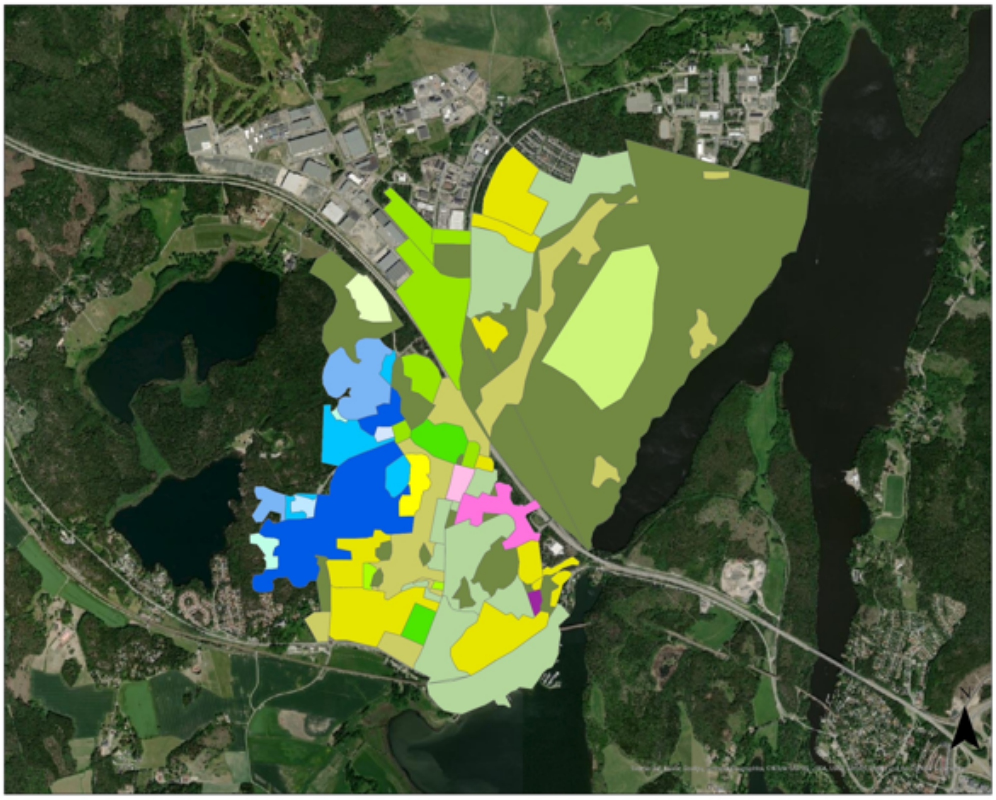

The impact of specific stormwater discharges on recipients

Detailed development planning and environmental quality standards

Master's thesis in the Master's Program Infrastructure and Environmental Engineering

KLARA LARSSON
JOHANNA PETTERSSON

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
Division of Water Environment Technology

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se

MASTER'S THESIS ACEX30

The impact of specific stormwater discharges on recipients

Detailed development planning and environmental quality standards

Master's thesis in the Master's Program Infrastructure and Environmental Engineering

KLARA LARSSON
JOHANNA PETTERSSON

Department of architecture and civil engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021

The impact of specific stormwater discharges on recipients

Detailed development planning and environmental quality standards

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

KLARA LARSSON
JOHANNA PETTERSSON

Examensarbete ACEX30
Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola, 2021

Supervisors:
Mia Bondelind, Chalmers University of Technology, Gothenburg
Emma Nilsson Keskitalo, Norconsult, Gothenburg
Johan Södergren, Norconsult, Gothenburg

Examiner:
Ann-Margret Hvitt Strömvall, Chalmers University of Technology, Gothenburg

Department of Architecture and Civil Engineering
Division of Water Environmental Technology
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Cover: Visual presentation of land use division of the watershed area of recipient Mälaren-Görväln, located in Upplands-Bro, Stockholm.

The impact of specific stormwater discharges on recipients
Detailed development planning and environmental quality standards
Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering
KLARA LARSSON
JOHANNA PETTERSSON
Department of Architecture and Civil Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY

Abstract

Stormwater poses a challenge with regards to urban expansion and the increase of impervious surfaces, resulting in pollution of receiving waters. The Water Framework Directive was adopted in the year of 2000 to tackle these issues. Sweden has adopted the Directive by developing Environmental Quality Standards for water bodies. The work with reaching and maintaining good status in all water bodies affects detailed development planning and its involved parties. In this study, the challenges concerning assessing the impact from stormwater discharges on the recipient when detailed development planning have been evaluated. A case study and an interview study were conducted in this project. The traditional stormwater assessment approach was evaluated using the modelling tools StormTac Web and MIKE Urban+. The area Gröna Dalen located in Upplands-Bro was used as a case study area. The area was evaluated by comparing the influence of different land use division choices, assessing its contribution to the annual stormwater pollutant load compared to the surrounding watershed area and by examining the possibility of developing site-specific guidelines. Results from StormTac showed that the land use division has a significant impact on the resulting stormwater pollution. The results also showed that the contribution of stormwater pollutant load from a delimited area compared to the entire watershed area was quite small, and that in order to develop proper site-specific guidelines, more input data would be required. Results from MIKE Urban+ were similar to StormTac results. The main impediment to stormwater quality modelling in detailed development planning was deemed to be lack of input data. However, there is an interest among concerned parties considering implementation of advanced modelling of stormwater pollution. The interview study was intended to compile the perspectives of parties concerned with stormwater quality assessments in detailed development planning. It included seven interviews. Results from the interviews showed that an array of difficulties are experienced by the requested parties. Overall, a need for increased timeframe and budget for consultants is required. Also, continued knowledge building and enhanced communication between parties are needed. Furthermore, it was deemed difficult and resource-intensive to develop general guidelines for stormwater quality in terms of discharging concentrations of stormwater pollutants.

Keywords: Detailed development planning, Environmental quality standards, MIKE Urban+, StormTac Web, Stormwater modelling, Stormwater pollution, Water Framework Directive, Water management, Weser verdict

Specifika dagvattenutsläpps påverkan på recipient
Detaljplanering och miljökvalitetsnormerna
Examensarbete inom masterprogrammet Infrastruktur och Miljöteknik
KLARA LARSSON
JOHANNA PETTERSSON
Institutionen for arkitektur och samhällsbyggnadsteknik
Avdelning for Vattenmiljöteknik
Chalmers tekniska högskola

Sammanfattning

Till följd av att städer expanderar har mängden hårdgjorda ytor ökat och lett till föroreningsbelastning på vattendrag. För att hantera dessa utmaningar utvecklades Vattendirektivet år 2000 för medlemsländerna i Europeiska unionen. I Sverige har direktivet tagits i bruk genom framtagningen av miljökvalitetsnormer för vatten. Arbetet med att nå och upprätthålla god status i vattendrag påverkar utformningen av detaljplaner och således alla dess involverade parter. I denna studie har de utmaningar som finns avseende att uppskatta påverkan från dagvattenutsläpp från detaljplan till recipient utvärderats. En referensstudie och en intervjustudie har genomförts. Den traditionella arbetsmetoden för en dagvattenutredning har utvärderats genom användning av modelleringsverktygen StormTac Web och MIKE Urban+. Området Gröna Dalen, beläget i Upplands-Bro, har använts för referensstudien. Området utvärderades med hänsyn till indelning av markanvändning, påverkan på den årliga föroreningsbelastningen från dagvatten jämfört med kringliggande avrinningsområdet och genom att försöka att ta fram platsspecifika riktlinjer för dagvattenkvalitet. Resultaten från StormTac Web visade att indelningen av markanvändningen hade en avgörande roll för mängden dagvattenföroreningar, att dess bidrag jämfört med hela avrinningsområdet blev relativt litet och att mer data hade krävts för att ta fram tillförlitliga platsspecifika riktlinjer. Resultaten från MIKE Urban+ liknade dem från StormTac Web. Brist på indata identifierades som den största begränsningen avseende implementering av dagvattenkvalitetsmodellering i detaljplanering. Emellertid fanns ett intresse hos de tillfrågade parterna för att använda mer avancerad modellering av dagvattenföroreningar. Intervjustudien var tänkt att sammanställa de olika perspektiven från de berörda parterna som involverads i detaljplaneplanering. Resultaten från intervjuerna visade på att olika svårigheter uppfattades av de tillfrågade parterna. Överlag efterfrågades en större tidsram och budget för konsulter som genomför dagvattenutredningar. Även ett behov av fortsatt kunskapsbyggande och utökad kommunikation mellan parterna identifierades. Vidare uppfattades det svårt och resurskrävande att utveckla generella riktlinjer för dagvattenkvalitet gällande utsläppskoncentrationer av dagvattenföroreningar.

Nyckelord: Dagvattenföroreningar, Dagvattenmodellering, Detaljplanering, MIKE Urban+, Miljökvalitetsnormerna, StormTac Web, Vattendirektivet, Vattenförvaltning, Weserdomen

Acknowledgements

This master's thesis was conducted in collaboration with Norconsult AB at the Department of Civil and Environmental Engineering at Chalmers University of Technology. We would like to thank our supervisors at Norconsult AB, Emma Nilsson Keskitalo and Johan Södergren, for all the help and support during this process. At Chalmers, we would like to thank our supervisor Mia Bondelind, for all the support, guidance and helpful inputs during the entire work process. We would also like to thank our examiner Ann-Margret Strömvall.

Furthermore, we would like to thank Sten Blomgren at DHI, for providing us with the student licenses for MIKE Urban+. We also want to express gratitude towards Thomas Larm for reviewing our results from StormTac Web. We would also like to thank Lennart Lorick at Falkenberg municipality for taking the time to answer all our questions and providing us with greater knowledge about stormwater management. We would also like to send a special thanks to all the co-workers at the VA-team at Norconsult AB for their helpfulness. We would especially like to thank Samatar Abdi for all the help with MIKE Urban+. Moreover, we would like to thank all the respondents in our interviews for taking the time to be involved and contribute with many valuable insights for our thesis.

Finally, we would like to thank our respective partners, families and friends for always being there and supporting us throughout this process.

Gothenburg, June 2021

Johanna Pettersson and Klara Larsson

Table of Contents

List of Figures

List of Tables

Abbreviations

CAB	County administrative board
Cd	Cadmium
Cr	Chromium
Cu	Copper
DDP	Detailed development plan
EC	Environmental Code
EMC	Event Mean Concentration
EQSs	Environmental Quality Standards for water
EU	European Union
Hg	Mercury
LAV	Lagen om allmänna vattentjänster (Law of Public Water Services)
LID	Low Impact Development
N	Nitrogen
Ni	Nickel
P	Phosphorus
PAH	Polycyclic aromatic compounds
Pb	Lead
PBA	Planning- and Building Act
SS	Suspended solids
SWMM	Stormwater Management Model
VISS	Vatteninformationssystem Sverige (the Swedish Water Information Database)
WFD	Water Framework Directive
Zn	Zinc

1. Introduction

The challenge of stormwater is increasing with regards to increasing amounts of impervious surfaces resulting from urban expansion (Goulden et al., 2018). Urban water management was developed before stormwater was considered an issue, where stormwater was discharged outside the cities. However, traditional water management results in several negative consequences, e.g., pollutants being discharged in recipients (Bertrand-Krajewsk, 2020). Another consequence is the enhanced stress on the traditional water management system. Coupled with the prediction of increasing and intensified precipitation due to climate changes, the challenge of stormwater continues to grow (Boverket, 2019).

Stormwater varies in quality and quantity depending on land use and other sources affecting the pollution load. For instance, traffic, industries and building material influence stormwater composition (Ekka et al., 2021). Stormwater affects the nearby area and contributes to impacts on the receiving waters (Marsalek, 2003). Currently, around 8% of all stormwater is being treated in Sweden, leaving the rest to be released into recipients without treatment (Naturvårdsverket, 2019a). It has been acknowledged since the 1960's that stormwater pollutes recipients. Despite this, the transition from traditional to more sustainable approaches to stormwater management have been relatively slow in Sweden (Cettner et al. 2012).

Sweden is a member state of the European Union. To protect European waters and prevent the water quality from being compromised, the Water Framework Directive (WFD) was adopted in the year of 2000. The WFD implies that all member states are obliged to achieve good ecological and chemical status of water bodies as well as maintaining good status of those already possessing it. The status is measured by a selection of quality parameters concerning ecological and chemical status. In addition to this, the Weser verdict C-461/13 BUND V GERMANY, which concerned possible negative effects on the Weser river due to construction, clarified how the non-deterioration principle, included in the WFD, should be interpreted. The non-deterioration principle, as interpreted from the Weser verdict, implies that the deterioration of a single quality parameter is not allowed, as opposed to before, when deterioration implied that an entire status class would deteriorate (Paloniitty, 2016).

The Swedish interpretation of the WFD is expressed as Environmental Quality Standards (EQSs) for water. The EQSs are developed using the Swedish Environmental Code (Miljöbalken [MB], 1998:808) (EC). The EQSs for water are centered around the status of all types of lakes and waterbodies. Specific regulations for assessing the status of a recipient have been developed by Havs- och Vattenmyndigheten (Havs- och Vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten, 2019). However, there are no nationally implemented regulations, nor guidelines, for stormwater quality (Jacobs et al., 2009).

The municipalities are responsible for proving that the EQSs will be fulfilled when developing detailed development plans (Boverket, 2014). The county administrative boards are, in their turn, responsible for ensuring that the EQSs are fulfilled in detailed development plans (Boverket, 2015b). Besides the EQSs expressed in the Swedish EC (MB, 1998:808), the Planning and Building Act (PBA) (SFS 2010:900) and Lagen om allmänna vattentjänster (LAV) (SFS 2006:412) regulate stormwater in detailed development plans. Currently, most of the responsibility is placed on the municipalities to manage and treat stormwater within the borders of public land. In this, a discussion concerning whether a more equal distribution of responsibility should be implemented between the municipality and the private property owner has emerged (Svenskt Vatten, 2020).

An issue lifted by the Swedish association of water utilities, Svenskt Vatten (2016b), concerning the implementation of the EQSs and the non-deterioration principle is that enhancing factors are not considered, i.e., if a single parameter is deteriorated but all others enhanced, a project is not allowed. An example which has been highlighted is the development of wastewater treatment plants due to an increased population, which is required according to the Urban Waste Water Directive (91/71/EEG), but not allowed according to the WFD and the Weser verdict. However, potential difficulties concerning how stormwater quality demands should be assessed within the scope of following the EQSs has not been lifted in literature. Therefore, this issue will be handled in this thesis.

1.1 Aim

The aim of this thesis is to evaluate the challenges concerning assessing the impact from stormwater discharges on the recipient when developing detailed development plans. The case study performed evaluates the traditional approach to stormwater assessments.

1.2 Research questions

The formulated research questions (RQs) of this thesis are

RQ1. What difficulties do consultants, county administrative boards and municipalities experience in their respective work tasks and co-operation connected to stormwater management and the environmental quality standards?
RQ2. What has potential to be improved in a traditional stormwater assessment concerning evaluating pollutants in stormwater from a detailed development area?
RQ3. What are the benefits of using the modelling tools StormTac Web and MIKE Urban+ within the scope of detailed development planning when evaluating the pollutant load from stormwater on the recipient, and what has potential to be improved?
RQ4. Can general guidelines be suggested for evaluating the impact on the recipient from stormwater discharges from a detailed development area?

1.3 Delimitations

The numbers of conducted interviews were restricted. The interview study was also dependent on the engagement of the parties requested to be interviewed. Some requested parties did not reply.

The case study carried out was, due to lack of time and resources, confined to evaluating the stormwater quality from a specific area and resulted in a site-specific study. As for the data used, it was limited to the data available for the area investigated and therefore, no field sampling was done. The selection of pollutants analyzed was narrowed. The selection was based on the most common forms of stormwater pollutants being assessed as well as the pollutants of most concern for the recipient in the case study. These included metals and nutrients. The issue of stormwater quality was only dealt with within the scope of detailed development planning.

The modelling programs used in the case study was limited to StormTac Web and MIKE Urban+, due to the time needed to understand the software and that using solely the two was considered sufficient.

2. Theory

In this chapter, a literature background of stormwater is provided. This chapter firstly covers urbanization relating to stormwater and stormwater pollution. Secondly, it covers the Water Framework Directive and the Swedish Environmental Quality standards for water. A swift outlook of water management outside of the European Union is presented. Thirdly, it covers how stormwater is managed in Sweden, and how it is assessed in detailed development plans. Lastly, stormwater quality modelling is dealt with, where StormTac Web and MIKE Urban+ are described further.

2.1 Urbanization and stormwater pollution

Surfaces unable to infiltrate water produce stormwater during the event of heavy rain. Urban areas such as industrial areas, roads and commercial areas contribute to stormwater production. The amount of stormwater produced increases with the level of imperviousness. The hydrologic impacts of urbanization can lead to an array of consequences (Liu et. al., 2015), such as an increase of flood risk and degradation of land (Shaver et al., 2007). Impacts associated with stormwater quality pollution influence the surrounding areas and consequently receiving waters (Marsalek, 2003). An array of pollutants can be found in stormwater runoff. Although many of them are known, there are still pollution sources not yet identified (Müller et al., 2020).

The largest stormwater pollutant source is suspended solids, which is also considered to be of most concern. Its properties enable other pollutants to sorb onto its surface. Sources of suspended solids include construction sites, rooftops and roads (Liu et al., 2015). Heavy metals are another example of pollutants existent in stormwater, due to either anthropogenic or natural activities. The heavy metals considered to be of most concern are Cd, Cu, Pb, Ni, Cr and Zn. The largest anthropogenic source of heavy metals in stormwater are traffic related activities (Gunawardena et al., 2018).

Furthermore, traffic is a big contributor of microplastics (Andersson-Sköld et al., 2020) as well as polycyclic aromatic compounds (PAHs) (Gunawardena et al., 2018). Currently traffic generates around 50% of all microplastics. The largest source of microplastics is tire wear, but other sources such as material and painting of the road are also contributors. The resulting emissions from microplastics spread throughout the environment and affect water bodies. However, the knowledge of these small fragments of plastics are limited and the subject requires more investigations (Andersson-Sköld et al., 2020). PAHs largely stem from traffic related activities (Gunawardena et al., 2018) such as vehicle exhaust, tire rubber as well as from petroleum products (Markiewicz et al., 2017). 16 priority PAH compounds have been identified due to their inherent toxicity and genotoxicity to aquatic life (Gunawardena et al., 2018).

Consequences for receiving waters due to stormwater pollution are divided into three types of impacts: physical, chemical and microbiological pollution (Marsalek, 2003). Physical impacts include, as mentioned above, risk of flooding and erosion (Marsalek, 2003; Shaver et al., 2007), while chemical impacts can cause negative effects on human and aquatic life. Other than metals (Andersson-Sköld et al., 2020) and pesticides (Marsalek, 2003), an excess of nutrients is an example of a chemical impact. Nutrients include P and N, which stem from, for example, lawn fertilizers and animal waste. An effect of excess nutrients in receiving waters is eutrophication, which is the process of abundant plant growth resulting in oxygen depletion, consequently resulting in the production of anaerobic bacteria and depletion of aquatic organisms (Liu et al., 2015).

Microbiological pollution impacts are due to discharge of fecal bacteria, i.e., *E. coli,* which also causes negative effects on human and aquatic life (Marsalek, 2003).

Stormwater has traditionally been handled by curbs, gutters and pipes (Qiao et al., 2019). For combined systems it results in stormwater, joint with wastewater, being discharged to a wastewater treatment plant. During normal weather conditions, all water is treated and therefore the possibility of releasing different types of pollutants is reduced. However, the composition of the stormwater and domestic wastewater differs and would therefore preferably need different types of treatments (Butler & Davies, 2004). During periods of heavy rain, the capacity of the combined sewer system may be overridden, resulting in direct discharge of stormwater and wastewater into water bodies without treatment (Qiao et al., 2019). In separate systems, wastewater is first treated at its source or directly discharged to nearby receiving waters. Overflow does not occur in separate systems to the same extent, since the wastewater does not burden the wastewater treatment plant (Butler & Davies, 2004). The estimated annual percentage of stormwater being treated is 8% in Sweden (Naturvårdsverket, 2017).

2.2 The Water Framework Directive

In 2000, the Water Framework Directive 2000/60/EC (WFD) was adopted by the European Union (EU). The WFD applies to all member states and its purpose concerns the protection of European waters. It is an effort to ensure that the water quality is not compromised. Further, it was deemed necessary to develop legislation which covers ecological quality to avoid long-term deterioration of freshwater quality and quantity (European Commission, n.d.). According to the WFD, it is the obligation of the member states to work with achieving as well as maintaining good status in water bodies. For water bodies so heavily impaired by anthropogenic activity that it is unfeasible to achieve good status, less stringent objectives can be implemented, although further deterioration should be prevented. The approach of working to achieve the goals of the WFD has been divided into different cycles, where each cycle covers a period of six years (Voulvoulis et al., 2017).

The initially set goal of achieving good status for all surface waters was due in the year of 2015 (European Commission, 2019). The goal has not been reached within the set timeframe. Approximately 40% of the European surface waters reach ‘good’ ecological status, while the rest are still in need of various measures for the target to be reached. As for the chemical status, 38% of surface waters reach ‘good’ status as of 2018 (European Environment Agency, 2018).

2.2.1 The Weser verdict and the non-deterioration principle

The implementation of the WFD has been influenced by the Weser case C-461/13 BUND V GERMANY, which took place in Germany. A project which concerned a deepening through dredging of the river Weser was planned, where the dredged masses would be dumped by the mouth of the river. When the case was brought to the Supreme Federal Administrative Court, it was ruled that the deterioration of a single quality parameter within a status class implies a deterioration of the overall status. Before the Weser verdict, deterioration implied the total deterioration of a status class. The project was therefore not allowed (Bjällås et al., 2015), and the verdict cleared up some confusion of how the WFD should be interpreted. The ‘non-deterioration principle’, that is, the obligation to prevent quality deterioration has since been undertaken in projects concerning possible effects on receiving waters (Paloniitty, 2016).

Implications concerning the non-deterioration principle have been reported, as the principle makes it impossible to consider enhancing factors. A project which results in the deterioration of a single quality parameter is rejected. It is irrelevant whether it results in the enhancement of other quality parameters. Another issue of the non-deterioration principle has been lifted by Svenskt Vatten (2016b). The reported issue is the paradox of the implementation of the Weser verdict resulting in a collision between the WFD and the Urban Waste Water Directive 91/271/EEG. According to the latter directive, it is obliged to, upon an increase in residentials within an urban area, develop wastewater treatment plants. The implication of this is that regardless of application of best available technology, due to the increased population the load on the recipient from the wastewater treatment plant will likely increase. According to the Weser verdict, in cases such as this, development of wastewater treatment plants will not be allowed (Svenskt Vatten, 2016b).

2.2.2 Environmental Quality Standards

Environmental quality standards (EQSs) are Swedish regulations containing guidelines for several different types of environmental impacting emission sources. The EQSs were developed using the Environmental Code (Miljöbalken [MB], 1998:808) (EC). They are expressed in three sub-categories, focusing on noise, air, or water (Naturvårdsverket, 2020). The EQSs for water (henceforth referred to as the EQSs) were developed at the end of the 20th century and set out to change the focus from previously used instruments. The overall focus of the EQSs is that all water bodies shall reach good status. The EQSs are devised by agencies from the Swedish government (Havs- och vattenmyndigheten, 2020).

The EQSs were developed with the aim of adopting the directives developed by the EU in the WFD. They are centered around the status of all types of lakes and waterbodies. If the EQSs are fulfilled, the waterbody is set to have 'good' status. 'Good' status implies that the impacts from different sources does not influence the waterbody negatively (Vattenmyndigheterna, n.d.b). In order to map the status of Swedish waterbodies, Vatteninformationssystem Sverige (VISS), a Swedish database, has been developed by the Swedish water authorities, the county administrative boards (CABs) and Havs- och Vattenmyndigheten. VISS provides information of the larger lakes, watercourses, groundwaters and coastal waters in Sweden. The status class of waterbodies is found here, as well as ongoing or planned measures for improvement of the status class. Maps of the waterbodies are also available, as well as environmental protection areas. All assessments intended to evaluate the status of water bodies must be reported to and made available at VISS (2018). It has been voiced that the collection of data to VISS needs to increase to broaden the base of knowledge in the work with the environmental quality standards. Furthermore, there is a need for better regulation of data collection in VISS, due to that legal contexts rely on this data (Svenskt vatten, 2015).

Sweden is divided into five different water districts, according to decisions stated in the EC (MB, 1998:808). Each district has been assigned to a selected CAB which acts as the agency responsible for following the EQSs within the district. The five different districts and CABs are presented in Table 1 (Vattenmyndigheten, n.d.c.).

Table 1. Responsible county administrative boards (CABs) in each water district (Vattenmyndigheterna, n.d.c).

Water district	County administrative board
Bottenviken	Norrbotten
Bottenhavet	Västernorrland
Norra Östersjön	Västmanland
Södra Östersjön	Kalmar
Västerhavet	Västra Götaland

The Swedish water authorities are responsible for tasks such as revising management plans, regulate EQSs and water management work, as well as withhold a cooperation on all levels within the water sector. The Swedish water authority is also responsible for handing over collected data to Havs- och Vattenmyndigheten. In every water district, a water delegation is responsible for implementing the decisions of the water authorities (Vattenmyndigheterna, n.d.d). All the 21 county administrative boards have evaluation secretariats attached to them, which handle for instance data and expert assessments for status classification of recipients (Vattenmyndigheterna, n.d.e). In link to related issues of water management in Sweden the association of public water utilities, Svenskt Vatten has been an active contributor of highlighting various difficulties surrounding the EQSs (Svenskt Vatten, 2021). They have also developed publications concerning sustainable stormwater management that have been adopted by the industry (Svenskt Vatten, 2019).

2.2.3 Quality parameters deciding the status of a waterbody

Havs- och vattenmyndigheten is responsible for classification of surface watercourses (Havs- och Vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten, 2019). The two categories assessed in the classification are ecological status and chemical status. Chemical status is decided based on whether limit concentrations are exceeded for a selected number of pollutants. The ecological status is expressed as its potential of reaching or maintaining its reference conditions, and can be either ‘high’, ‘good’, moderate’, ‘poor’ or ‘bad’. The chemical status is classified either as ‘good’ or ‘bad’. For a watercourse to be classified as of bad chemical status, only one substance needs to exceed its limit concentration. According to the latest assessment concerning ecological status made by VISS, 1% of surface water bodies in Sweden are of bad status, 4% of poor status, 45% of moderate status, 24% of good status and 11% of high status. 14% are not classified due to lack of data. 87% of surface waters are of bad chemical status, while 13% are of good status (VISS, n.d.b).

2.2.4 Water management outside of the European Union

Similar implementation of approaches such as the EQSs in countries outside of the EU have not been identified. However, in USA the Ambient Water Quality Criteria has been implemented and in Canada, the Canadian Drinking Water Quality Guidelines (Inglezakis et. al., 2016). The Ambient Water Quality Criteria are similar to the WFD, containing a centralized structure and legally binding water quality standards (US EPA, n.d.b).

In Canada the water management system is decentralized. This means that the 13 provinces and territories, which the country is divided into, all have their own approach to water management work. Since the system is not heavily regulated, the provinces have carried out their own basis for policymaking. This approach has been evaluated in scientific reports to determine potential benefits or shortcomings compared to more centralized structures, such as in the US and in the EU. Conclusions were that the lack of a general approach outweighs the benefits of local system knowledge. Further, an approach that reminds of the Swedish structure with the EQSs, was presented as beneficial (Dunn et al., 2014).

2.3 Stormwater management in Sweden

The majority of stormwater in Sweden is currently handled by piped drainage systems. The main reason for this is that a large part of the piped network was built when stormwater was not yet considered an issue (Cettner et al., 2012). However, the issue of shifting from piped systems to other alternatives for stormwater management has been dealt with for at least 40 years. A study conducted in 1959 concluded that due to heavy pollution, stormwater should not be deposited directly into a watercourse (Cettner et al., 2013). Further, in association with an increased awareness of pollution and its effects, studies associated with the stormwater quality from roads and cities were carried out in the 1970s as a result of stricter environmental regulations. These studies concluded that stormwater from these sources contained oil, fat and heavy metals (Cettner, 2012). Furthermore, strong evidence suggests that heavy precipitation will increase and intensify in Sweden as a result of climate change (Svenskt Vatten & SMHI, 2020), which has made it necessary to manage stormwater runoff (US EPA, n.d.a).

The implementation of green infrastructure has in recent years increased. Cities worldwide implement it in order to reduce the quantity, and improve the quality, of stormwater runoff (Liao et al., 2017). The concept has been given many names; low impact development (LID) in USA, low impact urban design and development (LIUDD) in New Zealand, sustainable urban drainage systems (SUDS) in the UK and so on (Qiao et al., 2019). The main principles of green infrastructure imply dependency on natural processes whereas traditional management of stormwater depends on engineered. Natural processes include biophysical ones: detention, storage, infiltration, and biological uptake of pollutants. Some examples of green infrastructural stormwater solutions are rain gardens, bioswales, dry or wet ponds and green roofs (Liao et al., 2017).

Despite the increased implementation of green infrastructure worldwide, as well as it being known for a long time that stormwater is polluting, the process of changing from traditional approaches has been slower in Sweden (Cettner, 2012). Moreover, the sustainable stormwater measures have been implemented primarily only in relation to new exploitation (Cettner et al., 2012). Brown & Farrelly (2009) have identified 12 different parameters negatively affecting the implementation of sustainable stormwater measures, where the three parameters reported to occur most frequently were uncoordinated institutional framework, limited community engagement and participation and limits of the regulatory framework. Other parameters identified include uncertainties regarding roles and inherent responsibilities, poor communication and lack of political and public will. They suggest that in order to tackle this problem, actions are necessary which target the inherent relationships of, and structures associated with institutions concerned with stormwater management. Other problems identified in the implementation of stormwater measures, concerns uncertainties in the performance and cost of stormwater measures, resistance to change as well as lacking engineering standards and guidelines (Roy et al., 2008).

National guidelines and regulations for stormwater quality are lacking in Sweden. Nevertheless, according to the EQSs pollutant loads in stormwater from a specified area cannot lead to deterioration of the status in the connected recipient (Jacobs et al., 2009). Svenskt Vatten has developed the publication P110 for design of stormwater measures with regards to flow reduction. No publication is yet developed for pollution reduction (Svenskt Vatten, 2016a). As of in the beginning of year 2021, Naturvårdsverket has been assigned the task of ensuring sustainable stormwater management by the government. The assignment is divided into two phases, and the second phase is planned to be finished by 2025 (Naturvårdsverket, 2019b).

The City of Gothenburg has developed general stormwater pollutant guidelines applicable for stormwater discharges, which are dependent on the status of the recipients located in the city (Göteborgs stad, 2020). For the City of Stockholm, suggestions for general stormwater pollutant guidelines applicable for the city are also developed (Regionplane- och trafikkontoret, 2009). The guidelines are based on pollutant concentrations assumed to stem from less polluted areas, such as forests, meadows and normal residential areas. Furthermore, guidelines have been developed for parking spaces (Stockholms stad, 2016b) and neighborhood grounds (Stockholms stad, 2016a) in Stockholm. These are however based on a minimum requirement of stormwater detainment and not on pollutant concentrations, although the guideline documents contain suggestions of stormwater treatment facilities that can be implemented.

2.4 Stormwater in detailed development planning

The municipality is responsible for developing a relevant comprehensive plan and detailed development plans (DDPs). The comprehensive plan states the intended use of ground and water areas. It is not legally binding but should work as guidance for decision making about intended use of ground and water areas (Boverket, 2020b). The CABs are responsible for ensuring that the EQSs are fulfilled in comprehensive plans. In order to fulfill the EQSs in a comprehensive plan, the impact on water bodies by construction are considered early in the process. A potential negative impact on receiving water bodies is to be prevented. The land use should therefore be planned in such a way that the status classification of water bodies will not be lowered, which is measured using different qualification factors and limits (Boverket, 2015b).

A DDP must be developed by the municipality to evaluate whether an area is appropriate for exploitation or not. Exploitation includes new settlements and change of existing settlements. Detailed development plans are regulated by the Planning and Building Act (PBA) (Plan- och bygglagen [PBL], SFS 2010:900). In a DDP public grounds, quarter grounds and water areas are declared. It is the responsibility of the CAB to either accept, change, or reject a DDP depending on whether it is decided that the DDP ensures that the EQSs are to be followed. A DDP must state how the occurrence of water within the area is intended to be handled. The PBA (SFS 2010:900) controls the usage of ground- and water areas, as well as supplies the municipality with tools for detailed development planning. According to the PBA (SFS 2010:900) settlements should be localized on appropriate ground, with respect to, e.g., soil- bedrock- and water conditions, possibilities of providing for water demands and sewage, as well as the risk of flooding (PBL, 2010).

Apart from the PBA (SFS 2010:900), other legislation regulating stormwater in a detailed development plan include Lagen om allmänna vattentjänster (SFS 2006:412) (LAV) and the EC (MB, 1998:808). There is no legal definition for stormwater. However, it is included in the definition of sewage water in LAV (SFS 2006:412): *"*Discharge of stormwater and drainage water from an area with collected settlement." In a proposition (2005/06:78) the definition of stormwater is "occasional flows of for example rainwater, meltwater, irrigation water and protruding groundwater". According to LAV the municipality is responsible for supplying the need for water demands or sewage if it is needed in a larger context, however, it is not defined what a larger context implies (SFS 2006:412).

In the EC, stormwater is also included in the definition of sewage water. According to the EC, sewage water pertains to "water discharged for such dewatering not conducted for a certain or a few buildings". The EC considers discharge of sewage water to be an environmentally hazardous activity, and that it should therefore be treated or handled so that no inconvenience occurs for the health of people or the environment. Discharge of stormwater does, however, not necessarily pose an environmental hazard. In that case, stormwater can be defined as a water activity. Water activity occurs when an area is being dewatered, with the aim of increasing its appropriateness. In cases where stormwater management is not constituting environmentally hazardous activity nor water activity, there is no further legislation according to the EC (MB, 1998:808).

Difficulties concerning stormwater assessments in detailed development plans have been identified. Based on the regulations in the PBA (SFS 2010:900), the municipality is responsible for ensuring that the detailed development plan will not jeopardize the fulfilling of the EQSs. However, the PBA (SFS 2010:900) does not clearly state that the municipality can put demands on discharging stormwater flows and concentrations. Further, issues related to the lack of regulation of already existing development plans have been voiced. Instead, new development plans are often faced with high demands. There are also difficulties in assessing whether stormwater measures implemented fulfils the demands of pollution reduction and is properly maintained (Naturvårdsverket, 2017). In this, the use of compensatory measures, where stormwater unable to be treated within a DDP area can be dealt with in another area, have been highlighted. There are no regulations supporting the use of compensatory measures. However, it can be expected if the municipality and CAB claims that enough proof has been provided of its capability (Holmqvist et al., 2011).

2.5 Stormwater management responsibilities of municipalities and private property owners

Concerning stormwater management responsibilities of the municipalities, it is primarily the PBA (SFS 2010:900) and LAV (SFS 2006:412) that are relevant. In LAV (SFS 2006:412), the responsibility of the municipality is regulated and, in the PBA (SFS 2010:900), the planning of stormwater with regards to a sustainable future is regulated. Thus, the municipalities have a large responsibility for the management of stormwater (Länsstyrelsen Kalmar, 2018). In order to regulate the responsibility, the city council establishes a business unit (Swedish translation: verksamhetsområde) where facilities for water distribution and sewage are to be available. Within this area the municipalities are responsible for all stormwater concerning management and discharge. This applies to DDPs situated within the borders of the business unit. Within these borders the private property owners are relieved from all responsibilities of managing stormwater besides their own drainage (Boverket, 2020a).

The municipalities are obligated to plan for suitable drainage of a DDP but should not precise any specific measures. For example, they can describe the amount of hardened surface allowed, but not the exact size of a stormwater measure. According to the EC (MB, 1998:808), municipalities are responsible for fulfilling the EQSs and are therefore legally bound to do so. Individual actors do not have a legal responsibility but are instead indirectly affected by the decisions from the municipality. The municipalities can, for instance, regulate the number of impervious surfaces in a DDP. They are also allowed to regulate which private actors that can operate within their borders (Vattenmyndigheterna, n.d.a).

When a DDP is situated outside a business unit, the PBA (SFS 2010:900) and LAV (SFS 2006:412) no longer applies. Consequently, the responsibility of the municipality to manage the stormwater within the area decreases. Instead, the EC (MB, 1998:808) applies, and the responsibility is placed on the private property owner to manage the stormwater within their property. However, the municipality still have some responsibility in terms of supervision. The responsibility of the private property owners ends at the connection point, that is, where the pipes connect to the municipal water and sewage system. However, this does not apply if the private property owner is not connected to the municipal system. Then, the private property owner should instead implement LID solutions (Boverket, 2015a).

As a consequence of more estates being built, the demands on the municipalities to extend their business unit increases. This, in line with LAV (SFS 2006:412) and the requirement that the supply of water and sewage should be applied in a broader perspective. In practice, this implies that if more than approximately 25 households are connected, they should be included in the business unit. The result of this is an increasing demand on municipalities to manage more stormwater (Svenskt vatten, 2016c). They are also obligated to manage the stormwater on public land which has been highlighted as an issue in terms of lack of space and finance. Furthermore, the urban space available is limited, where different interests need to be coordinated (Stahre, 2008).

According to Svenskt Vatten (2020) it is difficult for the municipality to handle stormwater from both private and public ground and therefore it is necessary that all stakeholders, public and private, participate in taking measures. The current legislation makes it hard to access individual actors and businesses. According to Cettner (2012) other factors contributing to the issue are economical and space related. Different interests have to be coordinated within the municipal area. It is economically beneficial for the municipality to let developers exploit land for other uses than green infrastructure. It is further pointed out that infrastructure was originally constructed for handling stormwater by traditional piped systems. This implies there is a lack of sufficient space for implementation of stormwater measures.

In order to identify the current issues and improve the Swedish performance of implementation of water management, several inquiries have been conducted. The latest in a series was carried out by the Swedish Water Management Inquiry in 2019. The inquiry focused on the organization, including the responsible parties for planning of detailed development plans. Overall, the inquiry stated that lack of communication was an issue on all levels. Other central parts highlighted in the inquiry were the need for better structure of funding and increases in action work. The current structure involves many parties, and the complexity is, therefore, a widespread problem (Vattenförvaltningsutredningen, 2019).

2.6 Stormwater quality modelling

Stormwater quality modelling is useful as an instrument which can provide information about whether water quality goals set by regulatory authorities are met or not (Zoppou, 2001). It is an alternative to sampling, which is deemed expensive and sometimes not justified. This is partly due to that it only provides information about the current situation (Viklander et al., 2019). There are several models available for simulation of stormwater quality. The mathematical approach to the models differs, where they can be either stochastic or deterministic. Stochastic models utilize input data patterns in order to simulate phenomena, while deterministic models are based upon mathematical formulations (Clark, 1973). The models can also be classified as either lumped or distributed. Lumped models do not regard spatial variability, while distributed models to some extent do (Nix, 1994). Urban stormwater models typically contain the components rainfall-runoff modelling, the wash off-build up process of pollutants and modelling of transport through different media, such as, e.g., open channels and pipe networks. The processes of pollutants in urban areas are many, and includes, e.g., chemical processes, biological processes and physicochemical processes. In order to simulate stormwater quality, it is deemed necessary to first succeed in accurate modelling of stormwater quantity (Zoppou, 2001).

The inherent flaws of stormwater quality modelling include model complexity, lack of input data and model calibration and model uncertainty. The flaws are interlinked, since an increased model complexity requires more input data. Input data is not always accessible and reported to be an issue within stormwater quality modelling (Viklander et al., 2019). An increased level of complexity within a model requires calibration of more parameters to field data. According to Vezzaro et al. (2013) calibration of predictive models is seldomly done by modelers, which further increases the uncertainties of the models. Uncertainty assessments of stormwater quality modelling results are, as well as calibration, not conducted by modelers to a great extent. It is rather undertaken exclusively for academic purposes. Moges et al. (2021) evaluated six different techniques for evaluating the uncertainty of modelling stormwater quantity and quality. The techniques vary in complexity, and it was reported that the greatest differences between the techniques were computational endeavor and the required skills as well as expertise of the user.

There are a variety of stormwater quality modelling tools available on the market. They differ in type, where they can be either land use based, regression based, based on pollutant sources or process based (Viklander et al., 2019). An example of a land use-based modelling tool is StormTac Web, which is used in the case study and described in chapter 2.6.1. In a study the inherent uncertainties of modelling runoff flow and pollutant concentrations and loads in StormTac Web were evaluated. According to the results, it was indicated that there was a level of 24% uncertainty in modelling of runoff flow, and a level of 30% uncertainty in modelling of phosphorus (P), three metals and suspended solids (SS). The levels of uncertainties were reported to correspond to those of more complex stormwater quality models (Wu et al., 2021).

An example of a process-based model (Nix, 1994) is MIKE Urban+, which is also used in the case study and described in chapter 2.6.2 . The number of scientific articles handling modelling of stormwater pollution transport in MIKE Urban+ and its predecessor MIKE Urban is limited. However, Liu et al (2010), assessed the variability of the required inputs to the model when modelling stormwater quality. It was concluded that processes inherent of stormwater quality modelling shows extensive variability depending on, apart from land use, other characteristics as well. This was deemed to be a source of uncertainty of results.

Another example of a process-based model is Stormwater Management Model (SWMM). The model is strongly established worldwide and enables both flow and pollution simulation (Rossman, 2015). Similarly, to MIKE Urban+ and its predecessor, stormwater quality modelling is seldomly undertaken in SWMM. When SWMM is used in stormwater assessments, simplified methods are most often used which makes for time-sufficient simulations. However, the input values for the pollutants simulated are often retrieved from literature. Thus, the lack of site-specific data often results in high uncertainties (Tuomela et al., 2019). According to Niazi et al. (2017) there is a need for increased stormwater quality modelling without the requirements of sampling. Furthermore, Niazi et al. (2017) claim that the stormwater quality models need to be developed in such a way that makes them manageable without extensive user experience.

2.6.1 StormTac Web

StormTac Web is a modelling tool developed by Thomas Larm in a PhD study in the year of 2000. The modelling tool assesses the quality and quantity of stormwater (StormTac, n.d.), and is mostly used in urban planning (Viklander et al., 2019). It is a static model, meaning that average values are used as input data and the results are presented as average values per year. Therefore, extreme scenarios, such as periods of heavy rains, cannot be simulated. The model is built on simple principles and does not require much input data in order to provide a representation of pollutant generation and transport in stormwater. StormTac Web is also used to design and investigate the effectiveness of different stormwater management techniques. The calculations of the model are built on standard values. The values are selected based on a database which is constantly being updated to improve the accuracy in the model. The conditions can, however, be changed to site-specific if such data is available (StormTac, n.d.).

The approach of the inherent calculations of StormTac Web has been reviewed. According to Liu et al., (2012) besides the land use and impervious fraction being accounted for, the urban landform needs to be taken into consideration in order to obtain reliable results for pollution. The urban form includes the geographical distribution of urban areas, i.e., their position in relation to each other. There are no inherent functions in StormTac Web allowing for accounting for spatial distribution, although it is possible to manually account for it in a simplified manner (StormTac, n.d.).

StormTac Web is a web-based model, consisting of five interlinked modules: a runoff and baseflow module, a pollutant transport module, a stormwater treatment module, a receiving water module and a flow detention and transport module. See the worksheet, Figure 1, which is used when working in StormTac Web. Input parameters are handled by clicking the grey boxes. The arrows pointing from one module to the next represents the transmission of values to the next module (StormTac, n.d.). As the transport and flow detention module is not used in this thesis, it is not described further.

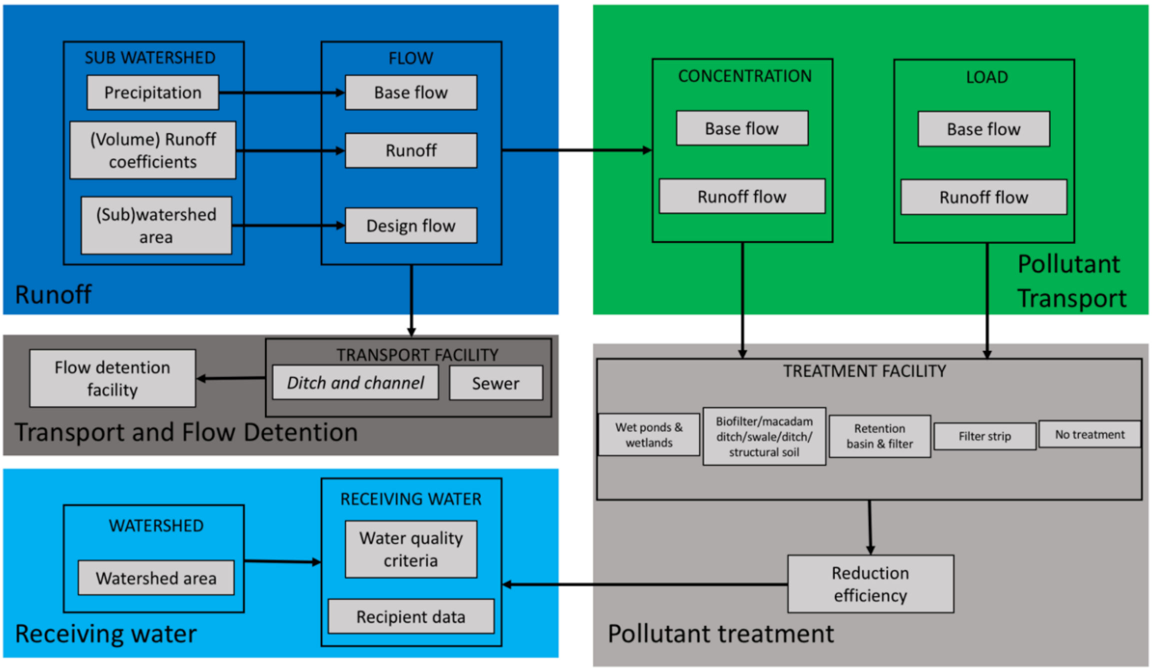

Figure 1. Schematic interpretation of StormTac Web. Author's picture.

In the runoff module, the yearly runoff flow Q is calculated using the parameters precipitation intensity, the yearly runoff coefficient for each land use and the size of each watershed area. The runoff flow is summarized from all sub-catchment areas according to equation 1 (Larm, 2000).

$$Q = 10p\sum_{i=1}^{N}(\varphi_i A_i) \qquad (1)$$

Q Runoff water flow [m^3/year]
p Rrecipitation intensity [mm/year]
φ_i Yearly runoff coefficient for land use i
A_i Size [ha] of land use i
i Land use i=1, 2, … N

Baseflow occurs between storms and runoff events (Delleur, 2006). Yearly baseflow is calculated according to equation 2, 3 and 4 (Larm, 2000).

$$Q_b = 10K_x K_{inf} pA \qquad (2)$$

$$K_{inf} = \frac{p - p\varphi - E}{p} \qquad (3)$$

$$E = 1000(0.50 - 0.55\varphi) \qquad (4)$$

Q_b Base flow [m^3/year]
K_x Share of K_{inf} that reaches the base flow

K_{inf} Fraction of the yearly precipitation that is infiltrated (assuming that surface water storage is neglected or included in the parameter values φ and E)
p Precipitation intensity [mm/year]
A Size [ha] of land use
φ Yearly runoff coefficient
E (Potential) evaporation intensity [mm/year]

The standard concentrations for each substance are available in the StormTac Web database. Yearly average concentrations are based on flow weighted sampling performed over an extended time series. In the case not enough sampling has been done for a specific land use, the standard concentrations are based on calibrations with case studies or on comparisons with land uses with similar properties (Larm, 2000).

In the pollutant transport module, the yearly pollution load L_j is calculated with equation 5, where the pollutant transport model multiplies annual runoff volume with standard concentrations for each sub-catchment area (Larm, 2000).

$$L_j = \frac{\sum_{i=1}^{N}(Q_i C_{ij})}{1000} \tag{5}$$

L_j Yearly pollution load (mass flux) [kg/year]
Q_i Yunoff water flow [m^3/year]
C_{ij} Standard concentration [mg/l]
i Land use i=1, 2, … N
j Substance

The base flow pollutant load is then calculated using equation 6 (Larm, 2000).

$$L_b = \frac{Q_b C_b}{1000} \tag{6}$$

L_b Base flow pollutant load [kg/year]
Q_b Base flow [m^3/year]
C_b Measured base flow pollutant concentration [mg/l]

The pollutant treatment module contains measures that could be taken in order to improve the quality of the stormwater reaching the recipient. These measures include wet ponds, filter strips, constructed wetlands, open ditches, swales and detention basins. It shall be noted that in order to determine the most suited measure, site specific investigations are needed (Larm, 2000). Equation 7 and equation 8 jointly describes the removal efficiency for wet ponds and wetlands (Larm & Alm, 2016).

$$RE = \left[k_1 * \ln\left(\frac{A_p}{A\varphi}\right) + k_2\right] * f_{Cin} * f_{veg} * f_{bypass} * f_{Vd} * f_{Cirr} * f_{temp} * f_{shape} \tag{7}$$

$$A_p = \varphi A K_{A\varphi} \tag{8}$$

RE Reduction efficiency for wet ponds and constructed wetlands [%]
k_1, k_2 Regression coefficients specific for each substance and facility
A_p Area of permanent pool [m^2]
A Total area of wet pond or wetland [m^2]
φ Specific runoff coefficient [-]
$K_{A\varphi}$ Regression constant, normally 150 (70-400) for wet ponds and 300 (100-800) for wetlands
f_{Cin} Factor for inlet concentration
f_{veg} Factor for vegetation
f_{bypass} Factor for bypass
f_{Vd} Factor for detention volume
f_{Cirr} Factor for irreducible concentration
f_{temp} Factor for temperature
f_{shape} Factor for shape

The reduction efficiency for grass ditches, swales, infiltrations trenches and biofilters is described by equation 9 (Larm & Alm, 2016).

$$RE = \left[k_1 * \ln(K_\varphi) + k_2\right] * f_{Cin} * f_{veg} * f_{bypass} * f_{Vd} \tag{9}$$

RE Reduction efficiency for grass ditches, swales, infiltrations trenches and biofilters [%]
K_φ Regression constant, facility specific [%]

The recipient model utilizes limit values for concentrations and loads of contaminants in order to compare these to corresponding stormwater pollutant concentrations. Developed stormwater quality criteria is available in the database and is updated as new criteria becomes available. The model determines which pollutant concentrations are considered to be acceptable depending on the sensitivity of the recipient. This is done in order to evaluate which emissions should be considered in terms of need of treatment (Larm, 2000). The total pollutant load L_{in} is calculated by equation 10.

$$L_{in} = L + L_b + L_a + L_{point} + L_{rel} \tag{10}$$

L_{in} Total pollutant load on the recipient [kg/year]
L Stormwater pollutant load [kg/year]
L_b Baseflow pollutant load [kg/year]
L_a Atmospheric deposition [kg/year]
L_{point} Point pollutant load on the recipient from other sources than above presented [kg/year]
L_{rel} Internal load from the sediments to the water of the recipient [kg/year]

The acceptable pollutant load L_{acc} on the recipient, if no input data for the concentration of the pollutant in the water mass is available, is calculated by equation 11. If input data of concentration of the pollutant in the water mass of the recipient is available, the acceptable load is calculated by equation 12. Needed reduction ΔL for the water quality criteria is calculated by equation 13 (Larm, 2003).

$$\mathrm{L_{acc}} = \mathrm{V_{rec}} \left(\frac{\mathrm{C_{cr}}}{\mathrm{x_j}}\right)^{\frac{1}{\mathrm{y_j}}} \frac{\left(1 + \mathrm{t_{dr}^{0.5}}\right)}{\mathrm{t_{dr}}} \tag{11}$$

$$\mathrm{L_{acc}} = \frac{\mathrm{C_{cr} L_{in}}}{\mathrm{C_{rec}^{*}}} \tag{12}$$

$$\Delta \mathrm{L} = \mathrm{L_{in}} - \mathrm{L_{acc}} \tag{13}$$

$\mathrm{L_{acc}}$ Acceptable (critical) pollutant load on the recipient [kg/year]
$\mathrm{V_{rec}}$ Water volume of the recipient [m^3]
$\mathrm{C_{cr}}$ Critical pollutant concentration on the water mass of the recipient for negative effects [mg/l]
$\mathrm{x_j}$, $\mathrm{y_j}$ Empirical coefficients for pollutant j
t_{dr} Recipient residence time, $t_{\mathrm{dr}} = \frac{V_{rec}}{\mathrm{Q_{out}}}$ [year]
$\mathrm{C_{rec}}$ Pollutant concentration in the water mass of the recipient [mg/l]
* Measured
$\Delta \mathrm{L}$ Pollutant load to be reduced for the acceptable load $\mathrm{L_{acc}}$ [kg/year]
$\mathrm{L_{in}}$ Total pollutant load on the receiving water [kg/year]

2.6.2 MIKE Urban +

MIKE is a software series developed by the Danish Hydrological Institute (DHI). The software package includes several modelling tools which provide the possibility to simulate and analyze aquatic environments such as floods, sediment transportation or water quality (DHI, n.d.) Its predecessor MIKE Urban is one of the most frequently used stormwater modelling tools in Sweden. The program is built on the computer engine Mouse and Mousetrap which is also developed by the Danish Hydrological Institute. The model is frequently used for simulating stormwater flows in piped systems and on catchment areas. Furthermore, the model can be used for simulating pollution transport (Viklander et al., 2019).

MIKE Urban has been available since the computer engine Mouse was developed in 1984. Mousetrap, which the pollutant simulations are built upon, was developed ten years later and includes the characteristics and processes of each pollutant. The areas of usage for the model are therefore large, and detailed pollutant transports can be traced. However, much input data is required for each pollutant which increases the uncertainties. The user is required to possess much knowledge about the program and each pollutant (Viklander et al, 2019).

MIKE Urban+ has recently, as of 2021, been updated to the new version of MIKE Urban, which is included in the newly released integrated modelling tool MIKE+. MIKE Urban+ is a GIS-based model and allows for simulation of both collection systems (CS) and water distribution systems (WD). In addition, the 2D Overland module is coupled with the CS-module in order to simulate pollution and flows (DHI, 2020b). MIKE+ contains several modelling tools, such as MIKE Urban+, MIKE FLOOD and Mike 21, in one program. In this study MIKE+ will be used, containing the MIKE Urban+ license activated within the program. When researching literature concerning use of MIKE Urban+ in projects, no articles were found, which is due to that the modelling tool has been launched quite recently. MIKE Urban+ corresponds to 2D functionality along with modelling and simulation of pipe networks (DHI, 2020a). For this reason, MIKE Urban+ will be explained further in the methodology.

The CS model describes the sub-surface network system and consists of an array of hydraulic elements. In order to simulate how the water in the drainage network system behaves, DHI's MIKE 1D calculation engine is utilized. It has replaced the formerly implemented MOUSE engine, since the pervious package to model CS and river have been joint together. The resulting has provided an increased calculation reliability (DHI, 2017). MIKE 1D is based upon the St. Venants equation (DHI, 2019). The St. Venant equation is the finite difference numerical solution of one-dimensional water equations and consists of two equations. Equation 14 takes into account the mass balance in the channel and is a continuity equation describing the water level in the channel depending on differences in in- and outflow. Equation 15 is a momentum equation describing the change of speed and movement of the water in the channel (DHI, 2020d).

$$\frac{\partial q}{\partial x} + \frac{\partial A_{fl}}{\partial t} = q_{in} \tag{14}$$

$$\frac{\partial q}{\partial t} + \frac{\partial \left(\alpha \frac{q^2}{A_{fl}} \right)}{\partial x} + gA_{fl}\frac{\partial h}{\partial x} + gA_{fl}l_f = \frac{f}{\rho_w} \tag{15}$$

q	discharge
A_{fl}	flow area
q_{in}	lateral inflow / length unit
g	gravity constant
h	water level
α	momentum distribution coefficient
l_f	flow resistance
f	momentum forcing / length unit
ρ_w	density of water

In order to simulate stormwater quality, the hydrological model first needs to be set up. The sub-module used for this is Rainfall-Runoff. This sub-module employs number of catchments and catchment connections, amount and interval of precipitation, runoff calculation as well as type of hydrological model. Catchments are defined as geographical polygon areas, which are then assigned model parameters and input data. Each catchment can be assigned unique parameters. Catchment connections specify where the runoff from the catchment flows into the network while precipitation involves site specific input data. The hydrological model includes surface runoff models and continuous hydrological models. The computed runoff makes up the hydraulic load on the network, and therefore the simulation occurs in two steps; firstly, the runoff is computed, and, secondly, the impact on the network from the load is computed (DHI, 2020c).

For surface runoff models, the event of rainfall results in runoff, and the runoff reduces to zero again after the rainfall has ended. There are different hydrological surface runoff models available for modelling: the Time-Area method, the Kinematic Wave method, the Linear Reservoir (C1 and C2) method and the Unit Hydrograph method. Which surface runoff model that is suitable for modelling depends largely on the amount of available information about the area assessed (DHI, 2020d). The principle of the Time-Area method is that the amount of runoff is controlled by three factors: initial loss, size of the contributing area and continuous hydrological loss. The only input data required for this method is the fraction of the catchment that is impervious [%]. This method contains the least hydrological parameters of the available methods. The hydrological parameters can be edited depending on the properties and available data of the catchment (DHI, 2020c).

Since precipitation, flows, land use coefficients are already set up in the model used in this study, only the stormwater quality (SWQ) and the advection-dispersion (AD) module will be added to the CS module. The SWQ module simulates stormwater runoff overland while the AD module simulates pollutant transport in the network (DHI, 2020c).

When modelling SWQ the global data must be defined. In the data editor, three parameters are to be specified: Initial ADWP, Minimum ADWP and Event threshold. ADWP stands for the adjacent dry weather period. The initial ADWP is to be defined as the number of hours of a dry weather period before the scenario was run. Minimum ADWP is the length of the dry period between precipitation events during the scenario. Event threshold is the maximum intensity set as the minimum limit value that should be involved in the scenario (DHI, 2020d).

Four different methods can be used for simulating stormwater quality processes (SWQ): simple concentration, table concentration or the two advanced methods Build-up/Wash-off or Event Mean Concentration (EMC). In this study the EMC method will be used and is therefore described further. The EMC method implies the same build-up mechanisms as the Build-up/Wash-off process. The build-up process describes the accumulation of pollutants or sediments on the surface during dry weather periods. The build-up during dry periods is assumed to be either linear or exponential functions of time. The exponential build-up function is given in equation 16 (DHI, 2020c).

$$\frac{\partial \mathrm{M}}{\partial \mathrm{t}} = \mathrm{A_c} - \mathrm{D_{rem}}\mathrm{M} \tag{16}$$

M accumulated mass per area of pollutants at time t [kg/ha]
t time in days
$\mathrm{A_c}$ daily accumulation rate [kg/ha/day]
$\mathrm{D_{rem}}$ removal coefficient [1/ha/day]

Pollutants are attached to the build-up of sediments through equation 17 (DHI, 2020d).

$$M_{i,Pollutant} = f_{i,PS} M_{sediment} \tag{17}$$

$M_{i,Pollutant}$	mass of pollutant [kg]
$f_{i,P}$	simple fraction [%]
$M_{sediment}$	mass of sediment [kg]

The parameter maximum EMC (mg/l) is used in the SWQ advanced method module to prevent the resulting EMC concentration in the stormwater during a rain event from becoming unreasonably high. The maximum EMC is the highest concentration that can be detected in the stormwater runoff from each catchment. If a dry period is long lasting, this parameter is used to reduce unreasonably high values of build-up and wash-off during rain events with low intensity (DHI, 2020c).

Sediments are used as an input to the Sediment Transport (ST) module while pollutants are used as an input to the Advection Dispersion (AD) module. The assumption of the wash-off process according to the EMC method is that it is not a dynamic process but related to the rainfall volume. It is assumed that all accumulated pollutants are washed off during a rainfall event. The pollutant concentration is calculated as a ratio between available pollutant mass and rainfall event volume. The water volume during a rain event is described by equation 18, which is a summation of all precipitation during a rainfall event (DHI, 2020d).

$$V = A \int_{t_{start}}^{t_{end}} i_r(t) dt \tag{18}$$

V	water volume during the rainfall
A	catchment area
i_r	rainfall intensity
t_{start}	start time of the rainfall
t_{end}	end time of the rainfall

The subsequent event mean concentration is then calculated by equation 19 (Maniquiz-Redillas et al., 2010). If several catchment areas partake in the simulation, pollutant mass and stormwater volume are summarized in order to retrieve the total mass and volume from the entire area.

$$EMC = \frac{\sum_{i=1}^{n} V_i C_i}{V} \tag{19}$$

EMC	event mean concentration [mg/l]
n	total number of samples during a single storm event
V_i	runoff volume proportional to the flow rate at time i
C_i	pollutant concentrtion at time i [mg/l]
V	total runoff volume per event [l]

The AD module allows for simulation of dissolved and suspended substance transport in the network. The assumptions related to the module are that the substance which is being simulated is assumed to be completely mixed, that the substance is either conservative or subject to linear decay, and that dispersive transport and concentration gradient are proportional to each other. In order to run, the model requires some input data. This input data includes either time series based on concentrations or initial concentrations, coefficients of dispersion or decay rates (DHI, 2020c).

Specification of decay coefficient can be specified. For non-conservative substances concentration, the decay can be expected to occur according to equation 20.

$$\frac{dC}{dt} = KC \tag{20}$$

K decay coefficient [1/h]
C concentration [µg/l]

The dispersion coefficient can be given either globally or locally and is defined as a function of flow, presented in equation 21.

$$D = au^b \tag{21}$$

D dispersion coefficient [m^2/s]
a dispersion factor [-]
u flow velocity [m/s]
b a dimensionless exponent [-]

3. Methodology

In this chapter, the methodology of the interview study is presented. Furthermore, the case study and the methodological implementations of the case study in StormTac Web and MIKE Urban+ are presented.

3.1 Interview study

Seven qualitative research interviews were conducted in this thesis. Qualitative research interviews are used to answer questions based on the experiences of individuals or organizations (Kvale & Brinkmann, 2014). First, information and knowledge about the subject was gathered through the literature study. During this process, questions emerged that were considered best answered through the interviews. Thus, the aims of the interview were formulated.

The aim when conducting the interviews was to gain insights to retrieve answers to the formulated research questions. Seven interviews were conducted with people representing different parties. This was done in order to gain understanding of the perception of how the aim of this thesis was perceived depending on party. The aim was to evaluate the challenges concerning assessing the impact from stormwater discharge on the recipient when developing detailed development plans. The number of respondents was limited to seven interviews partly as a result of the engagement of the parties requested as well as a limited timeframe. The interview questions formulated were centered around the environmental quality standards, stormwater treatment guidelines and detailed development planning. Interview questions for each interview are found in Appendix I. The parties represented in the interviews were authorities, municipalities and consultancy firms. The respondents are presented in Table *2*.

Table 2. Presentation of the interview number, the respondents, the respective role of the respondents and the date of the interviews.

No.	Respondent/s	Role	Date
1	Environmental consultant at Norconsult Gothenburg (group interview)	Consultant	24/02–2021
2	Representatives of the Water Districts Södra Östersjön, Bottenviken, Västerhavet, Norra Östersjön (the Water Authorities) (group interview)	Authority	23/03–2021
3	Water management planner at Falkenberg municipality with experience from working in Gothenburg municipality	Municipality	08/04–2021
4	Boverket	Authority	13/04–2021
5	County administrative board in Kalmar	Authority	15/04–2021
6	Stormwater consultant at Norconsult	Consultant	16/04–2021
7	Svenskt Vatten	Association of public water utilities	04/05–2021

The consultants interviewed are employed at Norconsult. Consultants were interviewed due to them being responsible for execution of assessments of stormwater quality within detailed development planning. Authorities were contacted via retrieving contact information on their respective website and sending a request via e-mail. The Water Authorities were interviewed due to their comprehensive responsibility of working with the environmental quality standards

(EQSs). Boverket was interviewed since they are responsible for the Planning- and Building Act (Plan- och bygglagen, SFS 2010:900) (PBA), a legislation relevant to detailed development planning. The county administrative board (CAB) was interviewed due to that it is their responsibility to review detailed development plans (DDPs). Six CABs were contacted, of which one responded to the request. Contact with the municipal water management planner was established via the supervisors at Norconsult. The water management planner had extended experience due to having previously worked with stormwater related issues in the municipality of Gothenburg and was therefore thought to provide insights about smaller as well as larger municipalities. Contact with Svenskt Vatten was established via retrieving contact information on their website and e-mailing a request. Svenskt Vatten were interviewed since they have been influential concerning many of the matters handled in this study. They also work as support for municipalities in stormwater related issues.

In Figure 2, the respective relationships, as interpreted from the literature study, between the parties interviewed are illustrated. The Water Authorities work as coordinators in stormwater management, coordinating the CABs and providing the municipalities with information of their watercourses. The municipalities orders stormwater assessments from consultants upon detailed development planning. Consultants then conduct stormwater assessments. The assessments are examined by the CAB in question, where it is determined whether it be approved, rejected or changed. The association of public water utilities, Svenskt Vatten, govern the stormwater management related interests of municipalities.

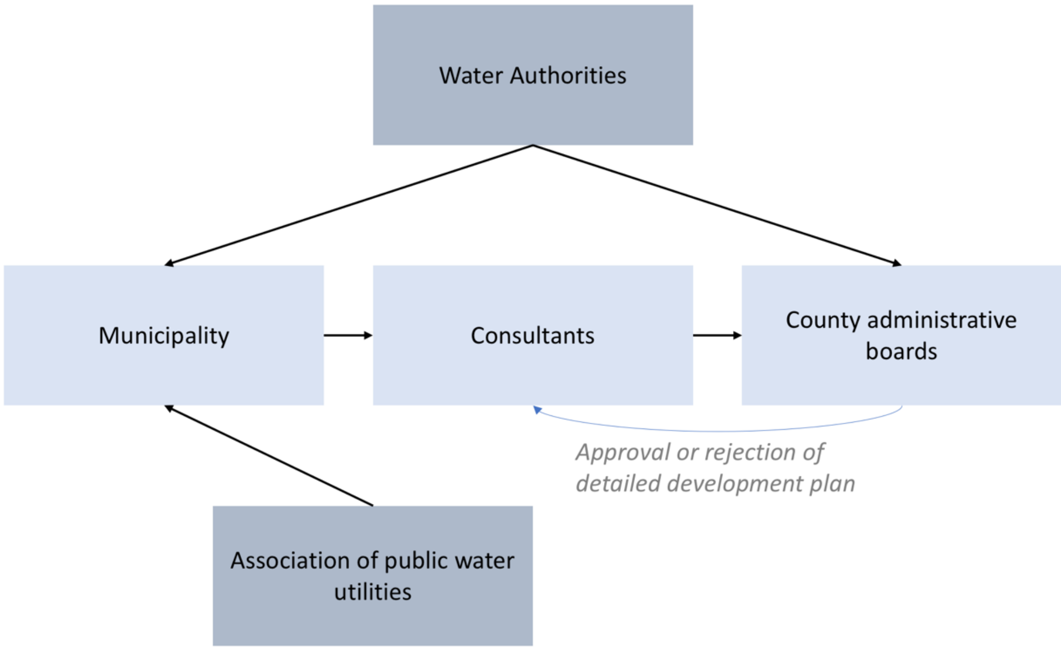

Figure 2. Flow chart of the parties interviewed and their inherent relationships.

The interviews were conducted remotely through the communication tool Teams. The selection of the interview technique for all the interviews was a semi-structured format. In a semi-structured interview, the questions are only approximately decided. Depending on the answers from the respondents and how the conversation develops, space is given to ask follow-up questions. The answers are given a broader width and the conversation can more freely evolve (Hallin & Helin, 2018). Interview 1 was a group interview, where several participants working with stormwater assessments at Norconsult participated. They were given the opportunity to ask questions to the respondent during the interview, which was included in the transcription. Interview 2 was carried out as a group interview where all respondents participated at the same time. The element of discussion was thought to provide further elements of information to the answer. The ambition was to aid a broader discussion between the respondents. The rest of the interviews conducted were individual, as only one respondent was present.

The goal when developing the interview questions was that they would be objective and not leading and concise. The questions were sent to the respondents a week before the interviews based on their wishes to be able to prepare themselves. With the approval of the respondents, the interviews were recorded, and they were offered to take part of the final results before publishing. The interviews were conducted according to the ethical recommendations presented by the Swedish Research Council in the text ‘God forskningssed’ (Vetenskapsrådet, 2017).

After the interviews were completed, the material was transcribed. In this process some limitations regarding the description of, i.e., gestures, facial expressions and art breaks was excluded from the written material. This was motivated by the fact that this can be difficult to document in a representative way. When summarizing the transcription, the results were divided according to four different themes:

- Difficulties when assessing stormwater in detailed development plans.
- The issue of division of responsibility between the municipality and the private property owner.
- Benefits and room for improvements for modelling of stormwater quality in detailed development planning.
- The issue of lacking guidelines concerning stormwater quality.

Results from the interviews were consequently sorted out according to the identified themes.

3.2 Case study Gröna dalen, Upplands-Bro

The study area is located in the municipality of Upplands-Bro and is marked with a black circle in Figure 3. Upplands-Bro is a municipality located in Mälardalen near Stockholm and is a part of the water district Norra Östersjön. The municipality has around 29,000 inhabitants and is expanding rapidly (Upplands-bro kommun, n.d.). As a part of a development program made by the municipality, a waterpark is planned to be implemented in the green area Gröna Dalen. The area is located adjacent to the urban center of Kungsängen and Brunna, situate in the municipality. The area is to be developed in line with the municipality vision for 2035. One of the main focuses of the area is to increase the treatment of stormwater from all parts of Kungsängen (Upplands-bro kommun, 2018).

Figure 3. Map where Upplands-Bro is marked. Background map retrieved from Esri (2021b).

3.2.1 Recipient Mälaren-Görväln

The recipient of the study area is Mälaren-Görväln, see Figure 4 where Mälaren-Görväln is marked with black, which is located in the east of lake Mälaren. The bay reaches from Upplands-Bro in the north to Lovön in the south. Its watershed area mainly consists of permeable soil such as forest, fields and agricultural land (Miljöbarometern, 2021).

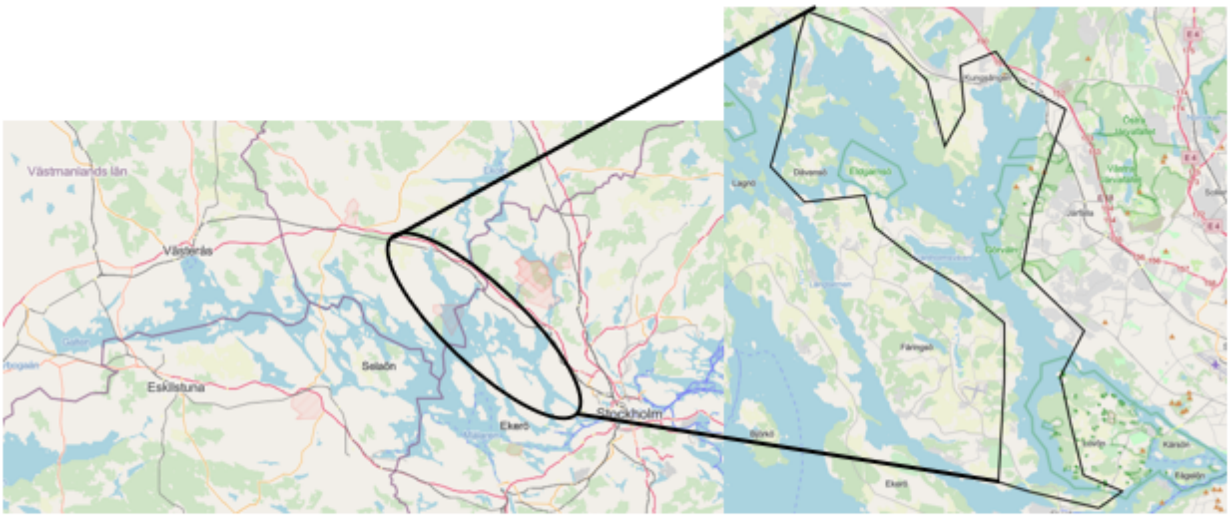

Figure 4. Map of recipient Mälaren-Görväln located in Mälaren. Background map retrieved from Esri (2021b).

The ecological status of Mälaren-Görväln is 'moderate', due to that Cu exceeds limit concentrations for the parameter 'specific polluting substances'. The chemical status is classified as 'bad' due to that a number of substances are exceeding limit concentrations. Polybrominated diphenyl ethers (PDBE) and Hg is assumed by a national interpolation to exceed limit concentrations in fish in all Swedish watercourses. Bromodiphenylether also exceed limit concentrations. However, less strict requirements are set in place for these substances due to that their source is atmospheric deposition. Time respites are in place for Cd, Pb, anthracene (ANT) and tribultyn (TBT), which all are exceeding concentration limits according to the regulations produced by Havs- och Vattenmyndigheten (Havs- och vattenmyndigheten föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten, 2019). It is deemed technically unfeasible to succeed in reducing concentrations of these substances. The limits for these substances are however to be met before 2027 according to the third management water cycle for Mälaren-Görväln (VISS, n.d.a).

Mälaren-Görväln is impacted by a variety of both point and diffuse pollution sources (VISS, n.d.a). The point sources which constitute a significant impact are discharge of urban wastewater, discharge of industrial wastewater and contaminated wastewater from contaminated sites such as abandoned industrial areas. Wastewater contributes to an additional load of P, while industrial wastewater contributes to Cd, Pb and Ni. Contaminated wastewater from contaminated sites contributes to Cd, Hg, ANT, Pb, Ni, TBT, Cu and PFAS (perfluorooctanesulfonic acid). Diffuse sources include urban and agricultural runoff, discharges not connected to sewerage systems, atmospheric deposition and horse farms. Urban runoff, agricultural runoff, unconnected discharges and horse farms contribute to an additional load of P, while atmospheric deposition contributes to an additional load of Hg and bromodiphenylether.

3.2.2 Planned stormwater measures

The area covers a length of 4 km, see the area marked with green in figure 5, which mainly is covered with grass fields and only a small amount of buildings is present. Plans contain exploiting surrounding areas, thereby increasing the number of impervious surfaces. The northern half of the area is intersected by the highway E18 and the southern parts by a railway. The municipality of Upplands-Bro (2018) also considers the valley to contribute with factors such as recreational values and ecosystem services (Upplands-bro kommun, 2018).

The study area in the centre of Gröna Dalen is planned to be developed into a waterpark containing several blue-green stormwater measures. The land use in this part of the area is currently open fields and grass. The aim of the stormwater implementations is to treat and delay the water locally as well as to create recreational values and promote biodiversity. Therefore, it has been requested from the municipality that the solutions should be open and sustainable. The area is occasionally flooded resulting in that the solutions must work to deal with high flows (Upplands-bro kommun, 2018).

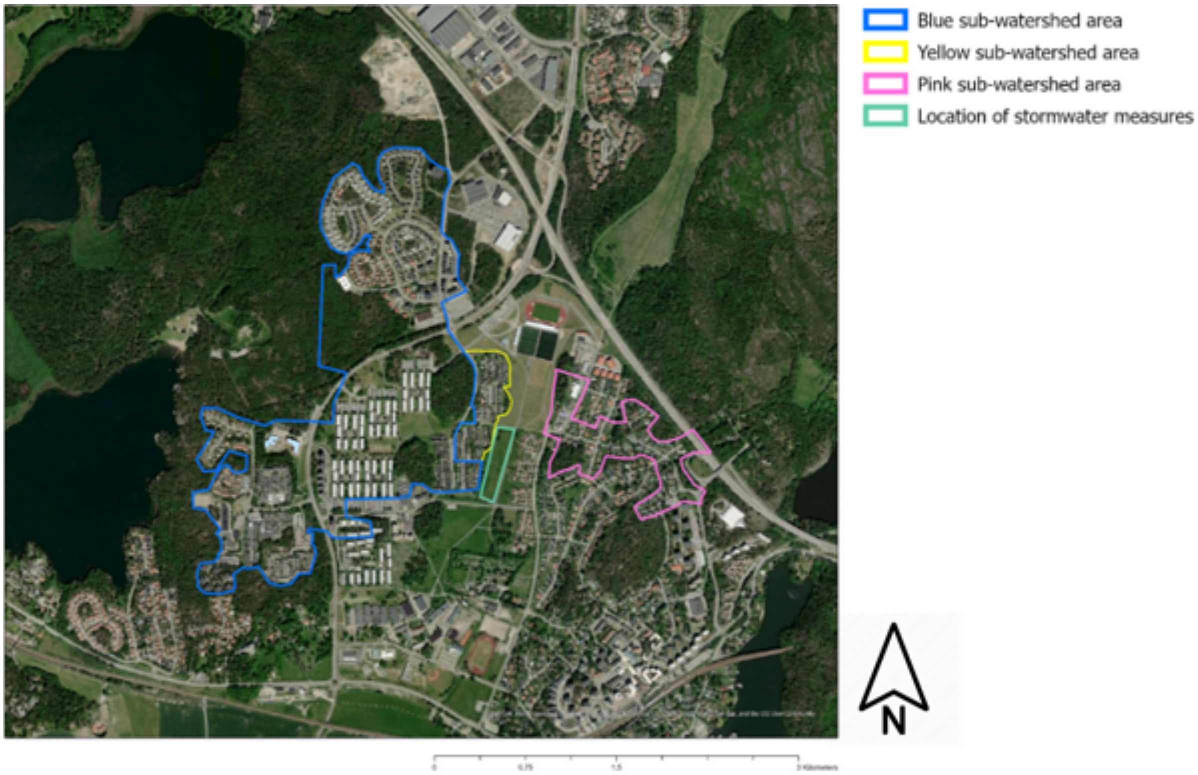

Figure 5. Presentation of the three sub-watershed areas as well as the location of the planned stormwater measures. Background map retrieved from Esri (2021a).

In line with the vision for 2035 set by the municipality, more sustainable and local care of stormwater is to be implemented in Gröna Dalen. The area is connected to the pipe network of Kungsängen which today is insufficient with regards to management of high flows. The treatment of pollutants transported with the stormwater has not been evaluated regarding the set requirements of the environmental quality standards. The municipality aims at developing stormwater solutions that can delay and treat the water locally, so that the pipe system can function during a rain with a return time of 20 years (Upplands-bro kommun, 2018).

To cope with the flows from the connected areas, Norconsult (2019) has provided suggestions for three different stormwater measures located in Gröna Dalen. These suggestions have been developed with regards to reducing high flows. However, no investigations have been done regarding pollution loads and whether the environmental quality standards would be fulfilled. The suggested stormwater measures are two stormwater ponds located in the north and south, as well as a trench connecting them. The investigation conducted by Norconsult has concluded that the three areas marked with blue, yellow and pink color in Figure 5 are producing stormwater runoff contributing to the stormwater measures.

3.3 Case study implementations in StormTac Web

In this chapter the case study implementations in StormTac Web are presented. StormTac Web was used for evaluating concentrations in stormwater as well as pollutant loads on the recipient.

3.3.1 Scenarios

When setting up the scenarios in StormTac Web, it was aimed to analyze how the choice of land use division influenced the resulting stormwater pollution. Further it was aimed to analyze the impact on the recipient in terms of annual pollutant loads when comparing the contribution from a delimited area with the contribution from the watershed area to recipient Mälaren-Görväln. Results without and with treatment according to the suggestions made by Norconsult (2019) were generated for the delimited area.

The delimited area was divided into a finer and coarser division of land use. In the finer division, a more detailed division of the land use in the area was made. Two different watershed area land uses were used in order to evaluate the impact of the land use division where the first was divided according to data from SMHI (SMHI, n.d.a) and the second was divided according to the MIKE Urban+ model created by Norconsult. The second watershed area is henceforth named "GIS watershed area". The scenarios for stormwater concentrations are presented in Table *3*, while the scenarios for the pollutant load on the recipient are presented in Table *4*.

Table 3. Scenarios for stormwater concentrations from the delimited area.

Scenario	Land use division (fine/coarse)	Treatment (Yes/No)
1.	Coarse	No
2.	Coarse	Yes
3.	Fine	No
4.	Fine	Yes

Table 4. Scenarios for annual pollutant loads on the recipient.

Scenario	Fine/coarse/SMHI watershed area/GIS watershed area	Treatment (Yes/No/-)
a.	Coarse	No
b.	Coarse	Yes
c.	Fine	No
d.	Fine	Yes
e.	SMHI	-
f.	MIKE	-

3.3.2 Land use division

The division of the delimited area in StormTac Web was made based on the by Norconsult three identified sub-watershed areas presented in Figure 5. To identify the different areas and land uses, the tool ArcGIS Pro was used, where a base map visualizing respective land uses were used for calculating respective areas of land uses by creating polygon layers and thereafter measuring their respective area. No further investigations were done regarding the actual land uses in the area. The coarse division of the area was executed by grouping larger areas together and assigning them more general land use properties such as 'residential area' or 'downtown area' while the finer division of the area was done by dividing the areas up according to 'roof', 'street', 'green area', 'parking' etc. For the finer land use division, assumptions were made regarding the roads, where roads assumed to run within residential areas were assigned as 'road 1', roads assumed to run between residential areas and other areas were assigned as 'road 3' and the larger road (E18) was assigned as ‘road 8’. The road types are dependent on number of vehicles per day. No roads were accounted for in the coarse land use division. For each land use category, concentrations of each substance are calculated based on data collected from earlier studies.

The land use type was selected according to the alternatives for land uses available in StormTac Web. Figure 6 and Figure 7 presents the coarse and fine land use division, respectively. The sub-areas ‘blue’, ‘pink’ and ‘yellow’ were added as separate sub-watershed areas into the runoff module of StormTac Web. Information about each land use division is found in Appendix II while Appendix III displays the uncertainties related to each land use category and substance.

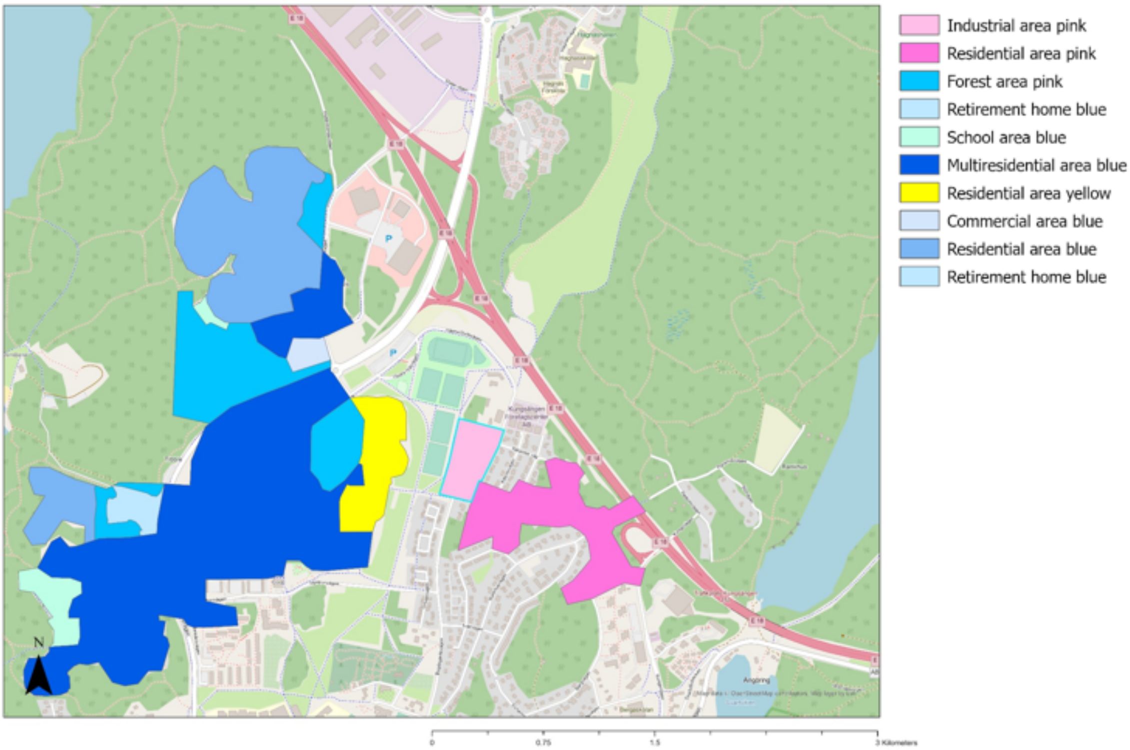

Figure 6. Coarse division of the delimited area. Background map retrieved from Esri (2021b).

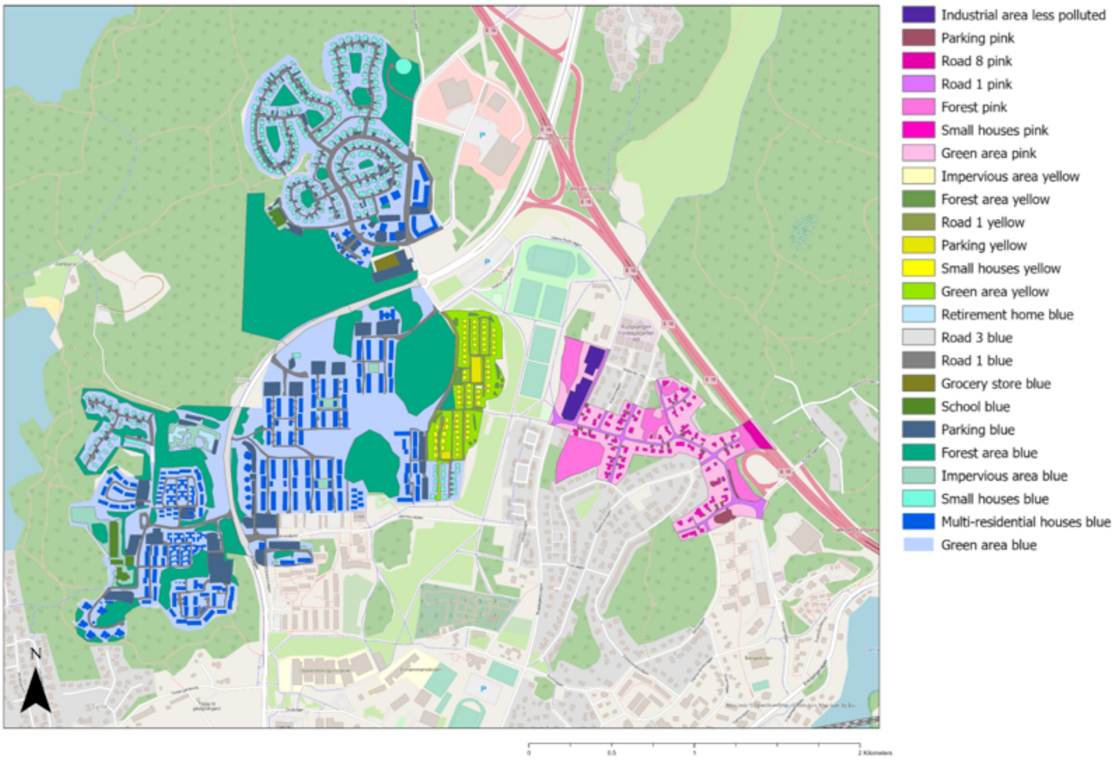

Figure 7. Fine division of the delimited area. Background map retrieved from Esri (2021b).

Two different land use divisions were set up for the watershed area in order to compare the difference on pollutant loads depending on how the land use division was conducted. The first watershed area was based on visual inspection of the MIKE Urban+ model provided by Norconsult. The land use division of the GIS watershed area was conducted as for the coarse and fine land use division. The map presenting the land use division of the GIS watershed is presented in Figure 8. The table presenting the land use division of the GIS watershed area is presented in Appendix II.

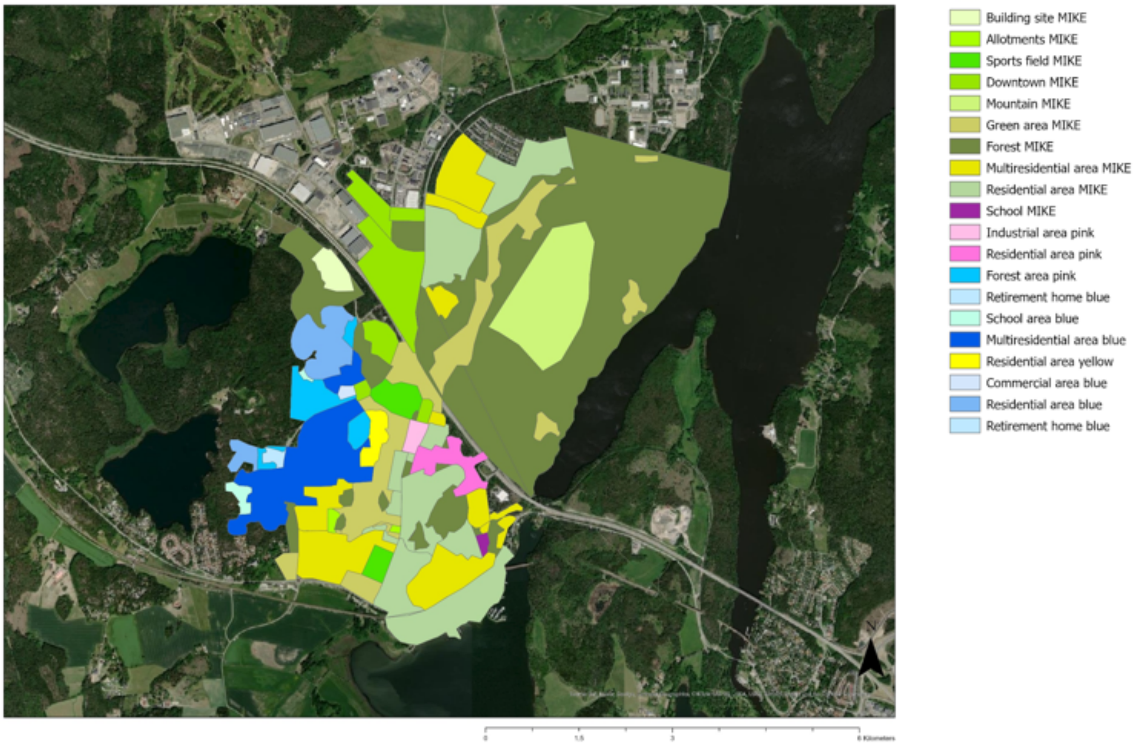

Figure 8. Land use division of the GIS watershed area. Background map retrieved from Esri (2021a).

The second watershed area was set up using data from the service VattenWebb provided by SMHI (n.d.a). The second watershed area is hereinafter referred to as SMHI watershed area. This alternative approach to land use division was selected since it is a time-efficient way of gaining information of the land uses in a watershed area. Information about the size of the area and its land use was retrieved for the municipality Upplands-Bro and the catchment area Mälaren-Görväln. The land uses are presented in Appendix II. The land use proportion stated as ‘urban area’ according to the data from SMHI (n.d.a) was divided according to data from SCB’s (Statistiska centralbyrån, 2003) investigation of land uses in urban areas in Sweden in the year of 2000. The land use division is found in Appendix II. An appropriate land use category for lakes and waterbodies could not be found in StormTac Web, and therefore it was not included.

3.3.3 Recipient data

Input data for the recipient was added in the receiving water module. The area and volume of the recipient was set to 73 km^2 and 1125 km^3, respectively. The precipitation was set to an average annual value of 590 mm/year based on data collection from the catchment area gathered by SMHI (n.d.a). The selection of pollutants for investigation in StormTac Web were based on pollutants reported to often occur in stormwater (Wiklander, 2017) as well as the pollutants in Mälaren-Görväln which currently exceed limit concentrations (VISS, n.d.a). In total 10 different substances were analyzed in StormTac Web. Measured concentrations at the measuring station Mälaren Broviken were found for P, N, Cu, Pb, Ni, Cr, Ni and Zn from the database Miljödata MVM provided by SLU (n.d). Mean concentrations of the assessed pollutants were used as input concentrations in the Recipient data box in the Receiving water module in StormTac Web. The rest of the substances were default concentrations based on the StormTac Web database.

The bioavailable concentration was calculated in order to compare substance concentrations to guideline limits for stormwater, see Appendix IV for stormwater quality guidelines provided by StormTac Web. To calculate the bioavailable concentration for substances Pb, Cu and Ni the tool bio-met (bio-met, n.d.) was used, for which input data is measured dissolved concentration of the selected substance, pH, dissolved organic carbon (DOC) and calcium (Ca). Values for pH, DOC and Ca were also collected from the station data. It was decided to limit the assessment of the recipient to the substances presented in Table *5*, and not include ecological parameters other than nutrients and specific polluting substances, due to that input data was insufficient for further assessment.

Table 5. Substances simulated in StormTac Web.

Substances	Type	Concentration	Source	Mean concentration (μg/l)
P	Nutrient	Total	SLU (n.d.)	22.0_{tot}
N	Nutrient	Total	SLU (n.d.)	464_{tot}
Pb	Metal	Bioavailable	SLU (n.d.)	0.00_{bio}
Cu	Metal	Bioavailable	SLU (n.d.)	0.04_{bio}
Zn	Metal	Filtered	SLU (n.d.)	0.14_{bio}
Cd	Metal	Filtered	StormTac Web	-
Cr	Metal	Filtered	SLU (n.d.)	0.08_{diss}
Ni	Metal	Bioavailable	SLU (n.d.)	0.47_{bio}
Hg	Metal	Filtered	StormTac Web	-
SS	Particles	Total	StormTac Web	-

3.3.4 Dimensioning of and connection to stormwater measures

A dimensioning was made of the two stormwater ponds based on recommendations made by Norconsult (2019). After iterations were made when changing the dimensions of the connecting trench, it was concluded that the removal efficiency was not varying significantly depending on dimensions, and the recommended standard dimensions calculated by StormTac Web were therefore kept. For the ponds it was aimed to obtain a permanent water surface (m^2) and permanent wet volume (m^3) of equal dimensions independent of whether coarse or fine land use division was analyzed. This was done by altering the share of reduced area ($K_{A\varphi}$, see equation 7 and equation 8) as well as the permanent water depth. The recommendations made by StormTac Web is that the share of reduced area should not be smaller than 70 m^2/ha_{red}, and therefore the resulting dimensions of the ponds are not identical. The dimensions of the north and south stormwater pond are found in Appendix V. The different sub-watershed areas of the delimited area will be connected to one stormwater measure each according to the investigation made by Norconsult (2019). The respective sub-watershed areas were therefore linked to the stormwater measures in StormTac Web according to Figure 9.

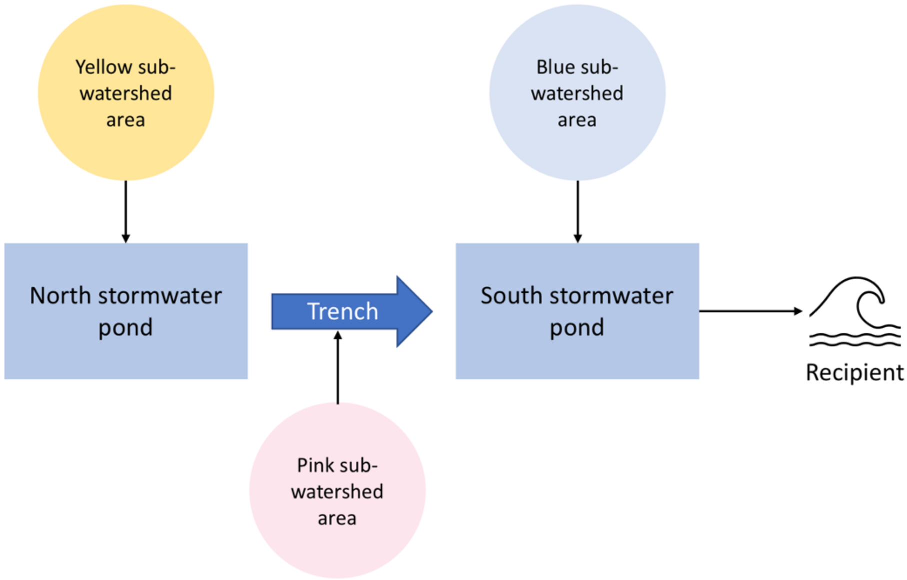

Figure 9. Schematic figure of the planned stormwater measures. Author's own picture.

It was assumed that no local stormwater measures were implemented within the sub-watershed areas (blue, yellow and pink) nor in the watershed areas (SMHI and GIS). Normally some form of stormwater flow retention and pollutant removal occurs within areas due to local caretaking such as filter strips and pervious pavement. In this case, all stormwater runoff generated from the areas ended up in the simulated stormwater measures, which is not necessarily representative for real conditions. The stormwater measures were altered to reflect those dimensions earlier suggested by Norconsult, resulting in substantially smaller dimensions than those proposed by the initial calculations made in StormTac Web.

3.3.5 Calculation of site-specific guideline concentrations

In order to retrieve site-specific stormwater concentration guidelines for the study area, the acceptable annual load suggested by StormTac Web for each substance was used as input along with the annual mean total flow. General stormwater concentration guidelines have not been suggested for all substances studied in this thesis. Therefore, only the substances for which general guidelines have been suggested will be assessed in this calculation. Equation 22 describes the site-specific recommended stormwater concentration $C_{recommended}$.

$$C_{recommended} = \frac{L_a}{Q_a} \tag{22}$$

$C_{recommended}$	site-specific recommended stormwater concentration guideline [µg/l]
L_a	annual load from the delimited area [µg]
Q_a	annual total mean flow $(Q + Q_b)$ from the delimited area [l/year]

3.4 Case study implementations in MIKE Urban+

In this chapter the case study implementations in MIKE Urban+ are presented. MIKE Urban+ was used merely for evaluating concentrations in stormwater.

3.4.1 Scenarios

The scenarios simulated in MIKE Urban+ were limited to only analyze total suspended solids (TSS) load in the runoff from the catchments, not considering implementation of stormwater measures. The aim was to compare the results with the ones retrieved from StormTac Web. Therefore, three scenarios were analyzed. EMC scenario 1 corresponds to the entire watershed area in the original MIKE model. EMC scenario 2 corresponds to the small area with a fine land use division, analyzed in StormTac Web. EMC scenario 3 corresponds to the same area but with a coarse division.

3.4.2 Model setup

The model used in MIKE Urban+ was based on an already existing hydrological model developed by Norconsult for MIKE Urban. The model was therefore converted for the new software and some modifications were made to match the updated software structures. The model consisted of 254 different catchments with different sizes, person equivalents and imperviousness fractions. The hydrological model used was the Time-Area method. The existing pipe-network and planned stormwater measures were also already added to the model, although the stormwater measures were only designed for flow retention and not pollutant removal. The previous model had been used to simulate flows from the connected catchment areas. Furthermore, the focus in this project was to simulate pollution loads in the stormwater, and more specifically TSS. A map of the model is presented in Figure 10. The green area corresponds to the delimited area.

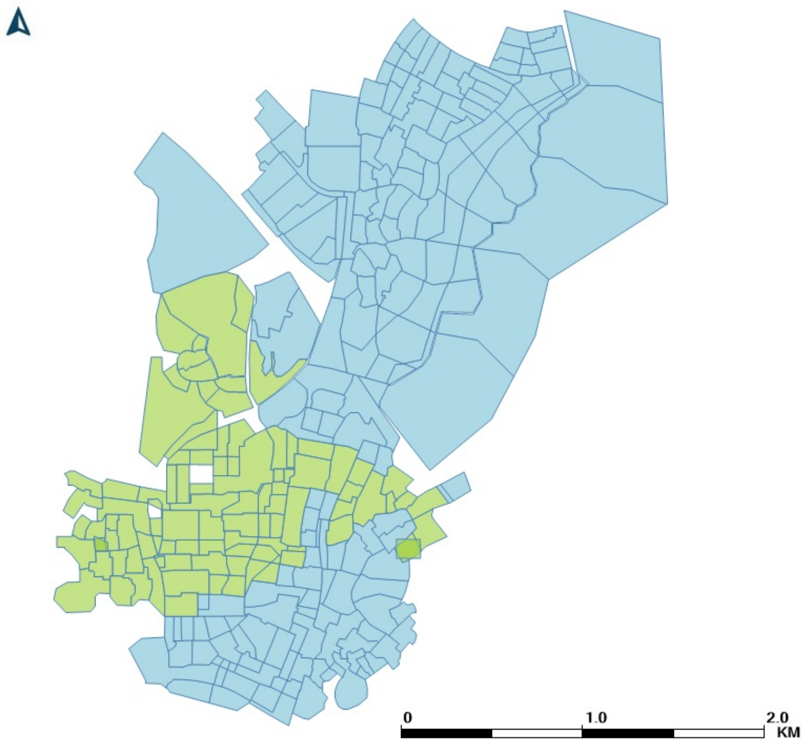

Figure 10. Map of simulated area in MIKE Urban+.

The rain data used for the simulations was retrieved from SMHI, from the measuring station Skjörby (SMHI, n.d.b) located 20 km north-west of the case study area. The data was gathered daily through both manual and automatic sampling. The selected time period was set from 2020-01-31 to 2021-01-31. The measuring of the precipitation collected during the last 24 hours was read at 06.00 each day. In Figure 11, the rainfall intensity for the simulated period is presented.

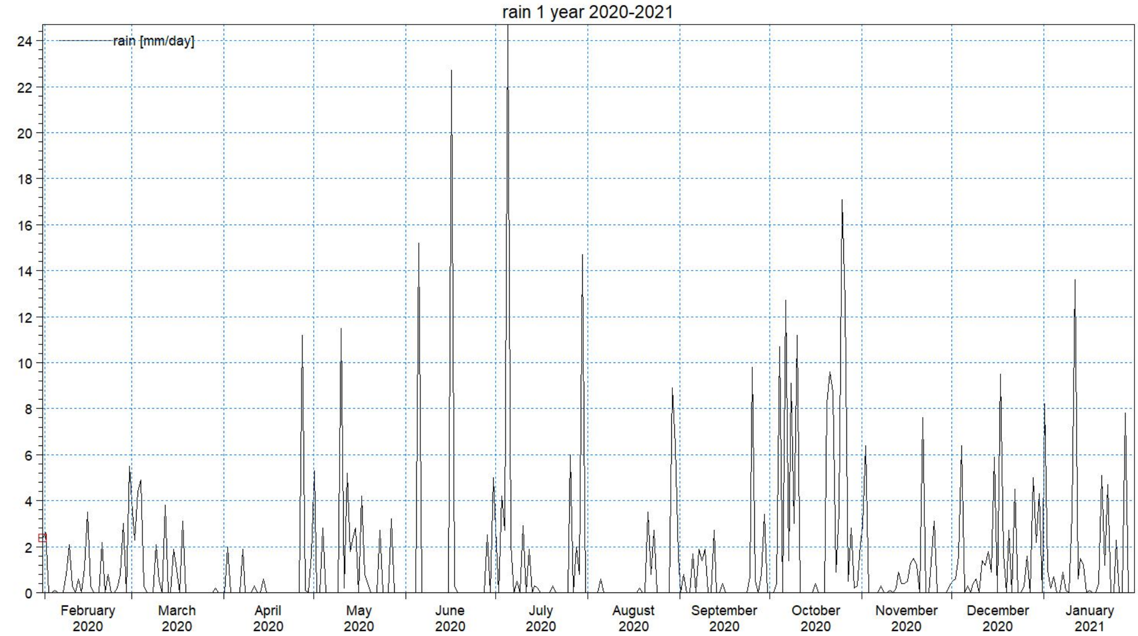

Figure 11. Rainfall intensity for the period 2020-01-31 to 2021-01-31 (mm/day) (SMHI, n.d.b.).

To simulate the pollutant, the module Advanced Stormwater Quality (SWQ) was used. In addition to this, the module Event Mean Concentration (EMC) was selected instead of Build-up/Wash-off due to lack of input data. The EMC method also allowed for using input data from the calculated weighted concentration in StormTac Web (see Appendix VI), which increased the relevancy of comparing the results from the respective programs. The module uses EMC and infiltration of stormwater over different land uses during precipitation. The land uses were expressed in percentage of impervious area and number of person equivalents. Input global data and input data for the EMC method are presented in Table 6. For the boundary conditions regarding SWQ, the surface runoff condition was used. This was motivated by that it was aimed to analyze the pollutant content in stormwater runoff.

Table 6. Input data for SWQ global data and advanced method.

Global data	**Type/value**	**Unit**	**Reference**
Event threshold	0.0056	mm/h	SMHI (average)
Initial ADWP	72	h	SMHI (average)
ADWPmin	5	h	-
Advanced method			
Surface load	TSS	-	-
EMC scenario 1	47	mg/l	Derived from StormTac Web
EMC scenario 2	45.1	mg/l	Derived from StormTac Web
EMC scenario 3	57.6	mg/l	Derived from StormTac Web

For EMC scenario 1 simulated in the model, all catchments were simulated. However, for EMC scenario 2 and 3 only a selection of catchments was used to correspond to the delimited area expressed in StormTac Web. As mentioned, the areas were expressed in imperviousness instead of land use. The size of impervious area for the bigger catchments included in the simulations are presented in Figure 12. The three catchments with the biggest impervious area are 156_2, 147_2 and 254.

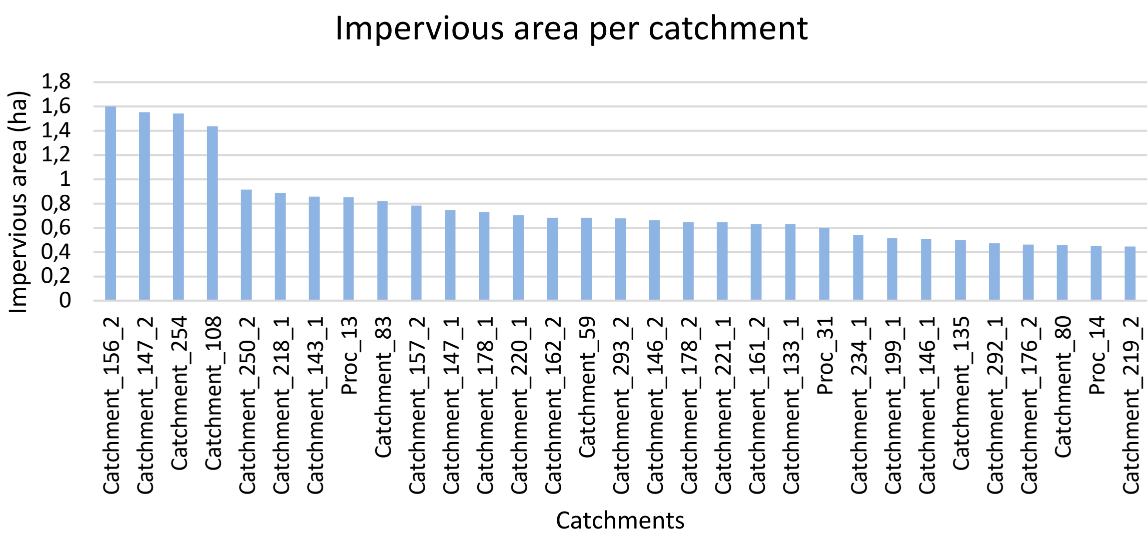

Figure 12. Presentation of the impervious area (ha) per catchment in the hydrologic model over Upplands-Bro based on values from MIKE Urban+ model.

4. Results

In this chapter the results retrieved from the conducted interviews as well as the modelling in StormTac Web and MIKE Urban+ are presented.

4.1 Interviews

The results from the interview study are presented according to the topics of the findings. The topics are as following, repeated from Chapter 3.1:

- Difficulties when assessing stormwater in detailed development plans
- The issue of division of responsibility between the municipality and the private property owner
- Benefits and room for improvements for modelling of stormwater quality in detailed development planning
- The issue of lacking guidelines concerning stormwater quality.

4.1.1 Difficulties in stormwater assessments

According to the results from the interview study, the normal procedure for stormwater assessments within detailed development planning is that the municipality orders consultants to conduct such. The county administrative board (CAB) is responsible for revising whether the results from the stormwater assessment ensure the environmental quality standards (EQSs) are followed. The stormwater consultant described the common procedure of conducting a stormwater assessment. Calculations of pollution concentrations in stormwater are made in StormTac Web and flow modelling in MIKE Urban. The recipient module in StormTac Web is rarely used. These assessments are done early in the process of a detailed development plan and later, after examination, it is concluded whether more extensive investigations are required. Based on these results, the inherent work tasks of and cooperation between the interviewed parties are presented in Figure *13*.

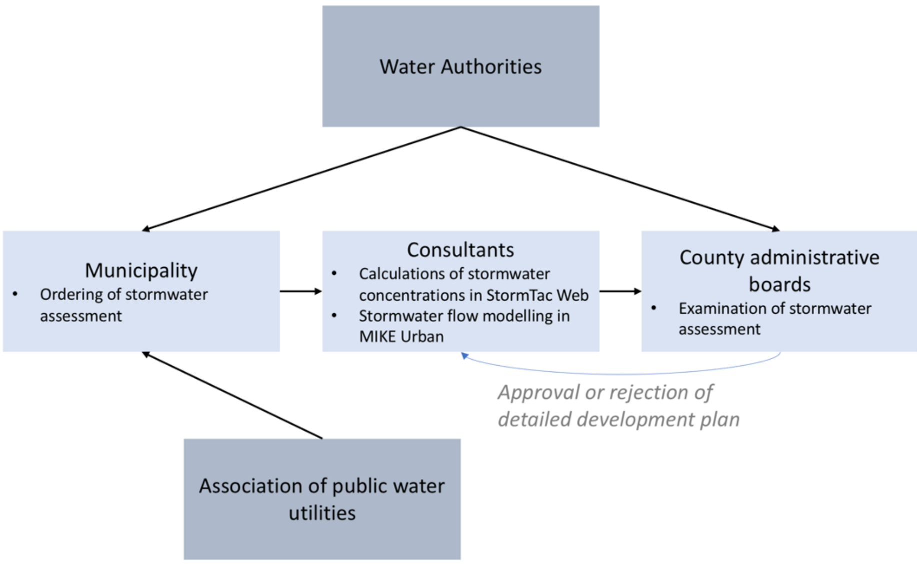

Figure 13. Filled out flow chart of the inherent work tasks of the interviewed parties (Author's own picture).

It was highlighted in the interviews with the consultants that a broader timeframe and increased knowledge is required in order to meet the set requirements from the CABs boards and customers concerning stormwater assessments. Knowledge being lacking was also mentioned by the CAB. It was experienced that planners have not yet caught up to the stormwater issues when developing a detailed development plan. It was deemed that this issue needs to be worked with over a long-time span.

> "[...]. That the municipalities and consultants perceive us as hard to work with or putting too high demands, it has to do with that planners are not informed about these questions, so it is about knowledge building, and also the consultants have proven not to follow along, so this is something that needs to be worked with successively for several years and it is long time spans we are talking about."

County administrative board, interview 5, Apr 15 2021
(Author's translation)

The municipal water management planner expressed that the quality of stormwater assessments conducted by consultants varied to a large extent. In some cases, the quality was satisfactory, and in other cases not. This was thought to be dependent on the recent expansion of the market, where the request for stormwater assessments have increased. The access to competent manpower is still limited in comparison to the market growth.

Svenskt Vatten agreed on that knowledge building is required among concerned parties and that communication between them needs to be improved.

> "I think both sides need to meet, I should be honest and say that. If you have responsibility such as the municipalities, which are those I represent, then we need to do our reading and be knowledgeable. And provide counterarguments. Perhaps you can look forward to more knowledge and dialogue building, that would be the dream. To have some sort of mutual platform were you more cleared up how we should interpret it in Sweden."

Representative from Svenskt Vatten, interview 7, May 4 2021
(Author's translation)

It was further emphasized by consultants and the CAB that consultants need to put demands on customers. If the customers are municipalities ordering a stormwater assessment, and require that more time and money is to be reserved in order to perform more extensive stormwater assessments. The reasoning from the CAB was that by them putting demands on municipalities it would ultimately result in consultants being able to request more resources from municipalities when conducting stormwater assessments.

By consultants, the demands put on them from the CABs were sometimes experienced as unreasonably high and partly skewed in certain situations. The demands on detailed development plans were experienced to differ depending on what the current land use is. An area which is currently industrial land is subject to lower demands. This is due to that future pollution from the area after planned exploitation has occurred will most likely be lower than today. Woodland, on the other side, is subject to very strict demands, due to the fact that the current pollution from the area will most likely increase irrelevant of what type of exploitation is planned. The CAB usually remarks on if there is an increase of a single pollutant after exploitation and treatment.

"[...]. We often think that it becomes very skewed, you put extremely high demands on some plans that do not become very polluting afterwards either, but almost no demands at all on an existing industrial area that is to be rebuilt. [...]."

Stormwater consultant, interview 6, Apr 16 2021 (Author's translation)

The CAB however considered to be putting adequate requirements on detailed development plans, referring to that regardless of the discharge from a detailed development plan being small, the additive effect from several detailed development plans will likely be large.

"[...] Some [detailed development plans] may show a kilogram [of pollutants] is discharged per year or so. Then you can imagine, if we have 100 detailed development plans and a kilogram is discharged from all of them, then the resulting discharge is very large."

County administrative board, interview 5, Apr 15 2021(Author's translation)

Further, according to the CAB, was that since it is difficult to assess the exact load in terms of kilograms stemming from a detailed development plan, the discharge should be reduced to zero. It was highlighted that in order to achieve this goal, the dialogue between planners mainly working with the Planning- and Building act (Plan- och Bygglagen [PBL], SFS 2010:900) (PBA), environmental people working with the Environmental Code (Miljöbalken [MB], 1998:808) (EC) and the municipality with their water matters needs to improve.

From the interview with Svenskt Vatten, the role of the CAB was discussed, where Svenskt Vatten emphasized that it is important that some sorts of demands are required by authorities, in order to avoid negative consequences. Furthermore, it was believed that authorities need to be harsh rather than allow certain projects, given that they lack knowledge or sufficient information about the concerned project.

The CAB encouraged planners to assess the entire watershed area when evaluating stormwater in a detailed development plan. It was deemed important to put the detailed development plan in question in relation to the surrounding area, in order to be able to work strategically with the stormwater issue. If this work style is adapted in detailed development planning, it is possible to refer to compensatory stormwater management outside of the detailed development planning area.

"[...] In the plan you can say, we do not do it here, but we do it over here. So, it is fully possible to work like this. You do not have to sit and scrimp in every detailed development plan. And that is what we are trying to tell the municipalities, that the more strategic you are, and work with these questions, the better and easier your detailed development plan work will become. So, we try to provide them with these tools."

County administrative board, interview 5, Apr 15 2021 (Author's translation)

Svenskt Vatten agreed on that it is vital to assess the entire watershed area. Their position was motivated by that a large-scale perspective on stormwater may prevent skewed verdicts. They further, believed that skewed verdicts would ultimately not necessarily result in the environment being improved in terms of reducing stormwater pollutant loads.

> "Authorities need to see the full-scale picture of the watershed area […] perhaps you constructed a wetland for that and the discharge in parallel. And then you should be able to account for that. Of course, that is not a pass for polluting another place, and that is not really how they [the authorities] reason, but the risk becomes obvious, that they drive us to implement borderline non-sustainable solutions, just in order to follow this dogma. Crazy, absurd reasonings and measures come as a result."
>
> *Representative from Svenskt Vatten, interview 7, May 4 2021 (Author's translation)*

It was by consultants experienced that compensatory measures outside of the planning area are not usually allowed. It is rather demanded by the CAB to stay within the planning area and plan when planning stormwater treatment measures. The consultant also mentioned that the judgments from the CABs differed from case to case, however, that it was for the most part not allowed. According to the CAB the approach of working with this issue might differ from one CAB to another, due to factors such as time-availability and level of knowledge, although it was believed that the approach is becoming more similar with time. Another reason as to why compensatory measures are not allowed was by the stormwater consultant thought to be that it is difficult to follow up on whether they are actually constructed.

> "[...] … and then I think it will be difficult if you suggest measures outside of the planning area, it will be difficult to follow up if they are actually constructed, because it is not possible to put demands outside of a planning area in a planning map. I think that might have something to do with it, knowing if it will actually be constructed."
>
> *Stormwater consultant, interview 6, Apr 16 2021 (Author's translation)*

4.1.2 Responsibility of the municipality versus the private property owner

According to Svenskt Vatten (2020), more responsibility must be placed on the private property owner concerning stormwater management. The results from the other interviews shows that the opinions on this issue differs. From the interview conducted with Svenskt Vatten it was highlighted that in order to develop climate-safe societies, the municipality alone will not be able to meet the challenge regarding stormwater management.

The perspective of the municipal water management planner was that the opinion on this matter may differ depending on to whom the question is being asked. For instance, a planning architect will likely oppose the statement, as they are not allowed to prescribe stormwater measures outside of the detailed development planning area.

> [..] If I talk to a planning architect, they are very keen on saying no, according to the PBA we may not prescribe one or the other on a development district. We might be allowed to say that it should be a certain number of permeable surfaces or similar. But basically, I feel that all the arrows in my mind point in all kinds of directions.
>
> *Municipal water management planner, interview 3, Apr 8 2021 (Author's translation)*

However, the municipal water management planner believed the municipality should be able to prescribe some sort of demands on private property owners. It was thought not to be reasonable for the municipality to handle all the stormwater within public ground.

The representative from Svenskt Vatten emphasized that the private property owner is not allowed to realize just anything at the connection point to the municipal water- and sewerage network. However, there are currently no limit values regarding pollution loads which was highlighted as a solution to the problem. In this, it was considered reasonable to place an increasing responsibility on those who generate the pollution.

> […] If one [private actor] can be proven guilty of destroying or polluting above a certain level, we think that it would be reasonable to place those demands. However, we do not have documents regarding stormwater, since it is difficult to assess what a normal level of pollutant would be.
>
> *Representative from Svenskt Vatten, interview 7, May 4 2021*
> *(Author's translation)*

The representative from Boverket at large agreed with the representative from Svenskt Vatten and thought that if the municipality voices concerns in this matter, it is necessary to deal with.

> I agree with that picture. As it looks today, it is an environmental issue that needs to be resolved in a larger context. [...]. So, it is a large responsibility for the municipality and the municipal water companies. You can always discuss if that should be the case. I do not really have an opinion about it but if you listen to the municipality and the municipal water companies, it is a problem. And then you should deal with it.
>
> *Representative from Boverket, interview 4, Apr 14 2021*
> *(Author's translation)*

The representative from the CAB did not agree with Svenskt Vatten. It was claimed that it is important that the municipality continually carries the greatest responsibility for stormwater management. The importance of this was partly attributed to the lack of knowledge about stormwater management among private property owners. Further, it was attributed to that the necessary information about pollutants in stormwater are lost if the municipality hands over too much responsibility to private property owners.

> Some municipalities unfortunately go about putting it on a private level, saying that this is something the property owners need to do, and then they put it as quarter ground, and say that it is private mandatorship and that the private person should solve it. We look a lot at these matters.
>
> *County administrative board, interview 5, Apr 15 2021*
> *(Author's translation)*

As a continuation of this standpoint, an example was brought forward by the CAB concerning this issue.

> [...] But how many of these 100 house owners do you think are informed of the stormwater issues. That behave, and do not wash cars on impervious surfaces. In that case the municipality needs to go out and supervise. [...] That is what Svenskt Vatten means, that in the best of worlds it should of course be managed by the private person. Local treatment is great if it works. But it is the municipality that really needs to take responsibility for that it really works. Because we cannot put all responsibility on the private person, that is completely impossible.
>
> *County administrative board, interview 5, Apr 15 2021*
> *(Author's translation)*

The representative from Svenskt Vatten agreed to some extent with the perspective highlighted by the CAB. For instance, the difficulties in drawing the line on whom the requirements would be placed on and what they would be set to. It was further highlighted that it may be difficult for every property owner to manage their facility, since they lack the competence. Therefore, the result may be, even if demands would be placed, that they won't be followed. In this, Svenskt Vatten highlighted the need for developing limit values regarding pollution, so that only those proven to pollute are required to act.

4.1.3 Use of stormwater quality modelling

According to the results from the interview conducted with the environmental consultant, hydrological modelling of stormwater quality and the impact on the recipient is not conducted in most cases but is beneficial. The typical approach to recipient assessments is of a manual manner, i.e., calculating the resulting recipient concentration for a certain substance or certain substances in an Excel sheet. It is stated in the interview that this contributes to some simplifications but overall provides results that are clear and, according to the respondent, near the truth.

The CAB stated that modelling could potentially be a good tool in order to assess how stormwater influences the recipient. However, it was not deemed possible until the exact sources of pollutants have been localized in the urban area. The issue of lacking data was reported to be a parameter not making it possible to yet integrate modelling of stormwater quality, since the outputs of a model is only as relevant as the inputs. It was further stated that modelling as an approach to stormwater management needs to be preceded by the actual implementation of surfaces within the urban area which are able to treat stormwater. It was deemed to be of more relevance to first assess how the municipalities work with stormwater management. It is by the CAB beneficial to in detailed development planning put the assessed plan into relation with its surrounding area.

The issue of sampling appropriate amounts of stormwater quality data was discussed in the interview with Svenskt Vatten. According to them, sampling stormwater, for instance in a city, requires a lot of resources and is not deemed possible in all cases.

> " [...] … but in a city we have hundreds of points of discharge which vary every rain is different, if we measure during one rain period the removal efficiency in a stormwater measure is different than after another rain period due to hydraulics and hydrology, as well as incoming pollution load. So, I think it has been a determining factor, that in the end it costs more just sampling [...]."
>
> *Representative from Svenskt Vatten, interview 7, May 4 2021*
> *(Author's translation)*

Furthermore, the issue of who should be responsible for the sampling was questioned. Since Svenskt Vatten represents the municipalities, it is their perspective that is lifted concerning the issue.

> "[...] … we have a lot of stormwater discharges which are collected from the city, enters the public system and then is discharged in a lot of pipes, or ditches. And then we should have very advanced sampling in them, although there is actually someone else who is polluting, that is kind of our perspective."

Representative from Svenskt Vatten, interview 7, May 4 2021
(Author's translation)

4.1.4 Guidelines for stormwater management

According to the results from the interview with the municipal water management planner it was thought that the unclear division of responsibility among authorities may result in that the issue is neglected and therefore no general guidelines for stormwater quality have been developed. It was not deemed efficient for each municipality to develop their own guidelines, but there is rather a need for clearer guidelines provided by the authorities.

The issue on developing general guidelines was discussed in the interview with Boverket. The representative mentioned that it certainly would be possible to develop regional guidelines for stormwater quality but also challenging, since the selection of legislation and authority responsible would be difficult. Furthermore, it was highlighted that there would still be a need for local adaptations of the regional guidelines.

> "[...] There is also a need for a variety [of guidelines] in the country since the situation differs regarding the environmental quality standards. It needs to be flexible in some sort of way. That is sort of what the entire concept of environmental quality standards (EQS) centers around, to make assessments based on the actual status of the waterbody. It is difficult to, at the same time, have both a national regulation as well as a local adoption."

Representative from Boverket, interview 4, Apr 14 2021
(Author's translation)

The need for local adaptations of guidelines was also mentioned during the interview with the Water Authorities. A representative emphasized that the work could occur in different manners from one CAB, as well as from one municipality to another.

> "The situation is different for different waters. Some waters may not be resistant to more impact, and then the requirements are based upon that. That is the thing, it might not be the same between 290 municipalities and 21 county administrative boards due to the fact that the waters are different. The status of the water is the determining factor of whether there is a need for measures, and whether further exploitation is allowed."

Representative from the Water Authority, interview 2, Mar 23 2021
(Author's translation)

The representative from Svenskt Vatten did not agree with that there is a need for developing general guidelines. In line with what was mentioned in the interviews with the Water Authorities and Boverket, it was mentioned that the need for local adaptations, which the principals of EQSs are based on, makes general guidelines unnecessary. Instead, more guidance was called upon for on how to select appropriate stormwater treatment measures with regards to pollution reduction.

Concerning the need for guidelines, the lack of thereof has resulted in the larger municipalities evolving faster in terms of stormwater management, according to the results from the interview with the municipal water management planner. A cause of this was thought to be the access and availability of resources such as competence, personnel, and money. Another cause was thought to be the level of planned exploitation. It is more relevant for a large, growing municipality to shed light on stormwater issues than for a small, sparsely populated municipality.

> [...] In many different ways resources are not available, nor economical or personal for developing specific guidelines. That everyone [every municipality] would develop specific guidelines is a tremendous waste of resources. So, it would be great if there were clearer guidelines. [...]. What happens when we do not have clear guidelines from the authorities that we can depend on, is that the larger cities develop faster. Because in the larger cities there are resources, in Stockholm, Gothenburg and Malmö there is staff available only working with policy issues surrounding stormwater.
>
> *Municipal water management planner, interview 3, Apr 8 2021*
> *(Author's translation)*

4.2 StormTac Web

The results include stormwater concentrations for coarse and fine land use division of the delimited area, respectively. The load on the recipient from the delimited area as well as the watershed area is presented. Furthermore, the comparative contribution when comparing the delimited area to the entire watershed area is presented. Lastly, suggested site-specific stormwater guidelines are presented.

4.2.1 Stormwater concentrations and loads from the delimited area

The delimited area corresponds to coarse and fine land use division, respectively. The pollutant concentrations and annual loads before and after stormwater measure implementations are presented in Table 7. The results correspond to scenarios 1-4. Concentrations exceeding limit guidelines are colored in the table. General limit guidelines are found in Appendix V. Overall, the concentrations generated from the coarse division are higher than the concentrations generated from the fine division. The same trend applies when comparing loads for the different land use divisions.

Table 7. Stormwater concentrations and loads before and after treatment for coarse and fine land use division. Colored cells mark where concentrations are exceeding limit guidelines.

	Coarse land use division				**Fine land use division**			
Substance	No treatment		Treatment		No treatment		Treatment	
	μg/l	kg/year	μg/l	kg/year	μg/l	kg/year	μg/l	kg/year
P	180	230	92	110	110	130	60	79
N	1400	1700	950	1200	1200	1500	880	1200
Pb	11	14	5	6.1	7	8.3	2.6	3.5
Cu	22	27	11	13	14	16	7.5	9.9
Zn	82	100	32	39	39	46	15	20
Cd	0.52	0.65	0.26	0.32	0.4	0.48	0.2	0.27
Cr	7.9	9.8	2.7	3.3	4.9	5.8	1.9	2.5
Ni	7.3	9	3.5	4.3	5	5.9	2.6	3.4
Hg	0.021	0.026	0.013	0.016	0.025	0.03	0.019	0.025
SS	52 000	64 000	20 000	25 000	45 000	53 000	19 000	25 000

4.2.2 Loads on the recipient from the entire watershed area

Table *8* presents the yearly pollutant loads on the recipient from the GIS watershed area and the SMHI watershed area, the acceptable load as well as the required load reduction. The calculations are based on equation 11 and 12 for acceptable load and equation 13 for required load reduction. The results correspond to scenarios e and f. The GIS watershed area entails generally higher pollutant loads than the SMHI watershed area. These results are entirely dependent on the land use choices made, where the land uses chosen for the GIS watershed area results in higher pollutant. For all cases, no substances exceed limit guidelines.

Table 8. Pollutant loads (kg/year) from the SMHI and the GIS watershed area, as well as the acceptable annual load and the required load reduction. ND implies no data, as for these substances general recipient guideline concentrations have not been established.

	SMHI watershed area			**GIS watershed area**		
Substance [kg/year]	Load	Acceptable load	Required load reduction	Load	Acceptable load	Required load reduction
P	2000	*ND*	*ND*	2200	*ND*	*ND*
N	59 000	*ND*	*ND*	54 000	*ND*	*ND*
Pb	96	5700	0	120	6900	0
Cu	180	1800	0	190	1900	0
Zn	530	21 000	0	750	30 000	0
Cd	5.1	1400	0	6.4	1500	0
Cr	42	1800	0	49	2100	0
Ni	48	410	0	63	530	0
Hg	0.84	*ND*	*ND*	0.86	*ND*	*ND*
SS	300 000	*ND*	*ND*	280 000	*ND*	*ND*

4.2.3 Contribution of load to the watershed areas

The percental contribution to the annual load of stormwater pollution from the coarse and fine land use division to the entire watershed area (the SMHI and the GIS watershed area, respectively) is presented in Figure 14 and Figure 15 Figure 15. The delimited area corresponds to around 16 percent of the entire watershed area. The results correspond to scenarios a-f. Input data for the calculations are found in Appendix IV. According to the results the impact on load from the delimited areas (coarse and fine land use division) were small when comparing to the entire watershed area, especially after treatment.

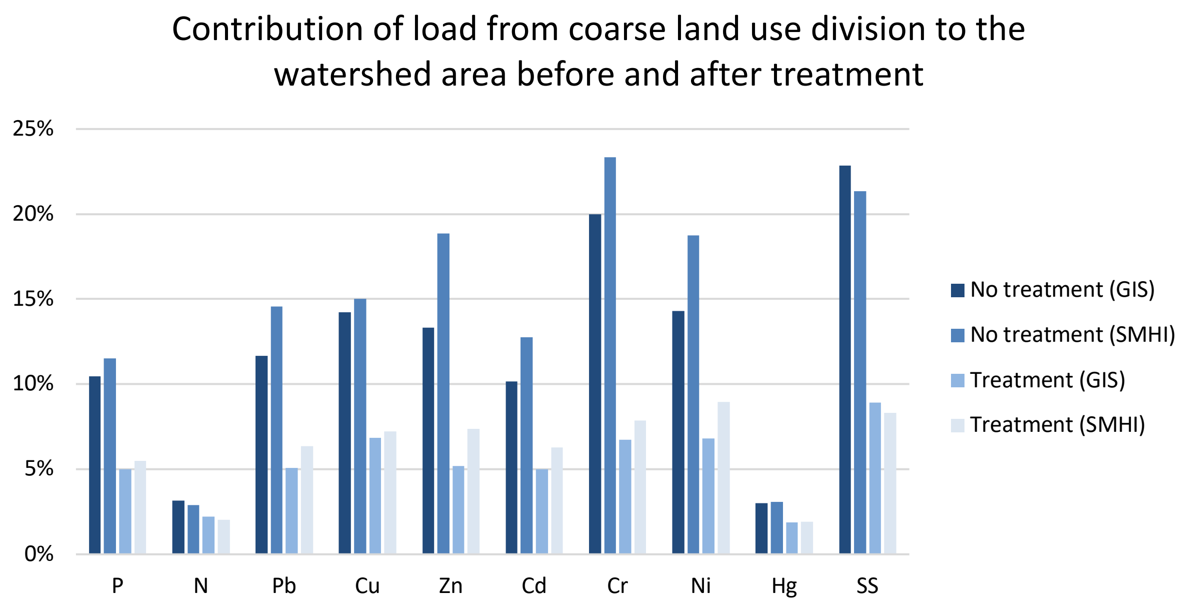

Figure 14. Percental contribution of stormwater pollutant load from coarse land use division to the load from the entire watershed area.

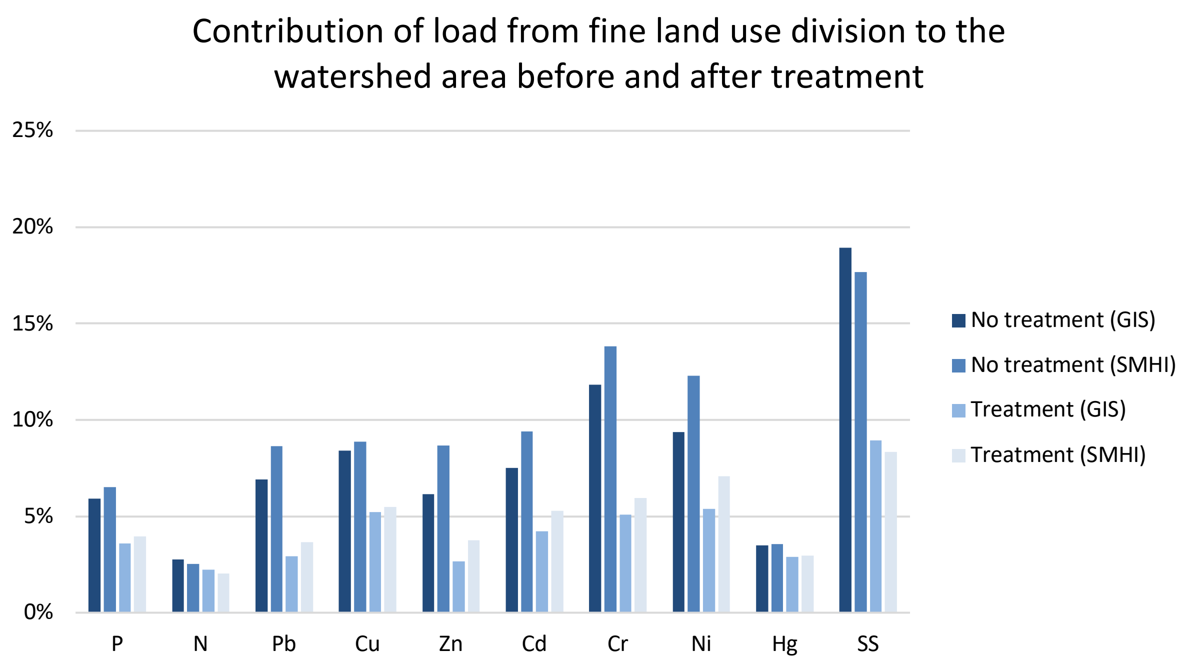

Figure 15. Percental contribution of load from fine land use division to the load from the entire watershed area.

4.2.4 Site-specific stormwater guideline concentrations

In Table *9* site-specific stormwater guideline concentrations (calculated with equation 22) are presented for coarse and fine land use division respectively, corresponding to scenario 1 and 3. No acceptable loads were retrieved for substances P, N, Hg and SS since the acceptable load calculated in StormTac Web is based on general stormwater concentration guidelines. No general guidelines are developed for these substances. By comparison of the site-specific guidelines to general, it can be concluded that the site-specific guidelines allow for higher concentrations of pollutants.

Table 9. Suggested site-specific stormwater guideline concentrations for coarse and fine land use division, respectively.

Substance	Coarse land use division (µg/l)	Fine land use division (µg/l)	General guidelines (µg/l)
P	-	-	160
N	-	-	2000
Pb	750	740	8.0
Cu	220	220	8
Zn	2700	2600	18
Cd	180	180	0.4
Cr	230	230	10
Ni	51	50	15
Hg	-	-	0.030
SS	-	-	40,000

4.3 MIKE Urban+

MIKE Urban+ was used in this thesis in order to evaluate its benefits and useability in detailed development planning. Input data was retrieved from StormTac Web. The results from Mike Urban+ were generated for TSS loads in the stormwater runoff. The loads were analyzed both for the entire watershed area and for the selected catchments corresponding to the small area in StormTac Web. Based on the total runoff volume and TSS load generated from the catchments during the simulated time-interval, the event mean concentration (EMC) was calculated for all the three scenarios simulated.

4.3.1 Resulting EMC's and time series

The resulting EMC for the scenarios is presented in Table 10. Calculations for input EMC's from StormTac Web are presented in Appendix . The calculation of the resulting EMC's was conducted with equation 19. The input data for the calculation was based on the total runoff volume and TSS load generated from all the catchments during the simulated time (see Appendix VII). The general trend displayed indicates that the resulting EMC's are somewhat smaller than the input maximum EMC. The time-series of the TSS load for the different scenarios are presented in Figure 16, Figure 17 and Figure 18.

Table 10. Input and resulting EMC's for the simulated scenarios 1-3.

Scenario	Type of scenario	Input max. EMC from StormTac [mg/L]	Resulting EMC [mg/L]
1	Entire watershed area	47	46.8
2	Delimited area, fine division	45.1	44.6
3	Delimited area, coarse division	57.6	57.3

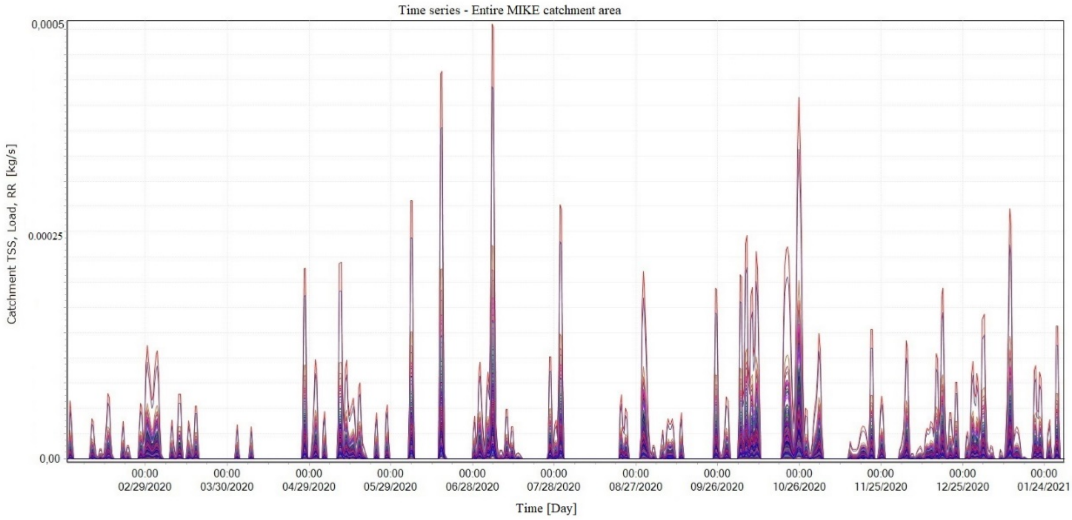

Figure 16. Time-series of the TSS load over the catchments in scenario 1 (entire watershed area) (kg/s).

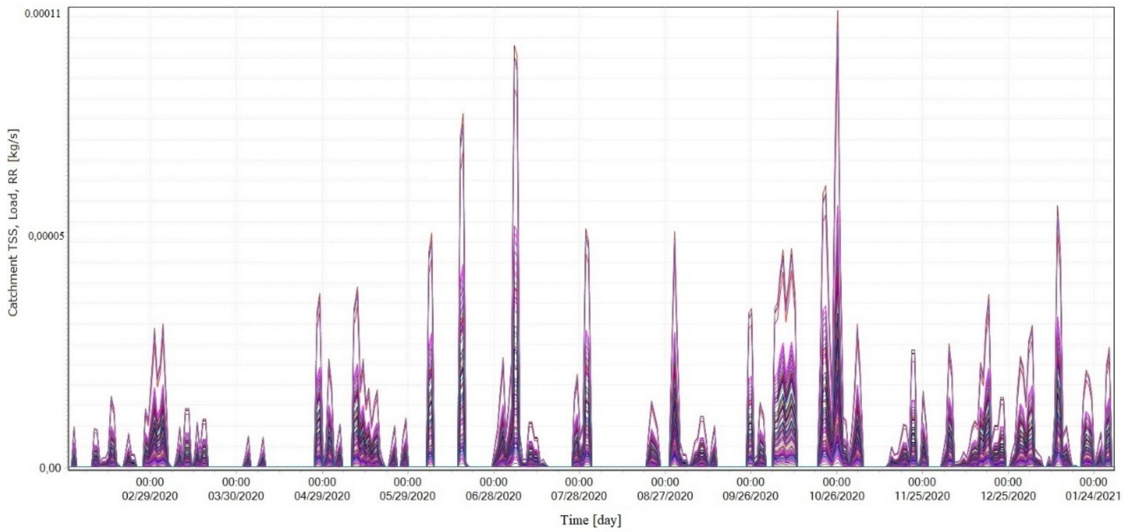

Figure 17. Time-series of the TSS load over the catchments in scenario 2 (delimited area, fine division) (kg/s).

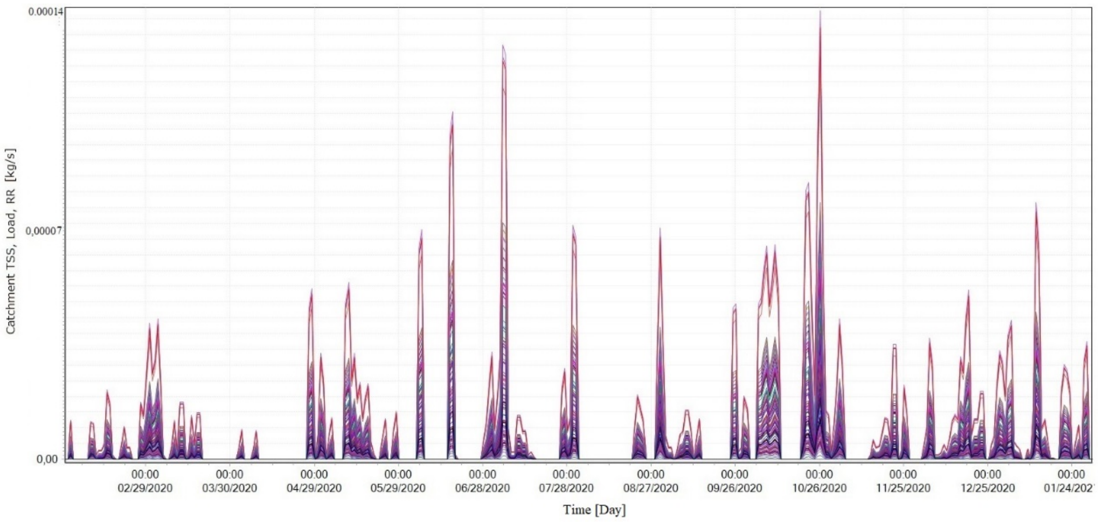

Figure 18. Time-series of the TSS load over the catchments in scenario 3 (delimited area, coarse division) (kg/s).

4.3.2 Maximum contribution of catchments to TSS load

For scenario 1, the catchment with the highest value for accumulated load of TSS on its surface, located in the watershed area, is presented in Figure 19. It is called catchment_240 and is located in outer border in the northern parts of the area. The land use in this catchment has a high imperviousness and is mainly industry resulting in higher contribution. At one point, it exceeded 0.00031 kg/s, which were significantly higher than the other catchments.

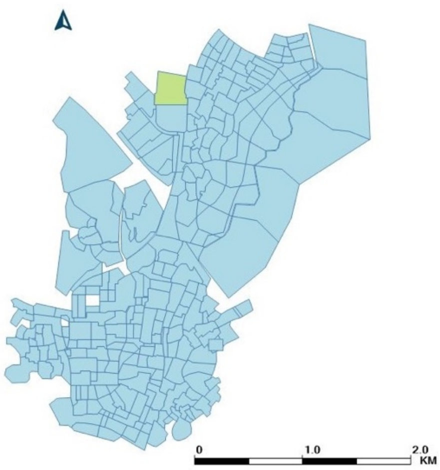

Figure 19. Mapping of catchment 240, contributing the most to an increase of the EMC in scenario 1.

Figure 20. Mapping of catchment 147_2, contributing the most to an increase of the EMC for scenario 2 and 3.

For scenario 2 and 3, the catchment with the highest value for accumulated load of TSS on its surface was the same and is presented in Figure 20. The catchment, called 147_2, located in the south-west parts of the simulated area, right next to the outer boarder had little ability to naturally flow to the Gröna dalen area. Therefore, the accumulation and load of TSS on that catchment is larger. The high values of the TSS resulted in an increase of the overall EMC-value.

5. Discussion

In this chapter the results of the research questions (RQs) are discussed.

5.1 Discussion of RQ1

What difficulties do consultants, county administrative boards and municipalities experience in their respective work tasks and co-operation connected to stormwater management and the environmental quality standards?

The consultants mainly experienced unreasonably high demands from county administrative boards (CABs) and customers. The demands differed in type. The CABs often required very low levels of discharge of stormwater pollutants from a detailed development plan. Concerning the 'harshness' from CABs experienced by consultants, Svenskt Vatten believed that a reason could be that they rather dismissed projects they had insufficient information about or lacked enough knowledge to assess properly. Concerning customers, they had unrealistic expectations of how much material consultants would be able to supply in order to prove the potential impact on the recipient.

The consultants reported that there was a lack of resources in terms of finance and time, for fulfilling the customers' expectations. Lacking knowledge was also reported among them. Consultants and the CABs jointly voiced the need for more resources in order to tackle this issue. According to the CAB, planners do not yet possess sufficient knowledge about what needs to be assessed considering stormwater in detailed development planning. It was believed that this issue needs time and joint efforts from parties involved in order to resolve itself. It was emphasized that the entire watershed area needed to be accounted for when assessing stormwater quality in detailed development planning. Svenskt Vatten agreed on this approach to stormwater quality assessments. The municipal water management planner lifted that the quality of stormwater assessments varies to an extent, where some are deemed good while other are not satisfactory. The municipal water management planner lifted that the quality of stormwater assessments varies to an extent. Some are of high quality while others are not satisfactory. This was reported to vary from one consultancy firm to another.

Our perception is that one source of this issue may stem from that the objectives of each party are different. That is, the consultants are under pressure from customers to deliver stormwater assessments within a limited amount of time. CABs are on the other hand obliged to follow legislation (Boverket, 2020a). It is possible that these different objectives collide in some cases. Due to limited time and budget, consultants have developed a standardised approach of performing stormwater assessments. In cases where this standardised approach is not sufficient for review by the CABs, problems can occur. Partly due to the combination of the budget being expended as well as the expressed lack of sufficient knowledge of stormwater consultants. It is possible that the standardised approach varies from one consultancy firm to another, where some have managed to adapt to the relatively new requirements, while others have not. It shall be noted that only one consultancy firm was interviewed in this thesis. Therefore, the discussion cannot be applied for all consultancy firms.

It is indicated that not enough resources are allocated to sufficiently plan for stormwater quality management. The question arising from this is who should be responsible for provision of such resources. The reasoning by the CAB was that putting higher demands on consultants would ultimately result in consultants placing higher demands on municipalities. Thereby access to sufficient resources would be gained. However, in the interview with Falkenberg municipality it was stated that the access to resources vary from one municipality to another. Considering that the need for stormwater management increases with expanding urbanization (US EPA, n.d.a) and climate change (Svenskt Vatten & SMHI, 2020), as well as the goals of the Water Framework Directive (European Commission, 2019) being rather ambitious, we consider it important to assess the financial aspect. That is, consider whether extended resources are needed as well as where they need to be allocated.

Skewed demands from the CABs were another example of difficulties experienced by consultants. It was reported that CABs often compared concentrations in stormwater before and after exploitation. Were a single pollutant to exceed current concentrations, this would be remarked. In practice, this resulted in previously unexploited grounds, such as forest areas, were subject to substantially higher demands than, e.g., industrial areas. However, verdicts were reported to differ depending on the CAB evaluating the stormwater assessment. The CAB believed that the approach to working with this issue differed slightly between CABs. It was, however, thought that the approach was becoming more similar over time. Concerning the reported skewed demands, Svenskt Vatten was of the opinion that the described approach by the CAB does not necessarily result in benefits for the environment. It rather forces planners to take extreme, sometimes unnecessary measures in order to receive a permit from the CAB.

It has been reported by Svenskt Vatten (2016b) that the implementation of the non-deterioration principle due to the Weser verdict may result in implications. It mainly relates to construction and development of wastewater treatment plants. Our notion from analysing the interview results is that the non-deterioration principle is interpreted in two different ways by the CABs. Some CABs have adopted the watershed area-perspective and thereby allowing compensatory measures. Other CABs dismiss plans where the stormwater pollution is not handled within the detailed development plan. According to the results from Vattenförvaltningsutredningen (2019) communication between concerned parties was identified as an issue impeding water management in Sweden. It is, from the results of this thesis as well as the results from the inquiry, indicated that communication between CABs need to improve. In that way, their verdicts on DDPs may become more uniform.

The issue of the division of responsibility between private property owners and municipalities was also identified during the interviews, as well as in literature. This was primarily reported by Svenskt Vatten (2020), but also expressed during the interviews. Due to current legalization, where the three regulations Lagen om Allmänna Vattentjänster (Lagen om Allmänna vattentjänster [LAV], SFS 2006:412) (LAV), The Planning and Building Act (Plan- och bygglagen [PBL], SFS 2010:900) (PBA) and the Environmental code (Miljöbalken [MB], 1998:808) (EC) apply in different cases, the responsibility falls almost exclusively on the municipality. The inherent problem of this division of responsibility is reported to be that the public space available for stormwater management is limited. Therefore, a change has been expressed as required. As was mentioned by Stahre (2008), the limited urban space requires coordination of different interests. Cettner (2012) also pointed out that stormwater measures are required to fit into an infrastructure which was originally constructed for handling stormwater by traditional piped systems.

Svenskt Vatten voiced that all responsibility of developing climate-safe societies cannot be put on municipalities. The representative from Boverket expressed that a change in responsibility between the private property owners and municipalities would perhaps be necessary. However, the CAB voiced the problem of placing too much responsibility on private property owners. This was due to that they seldom have the knowledge for appropriately implementing suitable stormwater management. This was considered by Svenskt Vatten as an important point to discuss. It was further suggested that this problem could be solved by implementing limit values for pollution discharges by private property owners. Limit values would place clear demands only on those who are responsible for more severe pollution. The problem of responsibility division is deeply rooted, as in legislation private actors are absolved from responsibility (Svenskt Vatten, 2020). We find all the opinions of the respondents reasonable. We believe that this issue will become increasingly relevant with regards urban development and climate change. If demands are to be placed on private property owners, it might be required by the municipalities to properly inform them of their responsibilities. It was voiced that there is a lack of sufficient knowledge of stormwater quality management amongst private property owners. Current legalisation (SFS 2010:900) only describes that private property owners need to regulate flows. As the PBA does not sufficiently prescribe clear demands which municipalities can put on private property owners, this further complicates the issue. It is indicated that the PBA needs to be clarified concerning this issue. A clarification would provide information of how the responsibility of stormwater quality management is to be distributed between the concerned parties.

5.2 Discussion of RQ2

What has potential to be improved in a traditional stormwater assessment concerning evaluating pollutants in stormwater from a detailed development area?

The potential for improvement was analysed in the context of enhancing the process of stormwater assessments in detailed development planning. The issue of stormwater management in order to reduce pollution of receiving waters is not a new finding as such (Cettner et al., 2012). However, from the interview conducted with the CAB it was expressed that the implementation of stormwater quality management in detailed development planning is relatively new. It is an approach that has gained attention in relatively recent years. Confirming this statement, Cettner et al. (2012) has reported that implementation of sustainable stormwater measures has been a slow process in Sweden historically. From our perspective, it seems the issue still suffers from it being relatively new, that is, the total experience and knowledge of parties involved is not yet substantial enough. From the results generated we cannot draw further conclusions considering this.

Our notion is that consultants need to more clearly express the need for more resources, in terms of budget and time from customers. This, in order to sufficiently fulfil the demands placed on them by the CABs. We therefore suggest that it is worth assessing the feasibility of putting higher demands on municipalities. Although higher demands may be experienced as unjust, the issue of stormwater management becomes more relevant with time. It is no longer affordable to neglect it (US EPA, n.d.a). The inherent resources needed for stormwater assessments, according to the results of the interview study, need to increase. Therefore, we further suggest that implementation of more advanced modelling of stormwater pollution would be possible. This would support both consultants and CABs in their respective work tasks, as more profound material would be available for assessment.

It has been reported by Svenskt Vatten (2016b) that the implementation of the non-deterioration principle due to the Weser verdict may result in implications. This considers mainly construction and development of wastewater treatment plants. Our notion from analysing the interview results is that the interpretation of the non-deterioration principle differs from one CAB to another. Some have adopted the watershed area-perspective and thereby allowing compensatory measures. Others dismiss plans where the stormwater pollution is not handled within the detailed development plan. Brown & Farrelly (2009) identified parameters impeding the implementation of stormwater measures. These include, among others, uncoordinated institutional framework and lack of communication between concerned parties. According to Cettner et al. (2012) and Naturvårdsverket (2017) stormwater measures are mainly implemented in relation to new exploitation in Sweden. This indicates that, despite assessing the entire watershed area when conducting stormwater assessments, the burden of stormwater pollution from the already existing exploitation needs to be handled by new exploitation. We believe that only considering new or reopened DDPs, while not taking existing infrastructure into consideration, further results in skewness. It can be questioned whether this is a sufficient approach of ensuring the EQSs are to be followed. However, some form of prioritization is necessary. Perhaps it can be deemed as justified to prioritize these DDPs, in cases such as these.

5.3 Discussion of RQ3

What are the benefits of using the modelling tools StormTac Web and MIKE Urban+ within the scope of detailed development planning when evaluating the pollutant load from stormwater on the recipient, and what has potential to be improved?

From our experience of modelling in StormTac Web, we consider it to be a user-friendly, time-sufficient program. It provides estimations of pollutant loads before and after implementation of stormwater measures. It also enables estimations of stormwater discharges on the recipient. However, the model is static. This means that it only provides estimated yearly concentrations based on average values and can thus not model extreme scenarios such as heavy rains. Since the software is not GIS-based it does not take into account spatial conditions, i.e., the geographical conditions of the area. According to Liu et al. (2012) only accounting for level of imperviousness and land use might negatively influence the adequacy of results for stormwater pollution concentrations. We partially accounted for spatial conditions by connecting the different sub-watershed areas to each other as well as the stormwater measures. However, this approach does not sufficiently account for spatial conditions due to that, e.g., topography was not accounted for.

From the results of the modelling in StormTac Web, it is clear that the choice of land use division influences the resulting stormwater concentrations. The coarse land use division of the delimited area entailed a higher load of pollution than the fine division. It is implied that the approach of conducting a fine division entail a loss of characteristics for a specific area, pollutant wise. This, since the land use choices made limits the possibilities of assigning an area with specific characteristics, e.g., when dividing a commercial area into 'roof', 'parking', 'green area' etc. However, to conduct fine land use divisions can be limited in cases where new exploitations is to be conducted. This, since knowledge of is visual appearance is limited at an early stage. ., thereby losing specific characteristics of a commercial area. Furthermore, it is important to note that it is difficult to estimate land use division of an area to be exploited in an early stage.

The contributing load from the delimited area to the watershed area was quite small both before and after treatment in all cases. It is important to note that the results from StormTac Web only present the load from stormwater pollution. Input data for loads from other sources, such as combined sewer overflows, could not be found. It would therefore be of interest to study the contribution to the watershed when accounting for these sources as well. Moreover, in order to verify that the contributing load is relatively small it would be interesting to study other delimited areas of varying sizes and properties. According to the CAB, they encourage taking the entire watershed area into account when evaluating stormwater within a detailed development plan area.

It can be concluded that StormTac is applicable early in the detailed development process. It can be used for assessing whether it is possible to exploit an area while not negatively affecting the EQSs. Very little input data is necessary for a quick assessment of present and future conditions. It is reasonable to believe that not much sampling is done early in the process. Although the results from the case study do not properly reflect the entire load from a watershed area. This was due to lack of input data as well as not taking spatial conditions into account. However, approach could work as supporting material when conducting more in-depth analyses, coupled with other assessments.

MIKE Urban+ is, in contrast to StormTac Web, a dynamic and GIS-based modelling tool which provides the user with almost endless possibilities. Flow and pollutant load of stormwater can be modelled at the same time, which is beneficial in stormwater assessments. The results from the modelling provided similar event mean concentrations (EMC) of the simulated pollutant TSS when comparing to the weighted concentration calculated from the land use divisions made in StormTac Web (see Appendix VI). As the weighted concentrations were used as input to the simulations, we find it reasonable that the output EMC was similar.

Apart from the differences in methods for the two programs, type of input data also differentiated. In StormTac Web land uses and sizes of catchment areas are defined. In MIKE Urban+ impervious percentage, size of area and people connected to the network are defined. However, since the simulations in MIKE Urban+ were limited to runoff over land, people connected to the network did not affect the results. The input rain data also differed between the programs. For StormTac Web a single value was added, representing the mean precipitation over a year. For MIKE Urban+ a time series of rainfall was used. MIKE Urban+ also provides the user with the possibility to identify which part of the simulated area that contributes the most to the pollution load, as was done in our modelling. This provides possibilities to assess the critical areas in a detailed development plan which could result in suggestions for suitable location of additional measures.

Our experience when modelling with MIKE Urban+ was that it required high user experience to receive reliable results, especially with regards to simulations of stormwater pollution. Since no predefined input data of pollutants are available in the program, the information needed for their characteristics required either sampling or advanced knowledge of pollutants. Using the EMC (Event Mean Concentration) method required less input data and parameters compared to the build-up/wash-off method. It was therefore by us considered more manageable and was used for modelling stormwater quality in MIKE Urban+. According to Tuomela et al. (2019) the EMC method is easier to use when modelling of stormwater quality in the modelling tool SWMM, as well. However, modelling stormwater quality using the EMC method often results in great uncertainties due to the lack of site-specific data. In the study conducted by Toumela et al. (2019) the EMC values were based on literature values. In our modelling in MIKE Urban+ the input data was retrieved from the Stormtac Web database and thus, based on sampling, although not site-specific.

Based on the literature found on this subject, it does not seem MIKE Urban+ has been investigated or used in many scientific articles. However, this we believe has to do with the fact that the program was recently launched and therefore, publications have not yet been published. Furthermore, only a few papers were found where the stormwater quality module was used with the previous versions of MIKE Urban. This indicates that the program is overall not frequently used to model pollutants. Niazi et al. (2017) claimed that there is a need for more manageable stormwater quality models which are not dependent on a high level of expertise, which we agree on. Based on the expressed need for more accurate stormwater assessments during the interviews with both the consultants and the CAB, we believe that an increased knowledge to model in programs such as MIKE Urban+ should be promoted. It would be beneficial for all parties involved in a detailed development plan to conduct more advanced assessments.

The level of uncertainties related to the results from modelling of stormwater quality in the respective programs have been assessed in literature. Wu et al. (2021) concluded that the uncertainty of modelling of some of the common stormwater pollutants in StormTac Web were 30%. These pollutants belong to those being more documented than less common stormwater pollutants (see Appendix III for documentation of uncertainties related to pollutants and land uses). Liu et al. (2010) assessed variability related to stormwater quality modelling in MIKE Urban, where it was concluded that it contributes to uncertainty of the results. It can therefore be concluded that the certainty of results from modelling of stormwater pollution is not yet satisfactory. Dotto et al. (2012) reached the conclusion that some sort of uncertainty analysis be carried out when evaluating stormwater quality modelling results. The complexity of the chosen technique should be suited for the problem in question. As it was concluded from the interview study that StormTac Web results serves as decision making material for the CAB, we consider it important to enlighten decision makers of the inherent uncertainties related to the material they revise.

The results from the interviews indicate that there is mutual interest from both consultants and CABs regarding further development of hydrological models. However, due to the current uncertainties regarding accessing accurate input data, more focus must first be placed on solving these issues. According to Müller et al. (2020) there are still a large number of uncertainties as to where pollution sources originate. Furthermore, in the interview with Svenskt Vatten it was pointed out that the amount of sampling in order to gain a full-scale view of, e.g., a city, would be very costly. The issue of whether it is always justified to pursue extensive sampling has also been lifted by Viklander et al. (2019). This, due to the expense and that it only provides information about the current situation. Niazi et al. (2017) emphasized the need for development of stormwater quality modelling without required sampling. It is by us perceived relevant to first overcome the current obstacles, before pursuing future focus on hydrological modelling. However, it is our belief that the use of the type of modelling would be beneficial in the future. Then it would be possible to study the pollution transport from a selected area to the recipient and more easily evaluate the actual impact from planned or existing exploitation.

5.4 Discussion of RQ4

Can general guidelines be suggested for evaluating the impact on the recipient from stormwater discharges from a detailed development area?

Currently there are no national guidelines available for implementation of the EQSs in stormwater assessments. Our attempt to provide a manner of implementing site-specific guideline concentrations for recipient Mälaren-Görveln is flawed. It is flawed primarily due to lack of input data. According to Equation 10, which is used in the calculation of the acceptable yearly concentration, Equation 22 , point loads should be accounted for, as stormwater is not the only source influencing the status of the recipient. Information of the recipient in the case study, Mälaren-Görväln, was retrieved from VISS (VISS, n.d.a). Information of point and diffuse sources influencing the recipient was stated, although no sampling data was available for them. Furthermore, data from VISS was not used in the case study due to that it was either lacking or not expressed in unit per water mass, which was required for modelling in StormTac Web. The lack of input data is overall reported to be an issue, as the database VISS has been criticised concerning this matter, among others (Svenskt Vatten, 2015). As was mentioned in the results from the interviews, the CAB does not deem it sufficient to prove that only a small amount of pollutants are discharged from a detailed development plan. It is rather advised to put the plan into a larger context. More input data would be required in order to do this. Since our point of view was from that of performing a conventional stormwater quality assessment, we found it restricting to not be able to retrieve appropriate data from VISS. We believe this may constitute an obstacle for consultants working with stormwater assessments.

According to the results from the interviews, there were different opinions on whether national guidelines are needed. It was highlighted during several of the interviews that there is a need for some kind of guidelines concerning implementation of the EQSs in DDPs. However, difficulties concerning the need for local adaption and an unclear division of responsibility concerning who should be responsible for developing such guidelines, were reported as impediments. According to Svenskt Vatten, general guidelines should not be focused on the status of the recipient. This, since the status differs significantly from one recipient to another. The approach to general guidelines should, according to them, rather provide guidance of suitable stormwater quality treatment. An example was to suggest suitable stormwater measures depending on which pollutants are of concern for the area in question. The need for extensive amounts of input data was highlighted in the interview with Svenskt Vatten, who stated that it is in most cases not feasible to sample stormwater for the purpose of developing guidelines.

Developing site-specific guidelines is, according to us, an instrument which is necessary in some cases, for example if the recipient concerned is in a very poor state. However, from our experience a lot of resources are required in order to establish site-specific guidelines of good enough reliability. Furthermore, we agree with Svenskt Vatten that developing guidelines for treatment of stormwater pollutants would be a simpler approach of tackling stormwater pollution. This is due to that it would hopefully enhance the process of implementing sustainable stormwater measures.

6. Conclusion

In this chapter the conclusions for the research questions (RQs) are presented:

6.1 Conclusion of RQ1

The difficulties experienced by consultants, county administrative boards (CABs) and municipalities in their respective work tasks and co-operation connected to stormwater management and the environmental quality standards was identified in four main themes:

- Skewed demands on consultants from the CABs, i.e., high demands being placed on some detailed development plans but not on others, depending on current land use.
- High demands on consultants from customers and the CABs in terms of level of results during a limited timeframe and budget.
- The division of responsibility of stormwater management between private property owners and municipalities.

6.2 Conclusion of RQ2

Potential improvements in a traditional stormwater assessment concerning evaluating pollutants in stormwater from a detailed development area have been identified as:

- Knowledge building and enhanced communication between involved parties in order to clarify the approach of verdicts from the CAB as well as what should be included by consultants when assessing stormwater quality
- An increased timeframe and budget for consultants to conduct stormwater assessments.
- The implementation of more advanced modelling of stormwater pollution to increase the accuracy and reliability.
- Further assessments of the interpretation of the non-deterioration principle in higher instances, as it is deemed the exact meaning of it needs to be further clarified.

6.3 Conclusion of RQ3

The respective benefits and room for improvements of the modelling tools StormTac Web and MIKE Urban+ within the scope of detailed development planning when evaluating the pollutant load from stormwater on the recipient was identified. The general room for improvements for the two programs was also identified.

- The benefit of StormTac Web is that it is a manageable tool providing possibilities to calculate estimated yearly pollutants load from stormwater on recipients.
- Potential improvements of the general use of StormTac Web in stormwater assessments have been identified as the need for coupling it with other assessments. Other assessments include accounting for spatial conditions.
- The benefits of MIKE Urban+ have been identified as the possibility to simulate extreme scenarios as well as stormwater flow and pollution at the same time.

- The room for improvements of MIKE Urban+ have been identified to be the need for increased modeling-knowledge of the program. The program is unable to simulate the effects on the recipient.
- The general issue identified when modelling in StormTac Web and MIKE Urban+ was lack of input data. For stormwater quality modelling to become more accurate, more sampling needs to be done.

6.4 Conclusion of RQ4

To develop general guidelines for stormwater quality in terms of discharging concentrations, was deemed to be difficult and resource-intensive due to the need for local adaption and an extensive need for input data. However, it is not deemed impossible. An alternative approach to guidelines is to instead develop guidance concerning suitable stormwater measures depending on the stormwater pollution characteristics of a certain area.

6.5 Recommendations for future research

We believe it would be of interest to conduct further investigations through supplementary interviews. This, to provide a broader perspective on the issues identified in the interview study conducted in this thesis. Our recommendation is to interview more county administrative boards, more municipalities and gain the perspectives of private property owners.

As for the modelling in StormTac Web, more thorough input data would have been required to develop site-specific stormwater guidelines. This, to increase the knowledge of the recipient and to localize point sources. Therefore, we suggest that a recommendation for future research could be to conduct sampling as a complement to develop site-specific guidelines.

The modelling in MIKE Urban+ was limited due to the high user experience needed to conduct detailed simulations in the program. Due to the time available, the modelling in the program had to be limited to only simulating TSS. This was also motivated by the high knowledge required of each pollutant's characteristics. It would have required sampling or high knowledge of each pollutant to conduct detailed simulation of several pollution during the time available. Therefore, possibilities for future research in MIKE Urban+ could be conducting a combined stormwater investigation using the program to simulate both flow and quality at the same time. Furthermore, supplementing the input data for the stormwater quality modelling with sampling would, according to us, have been an interesting research approach.

References

Andersson-Sköld, Y., Gustafsson, M., Järlskog, I., Polukarova, M., & Hvitt Strömvall, A.-M. (2020). *Microplastics from tyre and road wear: a literature review.* Statens Väg- och Transportforskningsinstitut.

Bertrand-Krajewsk, J.-L. (2020, Nov 27). Integrated urban stormwater management: Evolution and multidisciplinary perspective. *Journal of Hydro-environment Research*, p. https://doi.org/10.1016/j.jher.2020.11.003.

bio-met. (n.d.). About us. Retrieved 2021-03-04 from https://bio-met.net/about/

Bjällås, U., Fröberg, M., & Sundelin, A. (2015). *Hur ska EU-domstolens dom i mål C-461/13 (Weserdomen) tolkas och vad får den för betydelse?* Fröberg & Lundholm Advokatbyrå. https://www.svensktvatten.se/globalassets/avlopp-och-miljo/reningsverk-och-reningsprocesser/rapportweserdomen2015-12-15.pdf

Boverket. (2015a, Jun 10). *Ansvar för dagvatten i detaljplan*. Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/planering/detaljplan/temadelar-detaljplan/dagvatten-i-detaljplan/ansvar-for-dagvatten-i-detaljplan/

Boverket. (2015b, Jun 10). *Dagvatten i den översiktliga planeringen.* Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/planering/detaljplan/temadelar-detaljplan/dagvatten-i-detaljplan/dagvatten-i-den-oversiktliga-planeringen/

Boverket. (2015c, Jun 10). *Flera lagar reglerar dagvatten.* Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/planering/detaljplan/temadelar-detaljplan/dagvatten-i-detaljplan/flera-lagar-reglerar-dagvatten/

Boverket. (2020a, Okt 1). *Dagvatten vid detaljplaneläggning.* Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/planering/detaljplan/temadelar-detaljplan/dagvatten-i-detaljplan/dagvatten-vid-detaljplanelaggning/

Boverket. (2020b, Apr 1). *Översiktsplanen*. Retrieved from Boverket: https://www.boverket.se/sv/PBL-kunskapsbanken/planering/oversiktsplan/oversiktsplanen/

Boverket. (2019, Mar 28). *Vad kan man göra för att bevara, utveckla eller skapa ekosystemtjänster på hårdgjorda ytor?* Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/Allmant-om-PBL/teman/ekosystemtjanster/platser/hardgjorda/starka_hardgjort/

Boverket. (2014, Sep 23). *Vad är en detaljplan.* Retrieved from https://www.boverket.se/sv/PBL-kunskapsbanken/planering/detaljplan/detaljplaneinstrumentet/vad-ar-detaljplan1/

Brown, R., & Farrelly, M. (2009). Delivering sustainable urban water management: a review of the hurdles we face. *59*(5), 839-846. DOI:10.2166/wst.2009.028

Butler, D., & Davies, J. W. (2004). *Urban Drainage* (Vol. II). London: E & FN Spon.

Cettner, A. (2012). *Overcoming intertia to sustainable stormwater management.* (ISBN 978-91-7439-537-2). Department of Civil, Environmental and Natural Resources Engineering, Division of Architecture and Water. Luleå: Universitetstryckeriet. http://www.diva-portal.org/smash/get/diva2:991663/FULLTEXT01.pdf

Cettner, A., Ashley, R., Viklander, M., & Nilsson, K. (2013). Stormwater management and urban planning: Lessons from 20 years of innovation. *Journal of Environmental Planning and Management, 56*(6), pp. 786-801. https://doi.org/10.1080/09640568.2012.706216

Cettner, A., Söderholm, K., & Viklander, A. (2012). An Adaptive Stormwater Culture? Historical Perspectives on the Status of Stormwater within the Swedish Urban Water System. *Journal of Urban Technology, 19*(3), pp. 25-40. https://doi.org/10.1080/10630732.2012.673058

Clark, R. T. (1973). Mathematical models in hydrology, irrigation and drainage. *Paper, Food and Agriculture Organization of the United Nations.*

Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment: *The European Union's Official Journal.* L 135, 40-52. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0271

Delleur, J. W. (2006). *The Handbook of Groundwater Engineering.* Boca Raton: Taylor & Francis Group.

DHI. (2017). *What is included in MIKE 1D 2017?* Retrieved from MIKE Powered by Danish Hydrological Institute: https://manuals.mikepoweredbydhi.help/2017/Water_Resources/What_is_MIKE_1D.pdf

DHI. (2019, May 09). *MIKE Urban+ är här!* Retrieved from Danish Hydrological Institute: https://www.mikepoweredbydhi.com/presences/emea/sweden/news/2019/05/mike-urban-plus-ar-har

DHI. (2020a). *MIKE URBAN+ Model Manager.* Retrieved from Danish Hydrological Institute: https://manuals.mikepoweredbydhi.help/2020/Cities/MIKE_URBAN_MM.pdf

DHI. (2020b). *2D Overland User Guide.* Denmark: MIKE Powered by Danish Hydrological Institute. Retrieved from DHI: https://manuals.mikepoweredbydhi.help/2020/Cities/MIKE_URBAN_2DOverland.pdf

DHI. (2020c). *MIKE URBAN+ Collection system User Guide.* Retrieved from Danish Hydrological Institute: https://manuals.mikepoweredbydhi.help/2020/Cities/MIKE_URBAN_CS.pdf

DHI. (2020d). *MIKE 1D DHI Simulation Engine for 1D river and urban modelling Reference Manual.* Retrieved from Danish Hydrological Institute: https://manuals.mikepoweredbydhi.help/2020/Water_Resources/MIKE_1D_reference.pdf

DHI. (n.d.). *MIKE Programvara*. Retrieved from Danish Hydrological Institute: https://worldwide.dhigroup.com/se/mike%20programvara

Directive 2000/60/EC of the European Parliament and of the Council of the 23 Oct 2000 about establishing a framework for the Community action in the field of water policy. *The European Union's Official Journal,* L 327, 1-73. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

Dunn, G., Bakker, K., & Harris, L. (2014). Drinking Water Quality Guidelines across Canadian Provinces and Territories: Jurisdictional Variation in the Context of Decentralized Water Governance. *Int. J. Environ. Res. Public Health, 11(5)*, pp. 4634-4651; doi.org/10.3390/ijerph110504634.

Ekka, S., Rujner, H., Leonhardt, G., Blecken, G.-T., Viklander, M., & Hunt, W. (2021, February 1). Next generation swale design for stormwater runoff treatment: A comprehensive approach. *Journal of Environmental Management, 279*, p. 111756. DOI: 10.1016/j.jenvman.2020.111756

Esri. (2021a). "Imagery Hybrid" [basemap]. Scale Not given. "Imagery Hybrid Map".

Esri. (2021b). "Open street" [basemap]. Scale Not given. "Open Street Map".

European Commission. (2019). *Fitness Check of the Water Framework Directive and the Floods Directive.* Brussels. Retrieved from European Commission. https://ec.europa.eu/environment/water/fitness_check_of_the_eu_water_legislation/documents/Water%20Fitness%20Check%20-%20SWD(2019)439%20-%20web.pdf

European Commission. (n.d.). *Introduction to the EU Water Framework Directive*. Retrieved 2021-03-04 from from European Commission: https://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

European Environment Agency. (2018). *European waters Assessment of status and pressures 2018.* Luxembourg: Publications Office of the European Union.

Goulden, S., Portman, M. E., Carmon, N., & alon mozes, T. (2018, May). From conventional drainage to sustainable stormwater management: Beyond the technical challenges. *Journal of Environmental Management, 219*, p. DOI:10.1016/j.jenvman.2018.04.066

Gunawardena, J., Liu, A., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2018). Primary Traffic Related Pollutants and Urban Stormwater Quality. In J. M. Gunawardena, A. Liu, P. Egodawatta, G. A. Ayoko, & A. Goonetilleke, *Influence of Traffic and Land Use on Urban Stormwater Quality* (1st ed., pp. 1-16). Singapore: Springer. DOI:10.1007/978-981-10-5302-3_1

Göteborgs stad. (2020). *Riktlinjer och riktvärden för utsläpp av förorenat vatten till dagvattennät och recipient.* Göteborg: Göteborgs stad. https://goteborg.se/wps/wcm/connect/a227da55-ea58-4410-a00f-ba75014080e4/N800_R_2020_13_Riktlinjer+och+riktv%C3%A4rden+f%C3%B6r+utsl%C3%A4pp+av+f%C3%B6rorenat+vatten.pdf?MOD=AJPERES

Hallin, A., & Helin, J. (2018). *Intervjuer* (1st ed.). Studentlitteratur AB.

Havs- och vattenmyndigheten. (2020, Feb 17). *Hur är miljökvalitetsnormerna uppbyggda?* Retrieved Apr 27, from Havs- och vattenmyndigheten: https://www.havochvatten.se/vagledning-foreskrifter-och-lagar/vagledningar/provning-och-tillsynsvagledning/miljokvalitetsnormer-vid-provning-och-tillsyn/hur-ar-miljokvalitetsnormerna-uppbyggda.html

Havs- och vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten. (HVMFS 2019:25). Havs- och vattenmyndigheten. https://www.havochvatten.se/download/18.4705beb516f0bcf57ce1c145/1576576601249/HVMFS%202019-25-ev.pdf

Holmqvist, I., Malmberg, T., Enarsson, P., & Drotte, P. (2011). *Miljökvalitetsnormer för vatten.* Stockholm: Länsstyrelsen i Stockholms län.

Inglezakis, V. J., Poulopoulos, S. G., Arlhangelsky, E., Zorpas, A. A., & Menegaki, A. N. (2016). Chapter 3 - Aquatic Environment. *Environment and Development*, pp. 137-212 doi.org/10.1016/B978-0-444-62733-9.00003-4

Jacobs, A., Fagerberg, J., Prima, M., Öjermark, R., Thörnelöf, S., Alm, H., & Larm, T. (2009). *Förslag till riktvärden för dagvattenutsläpp.* Regionplane- och trafikkontoret, Stockholms läns landsting.

Kvale, S., & Brinkmann, S. (2014). *Den kvalitativa forskningsintervjun.* Lund: Studentlitteratur AB.

Larm, T. (2000). *Watershed-based design of stormwater treatment facilities: model development and applications.* [PhD Thesis, KTH].

Larm, T. (2003). An operative watershed management model for estimating existing and acceptable pollutant loads on receiving waters and for the design of the corresponding required treatment facilities. *International Conference on Urban Drainage and Highway Runoff in Cold Climate*, (pp. 235-245). Riksgränsen. http://stormtac.com/admin/Uploads/Paper%202003_StormTac%20recipient%20model.pdf

Larm, T., & Alm, H. (2016). *Design criteria for local stormwater facilities to meet pollution and flow requirements.* Lyon: Graie. http://hdl.handle.net/2042/60485

Liao, K., Deng, S., & Tan, P. (2017, March 30). Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management. *an P., Jim C. (eds) Greening Cities. Advances in 21st Century Human Settlements*. DOI:10.1007/978-981-10-4113-6_10

Liu, A., Egodawatta, P., Kjølby, M. J., & Goonetilleke, A. (2010). Development of pollutant build-up parameters for MIKE URBAN for Southeast Queensland, Australia. *International MIKE by DHI conference.* DHI.

Liu, A., Goonetilleke, A., & Egodawatta, P. (2012). Inadequacy of land use and impervious area fraction for determining urban stormwater quality. *Water Resources Management, 26*(8), pp. 2259-2265. https://doi.org/10.1007/s11269-012-0014-4

Liu, A., Goonetilleke, A., & Egodawatta, P. (2015). Urbanisation and Stormwater Quality. *Role of Rainfall and Catchment Characteristics on Urban Stormwater Quality. SpringerBriefs in Water Science and Technology*.

Länsstyrelsen Kalmar. (2018). *Dagvattenhantering i ett förändrat klimat.* Kalmar: Länsstyrelsen Kalmar.

Maniquiz-Redillas, M., Choi, J.-Y., Lee, S., & Cho, H.-J. (2010). Appropriate Methods in Determining the Event Mean Concentration and Pollutant Removal Efficiency of a Best Management Practice. *Environmental Engineering Research, 15*(4). DOI:10.4491/eer.2010.15.4.215

Markiewicz, A., Björklund, K., Eriksson, E., Kalmykova, Y., Strömvall, A.-M., & Siopi, A. (2017). Emissions of organic pollutants from traffic and roads: Priority pollutants selection and substance flow analysis. Science of The Total Environment, 580, 1162-1174. doi:https://doi.org/10.1016/j.scitotenv.2016.12.074

Marsalek, J. (2003). Overview of Urban Stormwater Impacts on Receiving Waters. In R. Arsov, J. Marsalek, E. Watt, & E. Zeman, *Urban Water Management: Science Technology and Service Delivery* (Vol. 25, pp. 1-10). Dordrecht: Springer. https://doi.org/10.1007/978-94-010-0057-4_1

MB 1998:808. *Miljöbalken.* Miljödepartementet. https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808

Miljöbarometern. (2021, Apr 13). *Mälaren - Görväln*. Retrieved Apr 14, 2021, from Stockholms stad: http://miljobarometern.stockholm.se/vatten/sjoar/gorvaln/

Moges, E.; Demissie, Y.; Larsen, L.; Yassin, F. Review: Sources of Hydrological Model Uncertainties and Advances in Their Analysis. *Water* 2021, *13*, 28. https://doi.org/10.3390/w13010028

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of The Total Environment, 702*. https://doi.org/10.1016/j.scitotenv.2019.136125

Naturvårdsverket. (2017). *Analys av kunskapsläget för dagvattenproblematiken.* Naturvårdsverket. https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2017/analys-kunskapslaget-dagvattenproblematiken.pdf

Naturvårdsverket. (2019a). *Bilaga 1 - Dagvattenhanteringen idag.* Naturvårdsverket. https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2019/bilaga-1-dagvattenhanteringen-idag.pdf

Naturvårdsverket. (2019b). *Regeringsuppdrag att föreslå etappmål om dagvatten.* Retrieved 2021-05-24 from https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2019/redovisning-ru-etappmal-for-dagvatten-skrivelse.pdf

Naturvårdsverket. (2020). *Kapitel 5 - Miljökvalitetsnormer.* Retrieved Feb 05, 2021, from Naturvårdsverket: https://www.naturvardsverket.se/Stod-imiljoarbetet/Rattsinformation/Miljobalken/Forfattningar-med-stod-av-miljobalken/Kapitel-5---Miljokvalitetsnormer/

Niazi, M., Nietch, C., Maghrebi, M., Jackson, N., Bennet, B. R., Tryby, M., & Massoudieh, A. (2017). Storm water management model: Performance review and gap analysis. *Journal of Sustainable Water in the Built Environment, 3(2)*. DOI: 10.1061/JSWBAY.0000817.

Nix, S. J. (1994). *Urban Stormwater Modeling and Simulation.* Boca Raton: Lewis Publishers.

Norconsult. (2019). *Utredning Dagvattenpark Gröna dalen Beräknings-PM.* [Unpublished material].

Paloniitty, T. (2016, March). The Weser Case: Case C-461/13 BUND V GERMANY. *Journal of Environmental Law, 28*(1), pp. 151-158. DOI:10.1093/jel/eqv032

Prop. 2005/06:78. Allmänna vattentjänster. Miljö- och samhällsbyggnadsdepartementet. https://data.riksdagen.se/fil/6C14A01E9624-4617-8588-9AE4D2E5A769

Qiao, X.-J., Liu, L., Kristoffersson, A., & Randrup, T. B. (2019). Governance factors of sustainable stormwater management: A study of case cities in China and Sweden. *J Environ Manage*. doi:10.1016/j.jenvman.2019.07.020

Regionplane- och trafikkontoret. (2009). *Förslag till riktvärden för dagvattenutsläpp.* Regionplane- och trafikkontoret. http://stormtac.com/admin/Uploads/Riktvarden_dagvatten_feb_2009.pdf

Rossman, L. A. (2015). Storm Water Management Model User's Manual Version 5.1. Cincinnati: U.S. Environmental Protection Agency EPA.

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., . . . Brown, R. R. (2008, August). Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. *Environ Manage, 42*(2), pp. 344-59. https://doi.org/10.1007/s00267-008-9119-1

SFS 2006:412. *Lagen om allmänna vattentjänster.* Miljödepartementet. https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-2006412-om-allmanna-vattentjanster_sfs-2006-412

SFS 2010:900. *Plan- och bygglagen.* Finansdepartementet. https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/plan--och-bygglag-2010900_sfs-2010-900

Shaver, E., Horner, R., Skupien, J., May, C., & Ridley, G. (2007). *Fundamentals of Urban Runoff Management: Technical and Institutional Issues* (Vol. II). Madison, Wisconsin: North American Lake Management Society.

SLU. (n.d.). *Miljödata MVM En webbtjänst med mark-, vatten- och miljödata*. Retrieved Feb 22, 2021, from SLU: https://miljodata.slu.se/MVM/

SMHI. (n.d.a). *Modelldata per område*. Retrieved February 22, 2021, from Vattenwebb: https://vattenwebb.smhi.se/modelarea/

SMHI. (n.d.b). *Ladda ner meteorologiska observationer*. Retrieved February 22, 2021, from SMHI: https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=precipitation24HourSum,stations=active,stationid=97330

Stahre, P. (2008). *Blue-green fingerprints in the city of Malmö, Sweden : Malmö's way towards a sustainable urban drainage.* Malmö: VA Syd.

Statistiska centralbyrån. (2003). *Land use in localities 2000 and changes 1995-2000.* Retrieved Mar 03, 2021, from SCB: https://www.scb.se/contentassets/cfc80cdc6cd04fa1bae949cb5b2470b2/mi0810_1995i00_sm_mi14sm0201.pdf

Stockholms stad. (2016a). *Dagvattenhantering - Riktlinjer för kvartersmark i tät stdsbebyggelse.* www.stockholmvattenochavfall.se/globalassets/dagvatten/pdf/riktlinjer_kvartersmark.pdf

Stockholms stad. (2016b). *Dagvattenhantering - Riktlinjer för parkeringsytor.* https://www.stockholmvattenochavfall.se/globalassets/dagvatten/pdf/riktlinjer_parkeringsytor.pdf

StormTac. (n.d.). *Method description StormTac Web*. Retrieved from StormTac Stormwater solutions: http://www.stormtac.com/?page_id=2049

Svenskt Vatten. (2016a). *Avledning av dag-, drän- och spillvatten Funktionskrav, hydraulisk dimensionering och utformning av allmänna avloppssystem.* (ISSN 1651-4947). Svenskt Vatten AB. http://vav.griffel.net/filer/P110_del1_web_low_180320.pdf

Svenskt Vatten. (2016b). *Hur miljökvalitetsnormer och Weserdomen påverkar reningsverk.* Bromma: Svenskt Vatten.

Svenskt Vatten. (2019). *Hållbar dagvattenhantering*. Retrieved March 22, 2021, from Svenskt Vatten: https://www.svensktvatten.se/vattentjanster/rornat-och-klimat/klimat-och-dagvatten/avledning-av-spill--dran--och-dagvatten-p110/

Svenskt Vatten. (2016c). *Kommunens skyldigheter.* Hämtat från https://www.svensktvatten.se/va-chefens-verktygslada/juridik/oversikt-regelverk/vattentjanster-regler-fragor-och-praxis/kommunens-skyldighet-att-ordna-vattentjanster/

Svenskt Vatten. (2020, January 27). *Hållbar hantering av dagvatten och skyfall*. Retrieved Mar 29, 2021, from Svenskt Vatten: https://www.svensktvatten.se/om-oss/svenskt-vatten-tycker/hallbar-hantering-av-dagvatten-och-skyfall/

Svenskt Vatten. (2021). *Miljökvalitetsnormer och Weserdomen påverkar VA-verksamheter.* Retrieved Apr 5, 2021 from https://www.svensktvatten.se/globalassets/avlopp-och-miljo/recipienter/pm-for-webben-210316.pdf

Svenskt Vatten & SMHI. (2020). *Rekommendationer vid val av nederbördsstatistik för dimensionering av dagvattensystem.* (ISSN 1651-6893). Svenskt Vatten AB. https://www.svensktvatten.se/globalassets/rornat-och-klimat/klimat-och-dagvatten/svensktvatten_smhi_pm-april-2020.pdf

Svenskt Vatten. (2015, April 24). *Samråd om miljökvalitetsnormer, förvaltningsplaner och åtgärdsprogram*. Retrieved Apr 14, 2021, from Svenskt Vatten: https://www.svensktvatten.se/globalassets/remissvar-150424.pdf

Tuomela, C., Sillanpää, N., & Koivusalo, H. (2019, March 1). Assessment of stormwater pollutant loads and source area contributions with storm water management model (SWMM). *Journal of Environmental Management (233)*, pp. 719–727 DOI: 10.1016/j.jenvman.2018.12.061.

Upplands-bro kommun. (2018). *Utvecklingsprogram för Gröna dalen.* Upplands-bro: Upplands-bro kommun. Retrieved from: https://www.upplands-bro.se/download/18.1a79e56b163d6e00e3a4731d/1528884701448/Utvecklingsprogram_Gr%C3%B6na%20dalen.pdf

Upplands-bro kommun. (n.d.). *Upplands-bro kommun*. Retrieved from Om kommunen: https://www.upplands-bro.se/kommun--politik/om-kommunen.html

US EPA. (n.d.a). *Climate Adaption and Stormwater Runoff*. Retrieved May 03, 2021 from United States Environmental Protection Agency: https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff#:~:text=When%20stormwater%20is%20absorbed%20into%20soil%2C%20it%20is,can%20exacerbate%20existing%2C%20or%20introduce%20new%2C%20pollution%20problems.

US EPA. (n.d.b). *Standards for Water Body Health.* Retrieved from United States Environmental Protection Agency: https://www.epa.gov/standards-water-body-health/what-are-water-quality-standards

Vattenförvaltningsutredningen. (2019). *En utvecklad vattenförvaltning Volym 1 och 2.* (SOU 2019:66). Norsteds Juridik. https://www.regeringen.se/4af95d/contentassets/3ca686d2da744f93a069c71601cf4830/en-utvecklad-vattenforvaltning---volyn-1-och-2-sou-201966

Vattenmyndigheterna. (n.d.a). *Kommunernas roll*. Retrieved Mar 31, 2021, from Vattenmyndigheterna: https://www.vattenmyndigheterna.se/vattenforvaltning/vattenforvaltning-i-sverige/kommunernas-roll.html

Vattenmyndigheterna. (n.d.b). *3.1 Påverkan, status och risk*. Retrieved Mar 15, 2021, from Vattenmyndigheterna: https://www.vattenmyndigheterna.se/vattenforvaltning/samrad-om-forvaltningsplan-atgardsprogram-och-miljokvalitetsnormer-2021-2027/forslag-till-forvaltningsplan/kapitel-3---tillstand-och-paverkan/3.1-paverkan-status-och-risk.html

Vattenmyndigheterna. (n.d.c). *Vattendistrikt i Sverige*. Retrieved Jan 20, 2021, from https://www.vattenmyndigheterna.se/om-vattenmyndigheterna/vattendistrikt-i-sverige.html

Vattenmyndigheterna. (n.d.d). *Vattenmyndigheternas uppdrag*. Retrieved Jan 20, 2021, from Vattenmyndigheterna: https://www.vattenmyndigheterna.se/om-vattenmyndigheterna/vattenmyndigheternas-uppdrag.html

Vattenmyndigheterna. (n.d.e). *Länsstyrelsernas roll*. Retrieved Apr 14, 2021, from Vattenmyndigheterna: https://www.vattenmyndigheterna.se/vattenforvaltning/vattenforvaltning-i-sverige/lansstyrelsernas-roll.html

Vetenskapsrådet. (2017). *God forskningssed.* Stockholm: Vetenskapsrådet.

Vezzaro, L., Mikkelsen, P. S., Deletic, A., & McCarthy, D. (2013). Urban drainage models-simplifying uncertainty analysis for practitioners. Water Science & Technology, 68(10), 2136–2143

Viklander, M., Österlund, H., Müller, A., Marsalek, J., & Borris, M. (2019). *Kunskapssammanställning Dagvattenkvalitet.* Svenskt Vatten Utveckling. https://www.svensktvatten.se/contentassets/f3d99ca8ce964851b9702d3dc85e4269/trvu-rrap-2019-02.pdf

VISS. (2018). *Vad är VISS?* Retrieved Jan 18, 2021, from VISS Vatteninformationssystem Sverige: https://viss.lansstyrelsen.se/About.aspx

VISS. (n.d.a). *Mälaren-Görväln*. Retrieved Feb 05, 2021, from VISS: https://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA11895268

VISS. (n.d.b). *Sverige - Land Områdesstatistik*. Retrieved Mar 20, 2021, from VISS: https://viss.lansstyrelsen.se/AreaStatisticsForm.aspx?area=10,1&subUnitType=0

Wiklander, M. (2017). *Föroreningar i dagvatten.* Luleå Tekniska universitet, Institutionen för samhällsbyggnad och naturresurser. Luleå: Luleå Tekniska universitet. https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2017/dagvattenproblematiken.pdf

Wu, J., Larm, T., Wahlsten, A., Marsalek, J., & Viklander, M. (2021). Uncertainty inherent to a conceptual model StormTac Web simulating urban runoff quantity, quality and control. *Urban Water Journal*, pp. 1-10. doi:10.1080/1573062X.2021.1878240.

Voulvoulis, N., Arpon, K., & Giakoumis, T. (2017). The EU Water Framework Directive: From great expectations to problems with implementation. *Science of The Total Environment, 575*, pp. 358-366. DOI:10.1016/j.scitotenv.2016.09.228

Zoppou, C. (Apr 2001). Review of urban storm water models . *Environmental Modelling & Software*, pp. 195-231. https://doi.org/10.1016/S1364-8152(00)00084-0

Appendix I - Interview questions

Questions for interview 1: Environmental consultant at Norconsult.

1. Kan du berätta lite om din bakgrund och nuvarande yrkesroll samt dina vanligaste arbetsuppgifter? // *Can you inform us a bit about your background, current work, and usual work tasks?*
2. Vad upplever du är problematiskt med att göra en recipientbedömning i en dagvattenutredning? // *What do you experience to be problematic in assessing the impact of the recipient in a stormwater assessment?*
3. Vi har haft vissa svårigheter med att utvärdera hur ett dagvattenutsläpp faktiskt påverkar recipienten. Vi har använt StormTac där vi lagt in vissa recipientspecifika data, men det resulterar ändå i en väldigt förenklad modell över recipienten. Hur arbetar du med det? Arbetar man så över huvud taget? // *We have had some issues in evaluating the actual impact of a stormwater discharge on the recipient. We have used StormTac where we have added some recipient specific data, however it still results in a very simplified model of the recipient. How do you work with that? Do you work that way at all?*
4. Tanken är att vi ska använda MIKE Urban+ för att simulera utsläpp också. Dock kommer vi bara kunna simulera koncentrationen i dagvattnet eftersom vi inte har tillgång till en modell över vårt vattendrag. Finns det sätt att arbeta runt att en modell inte finns tillgänglig och/eller att data över recipienten är begränsad? // *We will be using MIKE Urban+ in order to simulate stormwater discharges as well. However, we will only be able to simulate the stormwater concentration since we do not have access to a model of our recipient (Mälaren-Görväln). Are there ways of working around the fact that a model is not available and/or that data of the recipient is limited?*

Questions for interview 2: Representatives from the Water Authorities.

1. Inledningsvis tänkte vi att ni kunde presentera lite kort om vilka ni är och vilket vattendistrikt ni ansvarar för. // *Initially, we thought that you briefly could introduce yourself and which water district you are responsible for.*
2. Hur ser processen ut när ni stöttar län i sitt arbete att uppnå miljökvalitetsnormerna? // *How does the process look like when you support counties in their work to achieve the environmental quality standards?*
3. Händer det ofta att framtagningen av miljökvalitetsnormer (till exempel gränsvärden i recipient eller för dagvatten) sker på felaktiga grunder och måste omvärderas? *Does it often occur that the development of environmental quality standards (i.e. limit values in the recipient or for stormwater) is made on incorrect terms and needs to be re-evaluated?*
4. Hur fungerar arbetet mellan Sverige och andra nordiska länder (Norge, Danmark och Finland) om ett avrinningsområde sträcker sig över gränserna? // *How does the cooperation between Sweden and the other Nordic countries work, concerning when a watershed area crosses country borders?*

Questions for interview 3: Water management planner at Falkenberg municipality.

1. Vi har läst på ett antal håll att riktlinjerna kommuner får till sig är otillräckliga avseende dagvattenhantering. Vår uppfattning är att de större kommunerna utvecklat tydliga riktlinjer avseende detta, medan de mindre kommunerna inte gjort det. Stämmer detta, och i så fall, vad kan vara möjliga anledningar? // *We have, through literature, received the notion that the guidelines provided to municipalities considering stormwater management*

are insufficient. Our notion is that the larger municipalities have developed clear guidelines, while the smaller municipalities have not. Is this correct, and if so, what do you think are possible reasons?

2. Hade det varit möjligt, enligt dig, att för varje kommun utveckla riktlinjer som är applicerbara för just den kommunen? Är det nödvändigt? // *Would it according to you be possible for each municipality to develop guidelines applicable for that specific municipality? Is it necessary?*
3. Vi har fått uppfattningen att den rådande situationen, alltså att dagvatten ska hanteras på kommunal mark, är ohållbar, och kommer bli ännu mer ohållbar i takt med klimatförändringar (hänvisar till Svenskt Vatten). Håller du med om detta? På vilket sätt skulle problematiken kunna lösas? // *We are of the notion that the current situation, that is, stormwater being handled on municipal ground, is unsustainable, and will become more unsustainable with climate change. Do you agree on this? In what way could this issue be resolved?*

Questions for interview 4: Representative from Boverket.

1. Skiljer sig tillvägagångssätten för behandling av dagvatten sig åt från län till län? Finns det några anledningar till detta? // *Does the approach to treat stormwater differ between counties? Are there any reasons for this?*

1. Hade det varit möjligt att ta fram mer generella riktlinjer för dagvatten för hela Sverige, snarare än att de skiljer sig år beroende på vilken del av landet det gäller*?// Would it have been possible to develop more general guidelines concerning stormwater, applying to all of Sweden, rather than that they differ depending on which part of the country is considered?*
2. Svenskt Vatten anser delvis att dagvattenproblematiken består av de privata aktörerna inte behöver ta något ansvar för dagvattenhantering utan att det landar på kommunerna. En person vi tidigare intervjuat lyfte att medlemmarna i Svenskt Vatten består av kommuner/kommunala vattenorganisationer. Problemet blir därför att dokumenten är utvecklade av den ena parten. Det vi undrar är då om du har något intryck eller erfarenheter av detta. // *According to Svenskt Vatten, one of the stormwater issues consists of that not strict enough demands are put on private property owners concerning treatment of stormwater on private land. It is rather the municipality that needs to handle the stormwater. Do you have any experiences/impressions of this issue, and in that case, what kinds of experiences/impressions?*
3. Svenskt Vatten har gett ut massa policydokument och deras medlemmar är ju kommunerna eller kommunaljobbare. Detta material blir då grundläggande i rättstvister mellan fastighetsägare och kommuner. Då undrar vi då hur du ser på det och om du tror att det kan vara problematiskt att policydokument inte är framtagna av myndigheter. // *Svenskt Vatten has published an array of policy documents concerning stormwater treatment, which are often used in legislation where the parties are the municipality and the private property owner. A person which we have interviewed earlier has lifted that the members of Svenskt Vatten consists of municipalites/communal water companies. The problematics therefore are that the policy documents are developed by "one of the parties". How do you view this? Do you think it is problematic that policy documents are not developed by authorities?*

Questions for interview 5: Representative from the county administrative board in Kalmar.

1. Vill du berätta lite kort om vad ditt jobb innebär, kanske främst med fokus på recipientbedömning och dagvatten. // *Would you like to tell us a bit about your work, mostly with the focus on recipient assessments and stormwater.*
2. Från vilka kriterier utgår du när du bedömer om ett dagvattenutsläpps påverkan på recipienter är godkänt eller inte? Hur går den processen till? // *Which criteria's do you use when you assess if a stormwater discharges effect on the recipient is approved or not? What does that process look like?*
3. Hur mycket arbete läggs på att utvärdera redan exploaterade områden gentemot utformningen av detaljplanerna? Hur stöttar länsstyrelsen kommunerna i sin prioritering av områden? Finns det någon prioritering avseende redan exploaterade områden? // *How much work is placed on evaluating already exploited areas versus developments of new development plans? How does the county administrative board support the municipalities in their priorities of areas? Is there any prioritization with regards to already exploited areas?*
4. Skiljer sig tillvägagångssätten för behandling av dagvatten åt från län till län? Finns det några anledningar till detta? // *Do the approaches for management of stormwater differ from county to county? Are there any reasons for this?*
5. Vi har genom vår intervjustudie på flera håll stött på att det upplevs som att kraven som ställts av Länsstyrelsen på detaljplaner avseende dagvattenhantering ibland varit väldigt hårda (från kommun- och konsultsidan). Vi har utfört ett referensprojekt där vi räknat på föroreningar i dagvatten från ett område motsvarande ett detaljplaneområde, och tittat på hur recipienten påverkas av detta område. Resultaten indikerar att föroreningsmängden är försumbar i recipienten. Det ska nämnas att vi använt oss av StormTac och inte haft tillgång till all platsspecifika data som egentligen skulle krävas för att göra en sådan bedömning, dock. Vår fundering är dock om det alltid är rimligt att ställa så hårda krav på detaljplaner. Hur ser du/ni på detta?
   We have through our literature study, in several ways accoutered that the demands placed from the county administrative boards sometimes have been very strict (from municipality and consultants). We have conducted a case study where we have calculated the pollutants in stormwater from an area corresponding to a detail development plan and investigated how the recipient is affected by this area. The results indicate that the pollution load is neglectable in the recipient. Is shall be noted that we have been using StormTac and no site-specific data was available, which would have been needed to conduct such a judgment. Our reflection is however, if there is reasonable to place such hard demands on detailed development plans? What is your opinion on this?
6. Vad tycker du om implementering av modellering av markanvändning och vattendrag för att studera effekten från dagvatten på recipient? Tycker du mer krut borde läggas på att utveckla ett sånt här tillvägagångssätt för att underlätta bedömningsprocessen för er? // *What is your opinion on implementing modelling on land-use and recipients in order to study the effects from stormwater on the recipients? Do you consider that more efforts should be placed to develop such an approach to ease your assessments process?*

Questions for interview 6: Stormwater consultant at Norconsult.

1. Vad jobbar du med? // *What do you work with?*
2. Vi har hört från vår handledare att du velat få tag i Länsstyrelserna angående ett antal funderingar, skulle du vilja berätta lite mer om det? // *From our supervisor we have heard that you have wanted to get in contact with the county administrative boards concerning some issues, would you lite to talk a bit about that?*

3. I vår intervju med miljökonsulten på Norconsult fick vi intrycket av att länsstyrelsen kräver mer dagvattenlösningar snarare än att utreda påverkan på recipienten och efter de resultaten godkänna/avslå. Vad är din erfarenhet av detta? // *From our interview with the environmental consultant at Norconsult we received the impression that the county administrative board requires more stormwater measures rather than evaluating the impact on the recipient and allow or dismiss based on those results. What is your experience of this?*
4. Länsstyrelsen tycker att man ska se till hela avrinningsområdet vid detaljplanering (och dagvattenutredningar då). Hur ser det ut när du får en dagvattenutredning på ditt bord? Hur mycket finns det resurser för att göra? // *The county administrative board is of the opinion that the entire watershed area should be considered in detailed development planning (and stormwater assessments). How is the work process when you work with stormwater assessments? How much resources are available?*

Questions for interview 7: Representative from Svenskt Vatten.

1. Problematiken kring ansvarsfördelning hos kommun respektive privat fastighetsägare har identifierats i och med vår litteratur- och intervjustudie. Var står du/Svenskt Vatten i den här frågan? // *The issue concerning the division of responsibility between municipality and private property owners have been identified in our literature study and interview study. What is your/Svenskt Vatten's opinion on this matter?*
2. Vi har utifrån vår litteraturstudie och intervjustudie identifierat att det finns en del kommunikationssvårigheter mellan de parter som berörs av detaljplanering avseende dagvattenkvalitetsfrågan. Har du någon upplevelse av detta? // *From our literature study and interview study we have identified that there are some communication issues between the parties concerned with detailed development planning in regard to the stormwater quality issue. Do you have any experiences of this?*
3. Det övergripande syftet med vårt examensarbete är att identifiera svårigheter med att utvärdera dagvattenutsläpps påverkan på recipient, och vi har valt att fördjupa oss i detaljplaneprocessen och dagvattenutredningar. Det finns inga generella riktlinjer som kan tillämpas för detta (dock har större städer utvecklat egna riktlinjer i vissa fall). Anser du att generella riktlinjer avseende dagvattenkvalitet är något som behövs, och är det möjligt att ta fram sådana? // *The overall aim of our thesis is to identify difficulties in evaluating the impact from a stormwater discharge on the recipient, and we have chosen to focus on the detailed development process and stormwater assessments. There are no general guidelines available for this (however larger cities have developed their own in some cases). Do you consider general guidelines for stormwater quality needed, and in that case, possible to develop?*
4. Från vår intervjustudie har vi identifierat att det av konsulter upplevs att detaljplaner bedöms med viss skevhet av Länsstyrelsen avseende dagvattenkvalitet. Baserat på utlåtande i en annan intervju troddes detta bero på att icke-försämringsprincipen måste följas av Länsstyrelsen. Anser du att det finns problematiska aspekter avseende Weserdomens följder (vi har läst utlåtanden från Svenskt Vatten kring avloppsreningsverksproblematiken, dock inte något inom dagvattenfrågan)? // *From our interview study we have identified that consultants experience that detailed development plans are evaluated rather skewed by county administrative boards concerning stormwater quality. Based on an opinion in another interview this was thought to depend on that the non-deterioration principle must be followed by the county administrative boards. Do you think there are some problematic aspects concerning the effect of the Weser verdict (we have found opinions by Svenskt Vatten*

concerning the wastewater treatment plant issue, although not concerning the stormwater issue)?

Appendix II - Land use divisions

Land use, size of areas and runoff coefficients for the different land use divisions made in StormTac Web. Each land use corresponds to a pre-defined runoff coefficient.

Coarse land use division

Land use coarse division	Area [ha]	Runoff coefficient [-]
Blue area		
Residential area	99.32	0.25 *(0.20-0.40)*
Multi-residential area	229.81	0.40 *(0.35-0.60)*
Downtown area	4.97	0.60 *(0.40-0.70)*
Forest	72.44	0.15 *(0.010-0.44)*
School campus	13.61	0.45 *(0.35-0.90)*
Retirement home centre	8.29	0.30 *(0.25-0.45)*
Total blue area	**428.44**	**-**
Pink area		
Residential area	49.43	0.25 *(0.20-0.40)*
Industrial area less polluted	13.96	0.50 *(0.50-0.80)*
Total pink area	**63.39**	**-**
Yellow area		
Residential area	25.81	0.25 *(0.20-0.40)*
Total yellow area	**25.81**	**0.32**
TOTAL AREA	**517.64**	**-**

Fine land use division

Land use fine division	Area [ha]	Runoff coefficient [-]
Blue area		
Roof	57.59	0.90 *(0.80-1.0)*
Road 3	6.68	0.80 *(0.65-0.90)*
Forest	121.46	0.15 *(0.010-0.44)*
Mixed green areas	170.90	0.12 *(0-0.30)*
Road 1	34.86	0.80
Parking lots	27.87	0.80
Asphalt surface	8.24	0.80
Total blue area	**427.59**	-
Pink area		
Industrial area less polluted	3.73	0.50 *(0.50-0.80)*
Parking lots	2.18	0.80
Road 8	1.20	0.80 *(0.65-0.90)*
Road 1	6.73	0.80 *(0.65-0.90)*
Forest	13.49	0.15 *(0.010-0.44)*
Roof	4.61	0.90 *(0.80-1.0)*
Mixed green area	31.53	0.12 *(0-0.30)*
Total pink area	**63.48**	-
Yellow area		
Roof	3.58	0.90 *(0.80-1.0)*
Forest	1.29	0.15 *(0.010-0.44)*

Asphalt surface	0.077	0.80
Road 1	3.71	0.80 *(0.65-0.90)*
Mixed green area	15.73	0.12 *(0-0.30)*
Parking lots	1.65	0.80
Total yellow area	**26.04**	-
TOTAL AREA	**517.11**	0.33

Land use division of the SMHI watershed area. Information retrieved from SMHI (n.d.a)

Land use entire watershed area	**Percentage of entire watershed area [%]**	**Area [ha]**	**Runoff coefficient [-]**
Lakes and waterbodies	4.34	143.38	
Forest	45.93	1517.21	0.15 *(0.010-0.44)*
Woodland and meadow	7.60	251.17	0.12 *(0-0.35)*
Wetland	1.43	47.25	0.20 *(0.10-0.40)*
Agricultural property	25.60	845.56	0.26 *(0.10-0.30)*
Urban area	7.59	250.56	0.25 (*0.20-0.40)*
Asphalt surface	7.50	247.81	0.80
Total	**100**	**3302.95**	**-**

Division of the urban area within the SMHI watershed area. Information retrieved from Statiska centralbyrån (2003).

Land use urban area	**Area [ha]**	**Runoff coefficient [-]**
Residential area	43.848	
Multi-residential area	43.848	0.15 *(0.010-0.44)*
Downtown area	23.39	0.12 *(0-0.35)*
Industrial area	23.39	0.20 *(0.10-0.40)*
School campus	23.29	0.26 *(0.10-0.30)*
Forest	46.35	0.25 (*0.20-0.40)*
Grass area	46.35	0.80
Total	**250.56**	**-**

Land use division of the GIS watershed area

Land use GIS watershed area	**Area [ha]**	**Runoff coefficient [-]**
Residential area	660.88	0.25 *(0.20-0.40)*
Multi-family area	354.85	0.40 *(0.35-0.60)*
Allotment area	7.38	0.15 *(0.10-0.50)*
Downtown area	203.48	0.60 *(0.40-0.70)*
Industrial area	42.13	0.50 *(0.50-0.80)*
Forest	1626.42	0.15 *(0.010-0.44)*
School campus	71.92	0.45 *(0.35-0.90)*
Retirement home center	8.29	0.30 *(0.25-0.45)*
Mixed green area	311.77	0.12 *(0-0.30)*
Total area	**3287.12**	-

Appendix III - Uncertainties related to each land use and pollutant

Concentrations and coefficients of variation for each studied pollutant and land use (StormTac, n.d.). Green color indicates high certainty, yellow indicates average certainty and red low certainty. No color indicates that no data is available for assessment of certainty.

Fine land use division

Pollutants coefficients of variaton	Roof	Forest	Road 3	Road 1	Road 8	Parking	Asphalt surface	Mixed green area	Industrial area less polluted
P (µg/l)	170	17	148	143	50	140	85	120	292
N (µg/l)	1200	450	1955	1922	270	2400	1800	1000	1640
Pb (µg/l)	2.6	6.0	4.5	3.0	2766	30	3.0	6.0	25
Cu (µg/l)	7.5	6.5	23	21	40	40	21	12	35
Zn (µg/l)	28	15	24	8.5	68	140	20	23	214
Cd (µg/l)	0.80	0,20	0.28	0.27	396	0.45	0.27	0.27	1.1
Cr (µg/l)	4.0	3.9	7.5	7.0	0.62	15	7.0	2	10
Ni (µg/l)	4.5	6.3	5.9	5.5	19	15	4.0	1.0	12
Hg (µg/l)	0.0030	0.010	0.082	0.080	14	0.080	0.050	0.010	0.060
SS (µg/l)	25 000	34 000	77 232	73 769	0.14	140 000	7400	43 000	80 000

Coarse land use division

Pollutants coefficients of variation	Residential area	Multi-family area	Downtown area	Forest	School campus	Retirement home center	Mixed green area	Industrial less polluted
P (µg/l)	200	230	280	17	300	300	120	292
N (µg/l)	1400	1600	1850	450	1600	1600	1000	1640
Pb (µg/l)	10	15	20	6.0	15	15	6.0	25
Cu (µg/l)	20	30	22	6.5	27	30	12	35
Zn (µg/l)	80	100	140	15	100	100	23	214
Cd (µg/l)	0.50	0.70	1.0	0,20	0.70	0.70	0.27	1.1
Cr (µg/l)	5.8	12	5.0	3.9	12	12	2	10
Ni (µg/l)	6.0	9.0	8.5	6.3	9.0	9.0	1.0	12
Hg (µg/l)	0.015	0.025	0.070	0.010	0.030	0.025	0.010	0.060
SS (µg/l)	45 000	70 000	100 000	34 000	70 000	70 000	43 000	80 000

SMHI watershed area

Pollutants coefficient of variation	Forest	Meadow	Wetland	Agricultural land	Residential area	Multi-family area	Downtown area	Industrial area	Mixed green area	School campus	Asphalt surface
P (µg/l)	17	160	50	220	200	230	280	300	120	300	85
N (µg/l)	450	1000	900	5300	1400	1600	1850	1800	1000	1600	1800
Pb (µg/l)	6.0	6.0	6.0	6.0	10	15	20	30	6.0	15	3.0

Cu (µg/l)	6.5	11	3.0	11	20	30	22	45	12	27	21
Zn (µg/l)	15	30	5.0	20	80	100	140	270	23	100	20
Cd (µg/l)	0,20	0.40	0.15	0.10	0.50	0.70	1.0	1.5	0.27	0.70	0.27
Cr (µg/l)	3.9	3.0	0.15	3.0	5.8	12	5.0	14	2	12	7.0
Ni (µg/l)	6.3	2.0	0.50	2.0	6.0	9.0	8.5	16	1.0	9.0	4.0
Hg (µg/l)	0.010	0.0050	0.0050	0.0050	0.015	0.025	0.070	0.070	0.010	0.030	0.050
SS (µg/l)	34 000	45 000	16 000	100 000	45 000	70 000	100 000	100 000	43 000	70 000	7400

GIS watershed area

Pollutants coefficients of variation	Residential area	Multi-family area	Allotment area	Downtown area	Industrial area	Forest	School campus	Retirement home center	Mixed green area
P (µg/l)	200	230	200	280	300	17	300	300	120
N (µg/l)	1400	1600	5000	1850	1800	450	1600	1600	1000
Pb (µg/l)	10	15	5.0	20	30	6.0	15	15	6.0
Cu (µg/l)	20	30	15	22	45	6.5	27	30	12
Zn (µg/l)	80	100	50	140	270	15	100	100	23
Cd (µg/l)	0.50	0.70	0.20	1.0	1.5	0.20	0.70	0.70	0.27
Cr (µg/l)	5.8	12	2.0	5.0	14	3.9	12	12	2
Ni (µg/l)	6.0	9.0	1.0	8.5	16	6.3	9.0	9.0	1.0
Hg (µg/l)	0.015	0.025	0.012	0.070	0.070	0.010	0.030	0.025	0.010
SS (µg/l)	45 000	70 000	38 000	100 000	100 000	34 000	70 000	70 000	43 000

Appendix IV - Criteria concentrations for stormwater and recipient

Criteria concentrations for stormwater retrieved from StormTac.

Substance	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS
Concentration (µg/l)	160	2000	8.0	8	18	0.4	10	15	0.030	40,000

Criteria concentrations for recipients retrieved from StormTac.

Substance	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS
Concentration (µg/l)	-	-	0.025	0.50 (bio)	5.5 (bio)	0.080 (diss)	3.4 (diss)	4 (bio)	-	-

Appendix V - StormTac results

Presentation of dimensions of the north and south stormwater pond.

North pond	Coarse land use division	Fine land use division
Permanent water depth [m]	1.20	0.60
Share of reduced area [m^2/ha_{red}]	70	70
Permanent water surface [m^2]	450	680
Permanent wet volume [m^3]	230	270
South pond		
Permanent water depth [m]	2.10	2.20
Share of reduced area [m^2/ha_{red}]	80	70
Permanent water surface [m^2]	13 000	13 000
Permanent wet volume [m^3]	23 000	23 000

Calculation of contributing load from coarse and fine land use division to the entire watershed area.

Load on the recipient	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS
GIS watershed area [kg/year]	2200	54000	120	190	750	6,4	49	63	0,86	280000
SMHI watershed area [kg/year]	2000	59000	96	180	530	5,1	42	48	0,84	300000
Fine division before treatment [kg/year]	130	1500	8,3	16	46	0,48	5,8	5,9	0,03	53000
No treatment (SLU) [%]	7%	3%	9%	9%	9%	9%	14%	12%	4%	18%
No treatment (GIS) [%]	6%	3%	7%	8%	6%	8%	12%	9%	3%	19%
Fine division after treatment [kg/year]	79	1200	3,5	9,9	20	0,27	2,5	3,4	0,025	25000
Treatment (SMHI) [%]	4%	2%	4%	6%	4%	5%	6%	7%	3%	8%
Treatment (GIS) [%]	4%	2%	3%	5%	3%	4%	5%	5%	3%	9%
Coarse division before treatment [kg/year]	230	1700	14	27	100	0,65	9,8	9	0,026	64000
No treatment (SMHI) [%]	12%	3%	15%	15%	19%	13%	23%	19%	3%	21%
No treatment (GIS) [%]	10%	3%	12%	14%	13%	10%	20%	14%	3%	23%
Coarse division after treatment [kg/year]	110	1200	6,1	13	39	0,32	3,3	4,3	0,016	25000
Treatment (SMHI) [%]	6%	2%	6%	7%	7%	6%	8%	9%	2%	8%
Treatment (GIS) [%]	5%	2%	5%	7%	5%	5%	7%	7%	2%	9%

Appendix VI - Input data for MIKE Urban+

Calculation of weighted concentration of SS from MIKE watershed area.

Land use	Area (ha)	Concentration (mg/l)
Industrial	42,1	100
Residential	660	45
Multi-family	350	70
Allotment	7,4	38
Downtown	200	100
Forest	1600	34
School campus	71,9	70
Retirement home center	8,3	70
Mixed green area	310	43
Weighted concentration (mg/l)		46,7843801

Calculation of weighted concentration of SS for fine land use division.

	Area (ha)	Concentration (mikrog/l)
Road 1	17,12	73769
Road 3	6,68	7232
Road 8	1,2	160344
Parking	31,7	140000
Industrial area	3,73	100000
Forest	134,95	34000
Roof	65,78	25000
Mixed green area	218,16	43000
Ashpahlt surface	8,38	7400
Weighted concentration (mikrog/l)		45089,891

Calculation of weighted concentration of SS for coarse land use division.

	Area (ha)	Concentration (mikrog/l)
Residential area	174,56	45000
Multi-family area	229,81	70000
Downtown area	4,79	100000
Industrial area	13,96	100000
Forest	72,44	34000
School campus	13,61	70000
Retirement home center	8,29	70000
Weighted concentration (mikrog/l)		57613,8445

Appendix VII - Output data and results from MIKE Urban+

Results for runoff volume, TSS load and EMC for the three MIKE Urban+ scenarios.

Scenario 1	**Result**
Total run-off discharge volume [m^3/year]	204430585.2
Total TTS load, RR [kg/year]	9561482
EMC [µg/L]	46771.29

Scenario 2	**Result**
Total runoff discharge volume [m^3/year]	59410551
Total TTS load, RR [kg/year]	2788701.6
EMC [µg/L]	44599.6

Scenario 3	**Result**
Total runoff discharge volume [m^3/year]	59410551
Total TTS load, RR [kg/year]	3407462
EMC [µg/L]	57354.5