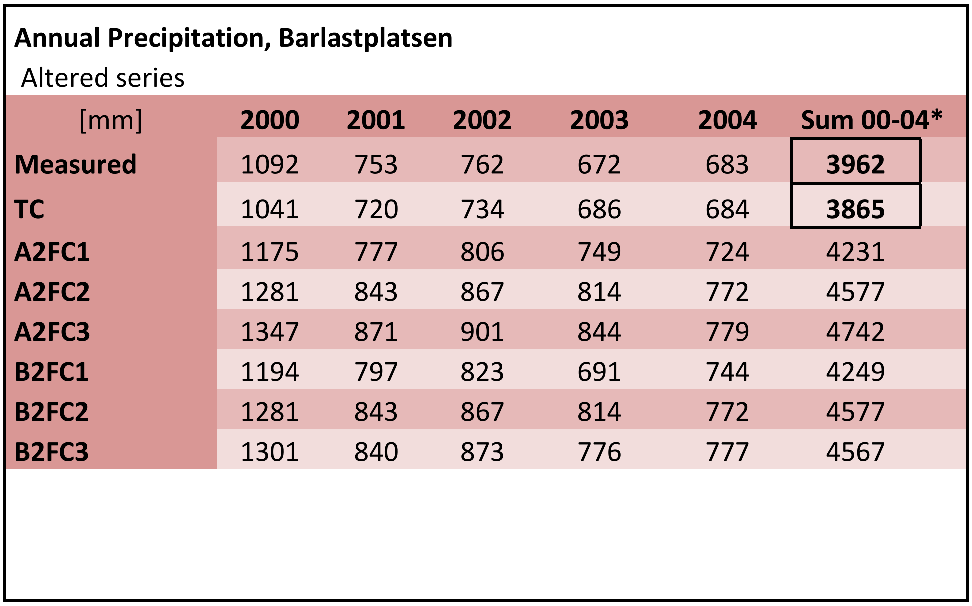


Annual Precipitation, Barlastplatsen

[mm]	2000	2001	2002	2003	2004*	Sum 00-04*
Measured	1092	753	762	672	683	**3962**
TC	827	720	734	558	683	**3522**
A2FC1	920	777	806	613	722	3838
A2FC2	999	843	867	662	770	4141
A2FC3	1049	871	901	687	787	4295
B2FC1	940	797	823	630	742	3932
B2FC2	998	850	872	668	786	4174
B2FC3	1004	840	873	665	776	4158

Results from simulations with the faulty series were considered too improbable to be used, and instead the input rain series were altered. The differences between the faulty series and new extractions from the database were evaluated manually by visual comparison in Microsoft Excel. Where inconsistencies were found, the faulty series were cut and extra rain events added until the accumulated precipitation for the date in question corresponded to Gothenburg Waters’s series. The added rain events were later transformed into future precipitation by applying dc factors. The result of the change can be seen in table 5. The changes is the base series also affects the future precipitation amounts, which is why the accumulated amount for the future time periods is higher in table 5 than in table 4. The altered series were converted to Mike Urban input files and used for simulations.

Table 5. Annual precipitation at Barlastplatsen, Gothenburg. Measured values are taken directly from Gothenburg Water, and scenario values are compiled from each rain series. As can be seen the consistency between measured values and the base scenario (TC) is better. *until October 30th .



Annual Precipitation, Barlastplatsen

Altered series

[mm]	**2000**	**2001**	**2002**	**2003**	**2004**	**Sum 00-04***
Measured	1092	753	762	672	683	**3962**
TC	1041	720	734	686	684	**3865**
A2FC1	1175	777	806	749	724	4231
A2FC2	1281	843	867	814	772	4577
A2FC3	1347	871	901	844	779	4742
B2FC1	1194	797	823	691	744	4249
B2FC2	1281	843	867	814	772	4577
B2FC3	1301	840	873	776	777	4567

5 Results

5.1 Long time simulation

The results from the rainfall simulation show how much inflow Kodammarna is expected to receive during a year in each future time period. The annual mean is calculated from a five-year rainfall simulation in each time period. Interesting is to see that when comparing simulations for present day (TC) and the distant future of 2071-2100 (A2FC3), the total inflow increases with approximately 19%, from 23.5 Mm^3 to 28 Mm^3, while the weir overflow at the same time increases with 150%, from 1 Mm^3 to 2.6 Mm^3. The number can be seen in table 6. The maximum inflow to the station in a specific point of time is 9.99 m^3/s, which is below the maximum capacity for the station.

Table 6. Annual incoming flow Kodammarna, Gothenburg. The maximum inflow to the station is in the most distant time period 9.99 m^3/s, which is below Kodammarna capacity 11 m^3/s.

Annual incoming flow, Kodammarna

	total	One pump		Two pumps		
	inflow [m3]	weir [m3]	Towards RYA [m3]	weir [m3]	Towards RYA [m3]	Max [m3/s]
TC	23 518 040	1 077 247	22 440 793	148 468	23 369 571	**9.17**
A2FC1	25 353 305	1 701 065	23 652 239	235 116	25 118 189	9.21
A2FC2	26 776 327	2 209 088	24 567 240	342 129	26 434 199	9.63
A2FC3	27 935 646	2 698 979	25 236 667	431 881	27 503 765	**9.99**
B2FC1	25 217 184	1 675 876	23 541 308	231 708	24 985 476	9.4
B2FC2	26 248 336	2 013 335	24 235 001	314 416	25 933 920	9.79
B2FC3	26 851 655	2 274 778	24 576 877	364 048	26 487 607	9.58

Although the increase in incoming flow to Kodammarna in the distant future is not alarming in itself, the maximum inflow to the station is at a level where all six pumps at the station would need to be in operation for the station to be able to handle all the water. Scenario A2 causes higher inflow volumes than scenario B2, which makes scenario period A2FC3 the scenario time period with the highest total inflow and the highest maximum inflow.

5.2 Simulation extreme rain event

The extreme precipitation event simulated is a 100-year return period rain. It is enhanced with a dc factor of 1.55, the 99th percentile for summer of 2071, and the result indicates that the maximum inflow to the pumping station during this rain event would be 13.10 m^3/s. This is above the station capacity and would overflow the station. As can be seen in figure 6, the flow exceeding the station capacity is the peak flow which has 64 minutes duration. This gives good possibilities to adapt the network and the station to accommodate the peak flow.

Also, after assessing the network around the station, questions arise whether it is possible that this water volume would in fact reach Kodammarna, or if it would flood at CSO locations prior to the pumping station.

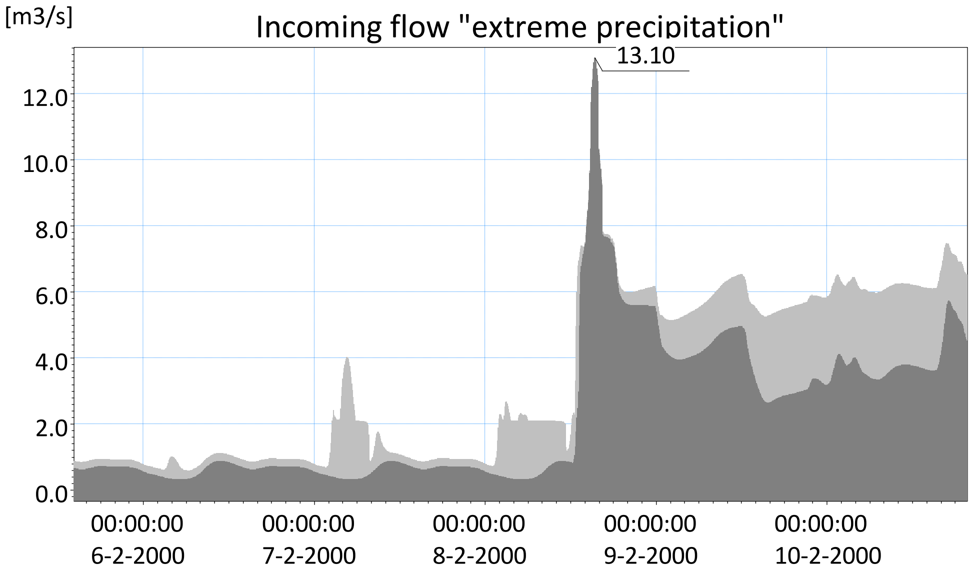


Figure 6. Above you can see the difference between the worst case events. The light grey area is showing a wet month followed by a 100-year return period event while the dark grey area is showing a dry month followed by 100-year return period event.

A simulation of this extreme rain event without the dc factor enhancement, thus representing a 100-year return period rain today, showed that the peak inflow to the station would be 10.9 m^3/s, which is below the station capacity. However, a rain event of this intensity would require all pumps at Kodammarna in operation, and with stated pump capacity.

6 Water Quality Assessment

Despite Kodammarna pumping station’s large receiving and pumping capacity, the amount of water that is forwarded to Ryaverket is in reality limited. The emission limits for wastewater treatment plants are strict whereas there are no existing emission limits for sewage overflows in the network system. In addition, Ryaverket is seeking to obtain a “green certificate” on its sewage sludge to be able to sell it for commercial purposes (Gryaab, 2009). This certificate requires low levels of metals in the sludge (Svenskt Vatten, 2008). Stormwater usually contains metals from cars and buildings, and large quantities of stormwater at Ryaverket treatment plant may affect the sewage sludge quality negatively. However, to release this water untreated will pose a threat to the Göta Älv river.

6.1 Quality control management

During dry periods, contaminants tend to accumulate on streets and in gully pots. When the rain comes, the first water to reach the pumping stations is therefore more contaminated than average (Butler, 2004). To ease the contaminant load on the receiving water, this water is pumped to the water treatment plant instead of being discharged as sewage overflow. This management practice of the first flush is called quality control.

At Kodammarna, this practice is in operation when the incoming flow to the pumping station is above 2.1 m^3 /s and the second pump has not been in operation for at least 96 hours previous. When this occurs the pumping station will for the 60 following minutes pump water to Ryaverket with two pumps at the same time instead of one. If the opposite occurs, i.e. that the second pump has been in operation during the 96 hours previous to the pump start, the pump will discharge the water to the river. Further, if the second pump has not been operated during the last 120 hours and the flow is above 2.1 m^3/s two pumps will pump the water to Ryaverket during 120 minutes following the pump start. After 60 and 120 minutes respectively, the second pump will redirect its water to the recipient. Untreated sewage discharge to Göta älv is required to have a dilution factor above three. This requirement is always met since the existing dry weather flow is 0.5 m^3/s, and one pump always are in operation towards Ryaverket, meaning that the dilution factor is above four at the beginning of the overflow. Still, there are requirements to achieve a dilution factor that is as low as possible. (SWECO VIAK, 2006).

At present, approximately 129 000 m^3 of stormwater per year are in reality pumped to Ryaverket instead of to the sewage overflow discharge as a quality control management practice (Gothenburg Water, 2007). It is hard to accurately estimate how large this number would be in the future if the present management practice is kept unchanged, except that it would be somewhere in between the result for pump one and pump two. Which practice that should be applied in the future depends both on Ryaverkets plans for a green sludge certificate and on future rain patterns.

Another factor that makes the prediction difficult is the fact that the standard concentration used for the calculation also will change, since the increased storm water volume will dilute the waste water further. Therefore, these numbers must be updated and tested continuously.

6.2 Sources of pollution

Wastewater, comprising of both storm water and foul water, contains a lot of pollutants, both organic and inorganic. Gothenburg Water monitors the discharge of pollutants by multiplying measured weir discharge volumes with standard values.

The standard values are provided by the aid of measurements and national values. Examples of pollutants that can be found in wastewater, possible sources and standard values can be found in table 7. The organic contaminants phosphorus and nitrogen comes from the foul water, whereas most of the metals that are taken into consideration can be traced back to dry runoff from roads or surface runoff from urban structures such as roofs and walls. (Butler, 2004)

Table 7 shows the contaminants that Gothenburg Water includes in their annual environmental report and the standard values that are used for calculating contaminant loads in wastewater in Gothenburg. In the last column examples of contaminant origin can be seen.

Contaminant	**Standard value** Stormwater [µg/l] (Gothenburg Water, 2009)	**Standard value** Sewage water [µg/l] (Gothenburg Water, 2009)	**Example of source** (Butler et al. 2004)
Tot - N	2 000	47 000	Human urine, urban runoff
Tot - P	300	7 000	Human faeces, washing detergents, urban runoff
Zn	118	82	Tyre wear, vehicle corrosion
Cd	0.55	0.22	Urban structures, batteries
Pb	13	4	Petrol, vehicle corrosion
Cu	53	36	Vehicle wear, roof runoff
Hg	0.10	0.18	Urban structures
Ni	15	7	Vehicle wear

6.3 Method for water quality assessment

The calculation of how much untreated water Kodammarna will discharge directly to the recipient, and thus how much the contaminant load will increase is done in Microsoft Excel. Output data from the MU simulations are incoming water to the pumping station, weir discharge and forwarded water to Ryaverket. All values are in m^3/s and are saved once every ten minutes.

The contaminant load is calculated with the following formula:

$$M^{tot} = Q_{storm}^{weir} * C_{storm} + Q_{sewage}^{weir} * C_{sewage} \quad (1)$$

Where M^{tot} is the contaminant load, Q_{storm}^{weir} is the annual weir discharge of stormwater, C_{storm} is the standard concentration of stormwater in the discharge water, Q_{sewage}^{weir} is the annual weir discharge of sewage water and C_{sewage} is the standard concentration for sewage discharge according to table 6 above.

The network model used in this project do not take Gothenburg Water's quality control management into consideration in the simulations, and therefore an alternative method have been used for calculating the volume of water that is discharged at the sewer overflow. Accumulated discharge volumes when continuously forwarding water to Ryaverket with one pump is compared to accumulated discharge volumes when continuously forwarding water with two pumps. The discharge volumes for each scenario and management practice can be seen in table 6. As expected, the discharge volume is significantly lower when two pumps operate towards Ryaverket than when only one operates. This implicates that a large part of the overflow volume is from intermediate intensity rain events which cause inflow volumes below 4.2 m^3/s. However, the standard values are assumed to be the same in the future as present thus neither material usage or dilution requirements are taken into consideration when doing calculations.

6.4 Water quality assessment results

The results from the Microsoft Excel calculations can be seen in table 8. The mean annual weir overflow volume when one pump and two pumps are in operation towards Ryaverket, divided into sewage water and stormwater. As can be seen in the table, the results indicate that the percentage of foul water in the wastewater discharge will remain the same in the future.

6.4.1 Weir overflow volumes

Table 8 Mean annual volume of sewage water and stormwater discharged to recipient through the weir overflow when one pump operates and when two pumps operate, respectively.

Mean annual weir overflow								
	Weir **overflow** one pump **sewage**	**of total volume**	Weir **overflow** one pump **storm**	**of total volume**	Weir **overflow** two pumps **sewage**	**of total volume**	Weir **overflow** Two pumps **storm**	**of total volume**
	[m3]	**[%]**	**[m3]**	**[%]**	**[m3]**	**[%]**	**[m3]**	**[%]**
TC	146 609	14	930 638	86	12 173	8	136 295	92
A2FC1	229 276	14	1 452 472	86	19 920	8	215 196	92
A2FC2	290 652	13	1 918 435	87	28 789	8	313 340	92
A2FC3	349 516	13	2 349 464	87	36 012	8	395 869	92
B2FC1	224 983	13	1 450 892	87	20 080	9	211 628	91
B2FC2	265 776	13	1 747 559	87	26 967	9	287 450	91
B2FC3	296 554	13	1 978 224	87	30 335	8	333 713	92

The percentage of sewage water that is discharged untreated decreases when operating two pumps towards Ryaverket instead of one, and this is because the dry weather flow is considered constant at 0.5 m^3/s, while the inflow volume to Kodammarna has to be above 4.2 m^3/s for the third pump to start and discharge water to the river. The dilution factor will thus always be at least 8 and the percentage of sewage water in the discharge will be lower.

The scenario time period that shows the biggest difference compared to today's volumes is the distant future time for emission scenario A2, A2FC3. In table 9, a specific comparison between the two is made on total inflow volume and total weir overflow volumes for one and two pumps towards Ryaverket, respectively. The increase in total inflow volume is 19%, whereas the increase in weir discharge is between 150-200%. This indicates that the largest impact of the change in precipitation patterns will be on the CSO discharges, and not on the inflow volume to the station.

Another indication of the change in future precipitation patterns is that more than 30% of the increase in total volume between now and scenario A2FC3 will be discharged as sewage overflow if one pump is in operation, but only 6% if two pumps are in operation. This adds to the earlier indications that the precipitation pattern changes that will have the most impact on the sewage system in Kodammarna drainage area are the intensity levels that cause inflow volumes between 2.1 and 4.2 m^3/s.

Table 9 Mean annual incoming flow to Kodammarna and the amount discharged to recipient through the weir overflow when one pump operates and when two pumps operate, respectively.

Annual incoming flow, Kodammarna			
	Total **inflow** **[m3]**	Weir **overflow** two pumps **[m3]**	Weir **overflow** one pump **[m3]**
TC	23 518 040	1 077 247	148 468
A2FC3	27 935 646	2 698 979	431 881
Difference	19 %	151 %	191%

6.4.2 Contaminant Loads

The contaminant load is calculated for the substances that Gothenburg Water includes in its annual environmental report. These substances are: Tot-N, Tot-P, Hg, Cd, Pb, Ni, Cu and Zn. Results are shown here for Tot-N, Tot-P, Hg and Cu. Results for the remaining contaminants can be seen in appendix D.

Phosphorus

Phosphorus is a powerful nutrient, and may cause a state of eutrophication in receiving waters with oxygen depletion as a result (Baird, 2008). As can be seen in figure 7, the annual contaminant load more than doubles to the year 2071, regardless of how many pumps that are operated.

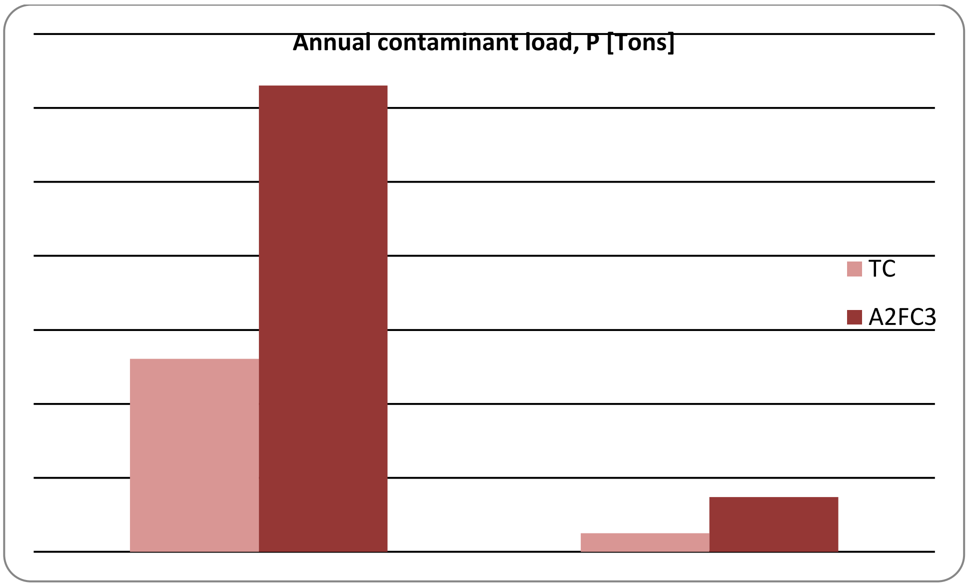


Figure 7 Annual contaminant load of phosphorus released into receiving water through the weir overflow. Comparison between the base scenario, TC, and the most extreme scenario A2FC3 and when operating one pump and two pumps towards Ryaverket, respectively.

Nitrogen

Nitrogen is also a substance that may cause a state of eutrophication if excessive amount are released into receiving waters (Butler, 2004). The contaminant load pattern for nitrogen is similar to the pattern for phosphorus, and displays a heavy increase in contaminant load from present day to the year 2071 (FC3) as can be seen in figure 8.

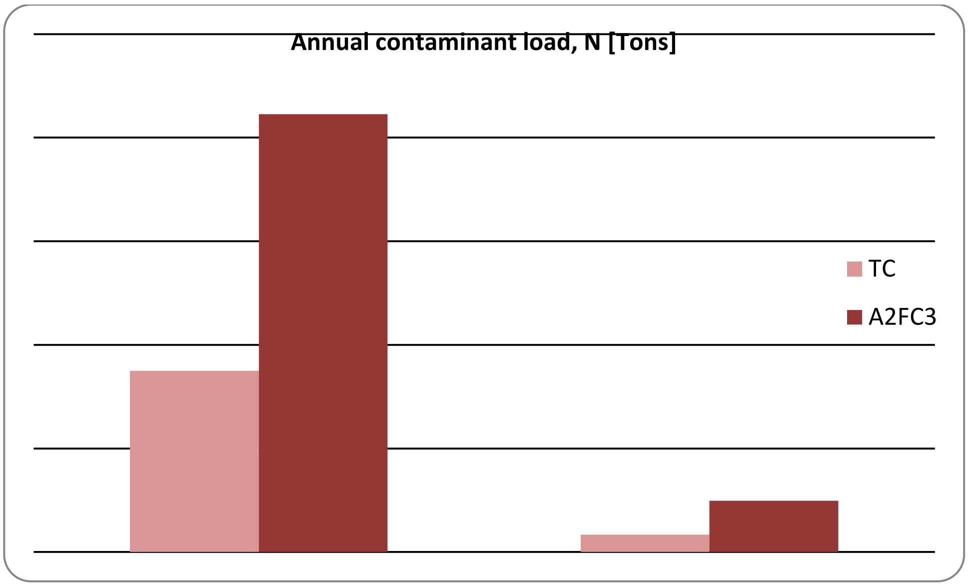


Figure 8 Annual contaminant load of nitrogen released into receiving waters through the weir overflow. Comparison between the base scenario, TC, and the most extreme scenario A2FC3 when operating one pump and two pumps towards Ryaverket, respectively.

Copper

Copper is an urban contaminant, widely used in urban constructions (roofs) as well as in vehicles. Daily wear causes copper to be transported by runoff into the sewage system (Butler, 2004). Together with the other urban contaminants, zinc and nickel, the discharge loads are monitored in freshwater systems because of their toxicity to aquatic organisms. (Naturvårdsverket, 2009) In figure 9 the simulation result for copper show that the contaminant load would have increased with close to three times the present load in 2071.

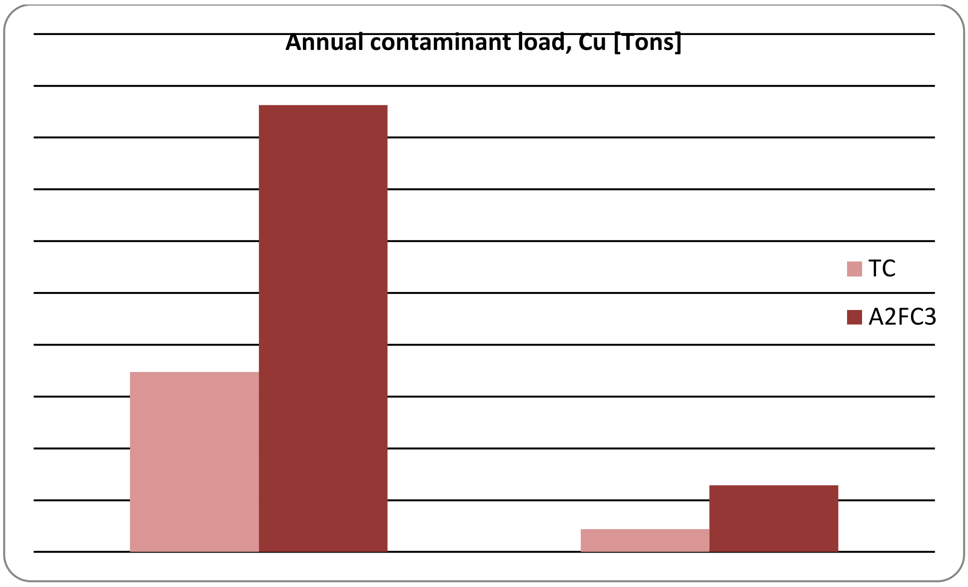


Figure 9 Annual contaminant load of copper released into receiving waters through the weir overflow. Comparison between the base scenario, TC, and the most extreme scenario A2FC3 when operating one pump and two pumps towards Ryaverket, respectively.

Mercury

Mercury is a heavy metal which together with the other heavy metals assessed in this project, lead and cadmium, can cause extensive damage to the aquatic environment if released into receiving waters. Humans can be exposed to mercury poisoning either by inhaling mercury vapour, or eating aquatic organisms containing mercury that has biomagnificated through the food chain. Mercury poisoning can cause problems with coordination, eyesight and tactile senses as a result of central nervous system damage. (Baird, 2008)

Mercury is found in urban environments and is used in street lamps and light bulbs. Recent years have seen a decline in mercury usage, since mercury because of its toxicity now is being phased out of many industrial processes and vehicle industries. (Baird, 2008)

For aquatic organisms to bioconcentrate mercury and other heavy metals from the water, the metal has to be dissolved. In stormwater however, a large part of the metal is in solid form, attached to particles, which will lead to sedimentation in the receiving waters. Here it may remain stable as long as the pH-levels do not sink too low causing the metal ions to dissolve. (Butler, 2004)

The contaminant load for mercury shows the same pattern as for the other substances, the contaminant load will more than double to the year 2071, as shown in figure 10. Operating two pumps towards Ryaverket considerably lessens the amount that is discharged without treatment, but the amount would still increase.

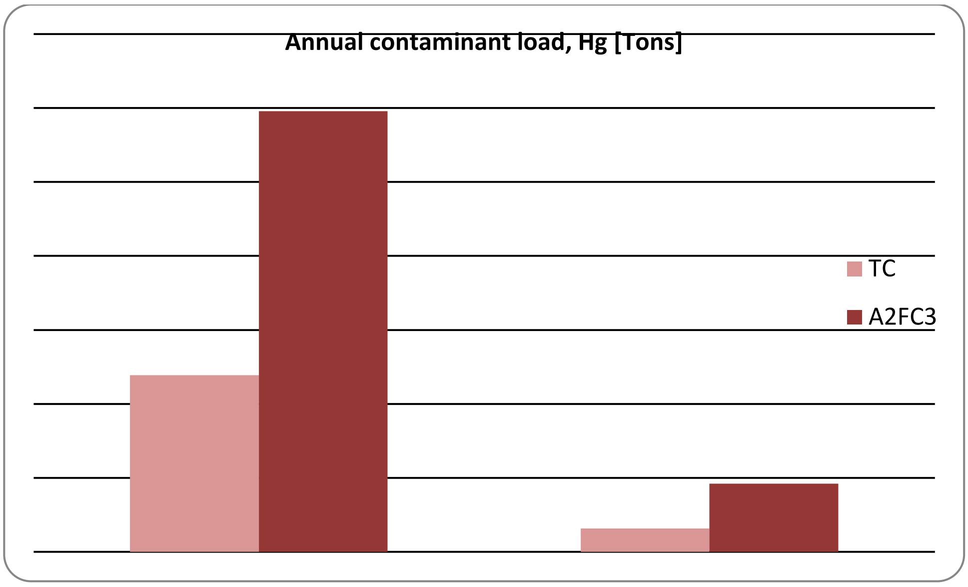


Figure 10 Mean annual contaminant load of mercury released into receiving waters through the weir overflow. Comparison between the base scenario, TC, and the most extreme scenario A2FC3 when operating one pump and two pumps towards Ryaverket, respectively.

7 Discussion

The words “climate change” usually spark many different emotions and feelings around the globe today. They can be frightening and threatening to some, or seen as a challenge to be met and overcome by others. Today, it is generally accepted in the scientific community that some kind of global warming will take place. Consequently, measures need to be taken primarily to adapt society to the changes that will come as a result of prior actions, but also to try and mitigate future consequences by reshaping existing society structures and attitudes into more sustainable solutions.

The awareness of society’s vulnerability has risen rapidly lately, as reports on the increasing speed of the climate change have been presented. For centuries, mankind has adapted to its environment, but recently, attempts to adapt the environment to mankind have been the popular way of doing things. Facing the threat of this approach now backfiring at us, research studies to assess and mitigate the damage are launched all over the world. This project is a part of such an assessment, and the importance of protecting society and its people from the environmental trap we have built ourselves into is crucial.

Building computer models of Earth’s complex ecosystem processes is one tool used to quantify and assess impacts of the climate change and they are at present starting to become detailed enough to give a satisfactory and reliable picture of how Earth functions. However, the model is only as good as its input, and predicting the future and deciding what reality will come tomorrow, only humans can do.

Results in this project are derived from the two emission scenarios that give results in the middle of the range in which it is believed that the true emission level will be. The precipitation amount could then in reality be either higher than what is shown in this report, or lower. To get a more accurate range of results, more scenarios could have been assessed, but more results lead to more information to process, and as this project is a first study of the subject this would probably have not have added to the results.

Today, quality control management of the CSO discharges serves its purpose; it hinders the most contaminated first flush to be released untreated into the recipient. However, the wastewater treatment plant has a limit of how much contaminants they can accommodate. Ryaverket is designed to remove phosphorus and nitrogen from the wastewater and other common stormwater pollutants such as metals and heavy metals end up in the sludge treatment at the wastewater treatment plant, where they are not desirable. Too much of these unwanted pollutants will make the sludge inappropriate for commercial use. The administrative authority in Sweden wishes for sludge to be reused, but then it has to be clean enough to be used for commercial purposes and spread on agricultural land. Heavy metals cannot be abundant.

The results show that the precipitation change will cause a maximum increase in CSO discharges with 150 % when one pump is in operation, causing the contaminant load on Göta Älv river to increase as well. This increase in discharge water is much larger than the increase in total inflow volume, which is only 18 %, indicating that much of the additional inflow of water to the station will be discharged over the sewage overflow. To release all this water into the river without prior treatment could cause problems with eutrophication or heavy metal poisoning, and some form of treatment would be preferable. However, to pump all this water to Ryaverket for treatment would be bad for both because of the impact on sludge quality and because it creates a risk that Ryaverket would not be able to treat all the incoming water. If this happened, the excess inflow to Ryaverket would be bypassed the plant and discharged without treatment at the outlet point. This dilemma should not be the decision of one single authority, but a discussion to be held amongst companies responsible for wastewater issues and the municipality. Another possible scenario is to install a stormwater treatment facility at Kodammarna, where harzardous substances could be settled separately for sludge used for commercial purposes. This sludge could instead be removed in a controlled way and deposited elsewhere.

The standard values used for contaminant load calculations in this project are based on different sources, both measurements and values from literature. The standard values for stormwater are based on an assumed dilution of sewage water in the stormwater based on these sources. If the rain patterns, and thus the discharge patters, were to change in the distant future, the standard values used today might in fact be overestimated. This was not taken into account in this project, and may cause the results to overestimate the pollutant load. In turn, the model calibration in chapter three showed that the sewage overflow was underestimated and thus that the pollutant load may be underestimated as well. Therefore, we think that the contaminant loads obtained in this project are good representatives for the future situation.

The best way to reduce toxic pollutants in sewage water is to encourage public awareness and opinion of what is poured down the sink or flushed down the toilet. Stormwater, however, is harder to control, since the pollutants in it comes from runoff water from streets and houses. Still, by evoking a public discussion about wastewater quality and the limitations at the treatment plant, more public knowledge and understanding about the process and the system could be gained. This in turn could lead to more management improvements to help change society into a state that is more sustainable.

This project is focused entirely on one point in a large sewage network, and when assessing impacts of the extreme rain event, this needs to be taken into consideration. When such extreme volumes of water are in motion, no part of the system would be fully functional. Most probably, the network would flood at many locations, and considering that Kodammarna is situated at a low lying point in the network, flooding of the system would occur at many other places before Kodammarna, reducing the incoming water volumes. To be certain of how much water that would reach the pumping station, and if this is more that the station capacity, a network model that is more focussed on the network CSOs need to be used. If results from this would show that the station capacity is too poor, solutions like closing parts of the network off or installing a flow limiting device on the incoming pipe could be put in use. The flow limitation would cause an upstream embankment in the network and most probably flooding at bad locations, but it would secure the pumping station.

8 Conclusions

Our summarizing conclusions are as follows:

Kodammarna wastewater pumping station is at no immediate risk from the changing climate. The rainfall simulation shows that for rain storm events that normally occur within a five-year period, the pump capacity at the station can manage the water volumes without problems, as long as all pumps are in place and functioning.

For extreme precipitation events, such as 100-year return period rain storm events, the station is less prepared. There are however some uncertainties in these results since the network response to such an event has not been assessed in this project. There is a possibility that the network model used in this project underestimates the CSO discharges in the pipe network prior to the pumping station.

The sewage overflow water quality assessment shows that the contaminant loads on the recipient will more than double to the year 2071 compared to present day. More foul water will be discharged untreated, but it will be more diluted than it is now.

The authors are hesitant to conclude that the same management practice for pump operation should be kept as it is today. Increased loads of metal contaminants may affect the treatment processes at Ryaverket negatively and make the sludge inappropriate for commercial purposes.

8.1 Recommendations

The knowledge gained during this thesis can be used as a base document when performing an investigation of Kodammarna.

The precipitation and the contaminant load are both predicted to rise in the future. Because of this, actions need to be taken in order to manage extreme precipitations and high contamination loads in both sludge and receiving water. These unwanted events can be managed by wastewater treatment at site. Both extreme events and large contaminant loads can be treated instead of discharged untreated to the receiving water.

Additionally treated sludge spread on agricultural land is one option. However, the amount of water that can be forwarded to Ryaverket is limited by the pollution loads. Too concentrated amount of stormwater pollutants can disable the wastewater treatment. This option to have two pumps in operation towards Ryaverket instead of one is thus unsustainable for reducing the contaminated load to recipient. Therefore, a wastewater treatment at site is a sufficient solution for reducing the contamination volumes, both to the receiving water and the water discharged to Ryaverket.

Although urban contaminants discharged towards Ryaverket will be reduced by revoking first flush, commercial production and the difficulty to manage and apprehends sludge remains. By evoking political discussion about where to deal with the contamination from urban areas an improvement of sludge quality and discharge quality can be obtained.

A further recommendation is to make an overview of vulnerability for extreme events. Pinpoint locations on the network that are keys for protecting the station from flooding in case of extreme inflow volumes.

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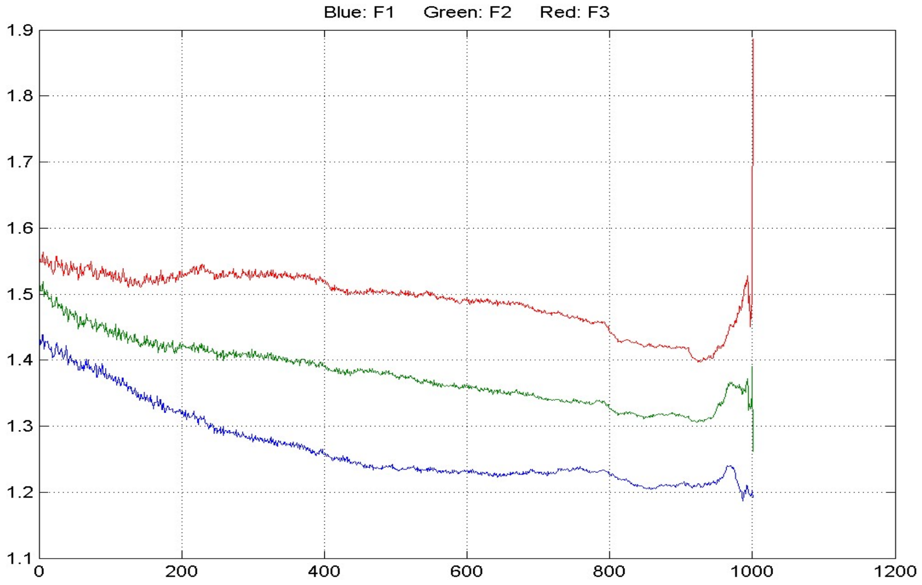
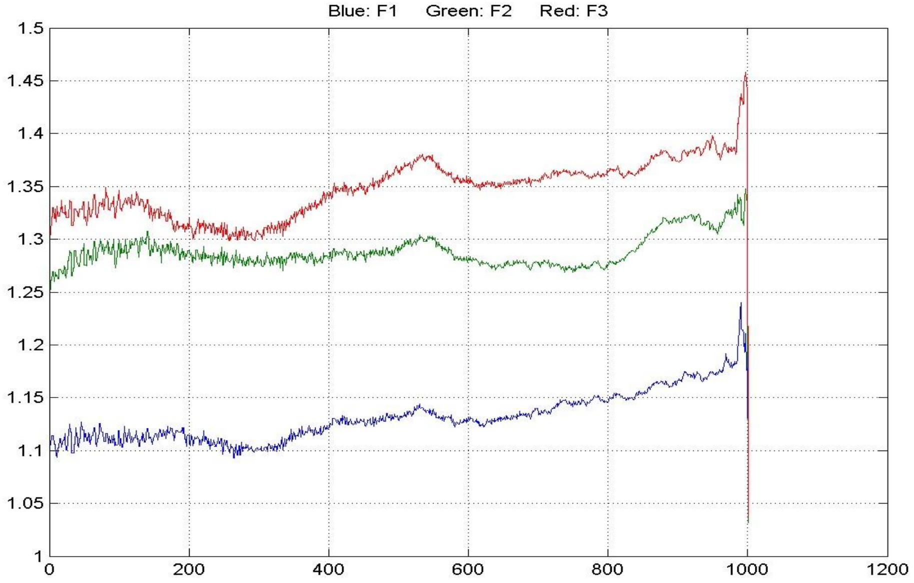
Appendix A

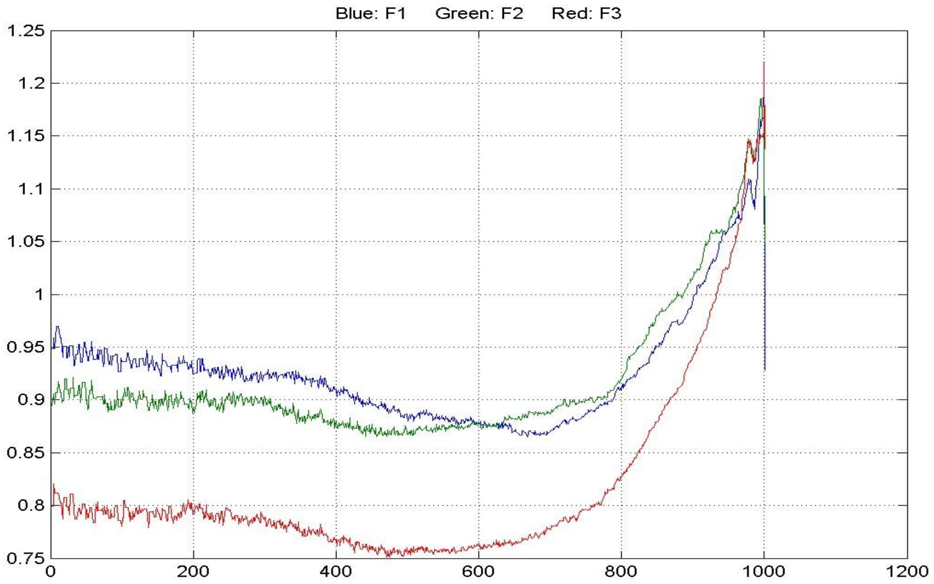
A.1 Delta change diagrams, emission scenario A2



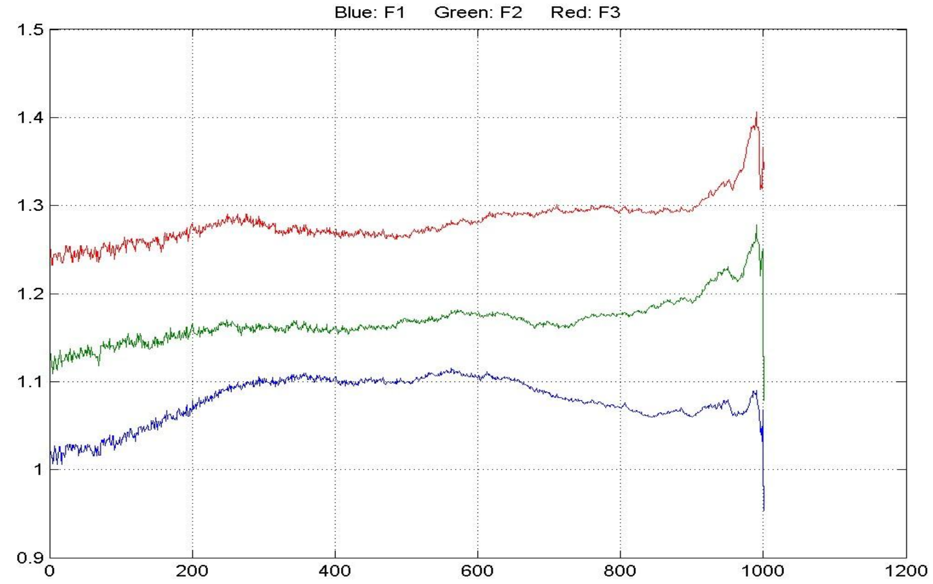
The diagram shows the future change in precipitation thus percentiles of dc factors distribution, emission scenario A2 are shown for the seasonal time period, December, January and February.



The diagram shows the percentiles of the dc factors distribution, emission scenario A2 are shown for seasonal time period Mars, April, and May.

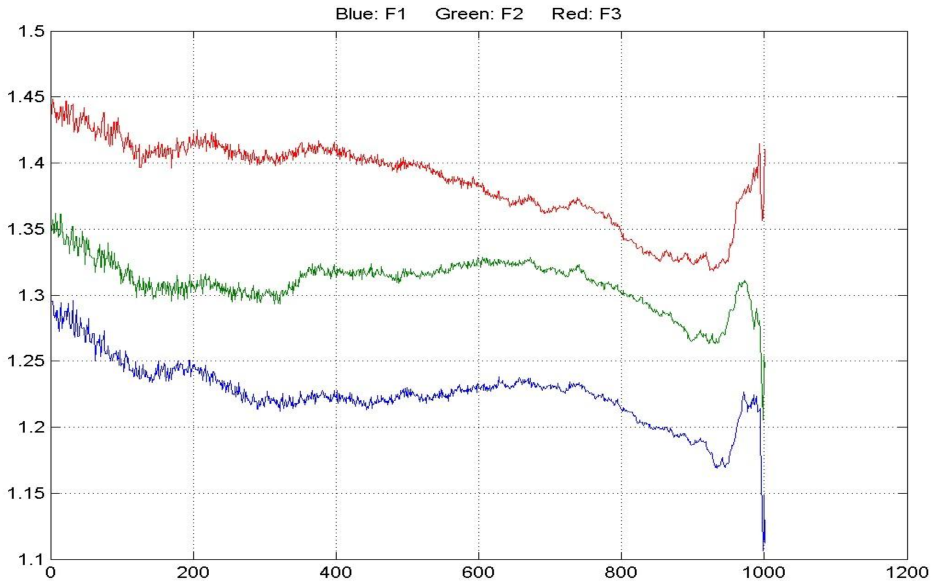


June, July and August are shown for emission scenario A2.

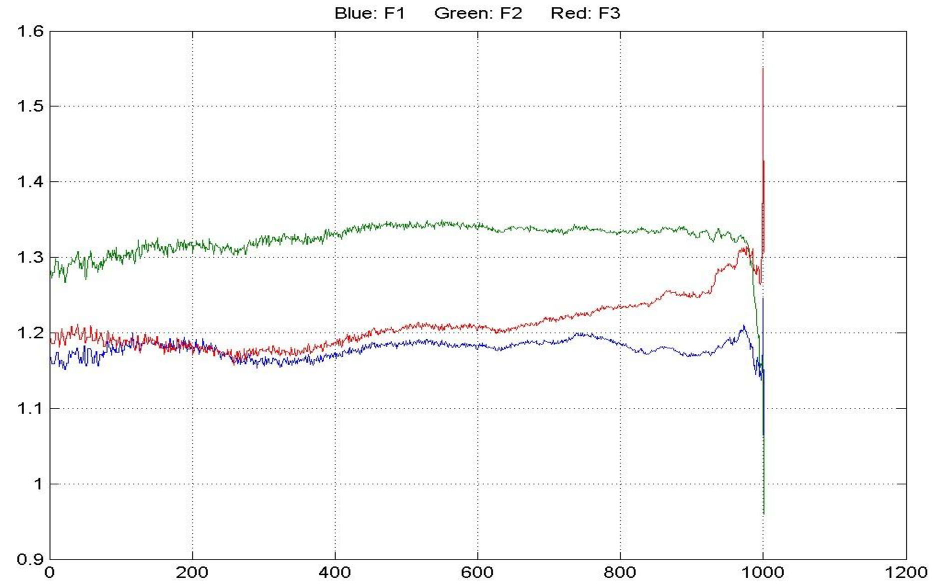


September, October and November are shown for emission scenario A2.

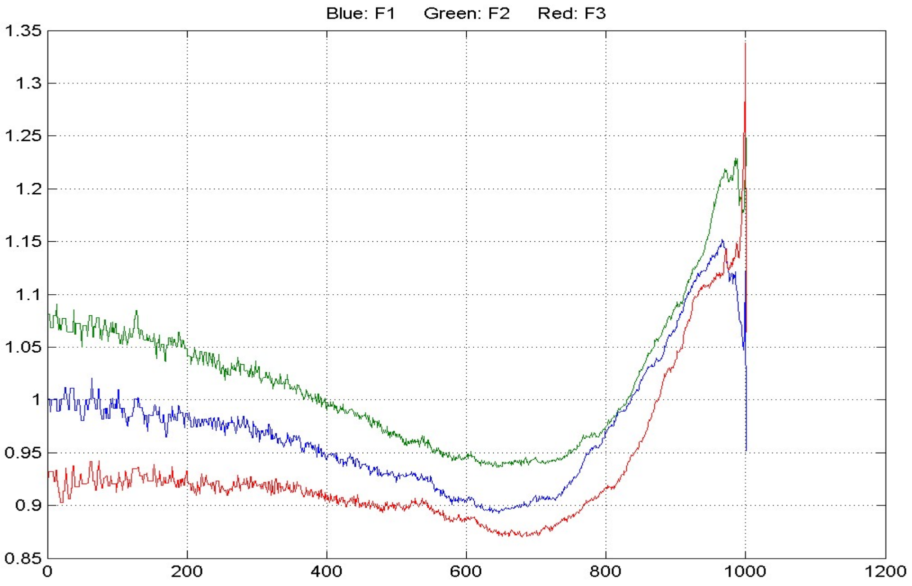
A.2 Delta change diagrams, emission scenario B2



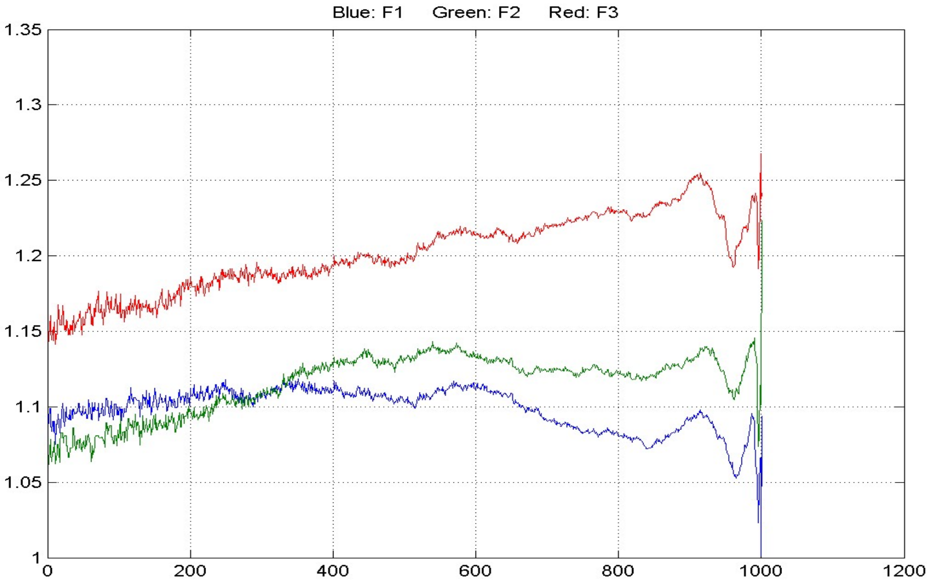
December, January and February are shown for emission scenario B2.



Mars, April and May are shown for emission scenario B2.

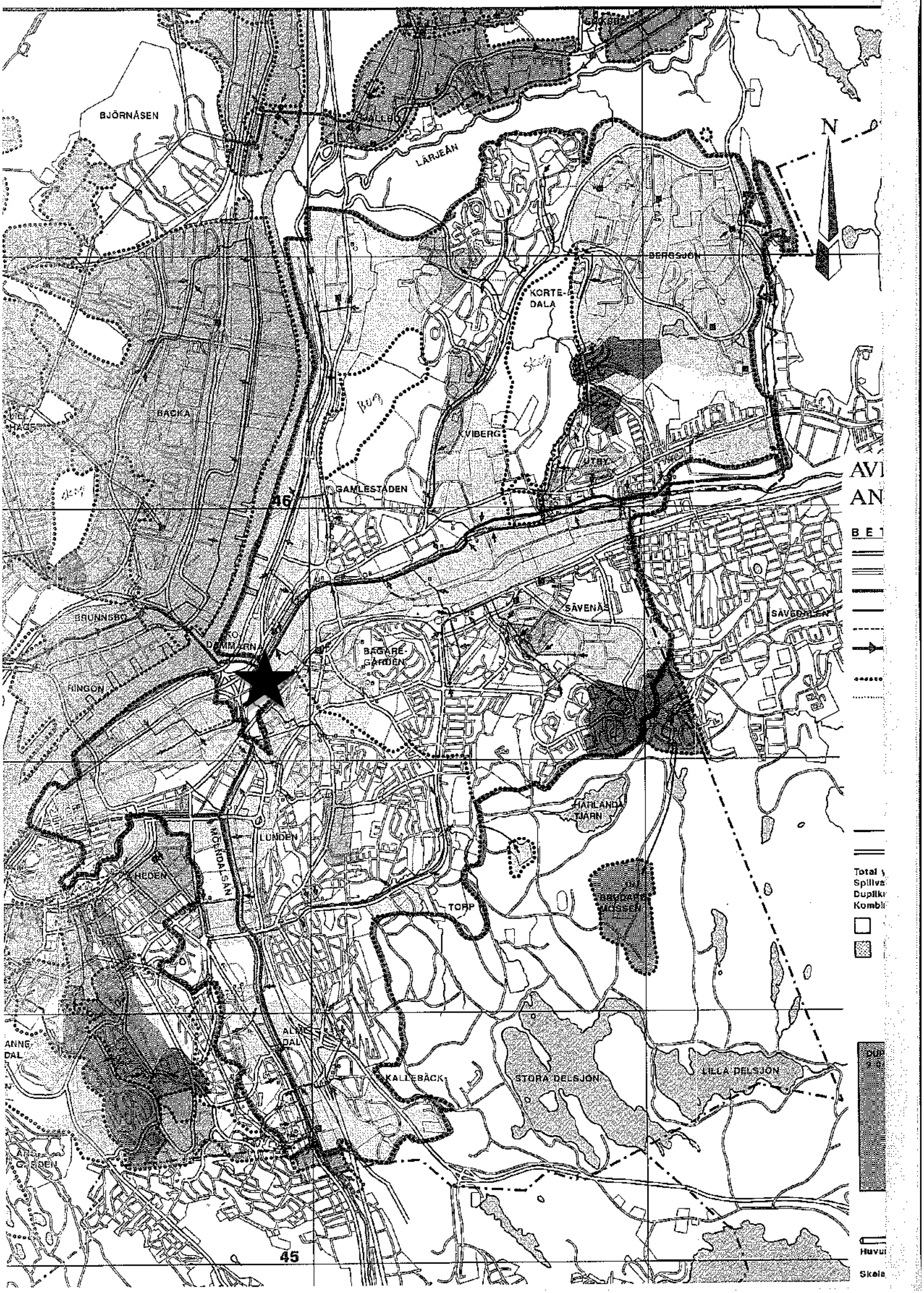


June, July and August are shown for emission scenario B2.



September, October and November are shown for emission scenario B2.

Appendix B



Area in Gothenburg that channel its wastewater through Kodammarna pumping station. The pumping station is located at the star.

Appendix C

Drainage areas connected to Kodammarna wastewater pumping station. Spreadsheet from Gothenburg water. The total drainage areas are correct, but the person equivalents and sewage flow values are old data and have been revised since the table was made. The values used in this thesis project are total values for person equivalents; sewage flow and dry weather flow calculated from measured incoming flow to Kodammarna and have not been broken down into drainage areas.

	Drainage area	Drainage area	Total area	Impermeable surfaces	*Dry weather flow*	*Person equivalents*	*Sewage flow*
No.	No.	Name	[Ha]	[Ha]	*[l/s]*	*[Pe]*	*[l/s]*
163	1.1	Kodammsgatan	20.20	0.00	*1.24*	*383*	*0.89*
163	1.2.1	Svangatan	81.20	23.93	*20.82*	*6425*	*14.87*
163	1.2.2	Storkgatan	18.20	0.50	*2.63*	*813*	*1.88*
163	2	Kodammsbron	5.30	3.18	*0.17*	*51*	*0.12*
163	3.1	Walckes gata	8.00	6.40	*0.67*	*208*	*0.48*
163	3.2	Bohusbanan	32.30	0.00	*3.85*	*1188*	*2.75*
163	3.3	Slakthusgatan	39.70	0.00	*1.38*	*425*	*0.98*
163	3.4.1	Marieholmsleden	30.80	0.00	*1.12*	*344*	*0.80*
163	3.4.2	Trojenborgsgatan	15.10	4.83	*1.64*	*505*	*1.17*
163	3.4.3	Nylösegatan	62.90	0.00	*8.16*	*2517*	*5.82*
163	3.4.4	Arfvidssonsgatan	18.10	10.86	*7.34*	*2266*	*5.25*
163	3.5	Alekärrsgatan	11.50	0.00	*0.20*	*62*	*0.14*
163	3.6	Marieholmsgatan	16.70	0.00	*0.36*	*110*	*0.25*
163	3.7	Alelyckan	37.00	0.00	*0.50*	*155*	*0.36*
163	3.8	Alelyckan S	85.70	0.00	*0.52*	*161*	*0.37*
163	4	Gamlestaden	27.80	0.00	*3.96*	*1221*	*2.83*
163	5	Säve Strandgata	17.20	4.20	*6.77*	*2088*	*4.83*
163	6	Sävenäs	13.00	0.00	*2.53*	*781*	*1.81*
163	7.1	von Utfallsgatan	24.00	9.60	*0.06*	*19*	*0.04*
163	7.2	Munkebäcksgatan	16.30	6.52	*1.66*	*512*	*1.19*
163	7.3.1	Ernst Torulfsgatan	20.40	10.20	*5.15*	*1588*	*3.68*
163	7.3.2	Colliandersgatan	12.00	6.00	*1.03*	*319*	*0.74*
163	7.3.3	Stobéegatan	110.10	44.04	*20.15*	*6219*	*14.39*
163	7.4	Torpavallen	6.50	2.28	*1.96*	*605*	*1.40*
163	7.5.1	Uddeholmsgatan	24.90	6.23	*1.61*	*498*	*1.15*
163	7.5.2	Billerudsgatan	5.00	1.25	*0.36*	*110*	*0.25*
163	7.6	Helleforsgatan	8.00	0.00	*5.08*	*1566*	*3.63*
163	7.7	Torpakolonin	9.00	0.00	*1.73*	*533*	*1.23*
163	7.8	Östra sjukhuset	51.00	0.00	*10.28*	*3173*	*7.35*
163	8	Furirsgatan	11.00	5.50	*1.22*	*376*	*0.87*
163	9.1	SKF	13.00	0.00	*1.82*	*562*	*1.30*
163	9.2.1	Kaggeledsgatan	24.00	7.20	*2.49*	*769*	*1.78*
163	9.2.2	Ellösgatan	50.00	15.00	*8.05*	*2484*	*5.75*
163	9.2.3	Lådämnesgatan	41.80	12.54	*8.77*	*2705*	*6.26*
163	9.3	Fjärrvärmecentralen	13.70	0.00	*2.74*	*845*	*1.96*
163	9.4	Gbg:s Kolsyre	40.00	0.00	*2.05*	*633*	*1.46*
163	9.5.1	Renhållningsverket	3.00	0.00	*6.64*	*2048*	*4.74*
163	9.6.1	Gränsvägen	41.20	17.68	*4.67*	*1442*	*3.34*
163	9.6.2	Snödroppegången	5.00	2.50	*0.12*	*38*	*0.09*
163	10.1.1	Styckjunkaregatan	20.10	1.44	*3.09*	*953*	*2.21*
163	10.1.2	Alivallsgatan	8.70	0.00	*3.24*	*998*	*2.31*

	Drainage area	Drainage area	Total area	Impermeable surfaces	*Dry weather flow*	*Person equivalents*	*Sewage flow*
No.	No.	Name	[Ha]	[Ha]	*[l/s]*	*[Pe]*	*[l/s]*
163	10.2	Fanjunkareg	43.20	3.73	*3.36*	*1037*	*2.40*
163	10.4	Befälsgatan	16.70	5.01	*2.01*	*620*	*1.44*
163	10.5.1	Månadsgatan	48.80	11.11	*9.44*	*2914*	*6.74*
163	10.5.2	Fullmånegatan	4.00	0.11	*0.40*	*122*	*0.28*
163	10.6.1	Kortedala torg	31.20	7.80	*5.83*	*1799*	*4.16*
163	10.6.2	Tideräkningsgatan	30.50	12.20	*5.10*	*1575*	*3.65*
163	10.7.1	Höstmånadsgatan	47.20	9.44	*8.08*	*2494*	*5.77*
163	10.7.2	Adventsvägen	37.50	15.00	*10.49*	*3237*	*7.49*
163	10.8.1	Aprilgatan	39.60	11.88	*7.39*	*2282*	*5.28*
163	10.8.2	Gräsmånadsgatan	4.10	0.00	*1.02*	*315*	*0.73*
163	11.1	LV 6	47.80	0.00	*0.10*	*31*	*0.07*
163	11.2	Brodalen	9.10	1.53	*0.52*	*160*	*0.37*
163	12.2	Bäckeflatsgatan	20.20	5.05	*1.67*	*514*	*1.19*
163	12.3	Österhedsgatan	6.70	2.00	*0.46*	*143*	*0.33*
163	12.4	Ungbrodersgatan	17.80	2.82	*2.21*	*682*	*1.58*
163	12.5	Snörmakaregatan	26.80	6.70	*2.22*	*685*	*1.59*
163	12.6.1	Barefjällsgatan	55.10	0.00	*2.88*	*890*	*2.06*
163	12.6.2	Teleskopgatan	12.70	0.00	*2.68*	*828*	*1.92*
163	12.7	Lilla Björn	46.10	0.60	*6.54*	*2017*	*4.67*
163	12.8.1	Gärdsåsgatan	36.30	0.00	*7.47*	*2305*	*5.34*
163	12.8.2	Galaxgatan	24.50	0.00	*4.04*	*1248*	*2.89*
163	13	Orrebacksgat	3.80	0.00	*0.28*	*87*	*0.20*
163	14	Strandängen	16.50	5.95	*1.48*	*458*	*1.06*
163	15	Fyrisvägen	11.30	2.33	*0.99*	*304*	*0.70*
163	16.1	Österlyckan	37.30	18.65	*5.69*	*1756*	*4.06*
163	16.2	Fjällbogatan	95.00	18.60	*3.20*	*989*	*2.29*
163	17.1	SJ:s vagnverk	29.60	0.00	*0.59*	*182*	*0.42*
163	17.2.1	Meteorgatan	28.20	0.00	*4.25*	*1311*	*3.04*
163	17.2.2	Bergsjösvängen	6.00	0.00	*1.01*	*311*	*0.72*
163	17.2.3	Kosmosgatan	38.30	0.00	*7.10*	*2190*	*5.07*
163	17.3	Bergsjödalen	68.60	0.00	*3.08*	*950*	*2.20*
163	17.4.1	Saturnusgatan	11.80	0.00	*2.15*	*664*	*1.54*
163	17.4.2	Rymdtorget	21.90	0.00	*11.00*	*3395*	*7.86*
164	1.1	Martin Anderssons gata	27.90	0.78	*14.93*	*4607*	*10.66*
164	1.2	Danska vägen	42.70	11.40	*22.42*	*6920*	*16.02*
164	2.1	Skansenbangården	32.00	0.18	*5.73*	*1769*	*4.10*
164	2.2	Gullbergsvass	24.10	0.00	*0.71*	*219*	*0.51*
164	2.3.1	Trollhättegatan	20.00	1.60	*6.77*	*2089*	*4.83*
164	2.3.2	Stadstjänaregatan	8.00	6.40	*2.76*	*852*	*1.97*
164	2.4	Mårten Krakowgatan	32.30	0.00	*12.32*	*3803*	*8.80*
164	2.5	St Hamnkanalen	24.60	13.44	*12.50*	*3858*	*8.93*
164	2.6.1	Kronhusgatan	12.30	0.00	*10.93*	*3372*	*7.80*
164	2.6.2	Norra Hamngatan	9.80	2.40	*5.30*	*1635*	*3.78*
164	3	S Gubberogatan	33.50	5.78	*6.47*	*1996*	*4.62*
164	4	Garverigatan	15.60	7.42	*5.29*	*1633*	*3.78*
164	5	Åvägen	26.70	9.20	*7.38*	*2277*	*5.27*
164	6	Burgrevegatan	35.50	25.44	*18.96*	*5852*	*13.55*
164	7	Ullevigatan	25.80	7.44	*2.23*	*689*	*1.59*

	Drainage area	Drainage area	Total area	Impermeable surfaces	*Dry weather flow*	*Person equivalents*	*Sewage flow*
No.	No.	Name	[Ha]	[Ha]	*[l/s]*	*[Pe]*	*[l/s]*
164	8	Drakegatan	16.30	0.00	*5.70*	*1759*	*4.07*
164	9	Tritongatan	22.50	5.94	*7.07*	*2183*	*5.05*
164	10.1	Skånegatan	18.80	9.96	*9.19*	*2836*	*6.57*
164	10.2	Berzeliigatan	19.30	13.51	*7.65*	*2360*	*5.46*
164	10.3.1	Korsvägen	26.70	11.29	*8.13*	*2509*	*5.81*
164	10.3.2	Södra vägen	5.00	2.50	*3.06*	*943*	*2.18*
164	10.3.3	Kristinehöjdsgatan	4.50	3.15	*3.33*	*1027*	*2.38*
164	11.1	Danska vägen	3.20	1.28	*0.36*	*111*	*0.26*
164	11.2	Delsjövägen	35.10	12.16	*3.93*	*1214*	*2.81*
164	11.3.1	Bäckeliden	15.50	2.33	*1.80*	*557*	*1.29*
164	11.3.2	Humlegårdsgatan	31.80	10.27	*4.72*	*1456*	*3.37*
164	11.4	Bögatan	59.00	17.70	*9.63*	*2973*	*6.88*
164	11.5.1	Birkagatan	55.50	2.86	*4.76*	*1470*	*3.40*
164	11.5.2	Sjölyckan	3.80	0.00	*0.16*	*50*	*0.12*
164	11.6.1	Welandergatan	27.60	4.14	*3.41*	*1051*	*2.43*
164	11.6.2	Skatås	6.50	0.00	*0.04*	*11*	*0.03*
164	11.7	Arosgatan	37.50	15.00	*5.78*	*1785*	*4.13*
164	12	Nejlikevägen	42.70	1.05	*1.94*	*598*	*1.38*
164	13.1	Mölndalsvägen	16.80	0.00	*7.63*	*2355*	*5.45*
164	13.2	Buråsliden	11.00	6.60	*3.13*	*965*	*2.23*
164	14	Milpålegatan	8.90	4.45	*1.23*	*380*	*0.88*
164	15.1	Grafiska vägen	20.70	0.80	*1.62*	*500*	*1.16*
164	15.2.1	Mejerigatan	56.20	0.90	*25.24*	*7790*	*18.03*
164	15.2.2	Saab Space	5.30	0.00	*0.29*	*90*	*0.21*
164	15.2.3	Gundla mosse	3.70	0.00	*0.75*	*230*	*0.53*
164	15.3	Kallebäcksvägen	14.60	3.65	*2.65*	*817*	*1.89*
164	15.4	Gulsparvsgatan	40.00	7.00	*3.01*	*929*	*2.15*
164	15.5	Boråsvägen	18.90	10.66	*4.48*	*1382*	*3.20*
164	15.6	Lövträdsgatan	22.70	13.62	*1.63*	*503*	*1.16*
164	15.7	St Sigfridsgatan	17.10	5.99	*3.08*	*951*	*2.20*
164	16	Fredriksdalsgatan	20.80	3.50	*6.65*	*2051*	*4.75*
164	17	Nordgårdsgatan	3.60	1.37	*1.25*	*386*	*0.89*
164	18	Falkenbergsgatan	3.80	1.44	*0.86*	*264*	*0.61*
164	19	Varbergsgatan	5.50	2.31	*1.24*	*384*	*0.89*
TOTAL			**3145.30**	**609.26**			

Appendix D

Mean annual contamination load on recipient from the sewage overflow. The squared boxes indicate that the released load would actually decrease if incoming water up to 4.2 m^3/s were treated in-situ or forwarded to Ryaverket instead of discharged at this location point.

Annual contaminant load								
	Ni		Pb		Cd		Zn	
	weir overflow		weir overflow		weir overflow		weir overflow	
[kg]	one pump	two pumps	one pump	two pumps	one pump	two pumps	one pump	two pumps
TC	14.99	2.13	12.68	1.82	0.54	0.08	121.84	17.08
A2FC1	23.39	3.37	19.80	2.88	0.85	0.12	190.19	27.03
A2FC2	30.81	4.90	26.10	4.19	1.12	0.18	250.21	39.33
A2FC3	37.69	6.19	31.94	5.29	1.37	0.23	305.90	49.67
B2FC1	23.34	3.31	19.76	2.83	0.85	0.12	189.65	26.62
B2FC2	28.07	4.50	23.78	3.84	1.02	0.16	228.01	36.13
B2FC3	31.75	5.22	26.90	4.46	1.15	0.19	257.75	41.87

Mean annual contamination load on recipient from the sewage overflow for contaminants Tot-N, Tot-P, Cu and Hg.

Annual contaminant load								
	N		P		Cu		Hg	
	weir overflow		weir overflow		weir overflow		weir overflow	
[kg]	one pump	two pumps	one pump	two pumps	one pump	two pumps	one pump	two pumps
TC	8 751.88	844.72	1 305.45	126.10	17.38	2.21	0.12	0.02
A2FC1	13 680.90	1 366.62	2 040.67	204.00	27.14	3.51	0.19	0.03
A2FC2	17 497.53	1 979.75	2 610.10	295.52	35.40	5.11	0.24	0.04
A2FC3	21 126.16	2 484.29	3 151.45	370.84	43.13	6.44	0.30	0.05
B2FC1	13 476.00	1 367.01	2 010.15	204.05	26.96	3.47	0.19	0.02
B2FC2	15 986.61	1 842.33	2 384.70	275.00	32.29	4.71	0.22	0.03
B2FC3	17 894.47	2 093.15	2 669.34	312.46	36.39	5.43	0.25	0.04