A stormwater quality analysis of future conditions in urban areas

Case study of Kvillebäcken, Gothenburg

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

CIHAN CORAP & PONTUS LILLIEHORN

Department of Architecture and Civil Engineering

Division of Water Environment Technology

CHALMERS UNIVERSITY OF TECHNOLOGY

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ABSTRACT

Cities around the world are growing at a steady rate, which means they become denser with increased impervious surfaces. The imperviousness hinders the precipitation from infiltrate into the ground. The water flows as urban surface runoff, and transports pollutants trapped on the surfaces. These pollutants end up in a nearby waterbody and could potentially affect the aquatic environment and harm the organisms living there. The aim of the project was to assess how changes in land use, traffic and climate affect the stormwater quality in an urban area. The effects of exploitation and reconstruction was studied with the catchment area of the stream Kvillebäcken in Gothenburg as a case-study area. The planned constructions in the catchment area until year 2035 were mapped and simulations with six different scenarios were performed to investigate the result of densification of the area, with regards to four stormwater pollutants: copper, zinc, phosphorus and benzo(a)pyrene. The different scenarios consider the change in land use, climate, traffic and stormwater treatment measures. The result shows that the impervious area increases in the future, compared to current situation. However, with the planned stormwater treatment measures, the concentrations of the investigated pollutants in the stream Kvillebäcken decrease. Benzo(a)pyrene poses the largest problem in the future, as target concentrations are not met in the stream Kvillebäcken. Phosphorus might be a problem depending on if the proposed ponds by Sustainable Waste and Water get implemented or not, while copper and zinc do not seem to be a problem in terms of target concentrations. The conclusion is that all planned stormwater treatment measures from the zoning plans, and 50 % of the proposed ponds by Sustainable Waste and Water should be implemented to reach the targets for copper, zinc and phosphorus. Having more treatment would still not be enough to reach the target concentration for benzo(a)pyrene in the stream of Kvillebäcken due to other sources, due to benzo(a)pyrene origin from other sources than stormwater.

ACKNOWLEDGEMENTS

The journey with the project has been both challenging and extremely educational. The knowledge we have gained through the project will hopefully be helpful in our professional lives.

Firstly, we want to thank each other for all the time and power that has been added to this report. Secondly, we want to thank our families for their support even when it was most challenging. Last, but not least, all thanks to our eminent supervisor, Karin Björklund, who has guided us enthusiastically and inspirationally throughout the project. Additionally, we would like to thank our second supervisor Helén Galfi and Sofia Polo Ruiz de Arechavaleta from Sustainable Waste and Water who have been helpful and provided well needed support.

Cihan Corap & Pontus Lilliehorn, Gothenburg, June 2019.

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1 INTRODUCTION

The lone purpose of conventional urban drainage systems is to act as a quantity control measure by preventing flooding. A disadvantage with this systems is the lack of quality control against pollutants (Charlesworth, 2010; Chocat et al., 2007; S Echols, 2007; Zhou, 2014). It has been observed that pollutants are harming various ecosystems in waterbodies, and measures to prevent pollution have been initiated. In Europe, the European union has set up regulations for its member states, called the water framework directive (WFD) (Zhou, 2014). In short, the purpose of the water framework directive is to set environmental quality targets, with the purpose to achieve good ecological and chemical status in waterbodies, by reducing the concentration of pollutants (EGT, 2000).

Considering the rapid urbanization rate and forecasted climate changes, stormwater will be more difficult to manage in the future, as pervious nature areas transform to impervious urban areas due to exploitation, and precipitation patterns evolve to more intense rainfall (Willems, Arnbjerg-Nielsen, Olsson, & Nguyen, 2012). Precipitation on impervious areas leads to surface runoff which transports diffuse pollutants in urban areas (Fletcher et al., 2015). The forecasted changes in urbanization and climate change are predicted to result in higher peak volumes of surface runoff and deteriorated stormwater quality (Butler & Davies, 2004; US EPA, 1996; Zhou, 2014). Hence creating challenges regarding flood management and pollutant treatment in cities and affected water bodies.

To achieve acceptable chemical status of waterbodies in urban areas sustainable stormwater techniques can be used. Techniques as ponds, rain gardens and biofilters operate as quality and quantity control using processes influenced by nature's behavior regarding conveyance, infiltration, retention and detention (Charlesworth, 2010; S Echols, 2007). The efficiency of the different techniques is important to investigate to implement the most optimal technique based on operating conditions (Svenskt Vatten, 2016).

Kvillebäcken is a stream located in central Gothenburg. The catchment area of Kvillebäcken has an area of about 1100 ha. Previous studies (Thomas Larm) have found that stormwater quality is impaired considering national and local regulations. The municipality of Gothenburg, the administration/department of Sustainable waste and water has initiated an action plan containing various stormwater techniques to counteract the deteriorated stormwater quality of Kvillebäcken catchment area. Impervious surfaces will increase with densification in urban areas. Subsequently, concentrations of heavy metals and polycyclic aromatic hydrocarbons (PAH) are predicted to increase due to increased traffic (Butler & Davies, 2004).

1.1 AIM

The aim of the project was to assess how changes in land use, traffic and climate affect the stormwater quality in an urban area.

The catchment area of stream Kvillebäcken in Gothenburg was used as a case study area for the project. The pollutants in the stream were analyzed considering the environmental quality standard set by the European Union and local regulations set by environmental protection agencies.

The thesis covers stormwater treatment techniques and their removal efficiencies against reduction of the heavy metals copper (Cu) and zinc (Zn), the nutrient phosphorus (P) and the organic pollutant benzo(a)pyrene (BaP), through a literature study and pollutant analysis by modelling.

1.2 Research questions

The following research questions were posed:

- How effective are the investigated stormwater treatment techniques to remove the pollutants P, Zn, Cu and BaP?
- What is the current (2018) and future (2035) annual load of pollutants discharged into the stream Kvillebäcken?
- How will the stormwater quality in the catchment area of Kvillebäcken, and in the stream be affected by the planned constructions until year 2035?
- What stormwater treatments techniques will be implemented in the catchment area of Kvillebäcken in 2035?
- Will the proposed treatment options be enough to reach stormwater and receiving water quality targets in 2035?

2 THEORY

The theory chapter describes the current methods utilized regarding conveyance of stormwater, the hydrological factors affecting stormwater flow, effects of climate change and urbanization on stormwater management, pollutants present in stormwater runoff, techniques used to treat stormwater and existing regulations considering stormwater quality management.

2.1 CONVEYANCE AND TREATMENT OF STORMWATER

Stormwater can be transported both naturally, as surface runoff, or in pipes. It can be transported directly to a receiving water body without treatment, or to a wastewater treatment plant, WWTP, where it gets the same treatment as the wastewater. Earlier, the focus has not been to treat stormwater, but rather to control the quantity. However, the treatment of stormwater is a topic that has received increasing attention recently. Reasons behind addressing stormwater treatment includes assuring a good water quality of the receiving waters, according to for example the EU water framework directive. Another problem with the current situation of the stormwater treatment and transportation is that the implementation and maintenance of underground pipes and structures requires many resources (Zhou, 2014).

2.2 PIPED SYSTEM

A sewerage is a system where foul water and stormwater is conveyed, either together, or separately. The foul water comes from households and industries and the stormwater comes from urban runoff which enters through gully pots, and as drainage from buildings (Svenskt Vatten, 2016).

2.2.1 Combined system

Combined systems convey both foul water and stormwater in the same pipe to the wastewater treatment plant, WWTP. When there is dry weather, the system only carries foul water and the pipes are far from full. During rain events, the capacity of the pipes may be reached. In this case, water can be pushed up from the sewers through gully pots onto the streets or into basements, causing flooding of urban areas and buildings. To prevent flooding, combined sewer overflows (CSOs) are installed within a combined system, where water can flow to the nearest stream in cases when the pipes reach their capacity (Figure 1) (Butler & Davies, 2004).

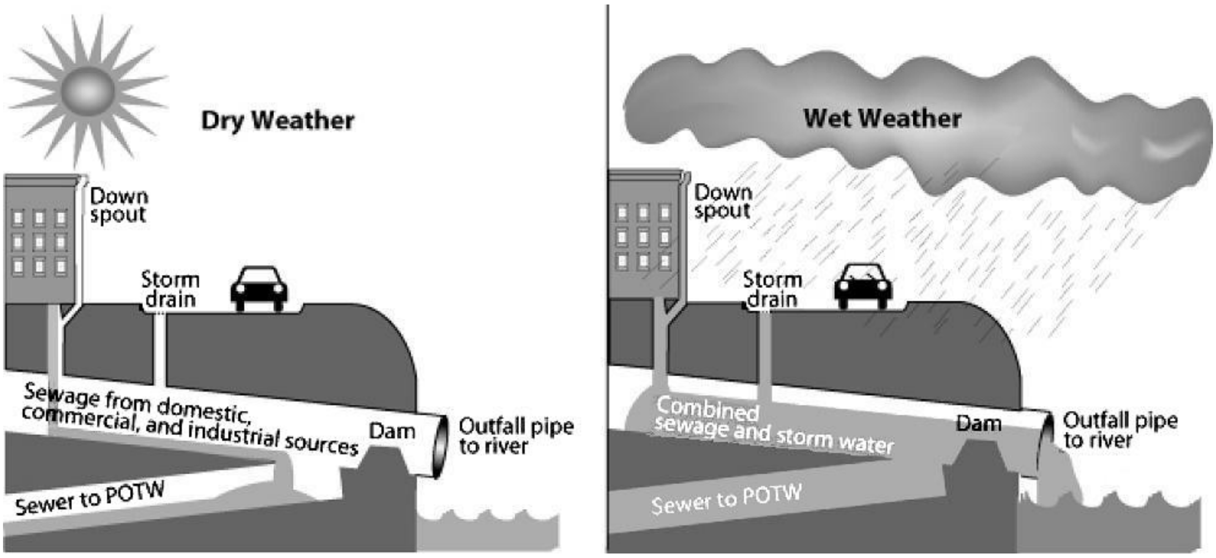

Figure 1 A combined sewer in dry and wet weather. All the water during dry weather is transported to POTW (Publicly owned treatment works). During wet weathers some of the water is overflowed to a waterbody without treatment, due to pipe capacity is reached (US EPA, 2004).

The combined system is the oldest type of piped sewage systems but is still a major part of the network in many countries (Butler & Davies, 2004). In Sweden, the combined sewer system was predominant in urban areas until the first half of the 20th century but today it amounts to 13 % of the total network length (Svenskt Vatten, 2016).

A disadvantage with the combined sewer systems is that stormwater and foul water gets the same treatment in the wastewater treatment plant. The stormwater and the foul water are different in their composition of pollutants, which means a separate treatment is preferable. The large volumes of stormwater transported to the wastewater treatment plants also results in a higher design treatment capacity, which means a higher cost (Butler & Davies, 2004).

2.2.2 Separate system

Separate systems convey foul water and stormwater in two different pipes. The foul water is transported to the WWTP. The stormwater is conveyed to a receiving water, or it is transported to a stormwater treatment practice before being discharged. The separate system does not have any overflows, which means that the foul water will not be released into the environment in case of heavy storm events, as in a combined system (Butler & Davies, 2004). In separate systems in Sweden, stormwater pipes are currently designed to handle 10-year rains, but the already existing system can be designed for a lower return period. However, stricter demands are set for the water pressure line reaching the ground level, with a recurrence of 30 years (Svenskt Vatten, 2016).

It is difficult to construct a separate system that is ideal in the sense that only foul water and stormwater is conveyed in their respective pipes. Reasons include misconnections and leakage (Svenskt Vatten, 2016).

2.2.3 Sustainable stormwater systems

The traditional mindset of managing urban drainage have been “out of sight, out of mind”. Invisible for the public eye, underground pipes have fulfilled a necessary social, technical and hygiene function with drainage. However, the idea of a sustainable stormwater system is that the conveyance of stormwater in pipes is minimal. The stormwater runoff is rather transported on the surface, as a natural flow path, toward a receiving water body (S Echols, 2007).

Transformation of the stormwater system is supported for several reasons. By sustainable stormwater systems, advantages like treatment of stormwater, increased capacity and detention can be gained (Butler & Davies, 2004).

The awareness of stormwater containing pollutants is increasing. However, the misconception of stormwater being clean was common amongst the public in earlier days (Butler & Davies, 2004).

Stormwater can be treated with focus on its specific pollutants. Apart from being treated, the stormwater is also easily detained and infiltrated when green areas are introduced into the cities (County, 2001).

Although stormwater management is utilized to treat contaminated water and to prevent flooding, there is also an important aesthetic aspect which is rarely taken advantage of (Echols, 2007). The idea of sustainable stormwater system functioning as quantity control, quality control and also gives added value through amenity is illustrated in Figure 2 (Stahre, 2006).

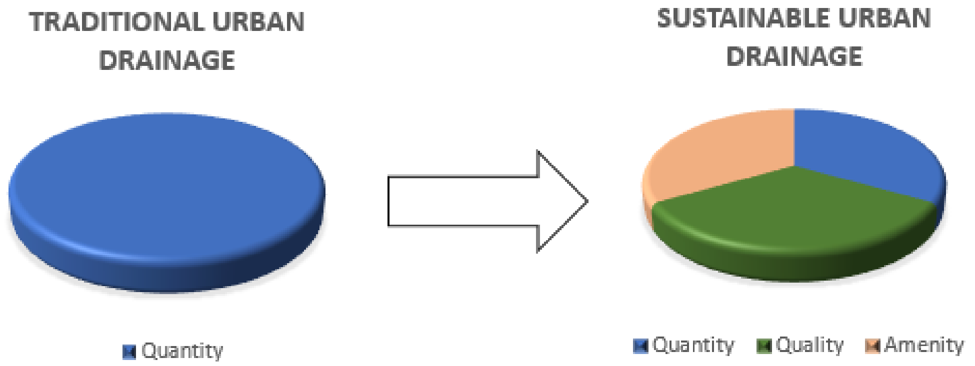

Figure 2 The aims of a traditional urban drainage system and a sustainable urban drainage system, respectively (Stahre, 2006).

The concept is called the urban drainage triangular and was developed by CIRIA (Construction Industry Research and Information Association). It is aimed to illustrate how drainage system has evolved from traditional to current conceptual thinking. In a sustainable system, the three parts are equally important. This intends to increase the importance of quality and amenity of stormwater management (Stuart Echols & Pennypacker, 2008).

The positive values achieved by constructed open stormwater techniques, with respect to amenity, have been described by Swedish stormwater researcher Peter Stahre (Stahre, 2006). Stahre mention several positive values, including economic and environmental, among others (Figure 3).

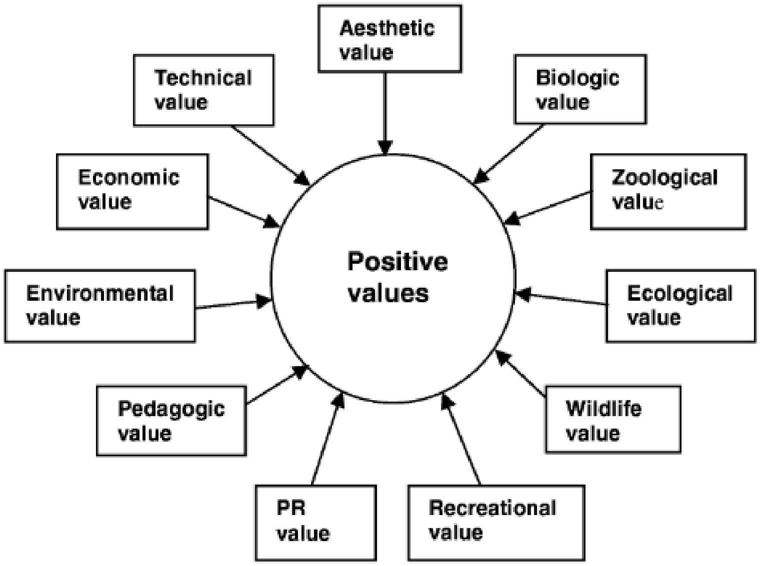

Figure 3 Positive values achieved by implementing open stormwater solutions (Stahre, 2006).

2.3 Hydrology

Hydrology is the study of water; where water occurs, how it is circulated and how it interacts with its surroundings. This can be described in the hydrological cycle, see Figure 4. Studies that are closely related to hydrology are climate studies and hydrogeology. Climate studies involve precipitation and evaporation, and the study of hydrogeology deals with the movement of the water under the earth's surface (Robinson & Ward, n.d.). All these terms are of importance when it comes to stormwater management, since the amount of precipitation, evaporation and infiltration to the soil has a direct impact on the surface runoff volume.

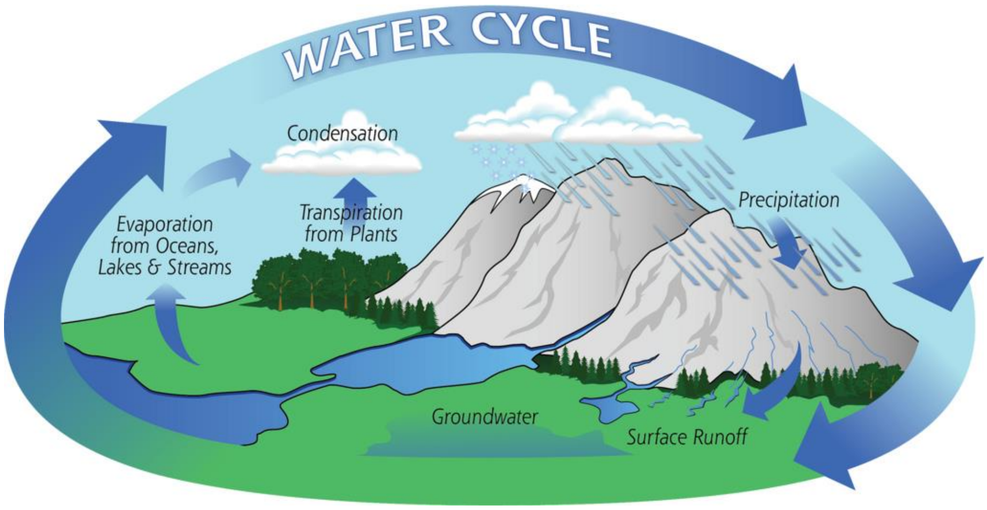

Figure 4 A simple illustration of the hydrological cycle with the processes included (Hordon, 2006).

2.3.1 Precipitation

The amount of rain/snow is paramount to the hydrological process and the transportation of water. During surface runoff, the water, along with pollutants trapped on surfaces and eroded sediments, are transported to a receiving water body. Snow does not result in an immediate surface runoff of water, but it accumulate pollutants from the surrounding in form of gas and particles from the atmosphere

(Robinson & Ward, n.d.). When the temperature rises and the snow melts, the amount of surface runoff increases and the pollutants that were trapped in the snow are transported to lakes and rivers.

The precipitation intensity and duration vary with time: each season has characteristic precipitation patterns. Precipitation also varies with space. The climate of different areas, as well as the topography affect formation of clouds, hence the precipitation (Robinson & Ward, n.d.).

Rain events that are more evenly distributed results in a more constant runoff volume, and a constant concentration of pollutants in the stormwater runoff. During dry weather, pollutants have time to accumulate on surfaces, like roofs and vegetation. When the first rain occurs, it will transport relatively high loads of concentration, known as first flush (Maestre & Pitt, n.d.).

2.3.2 Evapotranspiration

Evapotranspiration is the sum of evaporation and transpiration and is another large driver of hydrological processes, alongside precipitation. Evaporation occurs from all water bodies, but also from vegetation. It is the process where water is converted to a vapor and is returned to the atmosphere (Abtew & Melesse, 2013). In stormwater treatment, evapotranspiration in concerned since different vegetation and soils have different characteristics concerning the amount of water being evapotranspirated. Factors like temperature and humidity also influence the process (North California Climate Office, n.d.).

2.3.3 Interception

Some of the water that falls as rain or snow does not reach the earth’s surface. Water trapped on vegetation is called interception and contributes to a reduction in surface water runoff volume. The water trapped can then be taken up by the vegetation, called transpiration, where the water is transformed to vapor. Or, the water is evaporated directly from the surface of the vegetation (Robinson & Ward, n.d.).

2.3.4 Infiltration/Percolation

The precipitation that falls on the earth’s surface can infiltrate into the soil, either immediately or after being transported to a more permeable surface. In the soil, the water still has the possibility to become evaporated back into the atmosphere. However, some of the water is transported to the groundwater, a process known as percolation (Robinson & Ward, n.d.). The amount of water being infiltrated is strongly related to the amount of surface runoff, since the infiltration is hindered when impermeable surfaces are constructed, but also to the characteristics of the soil, see Figure 6.

2.4 CLIMATE CHANGE

The term climate is defined as variation of the weather over a certain geographical location and over a specified time interval. The concept of weather is a combination of different parameters such as temperature, precipitation and wind. By studying the different weather parameters for a specific geographical area over a long period of time, the climate for the area is compiled (SMHI, 2015).

Climate change is the umbrella term used to explain which ways climate systems and weather predicts to change in the future. Climate change is mainly caused by greenhouses gases from combusted fuels in various activities. Other significant contributors to climate change are industries, farming and landfills. Global warming and climate change are often used as synonyms, which is incorrect (National Geographic, n.d.). Global warming is one of many causes of climate change. In addition to global warming, there are several devastating consequences demonstrated due to climate change, such as;

disturbed ecosystems, melting glaciers, rising sea levels, reduction of freshwater availability, frequently occurring floods and shifting precipitation patterns (IPCC, 2012; National Geographic, n.d.).

To create an idea of the effect of climate change, different radiation scenarios are applicated with mathematically constructed climate models. A climate scenario is defined as a potential development of the future climate. Climate scenarios are used to assess future consequences of climate change and its effects. By compiling data from emission or radiation driving scenarios and putting these into different climate models, a climate scenario is given (SMHI, 2017b).

A radiation force scenario describes how the radiate drift per square meter (W/m^2) is affected by increased greenhouse gas emissions. The scenario thus concretizes how different levels of greenhouse gases in the atmosphere affect the climate (Moss et al., 2010). One form of radiation scenario is the RCP, which stands for Representative Concentration Pathways. The various RCP scenarios deal with different emission trends and give a value to the increased radiation force. The values of the RCP account for the increase in radiation drift, for example, the radiation drive for RCP 8.5 increases by 8.5 W/m^2. RCP 8.5 is close to the currently measured trends in carbon dioxide emissions if no measures are taken and emissions continue to increase at the same rate as they do right now (SMHI, 2017b).

A climate model, in terms of mathematical terms, is a simplified three-dimensional description of the atmosphere. From the atmosphere's movements and conservation of mass, water and energy, the mathematical formulas, climatological variables such as wind, precipitation and temperature can be calculated. The various climate models are built with different conceptual models and assumptions. The common method is to create an *ensemble* that compiles the average of all the results of the different climate models, with the aim of getting most accurate results as possible (SMHI, 2017a).

An increase in precipitation during the winter months is observed in Europe in general, with local differences (IPCC, 2012). Conducted simulations has further shown that temperature increases will result in a decrease in the amount of precipitation in the form of snow in the Gothenburg region and its surrounding municipalities. Also, in Gothenburg, the amount of precipitation in 2100 is expected to have increased by a factor of 1.1-1.3, compared to today's average annual value. The spring flood generally observed from snow melt is becoming less distinguishable and might stop occurring during the coming 80 years. The volume of water reaching the rivers during winter and spring might, however, decrease because of higher temperatures and hence higher evapotranspiration (Länsstyrelsen i Västra Götalands län, 2012).

The predicted changes in climate and particularly precipitation will create challenges within stormwater management. The challenges awaits to feature both as quality and quantity issues, with increased concentration of pollutant stormwater and recurrent flood instances (Charlesworth, 2010). Assumed that landscape and composition of land remains as existing situation, increased volumes in runoff will be in question. Also, cloudbursts are expected to increase in volume and occurrence and in a combined sewer system this would result in increased volumes of water which could go untreated through CSOs and overflows at WWTPs. If new stormwater facilities do not consider predicted climate changes, the risk that they do not fulfill their purpose arises and remain under-dimensioned from the beginning (Mailhot & Duchesne, 2010).

2.5 URBANIZATION AND ITS EFFECT ON RUNOFF

Urbanization is observed globally without any exceptions. According to UN, around 30 % of the world's population were settled in urban areas in 1950. Over the years from 1950 to 2015, the number of urban settlers has increased worldwide, see Figure 5, and the rapid urbanization is forecasted to continue. The

2050 projection of population distribution shows that 68 % of the worldwide population will be living in urban areas (United Nations, 2018).

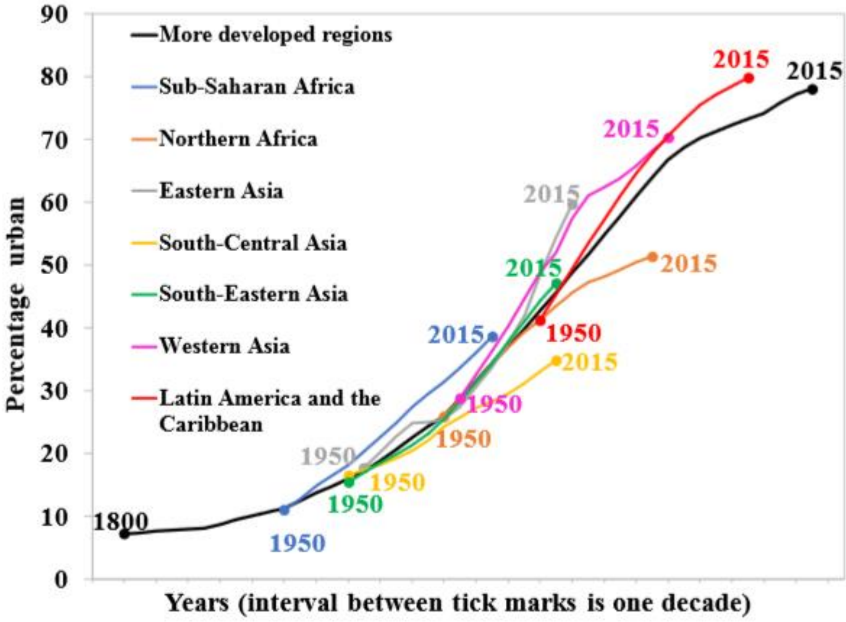

Figure 5 The percentage of urban settlers in several areas worldwide (United Nations, 2018).

Great impacts are caused in urban areas due to rapid urbanization and poor city planning. Urbanization have increased the demand for residences, which results in exploitation of nature areas of pervious character. With less pervious areas remaining in high density cities, increased urban surface runoff generation has become obvious (Hoang & Fenner, 2015). The increasing proportion of impervious surfaces in urban areas affects the infiltration, runoff and evapotranspiration. For example, the amount of stormwater runoff in a highly urbanized area can reach 55 %, but is only 10 % in a natural area, see Figure 6. The deep infiltration is 5 % and 25 % of precipitation in the highly urbanized area and the natural area, respectively. Waterbodies are constantly supplied with water from groundwater reservoirs. This inflow of groundwater is defined as base flow. Decrease of baseflows in urban areas is also a common issue due to less water infiltrated in the ground.

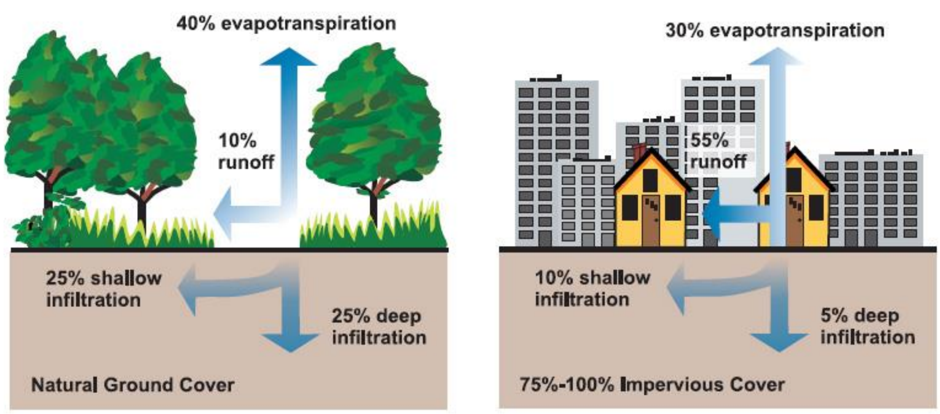

Figure 6 Comparison of runoff, evapotranspiration and infiltration in natural vs urbanized areas (75-100 % impervious surface) (Agency, 2003).

Another result of urbanization is increased peak flows in urban areas, see Figure 7. In conjunction with shorter duration of flows, the rain will also become more intensified with increased runoff rate. Consequently, current drainage systems will become undersized and the probability of sudden floods could increase (Butler & Davies, 2004). Furthermore, physical effects on nature, such as erosion, channel instability and increased sediments in water bodies could become a larger problem (US EPA, 1996).

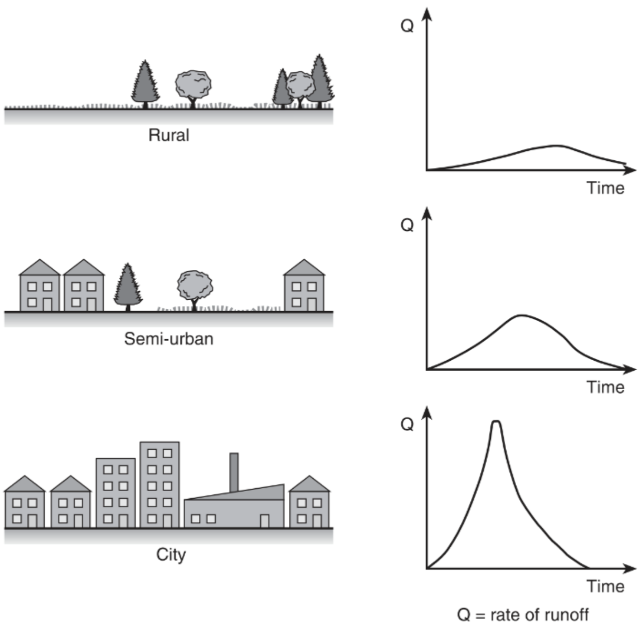

Figure 7 Changes in flow in different densities of urbanization (Butler & Davies, 2004)

There is a correlation between water quality in the receiving streams and the proportion of impervious cover in urban areas. With an increase in impervious cover, the stream water quality decreases. When the proportion of impervious surfaces of a watershed area is exceeding 25 %, it is assumed that the current circumstances do not support a rich aquatic ecosystem (Figure 8) (US EPA, 1996). Surface runoff transports pollutants from sources such as spills, animal feces, vehicle emission, fallen leaves, erosion and corrosion. The mentioned sources emit pollutants such as nutrients, heavy metals, solids and organic pollutants. Urban stormwater runoff may contain alarming amounts of pollutants which have severe effects on the quality of receiving waterbodies, such as harming aquatic ecosystems (Butler & Davies, 2004; US EPA, 1996).

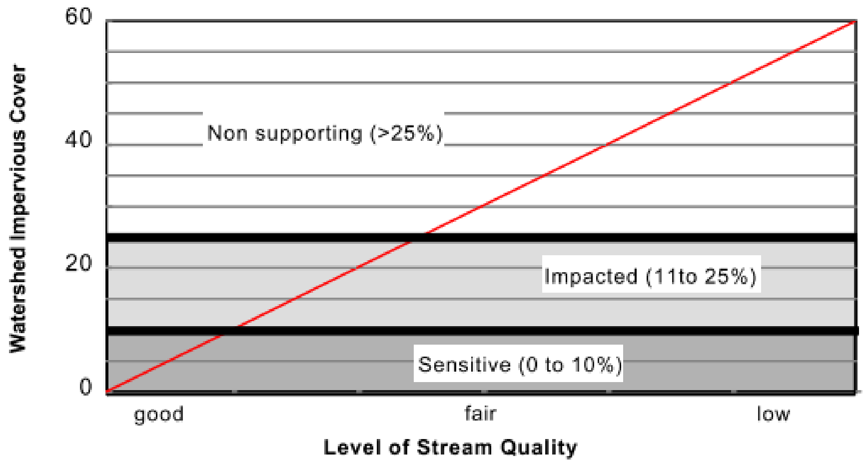

Figure 8 The relation between percentage of impervious surface in the watershed area and the water quality of the receiving stream (US EPA, 1996)

Another effect resulting from urbanization and global climate change is the urban heat island effect (UHIE). The UHIE results from higher air temperature in urban areas compared to bordering rural areas (Akbari et al., 2016). For example, in London, the air temperature during night can differ with 6-9 degrees compared to the surrounding rural areas, since less evapotranspiration occurs in urban areas. This results in an increased need of cooling in urban areas (Charlesworth, 2010). The cause of urban heat island is lack of green areas in dense cities and anthropogenic activities which generates heat, such as cooling by air conditioning, artificial heating, transportation and different industrial processes. The UHIE contribute to unfavorable thermal comfort and rise in energy consumption due to cooling. Furthermore, increase in temperature are creating less livable habitat for many aquatic organisms (Akbari et al., 2016; Charlesworth, 2010).

The article *Toward the sustainable management of urban storm-water* (Chocat et al., 2007) describes the effect of urban developments regarding water in detail (Figure 9), and summarizes impacts concerning stormwater quality and quantity.

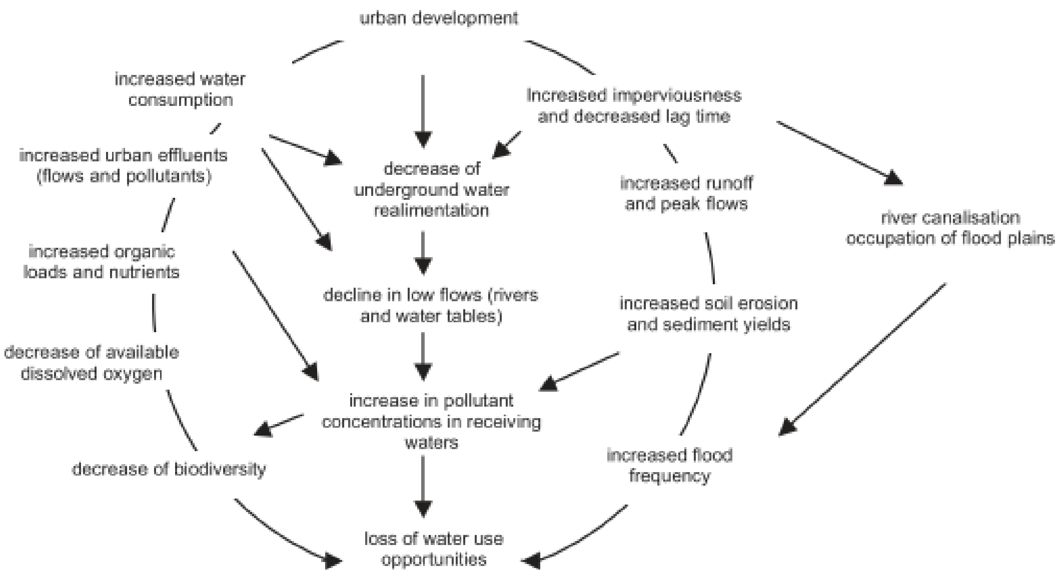

Figure 9 Effects on the water cycle in urban areas (Chocat et al., 2007).

Increased volumes of surface runoff and higher water velocities lead to environmental damage, property damage and lives being at stake due to floods, fallen trees and channels with lowered stability (Chocat et al., 2007; US EPA, 1996). To reduce these vulnerabilities, it is necessary to detain and convey urban water in an efficient way (Butler & Davies, 2004; County, 2001; Hoang & Fenner, 2015; Zhou, 2014). Positive values are also established by incorporating green areas to counteract the UHIE and to encourage amenity (Akbari et al., 2016; Charlesworth, 2010).

2.6 POLLUTANTS IN URBAN AREAS

Pollutants commonly observed in stormwater are presented here (

Table 1). The different pollutants are described in terms of their characteristics and origins.

Table 1 A summary of the pollutants considered in this project and their classification.

Pollutant	Class
Nitrogen	Nutrient
Phosphorus	Nutrient
Lead	Heavy metal
Copper	Heavy metal
Zinc	Heavy metal
Cadmium	Heavy metal
Chromium	Heavy metal
Nickel	Heavy metal
Mercury	Heavy metal
Arsenic	Heavy metal (metalloid)
Suspended solids	Solid
Benzo(a)pyrene	Organic pollutant
Anthracene	Organic pollutant
Fluoranthene	Organic pollutant
Naphthalene	Organic pollutant
4-tert-octylphenol	Organic pollutant
4-nonylphenol	Organic pollutant

2.6.1 Nutrients

Due to urbanization, the occurrence of nutrients in stormwater and transportation to water bodies is increasing. Negative effects of high concentrations of nutrients involve eutrophication and toxic effects on organisms (Selbig, 2016).

2.6.1.1 *Nitrogen (N)*

Nitrogen is a nutrient that occurs naturally on earth. Since the industrialization, N has been used on farmlands to improve the growth of crops, which has resulted in high concentrations of N in surface runoff. Another source of N in stormwater is fossil fuel combustion (Morse et al., 2018). The effects of elevated concentrations of N in waters include eutrophication and decrease in biodiversity.

N is often divided into its common forms in stormwater; organic, ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) (Butler & Davies, 2004). Ammonium is oxidized to nitrate in water, and nitrate is dangerous to the environment in high concentrations. The concentration of nitrate should be under 40 mg/l to be safe for fish and values above 80 mg/l may be toxic. Nitrite levels should under be 0.75 mg/l not to stress fish, and values above 5 mg/l can be toxic (Lenntech, n.d.).

2.6.1.2 *Phosphorus (P)*

Like nitrogen, P in stormwater originates from urban runoff, fuel combustion and leaf litter. The consequences of excessive amounts of P are similar to those of excessive nitrogen, where eutrophication is the most important (US EPA, 1996).

P is often divided into total, organic and inorganic P species. The most commonly occurring P in stormwater is the inorganic form. The inorganic P is further divided into orthophosphate and polyphosphate (Butler & Davies, 2004).

2.6.2 Heavy metals

Metals occur in stormwater in different forms; particulate, dissolved and as colloids (Butler & Davies, 2004). The form of most concern for health and environment is dissolved metals since they are more easily taken up and transported in organisms, mostly due to their small size. A better term to describe these forms is bioavailable metals. The bioavailability can result in bioaccumulation of the metal in organisms, which affects the food chain negatively with high concentrations of the metals found in the top predators (Yuan, 2000). Based on how common the metals are, and their availability for organisms, some metals are generally of most concern in stormwater. These include: Pb, Zn, Cu and Cd (Erickson, Weiss, & Gulliver, 2013).

Metals in stormwater originate mainly from transportation; highways and streets accumulate metal emissions and wear from vehicles. Studies has shown that the amount of annual average daily traffic (AADT) has an impact on the concentration of accumulated pollutants (Kayhanian, Singh, Suverkropp, & Borroum, 2003). It has also been shown that metals attached to particles and the number of suspended solids is closely related, since the metals can absorb on the particulate surface. These metals are settled, and the metals are stored in the sediment. However, certain conditions, such as turbulent water can resuspend metals into the water (Yuan, 2000).

2.6.2.1 *Lead (Pb)*

Lead in stormwater has a long history. It is present in large amounts on earth and in industrial products. Major sources of Pb from the past is paint and gasoline; although countries have stopped using it in these products. Other sources include roofs, ceramics and battery manufacturing (Aoki et al., n.d.).

The bioavailability of Pb depends on for example pH and the presence of ions and ligands in solution and tends to be relatively low (Aoki et al., n.d.), since Pb has a low solubility in aquatic environments (Van der Perk, 2013).

2.6.2.2 *Copper (Cu)*

Cu in stormwater originates from traffic, nearby farmlands, corrosive roofs and plumbing. The impacts of excessive Cu concentrations in aquatic life includes bioaccumulation and can hence harm aquatic organisms (Valencia, Kilner, Chang, & Wanielista, 2019). The ionic, or dissolved forms of Cu are of most concern in stormwater since Cu^{+} and Cu^{2+} are bioavailable (Van Sprang & Delbeke, 2019).

2.6.2.3 *Zinc (Zn)*

Zn in stormwater is strongly related to runoff from traffic and vehicles, and from corrosion of galvanized metal. Zn of concern in stormwater is ionic form, which is adsorbed to particles. Like Cu, Zn is important for organisms in small doses. Large doses can, however, result in bioaccumulation in aquatic organisms, and also harm fish by obstructing their gills (Quality Program & of Ecology, 2008). Zn is also phytotoxic to plants (Van der Perk, 2013).

2.6.2.4 *Cadmium (Cd)*
Cadmium originates mainly from fossil fuel combustion and from fertilizers on farmlands, which comes from sewage sludge. Cd is not a micronutrient, like for example Zn and Cu, which means no Cd should be ingested or taken up, ideally. The effects of Cd includes complications with the kidney in humans (Van der Perk, 2013). The effects on aquatic organisms are not well known, but Cd bioaccumulates and has been shown to cause a slower growth in some plants (Korte, 1982).

2.6.2.5 *Chromium (Cr)*
Chromium in stormwater can has its origin from landfill leachate, which is transported through soil and groundwater and from corrosion of cars (Van der Perk, 2013). It occurs mainly as Cr (III) and Cr (VI) in nature. Generally, Cr (VI) is of more concern than Cr (III) due to higher toxicity and since it is easily transported in organisms. A small amount of Cr is needed in humans and animals to maintain crucial processes, but high amounts can lead to kidney damage and be carcinogenic. Uses of Cr include improving the resistance of other metals (Salden, 2011).

2.6.2.6 *Nickel (Ni)*
Nickel often occurs in the Ni (II) form in stormwater and is mainly found adsorbed in sediment. Ni origins from fossil fuel combustion, mining and farmlands. It is a micronutrient for living organisms, but in high doses it slows down some important processes in organisms (Van der Perk, 2013). However, it has been observed that some mammals and plants are not bioaccumulating Ni and the concentration is low in their tissues (ATSDR, 2005).

2.6.2.7 *Mercury (Hg)*
Mercury is soluble in water and its sources in stormwater includes atmospheric deposition and coal incineration. The effects of the environment are high due to its high toxicity. The anthropogenic emissions are declining and has done so during the past decades. However, since the effects on both plants and animals are negative and can be severe, the levels should be kept low. The effects include neurology-related problems, as well as brain damage (Van der Perk, 2013).

2.6.2.8 *Arsenic (As)*
Arsenic is a metalloid, which means that it resembles a metal in its properties (Nationalencyklopedin, n.d.). It can be in organic and inorganic forms, where the inorganic is generally more toxic than the organic forms. As is a known toxic substance which is carcinogenic and DNA disruptive to human and affects the protein functioning in plants negatively. Sources of As in stormwater include fossil fuel combustion and pesticides and it also occurs in groundwater in high concentrations worldwide (Gupta & Chatterjee, 2017).

2.6.3 Solids
Suspended solids are present in stormwater and represents the particles that do not settle in the water column. These are kept afloat by mixing or by their light weight. Particles are considered a pollution since they can disturb the photosynthesis by hindering the sun light from reaching the aquatic organisms. Particles are also known to adsorb other pollutants such as organic pollutants and heavy metals (Van der Perk, 2013). The solids originate from erosion by the runoff, and particles trapped on the surfaces that gets conveyed with the stormwater. The suspended solids can be classified as total suspended solids, TSS, and volatile suspended solids, VSS. VSS represents the organic percentage of the TSS.

Further, the suspended solids can either be particulate or dissolved. They are classified as dissolved based on their diameter; solids in the filtrate after filtration through a 0.45 µm filter are defined as dissolved (Van der Perk, 2013).

2.6.4 Organic pollutants

Organic compounds are present in stormwater in different forms and at varying concentrations. If the organic compound is causing harm to the environment or to organisms, it is referred to as an organic pollutant. Persistent organic pollutants, POPs, is an established term to describe organic pollutants that are resistant to degradation in the environment (Fitzgerald & Wikoff, 2014).

Six organic pollutants will be discussed in this section, which are known to have a toxic effects in stormwater, or rather in the receiving water bodies, see Table 2. The chosen are based on their occurrence in the stream Kvillebäcken.

Table 2 The six organic pollutants which are considered in this project, and their classification.

Name	Classification
Benzo(a)pyrene	Polycyclic aromatic hydrocarbon
Anthracene	Polycyclic aromatic hydrocarbon
Fluoranthene	Polycyclic aromatic hydrocarbon
Naphthalene	Polycyclic aromatic hydrocarbon
4-tert-octylphenol	Alkylphenol
4-nonylphenol	Alkylphenol

One group of organic pollutants are composed of hydrogen and carbon molecules only, these are known as hydrocarbons. Some hydrocarbons are polycyclic aromatic hydrocarbons or PAHs, and these consist of multiple (poly) aromatic benzene rings (stable and cyclic) (Van der Perk, 2013). Four PAHs are presented here; benzo(a)pyrene, anthracene, fluoranthene and naphthalene. Benzene consists of a single benzene ring, and is hence not a PAH, but still an aromatic hydrocarbon. 4-tert-octylphenol and 4-nonylphenol are alkylphenols (Butler & Davies, 2004), (US EPA, 1985).

2.6.4.1 *Polycyclic aromatic hydrocarbons (PAH)*

PAHs are the most commonly found organic pollutants in stormwater. PAH consist of multiple benzene rings in different forms. The molecular structure of the four PAHs studied here can be seen in Figure 10. PAHs can be divided into low and high molecular weights, where molecules of four or more rings are classified as high. The weight of the molecules is generally related to the toxicity of the compounds, where a high molecular weight is associated with high negative effects on health and environment. The larger molecules are more persistent and bioaccumulative than the low weight molecules, and are also carcinogenic (John, Essien, Akpan, & Okpokwasili, 2012). The molecules tend to adsorb to sediment and solids (Hassan, Abdel-Shafy, & Mansour, 2018).

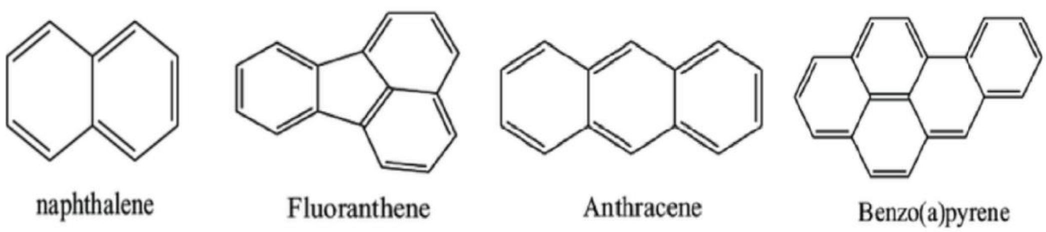

Figure 10 Molecular structure of the four PAH molecules concerned within the project.

The sources of PAHs are mostly anthropogenic, and a large part comes from incomplete combustion of coal and wood, vehicle emissions and waste incineration (Scottish Environment Protection Agency, 1999).

2.6.4.2 *Phenols*

Phenols are compounds consisting of a hydroxyl group bonded with an aromatic ring. They are used widely in several products including cleaning agents and paint (Naturvårdsverket, 2009). Alkylphenols is one group of phenols which include 4-nonylphenol and 4-tert-octylphenol, among others. These two substances are frequently found in the environment, and nonylphenols are classified as priority hazardous substances in water by the EU. Octylphenols are classified as priority substances (Europeiska kommissionen, 2013). Octylphenol can be released into waters directly from stormwater runoff and wastewater discharge, or can occur as a product of alkylphenol ethoxylates breakdown (Greenspecs, n.d.). It has also been shown that these substances can cause estrogenic effects in animals (Naturvårdsverket, 2009).

2.7 REGULATIONS REGARDING WATER QUALITY MANAGEMENT IN SWEDEN

This section describes the regulations of stormwater treatment in Sweden, which originate from EU and are implemented in Sweden according to Swedish legislation.

2.7.1 Water framework directive - WFD

In 2000, the European parliament and the council legislated the directive 2000/60/EC, referred to as the water framework directive (WFD). The WFD is intended to function as a common quality control for waterbodies. The term waterbodies refers to water presence in lakes, streams, groundwater, coastal water and water in transitional areas.

With rising demand on water resources due to increasing populations, water must be considered a heritage that must be protected and stored. To avoid deterioration of the quality and quantity of freshwater, it is necessary to implement an integrated protection and management action program through regulation and monitoring. Thus, the directive aims to preserve and improve the aquatic environment, which will result in better drinking water quality and reduction of harmful pollution. The purpose of the directive is also to create a common sustainable water policy for the European Union which is jointly accepted and worked towards collectively. As a result, common definitions of water status regarding *environmental quality standards* (EQS) are set by a common directive with regards to chemical and ecological quality (EGT, 2000)

2.7.2 Classification of waterbodies

According to the WFD, all bodies of surface water and groundwater must have good chemical and ecological status by 2015. However, due to technical or financial obstacles, the limit can be postponed to 2021 or 2027 in accordance with Article 4 in WFD (EGT, 2000).

The status of a certain water body is determined by assessing both the chemical and ecological status. The factor of lowest score determines the status (Länsstyrelsen, n.d.).

2.7.2.1 *Chemical status*

There are two classes of chemical status: good status and unachieved good status. The limit is determined by current EQS for the water body.

Based on the WFD from 2000, a list of 33 prioritized substances in water bodies was presented in 2001 (European Environment Agency, 2001). In 2013, 12 additional prioritized substances were suggested by the EU. Good chemical status for the additional 12 substances needs to be met by 2027, as opposed to the 33 initial substances, which needed to meet the limits by 2015, see Appendix A and B (Europeiska kommissionen, 2013).

The specific substances are deemed to pose a risk to the aquatic environment. If measurements show that a substance exceeds the values set by the water directive, efforts must be made (Havs och vattenmyndigheten, 2019).

2.7.2.2 *Ecological status*

The ecological status is determined by investigating biological quality elements, general chemical and physiochemical quality elements and hydromorphological quality elements. There are in total 14 elements which are assessed when determining the ecological status of a certain waterbody (Appendix C). The selection of elements within each category differ depending on the type of the waterbody. (Länsstyrelsen, n.d.)

Biological quality elements are assessed with a five-point scale from high to bad while general chemical and physiochemical and hydromorphological elements are assessed in three-point scale from high to moderate (Figure 11). The ecological status is determined by the lowest score from the elements, meaning that biological quality elements has the greatest impact determining the ecological status (Länsstyrelsen, n.d.).

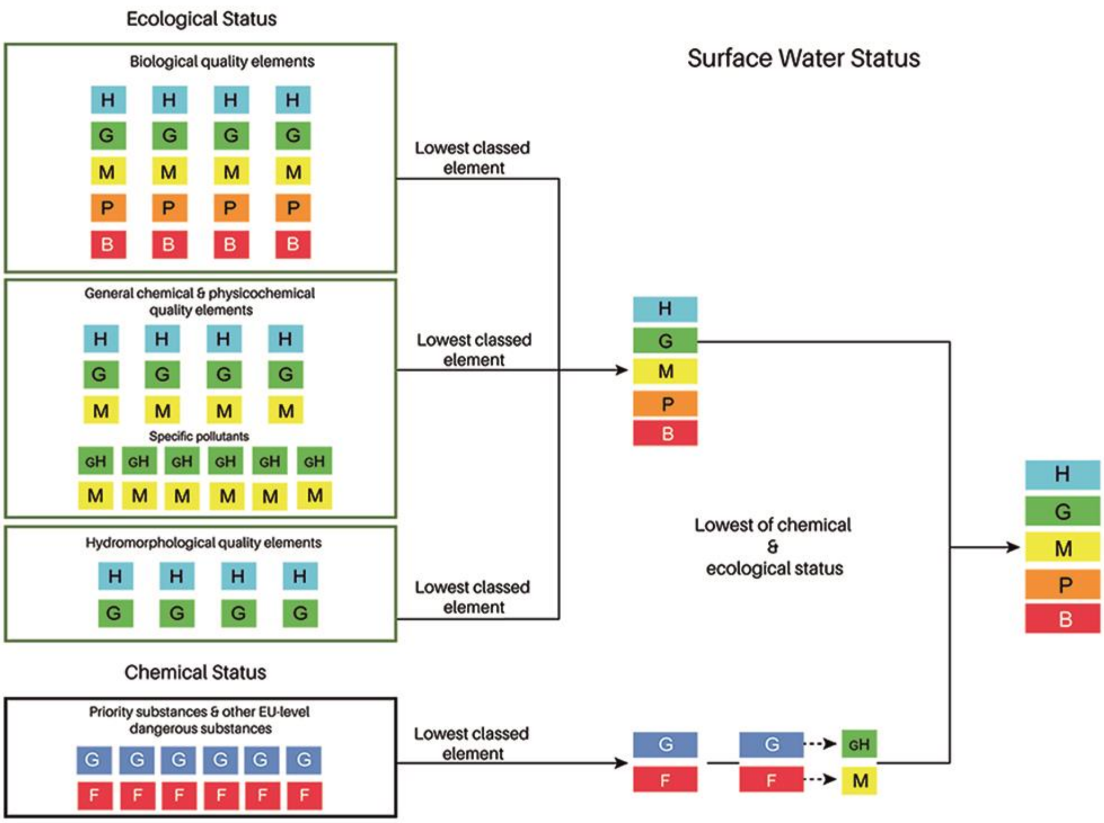

Figure 11 Schematic illustration of the approach to determine the status of waterbodies according to the WFD (Emberton, Wenning, & Treweek, 2017).

2.7.3 Implementation of the WFD in Sweden

The WFD has been implemented in Swedish legislation by:

- Chapter five in the Environmental code (Miljöbalken).
- Regulation (2004:660) regarding water management (Vattenförvaltningsförordningen)
- Regulation (2017:868) regarding county administration (Förordningen med länsstyrelseinstruktion).

The WFD has also been adapted in Sweden's national environmental objectives, managed by the Swedish Environmental Protection Agency (Naturvårdsverket). The national legislature of Sweden has adopted 16 environmental quality objectives that should be met by year 2020, see Appendix E. The purpose of the environmental quality objectives is to achieve environmentally sustainable development in the long term (Naturvårdsverket, n.d.).

The Swedish Agency for Marine and Water Management – SwAM (Havs- och vattenmyndigheten) – is responsible for 3 of the 16 environmental quality objectives: no eutrophication, living lakes and streams; and a balanced marine environment with flourishing coastal areas and archipelagos (Naturvårdsverket, n.d.).

2.7.3.1 *Water districts*

Sweden is divided into five different water districts, according to geographical areas and river basins. Since the districts consist of several counties, one county in each district has been authorized as a county administrative board. This means that five administrative boards exist, one for each water district (Vattenmyndigheterna, n.d.-a).

Figure 12 The location of the five water districts of Sweden (Vattenmyndigheterna, n.d.-a).

Each water authority has the task to prepare and coordinate a management plan within the water district. The management plan shall include a summary of the water conditions regarding the EQS and required actions if standards are not achieved. The county administrations functions as the executive organ determining specific details considering implementations in accordance with the action program and management plan. The management plan runs in cycles of six years (Figure 13). A cycle begins with water conditions being mapped based on existing monitoring data. The data is then used to assess and classify the state of the water and the impact on certain EQS; the data is entered in the VISS national program, which demonstrates the quality of the nation's water bodies by county administration. Each water authority is responsible to coordinate all water bodies within the area of responsibility, proposing measures regarding monitoring and actions with purpose to improve the status. To their aid, the county administrations have different municipal administrations as the municipal water and environmental administration whom contribute with their expertise (Vattenmyndigheterna, n.d.-c).

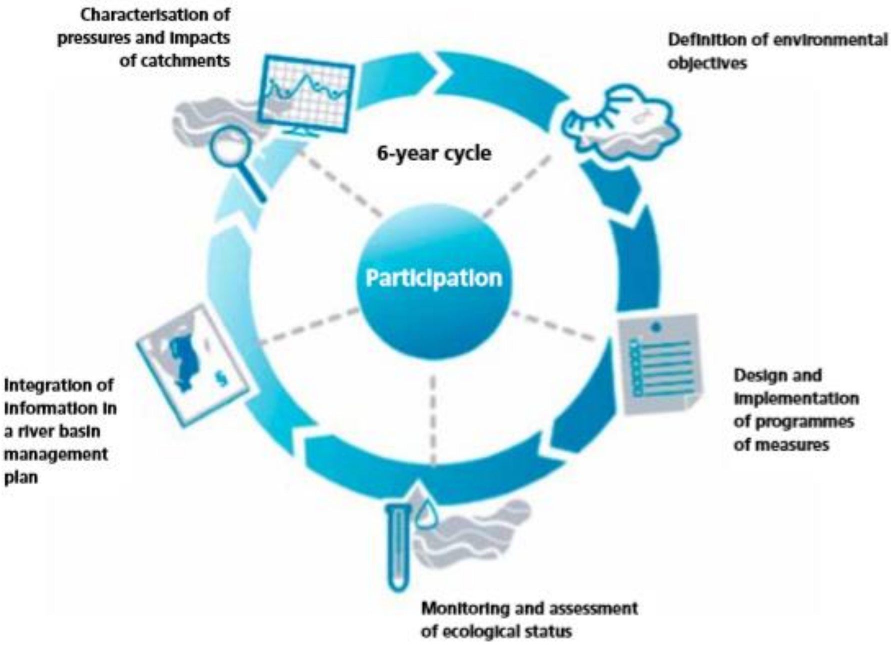

Figure 13 The 6-year cycle of tasks performed in connection with the WFD (Lingegarth, Carstensen, Johnson, & Wikström, 2016).

At the end of a cycle, data regarding a specific district are compiled by the water authority and reported to SwAM or the Geological Survey of Sweden - GSS (Sveriges Geologiska Undersökning - SGU) - depending on whether it concerns surface water or groundwater, respectively. SwAM and GSS will then evaluate submitted reports and report further to the European Commission. SwAM and GSS are also entrusted to concretize guidelines and regulations within their respective expertise (Vattenmyndigheterna, n.d.-c).

Each administrative board is connected to a water delegation, which has been assigned by the government. The water delegations intend to function as the government's extended arm and consists of 11 experts. The delegation's task is to decide the management plan, EQS and required action measures for each water district. The three crucial documents are aimed to guide the water authority, county administrations and municipalities (Vattenmyndigheterna, n.d.-b).

Finally, the water authority will prepare proposals for and establish a management plan, EQS and an action program for the water district regarding the forthcoming cycle. Descriptions, surveys and analyzes during the past cycle will lay the foundation of the proposals which will be presented to the water delegation. The water delegation will, as mentioned before, review the proposals and come to a decision. Their decisions will create guidelines to the work in the forthcoming cycle (Vattenmyndigheterna, n.d.-c).

2.7.4 Swedish legislation

Although the quality of all waterbodies is regulated through the WFD, there are no specific restrictions on stormwater, although it is one of the greatest sources of pollution (Zhou, 2014). In the Environmental Code, only wastewater is mentioned, which mainly refers how to manage foul water. Thus, municipalities that are responsible for stormwater management do not have any requirement for the stormwater emitted to waterbodies (Miljö- och energidepartementet, 1998). This makes the work against pollution in stormwater difficult, since municipalities do not have the legal power to improve the situation.

To concretize restrictions with focus on stormwater, the Swedish Environmental Protection Agency and local environmental administrations have worked with guidelines considering the content of pollutants in stormwater (Mossdal, 2013). The target values considering stormwater pollutants for Gothenburg are available in Appendix F.

2.8 STORMWATER MANAGEMENT TECHNIQUES

This chapter describes techniques to manage stormwater regarding quality and quantity issues. It begins with a description of the terminology concerning stormwater management techniques. After that, two classifications of treatment techniques are described. The classifications are based on either the main treatment process utilized, or the location of the treatment in the catchment area. This is followed by a description of the techniques, which are classified based on the main treatment process utilized.

2.8.1 Terminology of stormwater techniques

Different umbrella terms are used to classify stormwater management techniques. The terms are distinguished by either expressing an idea or a concrete practical action. Furthermore, the differing terms originate from different countries, which leads to various expressions depending on the geographic location. Some of the terms are almost equivalent, which creates ambiguity and results in difficulties to classify the different stormwater treatment techniques. The common feature for all terms is that the inspiration comes from natural processes such as filtration, infiltration, evaporation or detention (Butler & Davies, 2004).

Green infrastructure originates from USA in the early 1990s. The concept of green infrastructure encourages green areas and stormwater treatment techniques in dense urban areas. The main objective is to increase pervious areas which consequently result in increased biodiversity and reduce the UHIE. Green infrastructure is used to maximize the benefits by being multifunctional as well as taking amenity into account. Trenches, ponds, rain gardens and green roofs are examples of stormwater techniques which can act both as treatment as well as being a nice feature in the urban landscape (Fletcher et al., 2015).

The term Low Impact Development (LID) is widely used in North America and New Zeeland. Typical features of LID include stormwater management that resembles natural processes and including pervious areas for local source control. This can be achieved by implementation of rain gardens, swales and green roofs (Fletcher et al., 2015).

The North American expression Best Management practices (BMPs) is widely used since 1972. BMPs function particularly as quality control in stormwater management. BMPs aim to prevent increased pollution due to increased urbanization. LID and BMP are meant to complement each other in catchment areas to achieve satisfying results regarding stormwater quality and quantity (Fletcher et al., 2015).

The concept Sustainable Urban Drainage Systems (SUDS) was developed in Scotland in the late 1980s and later inspired the whole UK. SUDS is a broad idea which tries to capture the whole picture of stormwater management. It aims to function as a quality and quantity control in conjunction with benefits of amenity, biodiversity and recreation. The concept consists of serial measures within a specific catchment area creating a *treatment train*. Measures are implemented in catchment areas depending on the different locations, see section 2.8.3. The SUDS manual is a key document which assists the implementation of a measure, by describing implementation considerations and requirements (Woods Ballard et al., 2007).

Fletcher has illustrated a comprehensive model which describes the relation of the various umbrella terms with respect to their specificity and focus (Figure 14).

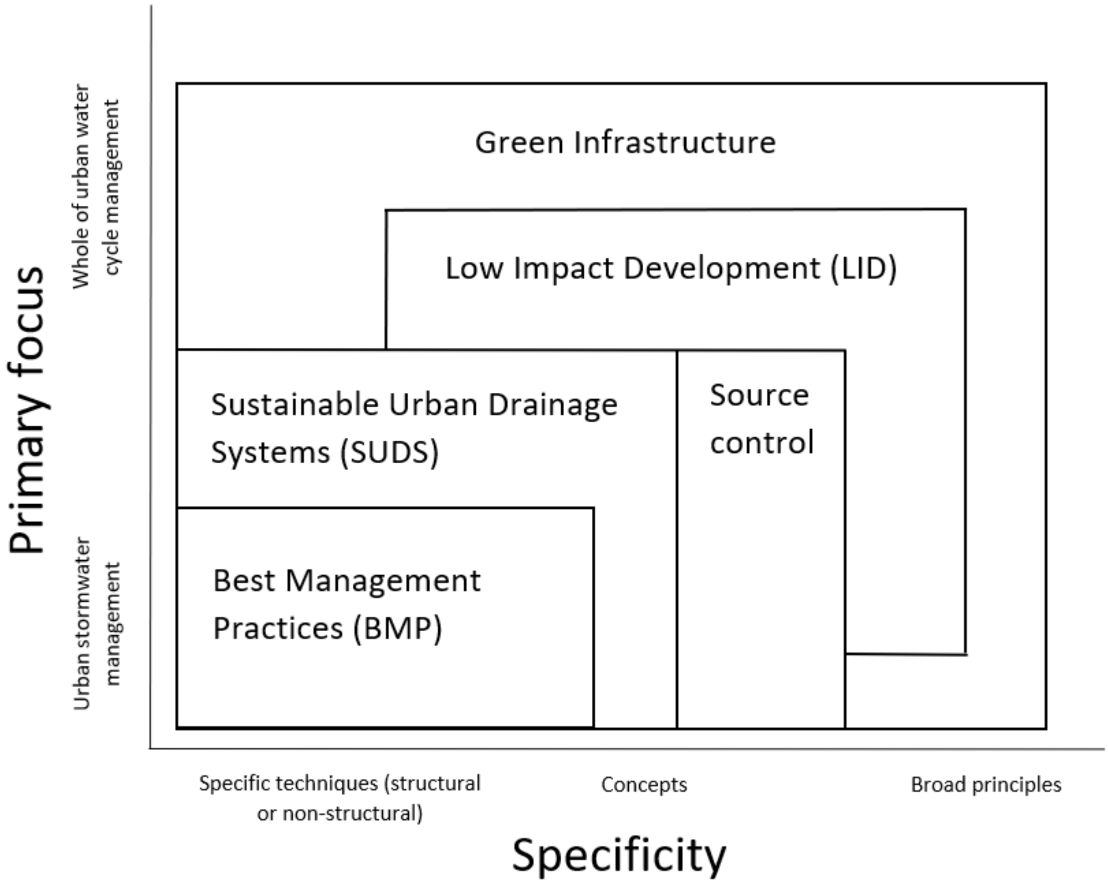

Figure 14 Fletchers model addressing the relation of existing terminology of stormwater management (Fletcher et al., 2015).

2.8.2 Processes

In this report, the different stormwater treatment techniques are classified into six groups depending on utilized process, see the left side of Figure 15. The selected techniques only include those suitable for urban areas. See Appendix K for a summary of the comparison of the processes and the techniques.

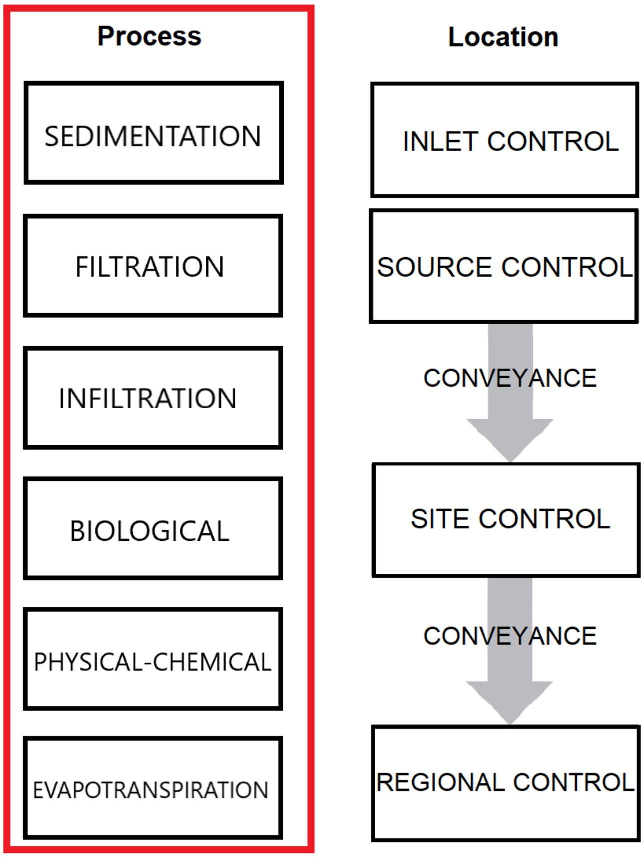

Figure 15 Two different classifications of treatment techniques. Process refers to the main treatment process that the treatment technique utilizes, and location refers to the location of the technique in the catchment, and how large drainage area they can handle. The processes are handled in section 2.8.2, hence being marked red.

2.8.2.1 *Sedimentation*

Sedimentation is a physical treatment process which uses gravity to settle particles in the water. This means that it targets larger particles, rather than the smaller and the dissolved solid fraction (Davis & McCuen, 2005). The settling rate of particles is affected by the water temperature, water viscosity, particle density and particle size (Erickson et al., 2013). Some common stormwater sedimentation treatment techniques include: detention ponds, retention ponds and underground storage chambers (Davis & McCuen, 2005; Erickson et al., 2013).

2.8.2.2 *Filtration*

Filtration of water will remove particles that are larger than the filter pore diameter. The size of the openings and the filter area will affect how quickly the water can be treated. Since particles can get trapped in and on the surface of the media, a pretreatment step can be needed. If sedimentation is used before filtration, the filter media can be in operation longer, before maintenance work is needed. Sand, gravel and organic media, such as bark, are typically used as a filter media for stormwater treatment. Different filter practices include sand filter, soil filter and filters with added metal particles to enhance adsorption and precipitation (Erickson et al., 2013).

2.8.2.3 *Infiltration*

Infiltration of stormwater occurs naturally where the surface is permeable. Grass-covered areas with soil underneath infiltrates the stormwater into the soil. Infiltration leads to reduced amounts of stormwater runoff and loads of pollutants to surface waters. Infiltration is dependent on infiltration rate, which is a result of the hydraulic conductivity, evaporation rate, rain intensity, soil moisture and temperature (Minnesota Pollution Control Agency, n.d.). Infiltration practices include: trenches, soakaways, filter strips, swales, green roofs and pervious pavement (Butler & Davies, 2004).

2.8.2.4 *Biological processes*

Biological processes that may occur in stormwater are for example oxidation of organic matter and denitrification. Oxidation of organic matter is a result of microorganisms using the organic matter for respiration. Denitrification is a process where nitrate-N is converted to nitrogen gas, under anaerobic conditions. Another biological treatment is using plants to bind nutrients, since phosphate-P and nitrate-N is needed for them to grow (Erickson et al., 2013).

2.8.2.5 *Physical-chemical processes*

Physical-chemical processes can be used to precipitate dissolved substances, such as metal and phosphate. Small particles, colloids, can be flocculated, and particles may adsorb to other particles which increases the settlement. Consequently, precipitates, flocs and particles can be removed through sedimentation or filtration. Since most of the dissolved metals are positively charged, they can adsorb to clay particles, which are generally negatively charged (Erickson et al., 2013). Another way is to use sorption filters which has a hydrophobic surface where the hydrophobic pollutants can attach. These filters, with for example activated carbon, have shown high efficiency on removing organic pollutants (Norman, 2018).

2.8.2.6 *Volatilization*

Volatilization is a process where volatile pollutants, such as some organic carbon, are vaporized (Pollack, 2012). On vegetated surfaces, like rain gardens or green roofs, volatilization occurs, which decreases the amount of pollutants in the surface runoff.

2.8.3 Location

The location of stormwater management techniques refers to their proximity to the pollution source and the size of the catchment area of the specific technique. The classification of the treatment processes – sedimentation, filtration, infiltration and biological/chemical – gives an overview of the technical performance of the process. The classification in location, however, gives a more practical overview of the suitability to implement the different treatment options in specific areas, see right side of Figure 16.

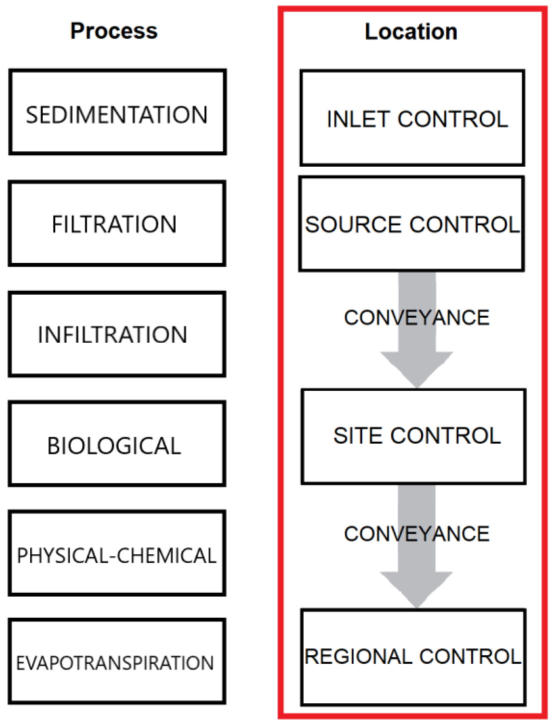

Figure 16 Two different classifications of treatment techniques. Process refers to the main treatment process that the treatment technique utilizes while location refers to the location of the technique in the catchment and how large drainage area they can handle. The locations are handled in section 2.8.3, hence being marked red.

2.8.3.1 *Inlet control*

The first level of control, based on location, is to control the stormwater at the point where it is first introduced to the drainage system. This refers to stormwater that can be stored through local ponding on roofs or on car parks (Butler & Davies, 2004).

2.8.3.2 *Source control*

The second level is the source control, which is the first step in the stormwater drainage system. The idea is to treat the stormwater locally, mainly through infiltration processed like trenches, soakaways and permeable surfaces (Butler & Davies, 2004).

2.8.3.3 *Conveyance*

The third level of control is conveyance, where stormwater is mainly transported on grass-covered areas and some treatment will occur due to infiltration into soil. The conveyance occurs at multiple locations within the whole stormwater management chain. Examples of conveyance includes swales, filter strips and filter drains (Butler & Davies, 2004).

2.8.3.4 *Site control*

The fourth level of control measures, site control, is similar to source control in that the techniques used here are often based on infiltration and on a larger scale than source control. Examples of site control measures are rain gardens, infiltration trenches and smaller ponds (Butler & Davies, 2004).

2.8.3.5 *Regional control*

The fifth level of control is regional control, and these treatment options are larger than treatment techniques in previously mentioned control levels. They treat stormwater runoff from larger areas and are often placed far from the source of the pollutants. Regional control measures include wet and dry ponds and constructed wetlands (Butler & Davies, 2004).

2.8.4 Techniques for stormwater quality improvement

Different stormwater treatment techniques are presented here, thus techniques focusing only on retention and detention of stormwater are excluded. The stormwater treatment techniques are presented in six different categories, based on the main pollutant removal process, see 2.8.2.

2.8.4.1 *Sedimentation*

Ponds

Ponds are commonly used for treatment of stormwater pollutants and utilizes gravitation to settle the particles. Some ponds are filled with water during storm events and emptied during dry weather. These are referred to as dry ponds or detention ponds. Other ponds are designed to have a constant level of water, controlled by the location of the outlet of the pond. These are referred to as wet ponds or retention ponds. Generally, wet ponds have a higher pollutant removal efficiency than dry ponds. Additionally, ponds can serve as an amenity and contribute to a green urban landscape and dry ponds can be multifunctional since the can be used for recreational purposes during dry weather (Erickson et al., 2013).

Underground storage chambers

Since ponds take up valuable spaces within urban areas, an underground storage chamber might be preferable. The underground storage consists of one or several tanks where water is stored, to delay the transportation. Some techniques, like concrete pipes, focus on storage only, while some underground storage chambers can also be designed for infiltration of the stormwater to the soil.

A device known as hydrodynamic separator can be used, which consists of a cylinder, see Figure 17. This device uses sedimentation to remove solids. Another option is to use soakaways. This technique is used both for storage of water, as well as for infiltration. Box-like structures are placed below ground, but above the groundwater table, for temporary storage and subsequent infiltration to surrounding soil (Erickson et al., 2013).

Figure 17 Two different stormwater treatment techniques that utilizes sedimentation as the main treatment process. The left picture is a wet pond in Warren county, Ohio, and the right picture shows the installation of a tank (hydrodynamic separator) for underground storage and treatment of stormwater (Wikimedia Commons, 2019a, 2019b).

2.8.4.2 *Filtration*

Filters

Filter are efficient in removing suspended solids from the water but are easily clogged if no pretreatment is done. The filter material can be organic, like peat, or inorganic like sand.

Since soil filter may utilize the in-situ soil, transportation of soil is minimized. Sand filters are constructed by excavating soil and filling it with sand. The drained water is transported away in pipes (Erickson et al., 2013). There are also filters used in manholes and underground storage chambers to improve the stormwater quality (Kangas, 2016).

2.8.4.3 *Infiltration*

Often, many treatment processes occur simultaneously. Sedimentation, infiltration and filtration can all occur in the same stormwater treatment technique. Infiltration is necessary to occur if sorption of pollutants to soil is the aim (Butler & Davies, 2004).

Infiltration basins

In flat areas of permeable soils, stormwater can infiltrate into the soil. An infiltration basin is often covered with vegetation. The function is similar to that of a dry pond. The practice removes large amount of stormwater runoff and treats the water from a wide range of pollutants using several processes, like filtration and sedimentation (NWRM, 2013).

Infiltration trenches

Like soakaways, infiltration trenches are constructed by excavation and refilling with the desired material, often gravel, on top of a geotextile. Gravel filled swales are often used for this purpose. These have a side slope of about 2:1. The infiltration trench is linear and can be integrated into the landscape by covering it with grass, if preferable (Butler & Davies, 2004).

Pervious pavement

Materials such as concrete and asphalt are impermeable, hence infiltration cannot occur on these surfaces. To increase the infiltration, pervious versions of these materials have been tested in for example large parking lots and pathways. There are several different designs, and some common includes: asphalt or concrete with a higher porosity, bricks with open joints and concrete grid with open centers. When a higher porosity material is used, infiltration occurs in the upper layer and can be collected in a gravel layer underneath. From there, the water can either percolate to the groundwater or get transported in underdrain pipes in case of low infiltration soils. The design is similar to an infiltration trench and works similarly, with the additional benefit of being capable of cars driving on it.

Figure 18 Two different stormwater treatment techniques that utilizes infiltration as the main treatment process. The left picture shows an infiltration trench (dark green strip) covered with bushes for interception and higher evapotranspiration, as well as for amenity. The right picture shows one alternative of a pervious pavement (concrete grid with open centers) (Montgomery County Planning Commission, 2014; Sodapop, 2008).

Swales

Swales are constructed by excavation and formed as trapezoids, covered with grass (Northern Virginia Soil and Water Conservation District, n.d.). Although the main aim with swales is conveyance, they still settle particles, and infiltrate water into the soil. They can be designed with additional barriers perpendicular to the flow path to allow for ponding, to improve settlement and infiltration (Drainage design, n.d.). Swales often collect overland flow in a channel-like flow, which results in faster drainage. However, too high velocities are not preferable since this can result in soil erosion in the swale. The length of the swale, together with the slope is crucial when it comes to its performance on stormwater quality improvement (Davis & McCuen, 2005). Typically works well for catchment areas of about 2 hectares (House, 2010).

Filter strips/drains

Filter strips are vegetated, slightly sloping, natural areas, and hence do not require excavation and fill. They should be constructed in larger, open impervious areas since the filter strips are most efficient in treating overland flow. The strips are readily used as a treatment step before swales, since they are efficient in removing solids, and pollutants attached to these. The strips can be placed along farmland, roads and streams (*Individual NWRM Filter strips*, n.d.).

Filter drains are similar to infiltration trenches but are generally not grass covered. They are linear and filled with gravel, to convey the water. The filter drains are preferably placed subsequent to filter strips, to reduce clogging (Wilson, Bray, & Associates, n.d.).

Rain gardens

In rain gardens, or bioretention practices, vegetation is planted in a permeable soil, preferably placed in a sink to capture the water during normal storm events. The soil is often topped with a layer of mulch. The rain gardens are often constructed with a geotextile placed beneath under the soil. The water is filtered and is often drained below the soil, which means water is not permanently ponded on the surface (Ishimatsu et al., 2017). If the garden does not have a drainage underneath the soil bed, the primary water transport process is infiltration to soil and groundwater. Suspended solids, heavy metals and P are removed efficiently (Erickson et al., 2013). Nitrification can occur in the soil, but denitrification is often not occurring due to aerobic conditions. To promote denitrification, an additional layer of carbon rich newspaper has been shown to be able to decrease nitrate (Davis & McCuen, 2005).

Most of the pollutants are trapped in the topsoil layer, and the layer is then in need of replacement when the performance is decreasing. Different design considerations for the plants can be used; either using plants that are highly efficient in taking up pollutants, which results in almost annual replacement of some of the plants, or a design where basically the whole installation is replaced after for example 15 years (Davis & McCuen, 2005).

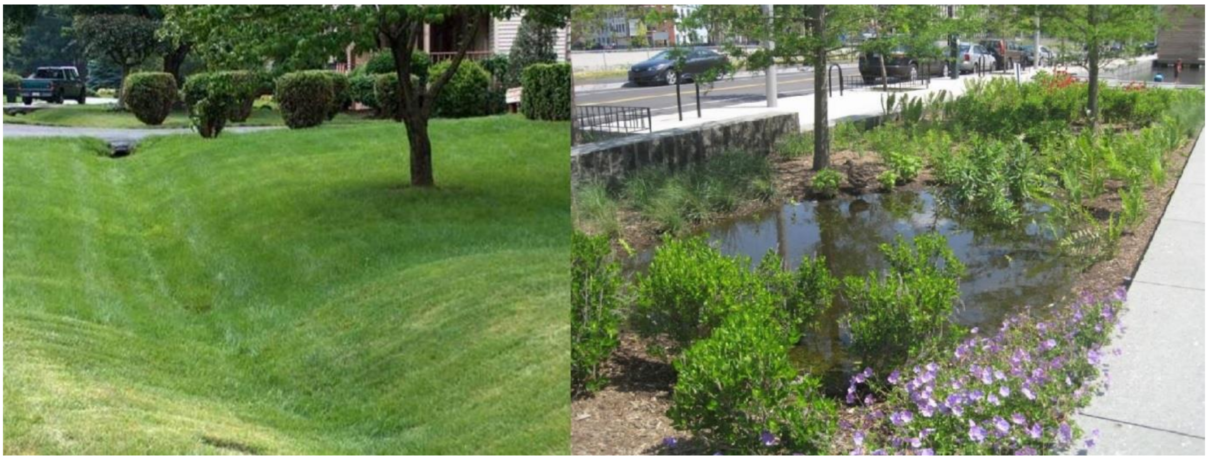

Figure 19 Two different stormwater treatment techniques that utilizes infiltration as the main treatment process. The left picture shows a swale. The right picture shows a rain garden along a walkway in USA. The top layer (brown mulch) can be seen (Alisha Goldstein, 2014; Wikimedia Commons, 2015).

2.8.4.4 *Biological*

Constructed wetlands

Constructed wetlands are built to mimic the positive benefits of a natural wetland, for example water and pollutant storage. The wetland consists of a water body, which is generally permanent due to a high groundwater level, but there are also wetlands that are allowed to dry out. The constructed wetlands also consist of a plant zone, known as a macrophyte zone. The plants can take up pollutants, particles can settle because of a reduced stormwater flow and nutrients attach to soil particles. The large surface area of the submerged plants and root systems create an extensive zone for microorganisms to grow. There are different configurations of a wetland, and the water flow can either be primarily on the surface of the wetland (Figure 20), or in the soil beneath (Kandasamy & Vigneswaran, 2008).

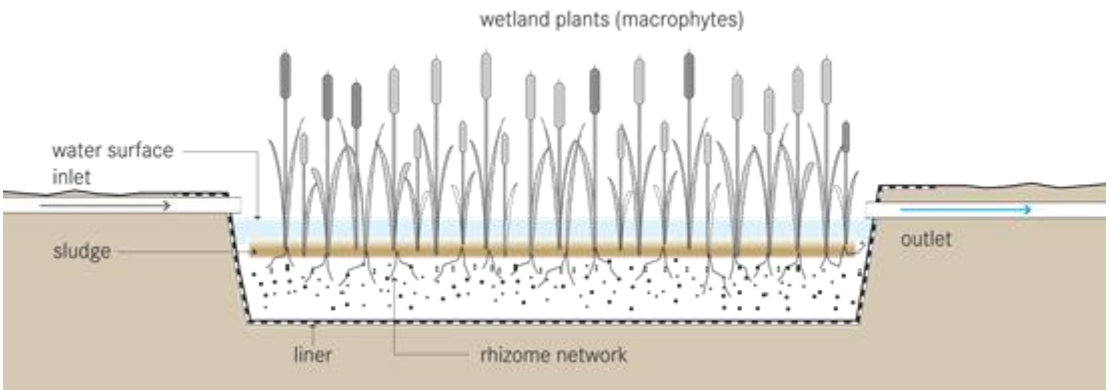

Figure 20 An example of a constructed wetland, with a free water surface (Wikimedia Commons, 2014).

2.8.4.5 *Physical-chemical*

Many of the techniques mentioned in this chapter utilizes physical-chemical processes such as sorption but have been placed under different processes as the main treatment process. For example, a filter with activated carbon obviously uses filtration as a treatment process, but also the physical-chemical process of sorption. The same goes for infiltration techniques that utilizes sorption of pollutants to the soil.

2.8.4.6 *Volatilization*

Green roofs

Green roof installations reduce runoff peaks via evapotranspiration and storage. The pollutant concentration of the runoff is, however, not always better, compared to runoff from a regular roof. Although plants take up nutrients, other pollutants can stick to the surface of the plants and be washed off in a storm event. However, the load of pollutants from a green roof could still be lower compared to a regular roof, since the green roofs reduce the volume of runoff water and hence reduce the pollutant runoff load (Rowe, 2011).

Figure 21 Green roof installation, Chicago City Hall (Wikimedia Commons, 2008).

2.9 MODELLING OF STORMWATER QUALITY

StormTac is a web-based modelling tool which is frequently used assessing stormwater quality in urban areas. The software consists of four sub models: the runoff model, the recipient model, the pollutant transport model and the stormwater management model (Larm, 2000). The sub models work in collaboration, which can be seen in the flow scheme in Appendix G. StormTac presents the effectiveness of pollutant reduction with respect to the specifically chosen stormwater treatment technique. The tool considers existing stormwater techniques in the catchment area and the condition in the recipient. (Larm, 2003).

2.9.1 The runoff model

The total inflow to a recipient is estimated from the base flow, the surface drainage volume, the atmospheric deposition and point flows. The calculation of the annual runoff [m^3/year] (Q) is calculated as seen in equation 1 (Larm, 2003). The outcome is later used in the pollutant transport model. Inputs necessary for the equation are: specific runoff coefficient (ϕ), area (A) [ha] and empirical precipitation (p) [mm/year].

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

The specific runoff coefficient expresses the proportion of precipitation that after evaporation, infiltration and storage in plants or submerged soil, becomes surface runoff. It ranges from 0 to 1, where 0 means no surface runoff and 1 means all precipitation becomes surface runoff (Svenskt Vatten, 2016), see Appendix H for specific values.

2.9.2 The pollutant transport model

Pollutants accumulated from sources as atmospheric deposition, surface runoff, groundwater flow and point sources are expressed as default standardized concentrations, since sampling at every source is unfeasible. The values are expressed in terms of annual pollutant mass and depend on circumstances such as hydrology and land use (Larm, 2003). The different default standard concentrations are described in Appendix H.

Equation 2 shows how to calculate the annual pollutant load (L_j) [kg/year]. Multiplying standard concentrations (C_{ij}) [mg/l] with annual runoff (Q) [m^3/year], from equation 1, resulting in the annual pollutant load in the receiving waters.

$$L_j = \frac{\sum_{i=1}^{N}(Q_i C_{ij})}{1000} \quad (2)$$

2.9.3 The recipient model

In the recipient model, the specific conditions considering size and type of the waterbody is entered, as well as the existing annual external pollutant load. The annual external pollutant load originates from other sources than stormwater such as base flow, atmospheric deposition or other diffuse or point sources.

The annual pollutant load [kg/year] to the specific recipient is calculated using equation 3. The contribution from all the different sources are summed up for each pollutant.

$$L_{in} = L + L_b + L_a + L_{point} + L_{rel} \quad (3)$$

Where; L_{in} is the total annual pollutant load

L is the annual pollutant load originated from stormwater

L_b is the annual pollutant load originated from groundwater flow

L_a is the annual pollutant load originated from atmospheric deposition

L_{point} is annual pollutant load originated from eventual point flow

L_{rel} is annual internal pollutant load originated from sediments.

The annual external pollutant mass is added to the existing contamination levels in the waterbody. The concentrations in the waterbody are compared to limit values set by local or global regulations such as the WFD. If the limit values are not satisfied, the next step is to use the final sub model to assess potential solutions.

2.9.4 The stormwater management model

In the stormwater management sub model, various stormwater techniques can be designed to reduce pollution levels. The design is based on equations that consider detention, pollutant removal efficiency and required facility area. Thus, the model considers both the quality and the quantity aspect (Larm, 2000).

After the proposed stormwater management options have be simulated, the recipient pollutant loads are re-evaluated according to the limit values. The results indicate whether the management design is adequate or if additional measures are required.

2.9.5 Standard concentrations

The calculation of the annual pollution load is carried out by specifying the size and type of land use. In StormTac, there are up to 70 different categorizations of land use differing from roads with specific traffic flows to different residential areas. All areas contribute to different levels of pollution. Therefore, StormTac has developed predetermined standard concentrations of pollutant concentrations depending on the land use.

The standard concentrations are based on literature studies, case studies and continuous measurements with the aim of calibrating the standard concentrations. The areas also have a minimum and maximum limit values of pollutant concentrations. The purpose of the minimum and maximum values is to allow for site adaptations if catchment specific information exists.

3 METHODOLOGY

The methodology describes the procedures and approach to answer the research questions.

3.1 LITERATURE STUDY

To answer the research questions and create a solid basis for the modeling, the report was initiated with a comprehensive literature study of stormwater quality in urban environments. Information was obtained mainly from scientific articles, course literature, papers and reports from state and municipal institutions.

The purpose of the literature study was to provide an overall picture of the challenges with stormwater management in urban environments. As a result, the report has initially dealt with driving forces such as climate change and increased urbanization, which contributes to the pollution of stormwater. In addition, the report deals with technical solutions and established restrictions with the purpose to counteract deterioration of stormwater quality.

3.2 THEORETICAL FRAMEWORK OF CASE STUDY

To concretize the issue of deteriorated stormwater quality in growing cities, an investigation of a specific case has been carried out. The case study covers the catchment area of the stream Kvillebäcken in Gothenburg, in terms of pollutants transported with stormwater to the stream. Areas that are investigated are Backaplan, Rambergsstaden, Skogome, Tolered and Tuve, all localized in the catchment area of Kvillebäcken, and with ongoing and planned construction.

Six different scenarios were simulated to give a good representation of the future, compared to current, conditions (Table 3). Scenario #1 is the current situation with current climate, land use, stormwater measures and traffic count. #2 is a future scenario with future (2035) climate, land use and future traffic, but no planned stormwater measures. #3, #4, #5 and #6 are scenarios simulating future climate, land use, traffic, and different degrees of planned measures. The reason for having different degrees of planned measures in the scenarios is because currently, ten ponds are planned to be implemented, by the Sustainable Waste and Water Administration in Gothenburg, but it is not yet decided whether to implement them or not, since financial funding is still needed.

In Table 4, “100 % ponds” means that all ten proposed ponds were included in the simulation, “50 % ponds” means that the five largest ponds were included, “10 % ponds” means the largest planned pond was included and 0 % means that none of the proposed ponds were included.

The specific choice of the year 2035 is based on the development strategy of the city of Gothenburg, which was adopted in 2014 by the Building Committee.

Table 3 The different scenarios simulated to investigate the effects of the future projections.

Scenario		Stormwater measures
#1	**Current situation** Current climate, land use and traffic	Current (swales)
#2	**2035 without planned measures** Future climate, land use and traffic	Current (swales)
#3	**2035 with planned measures** Future climate, land use, traffic and planned measures	100 % Ponds
#4		50 % Ponds
#5		10 % Ponds
#6		0 % Ponds

The accuracy of the scenarios' outcome is questionable for a period later than 2035 since the plans in the area are only until 2035. Furthermore, studying a time earlier than 2035 would be less relevant, because the effect of climate change and urban development are not as evident.

3.2.1 Mapping current and future land use conditions

Future urban development conditions were investigated through plans established by the City of Gothenburg (Göteborgs Stad, n.d.). The public website of the City of Gothenburg presents details of planned road and residence projects. Investigations regarding traffic and stormwater were conducted within each zoning area.

Traffic flow predictions for 2035 were found through surveys done in conjunction with the urban development plans presented by the City of Gothenburg. The predicted traffic flows are classified into different road types, see Table 4 for more information.

The planned measures were compiled through studies by the City of Gothenburg. The studies were carried out partly in connection with new development plans and partly related to Sustainable waste and water's specific measures within the catchment area, see section 4.2.7.

3.2.2 Climate analysis

To estimate the annual precipitation in 2035 an ensemble compiled by the Swedish Meteorological and Hydrological Institute (SMHI) was used. The chosen ensemble is a compilation of the nine different scenarios with respect to the radiation drift scenario RCP 8.5, describing the change factor for precipitation with a mean annual precipitation value from 1961-1990 set as an initial value. Out of ten existing climate models, nine are applicable to the climate of Sweden and selected radiation scenario (see Appendix M). The mean annual precipitation value from 1961-1990 was obtained from SMHI (see Appendix L).

3.3 POLLUTANT ANALYSIS

All the stormwater pollutants presented in the theory chapter are not considered a priority for Kvillebäcken by Sustainable Waste and Water in Gothenburg, since the concentrations of certain pollutants in the stream are below target values. Exceedance of the target values was the basis for choosing which pollutants to investigate in the case study of Kvillebäcken: Cu, Zn, P and BaP.

The pollutants were assessed in terms of two different concentrations: i) the concentration of the pollutants at the discharge point to Kvillebäcken; and ii) the concentration in the stream, and annual pollutant load to the recipient. The load and the second concentration (in the stream) are calculated from the same data, but the loads are presented in more detail in the results.

The stormwater treatment techniques were assessed in terms of their removal efficiency for the investigated pollutants, both as a treatment train with all techniques included, and as separate components. The efficiency of individual techniques was also assessed in terms of cost and area requirement. The cost and area efficiencies were calculated by dividing the cost or area of the technique with the achieved removal efficiency.

The six scenarios, presented in Table 3, were simulated using StormTac. The scenarios were simulated for the whole catchment area of Kvillebäcken. Modelling in StormTac was performed to estimate the current pollution concentration and to predict the future loads in the catchment area of Kvillebäcken. StormTac was chosen because of two reasons: The City of Gothenburg uses this software and there is an existing model of the case study area, and it is a user-friendly program that gives the opportunity to answer our research questions.

The climate was simulated using the current and future annual precipitation (2035).

The land use was simulated using the area of specific land uses, as was found in the zoning plans of the planned construction in the catchment area.

The traffic was simulated by changing the land use to a specific classification of road and attributed this road with an AADT to incorporate highly trafficked roads separately, see Table 4. The roads with traffic above 5000 AADT were investigated, since these are considered more important in terms of generating pollutants in stormwater. Roads with traffic flows less than 5000 ADT are included in land uses such as family house areas or mixed residential areas.

Table 4 Classification of the roads simulated in StormTac, based on the annual average daily traffic flow.

Classification	Traffic flow (AADT)
Road 1	0
Road 2	1 000
Road 3	2 000
Road 4	5 000
Road 5	10 000
Road 6	15 000
Road 7	25 000
Road 8	50 000
Road 9	100 000
Road 10	150 000

The planned stormwater treatment techniques were added in StormTac. In scenario #1 and #2, only the existing swales were added. In the rest of the scenarios, all the existing and planned measures are added in series.

4 CASE STUDY AREA

4.1 BACKGROUND

Sustainable Waste and Water in Gothenburg has analyzed the current water quality situation of 13 recipients (Table 5), in terms of the current pollution level and annual incoming load. The current situation is assessed in terms of EQS set by the EU and guidelines by the local EPA (Miljöförvaltningen). Modelling of water quality was done using the software StormTac.

The results show that all the 13 recipients need water quality improvement actions, since none of the recipients meet the target values for all the assessed pollutants.

Table 5 The 13 receiving waters assessed by Sustainable Waste and Water in Gothenburg in terms of water quality.

#	Stream
1	Delsjöbäcken
2	Göta älv
3	Haga ån
4	Hamnkanalen
5	Krogarebäcken
6	Kvillebäcken
7	Kvibergsbäcken
8	Lärjeån
9	Mölndalsån
10	Osbäcken
11	Stora ån
12	Säveån
13	Vitsippsbäcken

Sustainable Waste and Water found that there is an excess of P in almost all the recipients. Hence, an action program was suggested, with the focus to lower the levels of P. The aim of the action program was to identify green areas within each catchment area, in order to assess the existing stormwater treatment and to identify areas where stormwater treatment would be possible. The approach was to identify heavily trafficked roads and to estimate how much of the road area is drained to green areas. The road areas not drained to a green area were identified and classified based on how easily they can be converted to be drained to a green area. However, the reduction of the P load to each recipient that these measures would result in was not presented in the action plan. Moreover, areas within the catchment area that could be converted to a pond for regional treatment were identified and the reduction of P loads to the recipient was presented.

4.2 KVILLEBÄCKEN

One of the 13 recipients analyzed by Sustainable Waste and Water in Gothenburg is Kvillebäcken. Kvillebäcken is highly contaminated and exceeds the pollutant concentration targets found in local guidelines and the WFD. The stream Kvillebäcken is 5.5 km long and runs through the east side of the catchment area (Figure 22).

4.2.1 Land use

Kvillebäcken is a highly attractive catchment area located in the central part of Gothenburg. Kvillebäcken is historically an area of industries, such as porcelain, nails and paint factories located next to the stream, from the end of the 19th century until a couple of decades ago. From the 1950s to 1970s many residences were built and the area expanded (AHRE, 2019). The central and downstream area consist mainly of residential and trade areas. The south, highly exploited, part of the catchment area consists of roads with high traffic count and other impervious surfaces. Many building projects have been going on for several years in the area and are still on-going, which means that the already exploited area might be even more stressed, in terms of stormwater management.

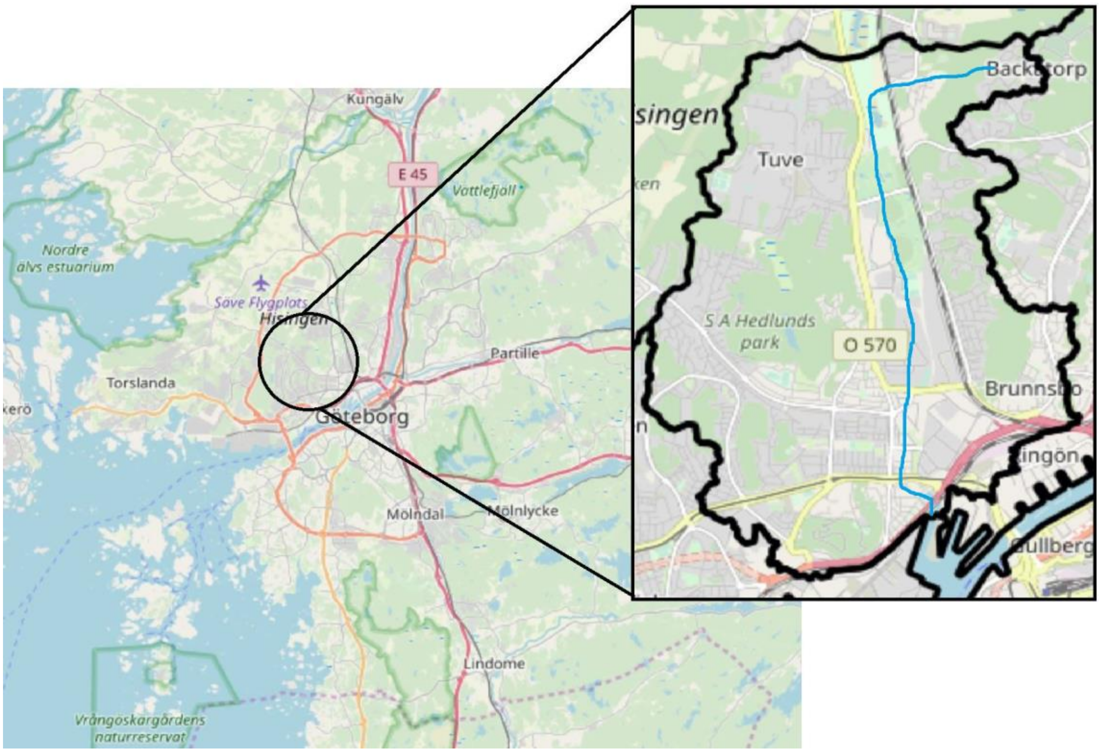

Figure 22 The left picture shows the location of the catchment of Kvillebäcken in Gothenburg, and the right picture shows the catchment area with its borders in black. The stream Kvillebäcken is marked in blue (Google, 2019).

4.2.2 Topography

Figure 23 shows the topography of the studied catchment area. It is possible to observe remarkable elevation differences of 50 – 80 meters comparing the level of the stream with the surrounding terrain. Stormwater from areas upstream flows to Kvillebäcken due to the elevation difference, which creates an accumulation sink of pollutants in the stream (Larm, 2017).

The area faces several stormwater quantity management difficulties. An investigation demonstrates that the stream and other low points will be affected by substantial increases in water level during rainfall with a longer return time, resulting in potential flooding hazards with significant damage (DHI, 2017). In addition, collection of contaminants in the sediment of the bottom of the stream may negatively affect the quality of the waterbody in times of turbulent flow (Schifman, Kasaraneni, & Oyanedel-Craver, 2018).

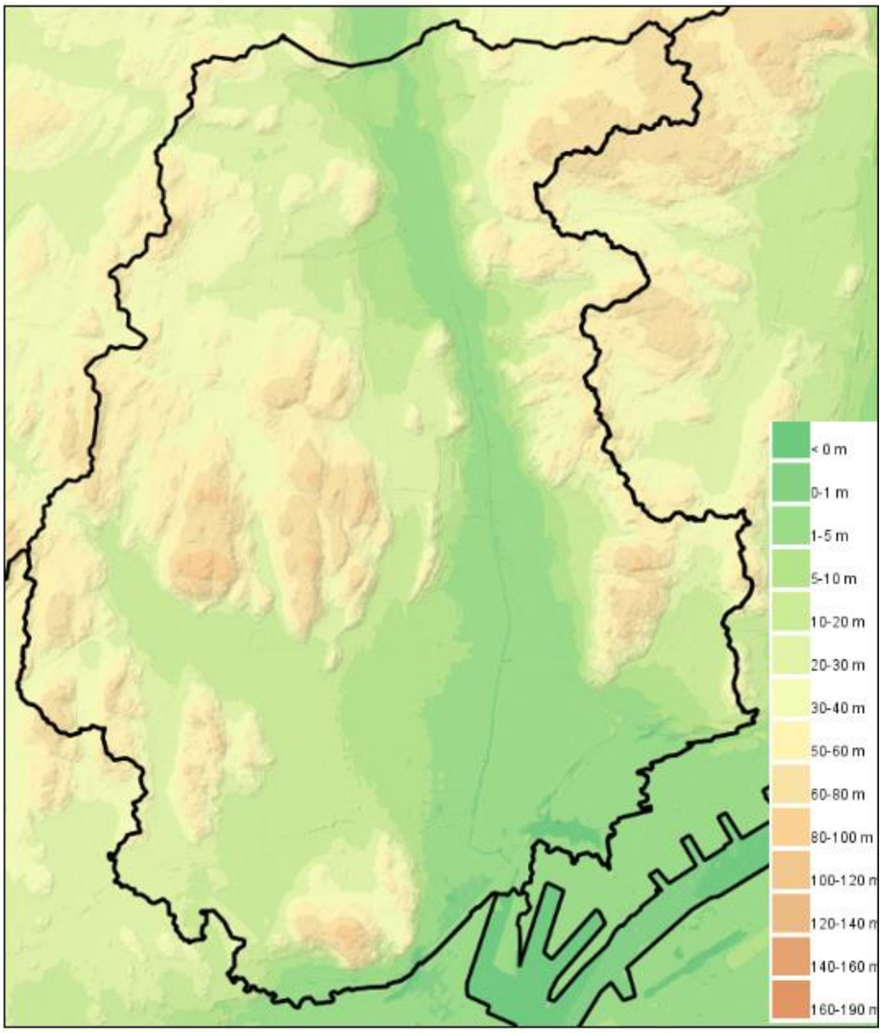

Figure 23 The topography of the catchment area of Kvillebäcken (Göteborgs Stad, 2019).

4.2.3 Climate

Gothenburg is expected to have an increase in precipitation by a factor of 1.1 to 1.3 in 2100 and a higher temperature which will result in less precipitation falling in the form of snow (Länsstyrelsen i Västra Götalands län, 2012).

Figure 24 illustrates the outcome of the completed climate analysis. The blue line corresponds to the mean value of the nine evaluated climate scenarios and the area marked with gray corresponds to the range of maximum and minimum values for each individual year.

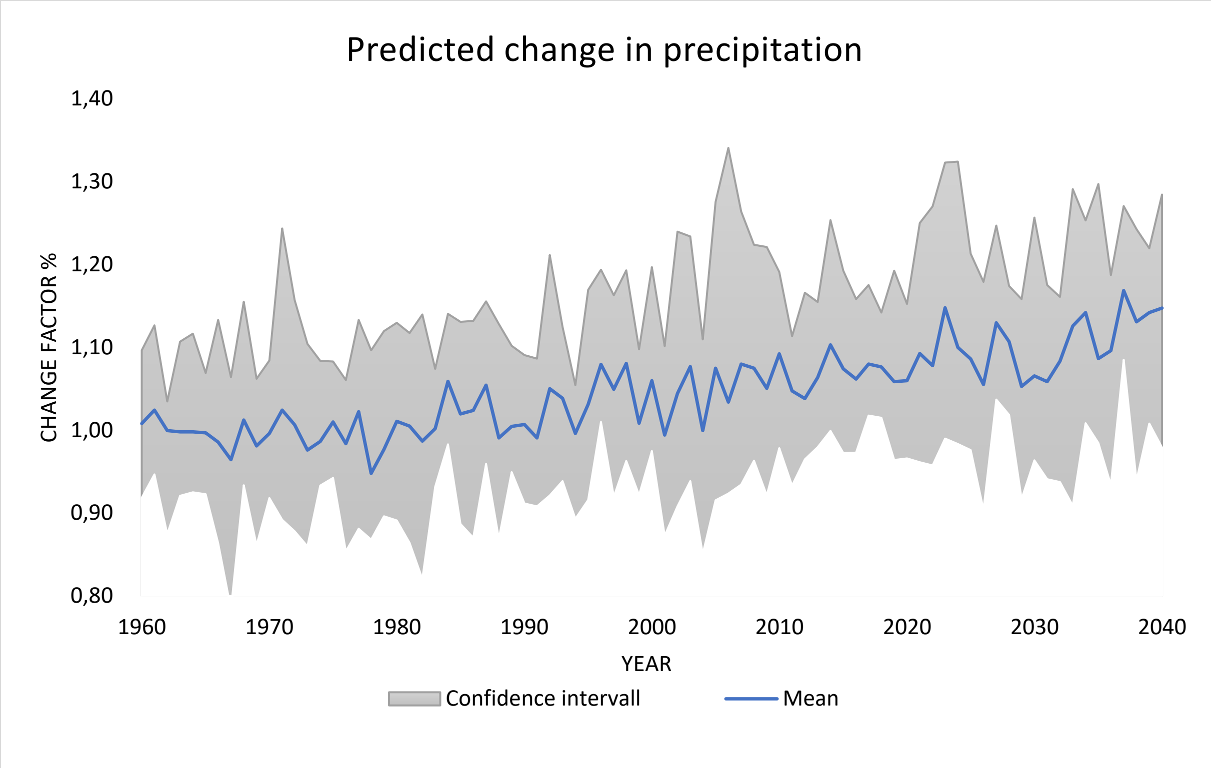

Figure 24. Predicted change in precipitation for the Gothenburg area.

The mean annual precipitation for the Gothenburg area for the years 1961-1990 is 900 mm (Appendix L). By multiplying the mean annual precipitation with the estimated change factor gained from Figure 24, predictions for the year 2035 are achieved (Table 6).

Table 6 Estimated change factor regarding mean, minimum and maximum precipitation loads [mm/year] considering 2035.

	Estimated change factor	Precipitation year 2035 [mm]
Mean	1.14	1026
Minimum	1.01	909
Maximum	1.25	1125

4.2.4 Receiving water quality

Good ecological and chemical status for Kvillebäcken should be achieved in 2027. According to VISS (Water Information System Sweden, Länsstyrelsen), the stream Kvillebäcken is considered to have moderate ecological status and does not achieve good chemical surface water status. Hence, the stream's overall status is determined to moderate (Figure 25).

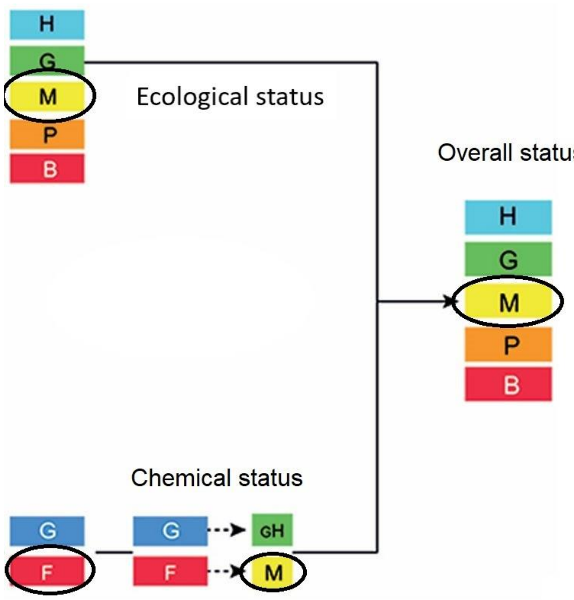

Figure 25 Ecological status of Kvillebäcken is moderate, and the chemical status is failing to achieve good status. The black circles indicate the scores given to Kvillebäcken by Länsstyrelsen (the county government). The overall status is moderate, according to the WFD methodology used to determine the water status of a water body (Emberton et al., 2017).

For chemical status there is an exception for the stream of Kvillebäcken considering the quality requirement for mercury and brominated diphenyl ethers (PBDE). The reason for the exception is that it is considered technically impossible to lower the levels of mercury and PBDE to the levels that correspond to good chemical surface water status. However, the concentrations of mercury and PBDE in Kvillebäcken must not increase.

Target concentrations in the recipient and in the outlet into the recipient (i.e. in stormwater) for the investigated pollutants P, Zn, Cu and BaP are presented in Table 7.

Table 7. Target concentrations of P, Cu, Zn and BaP in the stream and in stormwater (µg/l).

Pollutant	Target concentration in stream (Reference)	Target concentration in stormwater (Reference)
P	20 (Havs-och vatten myndigheten, 2011)	50 (Mossdal, 2013)
Cu	0.50 (Europeiska kommissionen, 2013)	30 (Mossdal, 2013)
Zn	5.5 (Europeiska kommissionen, 2013)	10 (Mossdal, 2013)
BaP	0.00017 (Europeiska kommissionen, 2013)	0.05 (Mossdal, 2013)

4.2.5 Traffic generation

The investigation of roads with significant traffic flows resulted in six routes over traffic flows of 5000 AADT (Figure 26). The current measured traffic flow of the municipal Traffic Office (Trafikkontoret) is presented in Table 8 (Göteborg Stad, n.d.). Existing infrastructure will be affected by development projects of new trading centers, residences and roads. The exploitation of Backaplan and the construction of the junction Kvillemotet will be expected to have a significant impact on the traffic flows. The roads Tuvevägen and Minelundsvägen are expected to have an increase traffic flow while Gustaf Dalénsgatan and Hjalmar Brantingsmotet are expected to reduce its traffic flow due to the new Kvillemotet. Roads like Björlandavägen and Lillhagsvägen lack forecasts for 2035; it is assumed that the traffic flow is unchanged till 2035 (Palmqvist, 2019).

Table 8 Description of the current and predicted annual average daily traffic, width and area of the main roads in the studied catchment area.

Traffic flow	Current AADT	Future AADT	Road width [m]	Road length [m]	Road area [m^2]
Minelundsvägen + Kvillemotet	20 000	30 000	15	1500	70 153
Hjalmar Brantingsmotet	20 600	17 000	15	1600	40 500
Tuvevägen	11 000	15 000	15	4000	60 000
Gustaf Dalénsgatan	16 000	14 000	8	1500	12 000
Björlandavägen	13 600	no data	9	2600	26 100
Lillhagsvägen	9 000	no data	8	4400	35 200

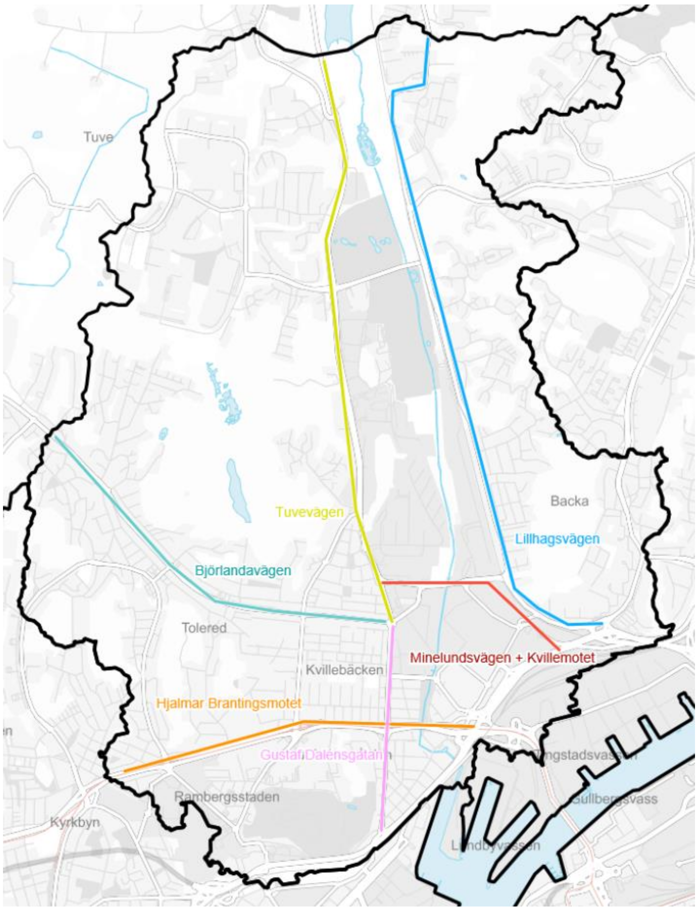

Figure 26 The location of the identified main roads (Göteborgs Stad, 2019).

4.2.6 Future densification and planned stormwater measures

The catchment area of Kvillebäcken has been divided into five major areas where exploitation and reconstruction will occur. These are: Backaplan, Rambergsstaden, Tolered, Skogome and Tuve (Figure 27).

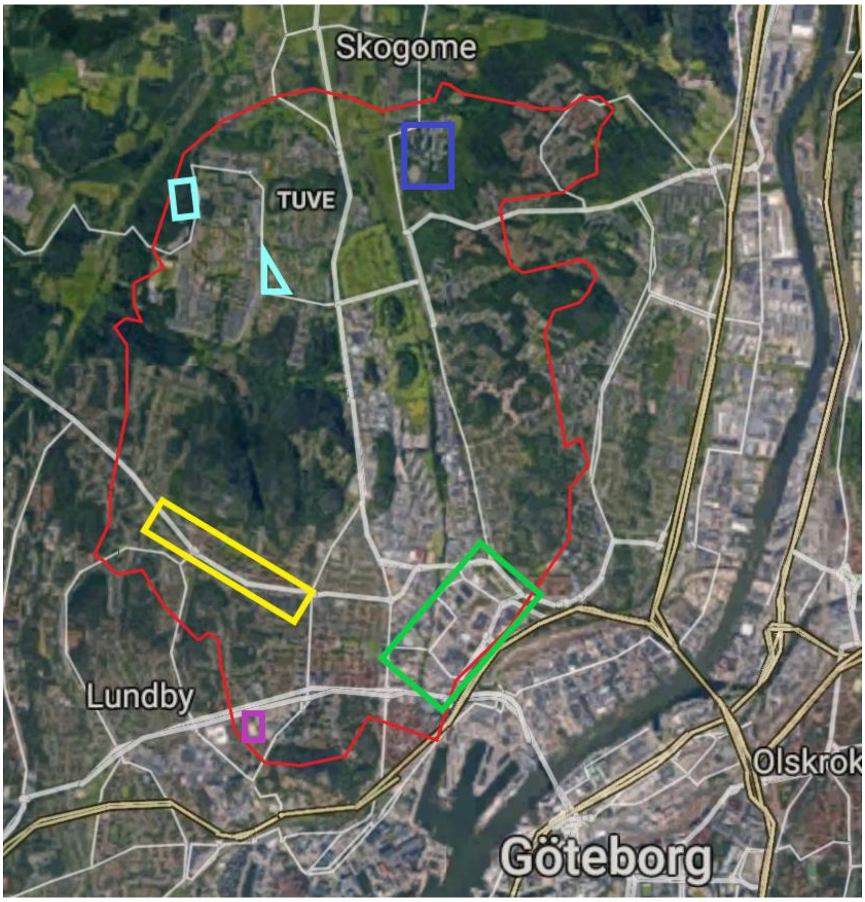

Figure 27 The catchment area of Kvillebäcken is marked in red. The different colors represent the different areas of exploitation investigated in this project. Green: Backaplan, purple: Rambergsstaden, yellow: Tolered, dark blue: Skogome and light blue: Tuve (Google, 2019).

4.2.6.1 *Backaplan*

Backaplan is developing quickly and is subject to on-going and planned projects, which will affect the stormwater in the area. The two major projects in Backaplan are: roads in the north eastern part and residential/retail area in the rest of the area.

4.2.6.1.1 Kvillemotet

The planned road area covers 8.5 ha, of which 5 ha is impermeable. The area already consists mainly of roads, but the road network must become more efficient in the area and there are also plans to connect Backaplan and Brunnsbo (east of Backaplan). There will be new roads, but also a new railway, a station and a junction. The planned roads will result in a loss of green areas, see Appendix N. The green area will be replaced by impermeable surface, increasing the impermeable area to 6 ha, which will result in an increased runoff flow. The traffic in the area is also expected to increase. The area has been used as a landfill from around 1940, which means that the ground is potentially polluted, mainly from oils and heavy metals. Exploitation of this area will require remediation of the polluted ground, which means the concentration of pollutants in the leachate water will be reduced. Implementation of a stormwater pond is considered in the northern part of the red area in Figure 27. Stormwater is currently conveyed in pipes and in swales placed along Lundbyleden. Two storage chambers and new stormwater pipes are proposed, and along pedestrian and bike paths, gravel-filled swales are proposed (Henriksson, Olsson, & Sjögren, 2014; Olsson & Sjögren, 2015).

4.2.6.1.2 New residence and trade area

The planned residence/urban retail area is 52 ha and is today mostly retail and parking area, with small green areas. The stormwater is conveyed in stormwater pipes but much of it is collected in a combined sewer. In the future, some stormwater treatment will be incorporated in the form of gravel-filled swales and biofilter (Lovell & Frohm, 2018).

4.2.6.2 *Rambergsstaden*

A residence area with four apartment blocks is planned at Rambergsvallen, with a total of 600 apartments. Each block will have a green courtyard in the center; however, parking space will be built underground which means infiltration is not possible. Swales are planned on the east side of the buildings, to treat and retain stormwater. The exploitation area is 2.9 ha and consists of a large green area, a gravel football field, and streets (Appendix N) (Göteborgs stad, 2013).

4.2.6.3 *Tolered*

Three constructions are planned in Tolered; a residential property at Klövervallsgatan, a residential property at Fyrklöversgatan and a combined pedestrian and bicycle path from the crossing at Sankt Olofsgatan to Swedenborgsplatsen (Appendix N).

4.2.6.3.1 Klövervallsgatan

A property with 114 apartments and an office space at ground level is planned in Tolered, along Björlandavägen. The property will have a courtyard, and parking space will be constructed under the building, see Appendix N. This area is 0.36 ha and currently consists mainly of impermeable concrete and parking space. After exploitation, about 0.29 ha will be impermeable and 0.07 will be green areas. Underground storage chambers will be installed to store stormwater, and these will be equipped with sand traps at the inlet of the chambers, to remove some solids (Gilveson, Nordlöf, & Lindström, 2017).

4.2.6.3.2 Fyrklöversgatan

The residential property planned along Fyrklöversgatan is currently 1.21 ha and consists of an asphalt parking lot. Separate pipes for foul water and stormwater exist, but they converge to a combined sewer. The property has four sections, and each has a courtyard, which will have rain gardens installed for slow release and treatment of stormwater. A parking lot will be placed east of the property and stormwater from this area is proposed to be handled by an underground storage chamber (Göteborgs stad, 2016).

The exploitation will result in less asphalt, and more roofs, making the total impermeable area slightly smaller after exploitation. However, since roofs has a higher runoff coefficient than asphalt, the reduced area will still increase (from 0.74 to 0.76), making the runoff volume higher after exploitation (Göteborgs stad, 2016).

4.2.6.3.3 Bicycle path

A 700 m long bicycle path along Björlandavägen is planned. This only represent stage 1 of the development of the path, from the junction at Sankt Olofsgatan in the north to the junction at Toleredsgatan (see Appendix N). Stage 2 is not included in the zoning plan. However, the whole stretch from Sankt Olofsgatan to Swedenborgsgatan will be built later on, making the total stretch about 2.6 km. The idea is to construct swales along the way for slow release and simultaneously treating stormwater (Lundin Konsult & Carlsson Emelie Heijmans, 2016).

4.2.6.4 *Skogome*

In Skogome, (Lillhagsparken) a residence area is planned where a total of 600-700 apartments, a school and a day care will be built. The planned area is 50 ha and consists today of residences, healthcare facilities and forest.

Stormwater is conveyed in a separate sewer system. The stormwater from existing copper roofs will be treated separately, if preferable, before conveyed to the sewer system. The roofs are preferably replaced by non-copper roofs. The proposed treatment techniques include gravel-filled swales, wetland, wet pond and swale (Göteborg Stad, 2013).

4.2.6.5 *Tuve*

Two residence areas are planned in Tuve; one at Gunnetorpsvägen and one at Glötorpsvägen, see Appendix N.

4.2.6.5.1 Gunnetorpsvägen

Approximately 380 residences and a day care are planned at Gunnetorpsvägen, which covers an area of 3.5 ha. The exploitation will result in an increased amount of impermeable surface: from current 1.5 ha to 2.7 ha. Stormwater pipes exist in the area, but green infrastructure will be implemented during the construction of the new area to manage the increased amount of stormwater (Stadsbyggnadskontoret Göteborgs Stad, 2016).

4.2.6.5.2 Västra Tuvevägen och Glöstorpsvägen

Two areas completely covered by forest will be converted to residence areas. This means that the areas are not currently in need of treatment. The area covers about 2.4 ha. The zoning plan is not yet completed, which means that the exact configuration of the buildings is not yet established, but approximately 200 residences are planned. The overall impact, however, will be an increase in impermeable surface and hence also an increased surface runoff, which must be considered (Fastighetskontoret Göteborgs Stad, 2019).

4.2.6.6 *Area conversion of the total area*

The whole catchment area of Kvillebäcken, both current situation (2018) and with planned exploitation (2035), has been categorized into land uses and areas for each land use have been estimated (Table 9). The land use areas are used as input in StormTac.

Table 9 Compilation of land uses and areas [ha] considering the current and future situation.

Land use	2018	2035
Multi-family area	34.8	43.8
Industrial Area	112.8	103.5
Park grounds	61.6	52.8
Agricultural property	34.1	34.1
Mixed multi-family area and downtown area	232.4	237.9
Mixed residential area	181.5	181.5
Road 1	0.0	0.0
Road 2	0.0	0.0
Road 3	0.0	0.0
Road 4	0.0	0.0
Road 5	9.5	3.5
Road 6	4.9	13.9
Road 7	4.1	7.0
Road 8	0.0	0.0
Road 9	0.0	0.0
Road 10	0.0	0.0
Total surface area [ha]	675.51	677.89

4.2.7 Compilation of current and planned stormwater measures

The existing stormwater treatment measures in the catchment area of Kvillebäcken consist only of swales. The total length of swales amount to approximately 19 000 m (see Appendix I) and was found by using GIS software.

In the zoning plans of the investigated areas local stormwater treatment techniques are suggested. Moreover, ten ponds with a total area of 73 200 m^2 have been proposed in the catchment area of Kvillebäcken by Sustainable Waste and Water in Gothenburg. The current, the planned (from the zoning plans) and the proposed (by Sustainable Waste and Water) are summarized in Table 10.

Table 10 Current, planned and proposed stormwater treatment techniques in the catchment area of Kvillebäcken. Six different techniques, together with their dimensions and units.

Measures	Current	Planned	Proposed	Total
Swale [m^2]	67 123	23 508	0	90 631
Graved filled swale [m^2]	0	5 067	0	5 067
Biofilter [m^2]	0	7 237	0	7 237
Wet pond [m^2]	0	433	73 200	73 633
Wet land [m^2]	0	160	0	160
Underground storage chamber [m^3]	0	101	0	101

The composition of current, planned and proposed measures for the six presented scenarios is presented in Table 11. There is no difference in measures between scenario #1 and #2 since the purpose with scenario #2 is to investigate the effects of future traffic and precipitation.

Table 11 Description of the stormwater measures for simulation scenarios 1 to 6.

	Scenarios[a]					
Measures	#1 Current no measure	#2 2035 no measure	#3 2035 100 % ponds	#4 2035 50 % ponds	#5 2035 10 % ponds	#6 2035 0 % ponds
Swale [m^2]	67 100	67 100	90 600	90 600	90 600	90 600
Gravel filled swale [m^2]	0	0	5 070	5 070	5 070	5 070
Biofilter [m^2]	0	0	7 240	7 240	7 240	7 240
Wet pond [m^2]	0	0	73 600	53 600	19 400	433
Wet land [m^2]	0	0	160	160	160	160
Underground storage chamber [m^3]	0	0	101	101	101	101

[a] Description of the scenarios see Table 3 page 33.

4.2.8 Efficiency analysis

The different stormwater treatment techniques have different implementation costs in Stormtac, which can be seen in Table 12. The information is used for the removal efficiency in the result.

Table 12 Implementation cost of the investigated treatment techniques in StormTac.

Measures	Amount	Cost per unit [SEK]	Total cost [SEK]	Required area [m^2]
Swale [m]	6 716	250	1 679 000	91 000
Gravel filled swale [m]	3 378	800	2 702 400	5 067
Biofilter [m^2]	7 300	10 000	73 000 000	7 300
Wet pond (100 % ponds) [m^2]	74 000	600	44 400 000	74 000

5 RESULTS

The case study shows that the urban areas in the catchment area of Kvillebäcken will increase by approximately 2 ha until year 2035. What this means is that the area of simulation in current situation increases in the future (Table 9). The increase is because this area was forested, and hence not considered in scenario #1, since Sustainable Waste and Water considers this area as natural, and not in need of treatment. The impervious surfaces will increase by 7 ha, corresponding to 2 %.

The construction of Kvillemotet will results in an increase of 32 % of roads with a traffic flow above 5000 AADT (Table 8). Moreover, 3 ha of existing traffic areas will have a higher traffic load in 2035. The average precipitation for Gothenburg is expected to increase from 900 mm (current) to 1026 (2035), which corresponds to a 14 % increase (Table 6).

The impact of urbanization, climate change and traffic on stormwater quality is presented in this section, in three sections:

- Section 5.1 shows the annual loads of each of the four investigated pollutants P, Zn, Cu and BaP reaching the stream Kvillebäcken for the six simulated scenarios.
- Section 5.2 shows two pollutant concentrations; one is the concentration of pollutants in the stormwater discharged into the stream, and the other is the pollutant concentration in the stream itself.
- Section 5.3 shows an efficiency analysis, where the capacity of the treatment techniques is investigated.

5.1 POLLUTANT LOADS IN THE STREAM KVILLEBÄCKEN

For each scenario and pollutant, the total load, acceptable load (based on targets from the City of Gothenburg), required load reduction to reach acceptable load, reduced load from the treatment techniques and remaining load to reduce are presented. Pollutants that exceed the acceptable loads and require further reduction are bolded in Table 13–Table 16. The pollution loads for Zn and Cu reach their targets, while BaP and P fail to reach the target values in several of the simulated scenarios.

Table 13 Summary of the outcomes from scenarios #1-6 regarding P load [kg/year] in Kvillebäcken.

P, load [kg/year]						
Scenario	#1	#2	#3	#4	#5	#6
Total load on recipient	1100	1400	1400	1400	1400	1400
Acceptable load	490	630	630	630	630	630
Required reduction	600	770	770	770	770	770
Reduced load	71	87	970	950	900	730
Remaining load to reduce	**530**	**660**	0	0	0	**45**

Table 14 Summary of the outcomes from scenarios #1-6 regarding Zn load [kg/year] in Kvillebäcken.

Zn, load [kg/year]						
Scenario	#1	#2	#3	#4	#5	#6
Total load on recipient	570	730	730	730	730	730
Acceptable load	1200	1500	1500	1500	1500	1500
Required reduction	0	0	0	0	0	0
Reduced load	240	290	630	630	630	620
Remaining load to reduce	0	0	0	0	0	0

Table 15 Summary of the outcomes from scenarios #1-6 regarding Cu load [kg/year] in Kvillebäcken

Cu, load [kg/year]						
Scenario	#1	#2	#3	#4	#5	#6
Total load on recipient	150	190	190	190	190	190
Acceptable load	990	1200	1300	1300	1300	1300
Required reduction	0	0	0	0	0	0
Reduced load	56	69	160	160	160	150
Remaining load to reduce	0	0	0	0	0	0

Table 16 Summary of the outcomes from scenarios #1-6 regarding BaP load [kg/year] in Kvillebäcken

BaP, load [kg/year]						
Scenario	#1	#2	#3	#4	#5	#6
Total load on recipient	0.28	0.34	0.34	0.34	0.34	0.34
Acceptable load	0.018	0.025	0.025	0.025	0.025	0.025
Required reduction	0.26	0.32	0.32	0.32	0.32	0.32
Reduced load	0.11	0.13	0.31	0.31	0.31	0.3
Remaining load to reduce	**0.15**	**0.18**	**0.0089**	**0.0089**	**0.0089**	**0.016**

5.2 POLLUTANT CONCENTRATIONS IN STORMWATER AND IN THE STREAM

The stormwater pollutant concentrations are presented in Table 17–Table 20. This is followed by the resulting pollutant concentrations in the stream (Table 21).

5.2.1 Pollutant concentrations in stormwater

The pollutant concentrations in stormwater are presented in Table 17–Table 20. Bolded values indicate that they do not reach the target concentrations set by the City of Gothenburg.

In scenarios #1 and #2, the target concentrations for Zn and Cu are not reached without treatment. With treatment, however, the targets are reached with a large margin. Furthermore, levels of P exceed the target concentration in several scenarios, while BaP reaches the target in all scenarios.

Table 17 Obtained stormwater concentration in StormTac for P [µg/l] assessed in the six investigated scenarios. Bolded values show concentrations exceeding target concentrations.

P, stormwater concentration						
Scenario	#1	#2	#3	#4	#5	#6
Before treatment	**250**	**240**	**240**	**240**	**240**	**240**
After treatment	**230**	**220**	45	49	**59**	**94**
Treatment efficiency	8 %	8 %	81 %	80 %	75 %	61 %

Table 18 Obtained stormwater concentration in StormTac for Zn [µg/l] assessed in the six investigated scenarios. Bolded values show concentrations exceeding target concentrations.

Zn, stormwater concentration						
Scenario	#1	#2	#3	#4	#5	#6
Before treatment	**140**	**130**	**130**	**130**	**130**	**130**
After treatment	**76**	**74**	6.7	6.7	6.7	9.2
Treatment efficiency	45 %	45 %	95 %	95 %	95 %	93 %

Table 19 Obtained stormwater concentration in StormTac for Cu [µg/l] assessed in the six investigated scenarios. Bolded values show concentrations exceeding target concentrations.

Cu, stormwater concentration						
Scenario	#1	#2	#3	#4	#5	#6
Before treatment	**35**	**34**	**34**	**34**	**34**	**34**
After treatment	**20**	**20**	1.8	1.9	2.3	3.7
Treatment efficiency	42 %	42 %	95 %	94 %	93 %	89 %

Table 20 Obtained stormwater concentration in StormTac for BaP [µg/l] assessed in the six investigated scenarios. Bolded values show concentrations exceeding target concentrations.

BaP, stormwater concentration						
Scenario	#1	#2	#3	#4	#5	#6
Before treatment	**0.071**	**0.067**	**0.067**	**0.067**	**0.067**	**0.067**
After treatment	0.042	0.04	0.005	0.005	0.005	0.0064
Treatment efficiency	40 %	40 %	93 %	93 %	93 %	91 %

5.2.2 Pollutant concentrations in the stream

The pollutant concentrations in Kvillebäcken are presented in Table 21. The pollution originates mainly from stormwater, but baseflow, atmospheric deposition and diffuse sources also contribute to the pollution. The bolded values in Table 21 are pollutant concentrations that exceed the target values. Pollutant concentrations for P and BaP do not reach the target values in several scenarios, meanwhile Zn and Cu reach the target in all scenarios.

Table 21 Pollutant concentrations from StormTac for the investigated pollutants [µg/l] in Kvillebäcken assessed in the six investigated scenarios. Bolded values show concentrations exceeding target concentrations.

	Scenarios					
Pollutant	#1	#2	#3	#4	#5	#6
P	**68**	**68**	23	24	26	**35**
Zn	1.5	1.5	0.34	0.34	0.34	0.38
Cu	0.048	0.048	0.013	0.014	0.014	0.017
BaP	**0.0016**	**0.0014**	**0.00023**	**0.00023**	**0.00023**	**0.00028**

5.3 Efficiency analysis

The removal efficiency for the different stormwater management techniques together with the cost and area efficiency are presented in Table 22–Table 25. The most effective measure to counteract the contaminants considering cost and area are bolded. The costs for the different treatment techniques in StormTac can be seen in Table 12. Swales are the cheapest alternative to reduce N, Zn and Cu, and gravel-filled swales is the cheapest technique for removing P. Gravel-filled swales are the most area efficient technique for all pollutants.

Table 22 Removal efficiencies obtained for swales in Kvillebäcken considering P, Zn, Cu and BaP. The removal efficiency is evaluated with the required area and cost for implementing the measure.

Swale (91 000 m^2)	Removal efficiency [%]	Cost per removal percentage [SEK]	Area required per removal percentage [m^2]
P	10	167 900	9 100
Zn	46	**36 500**	1 978
Cu	42	**39 976**	2 167
BaP	41	**40 951**	2 220

Table 23 Removal efficiencies for gravel-filled swales in Kvillebäcken considering P, Zn, Cu and BaP. The removal efficiency is evaluated with the required area and cost for implementing the measure

Gravel-filled swale (5 067 m^2)	Removal efficiency [%]	Cost per removal percentage [SEK]	Area required per removal percentage [m^2]
P	30	**90 080**	**169**
Zn	65	41 575	**78**
Cu	65	41 575	**78**
BaP	40	67 560	**127**

Table 24 Removal efficiencies for biofilters in Kvillebäcken considering P, Zn, Cu and BaP. The removal efficiency is evaluated with the required area and cost for implementing the measure

Biofilter (7 300 m^2)	Removal efficiency [%]	Cost per removal percentage [SEK]	Area required per removal percentage [m^2]
P	32	2 281 250	2 844
Zn	59	1 237 288	1 542
Cu	38	1 921 053	2 395
BaP	65	1 123 077	1 400

Table 25 Removal efficiencies for wet ponds in Kvillebäcken considering P, Zn, Cu and BaP. The removal efficiency is evaluated with the required area and cost for implementing the measure

Wet pond (74 000 m^2)	Removal efficiency [%]	Cost per removal percentage [SEK]	Area required per removal percentage [m^2]
P	56	792 857	1 321
Zn	68	652 941	1 088
Cu	58	765 517	1 276
BaP	72	616 667	1 028

6 DISCUSSION

Pollutant load

The total load of pollutants to the recipient changes with precipitation, land use and traffic, which is seen when comparing scenario #1 (current) with the other scenarios (Tables Table 13–Table 16). Scenario #1 leads to the lowest total load for all the investigated pollutants, while the future scenarios #2-#6 give rise to higher pollutant loads (same extent of sources for all future scenarios). During the simulations, it was observed that increased precipitation was the major contributor to an increase in the total load of pollutants to the recipient. This is because the total load in StormTac is calculated from the runoff volume multiplied with the standard concentrations of pollutants generated in the area. Hence, with a higher runoff volume, due to higher precipitation, the total load of pollutants increases.

The proposed ponds have a high reduction of the pollutant load to the recipient and are necessary for P removal (Table 13). If none of these ponds are implemented, the target load for P would not be reached. However, implementing only 10 %, of the total number of proposed ponds would be enough to reach the target for P. For BaP (Table 16), not even scenario #3 with all proposed ponds is enough to reach the target load. Having more than 10 % of the proposed ponds would thus not be justified based on the pollutant loads for any of the pollutant loads.

The total load of BaP amounts to 0.34 kg/year, of which 0.33 kg/year is from the stormwater in the catchment area of Kvillebäcken. The remaining load of 0.01 kg/year BaP originates from other diffuse sources and hence are not stormwater-related according to StormTac. Without the load of 0.01 kg/year from the diffuse sources, the load target for BaP would be reached in scenario #3-5 (Table 16).

Pollutant concentrations

The pollutant concentrations in stormwater decreased with an increased precipitation (Table 17–Table 20), due to dilution, as opposed to the load which increased (Table 13Table 16). The generation of pollutants from a specific area increases with an increased precipitation, but not enough to increase the pollutant concentration in the runoff, since the stormwater runoff volume also increases. A sensitivity analysis was performed on the stormwater pollutant concentrations using the inputs of scenario #2. It was found that precipitation was the main parameter that had an impact on the pollutant concentrations, when comparing scenarios #1 and #2. Hence, the effect of changes in traffic and land use, between scenarios #1 and #2, influence the concentration insignificantly.

The concentration of P in the stormwater reaches the target with 10 % of the proposed ponds (Table 21), however, the target of P in the stream is not reached unless 50 % of the ponds are installed (Table 17). Regarding BaP, the target concentration in the stormwater is reached in all scenarios (Table 20). However, the target concentration in the stream (Table 21) and the total load of BaP per year (Table 16) is not reached.

Pollutant concentration targets

We see that the two different concentrations (stormwater and in the stream) have conflicting target values. The target concentration of the pollutants in the stormwater is set by the Environmental Administration of the City of Gothenburg and is intended to serve as a guideline for the municipal department of Sustainable Waste and Water in charge of stormwater on municipal land. The target concentrations for the recipient itself is set by the WFD, and the County Administrative Board in Sweden is required by law to ensure that the target concentrations are reached if there are no special exceptions. It is not possible to draw a general connection between the two different requirements since one of them is dependent on the characteristics of the recipient, while the other is not. However, the requirements have been compiled by different disciplines and this can lead to one requirement being more stringent and more difficult to reach than the other. Nor can it be said that one requirement is more important than the other, since the WFD sets requirements for the recipient and intends to maintain or create good ecological and chemical quality in the recipient, while the regulations proposed by the environmental administrations demands that the discharge to the recipient is regulated.

Climate

The future precipitation is based on the scenario with highest concentration of carbon dioxide in the atmosphere (RCP 8.5). This assumption is a worst-case scenario and could be an overestimation of the future precipitation in 2035.

The precipitation in the future is accounted for simply by increasing the annual load in mm. The intensity is not accounted for. With short and intense rains, which are projected in the future, the soil would get saturated faster, resulting in a higher runoff volume to the receiving water bodies. This could then result in a higher load of pollutants reaching the waters. Moreover, intense rain could affect the soil by erosion, and with the land being potentially contaminated, this would generate a higher pollution than simulated.

Traffic

The traffic flow in 2035 for the investigated roads is estimated to increase, compared to the current situation. The traffic flow on some of the roads increased enough for the roads to be classified at a higher class, according to StormTac, in the simulation of 2035. Even if more public transportation and vehicles with lower emissions would be present on the roads in 2035, the time frame is not that long and a large conversion to a different way of transportation is not considered reasonable. Hence, the projection of an increased traffic flow in 2035 seems reasonable.

Efficiency analysis

The cost- and area-efficiency analysis shows that gravel-filled swales are the overall most preferable in terms of cost and area needed for implementation. In addition, their achieved removal efficiency is relatively good, compared to the other investigated treatment techniques. The swales are also cost-efficient but require more space than the gravel-filled swales. Furthermore, the swales are not capable of reducing as much pollutants as the other techniques, especially P. The highest removal efficiency is reached with the wet ponds for P, Zn and BaP, but the technique is more expensive than both swales and gravel-filled swales. The area-efficiency for ponds is the second best, after gravel-filled swales.

However, the cost-efficiency results are misleading when looking at the techniques in general. The results only apply for the investigated area, since the removal efficiency is based on the size of the catchment area and the area of the implemented technique, not the maximum removal efficiency for each technique. The maximal removal efficiencies for each technique found in the literature are presented in Appendix J. As can be seen in Appendix J, the removal efficiencies found in the literature and the removal efficiency from the simulations are of similar magnitude. Also, the investigated cost is only implementation cost, which means that the cost-efficiency could have shown a different result if for example maintenance cost and life span of the techniques were included as well. The P removal is, however, lower in the simulation than expected from literature. This is probably because StormTac calculates the removal efficiency based on the amount of treatment in the simulation. Having more treatment would give higher treatment efficiency. So, the lower P removal efficiency in the simulation, compared the literature, shows that the surface area of the treatment is too low.

The area-efficiency is based on the total investigated area divided by the achieved removal efficiency, which means the result from the area-efficiency analysis is specific to Kvillebäcken. However, since the aim was to study the catchment area of Kvillebäcken, these specific results from both the cost and area efficiency analyses seems like a reasonable way of presenting it.

Limitations with the simulations

StormTac simulates the treatment techniques as an end-of-pipe solution. This means that stormwater from the entire catchment area is simulated to be treated in each technique in series. This is not representative, since the stream Kvillebäcken is running through a large part of the catchment area. Hence, stormwater discharge should not be considered as a single point where the polluted water enters the stream or treatment facility. Also, since all the techniques are placed at the same location, it does not represent the actual location of the proposed treatment.

A solution to this could be to simulate a sub-catchment area where the treatment is supposed to be implemented and calculate the outlet concentration and annual load resulting from this area. However, StormTac can only account for pollutants generated in the specific area. This means that the output from the upstream catchment area cannot be considered in the downstream sub-catchment as an external source of pollutant within this software. Moreover, the water from an upstream sub-catchment area could be divided and discharge into two downstream sub-catchments. The problem then arises how to calculate the volume of water going to each downstream area.

StormTac estimates an irreducible pollutant concentration, based on technical limitations, which means that 100 % treatment might not be possible. The technical limitations include for example screens or filters consisting of materials that can leach pollutants, and reduced sedimentation occurring during high flows. As presented in Table 20, BaP concentrations are reduced by 93 % in scenarios #3-5, which shows that a larger pond has an effect on the pollutant removal, and the target concentration is not reached. If using the equation for removal efficiency used in StormTac, and calculating the removal efficiency for BaP manually, calculations results in 97 %, as opposed to the 93 % shown in StormTac. Here, StormTac then shows a 4 % irreducible concentration (Appendix O).

The pollution generated from the different land uses are standard values in StormTac, which means that a more accurate representation could be achieved by using site-specific measurement data and input these manually into the model. Although Sustainable Waste and Water has performed measurements on the recipient quality, these are not considered reliable. The reason is that the measurements have not been performed regularly, and do not demonstrates a clear trend. Thus, it would be advantageous to carry out regular measurements of the quality of the stormwater pollutants in the stream with the purpose of comparing with the simulations. A comparison of this kind could also be used to calibrate StormTac for further studies of the area.

However, StormTac simulates the stormwater as being released as a point source into Kvillebäcken. Therefore, the measurements of the pollutants in the stormwater should be representative for the entire catchment area, to be comparable with the simulated values. To achieve representative values for the entire catchment area is difficult. Another challenge is to achieve reliable measurements that represents the annual average concentrations, which is the unit in StormTac.

Comparing the results from StormTac with other similar pollution analysis models would give the possibility to evaluate how the results are affected by the various assumptions and approaches.

Implementation uncertainties

Another uncertainty is the willingness to implement the stormwater treatment techniques, since it might not be economically justified. All the zoning plans investigated have included stormwater treatment measures, except for one area which is in an early stage of planning. However, since they are not yet built, the extent of implementation of the treatment is not yet final.

The construction industry is extremely sensitive to the economic situation. The plans to build residential areas and trading centers according to the development strategy of the City of Gothenburg for 2035 presuppose that the economy remains stable. Any challenges in the economy will undoubtedly affect the success of the plans. Changes can occur, and projects can be cancelled, which would affect the future land use and traffic.

Green infrastructure

To achieve a green and open stormwater treatment and management, the treatment techniques must be easy to implement, and they should be integrated into the landscape. One benefits with using green stormwater treatment systems, instead of the traditional piped systems, is that the stormwater can get the treatment it needs. Instead of being conveyed to a receiving water untreated, or to a wastewater treatment plant where it gets treated poorly, the stormwater should be taken care of in a way that resembles a natural treatment. Stormwater treatment techniques such as swales and rain gardens can treat the stormwater in a way that imitates natural treatment processes such as infiltration and sedimentation of pollutants. Moreover, using source control measures for treating stormwater is efficient, since the concentration of the pollutants is high at the source. Also, if treating stormwater locally, the pollutions would be seen more as a point source than as a diffuse source coming from different areas.

Stormwater legislation

Treating stormwater as a point source would be optimal, since the origin of stormwater pollutants is generally highly uncertain. If the landowners of farms, industries, residences et cetera were legally obligated to treat stormwater on their land to meet the target values set by the WFD, the pollution could be regulated, and the pollution sources would be easier to trace back to its source. Some landowners would, based on the type of business on their land, need to treat stormwater to a higher degree, which means that this type of legislation can be viewed as highly unfair for some. Unfair in the sense that some businesses might have to spend a large amount of money on stormwater treatment, which could jeopardize their business. However, financial aid from EU could be one solution. It is important that the money from EU is invested in treatment of stormwater, and this should be ensured through monitoring of stormwater pollutants locally from all landowners. Legislation like this would drive the stormwater management sector and the treatment techniques would become more efficient in the future.

7 CONCLUSIONS

The mapping of stormwater treatment measures in the studied catchment area resulted in three categories: current measures, planned measures (from the zoning plans) and proposed measures (by Sustainable Waste and water). In the current situation, only swales exist. The planned stormwater management measures include additional swales, gravel-filled swales, a wetland, wet ponds and underground storage chambers. The proposed measures (by Sustainable Waste and Water) are consisting of ten ponds. The financing of the planned treatment (from the zoning plans) is more secure than the ponds proposed by Sustainable Waste and Water, according to people spoken to.

The simulations show that the total annual load of P, N, Zu and Cu to the stream Kvillebäcken is expected to increase significantly. This increase is a result of the amount of precipitation in 2035, which is expected to increase by 14 % compared to the current precipitation. Additionally, the proportion of impervious surfaces in catchment area of Kvillebäcken is expected to increase by 2 %, and this together with increased precipitation results in increased surface runoff.

The stormwater pollutant concentrations, on the other hand, are not expected to increase in the year 2035. When comparing scenario #1 (current situation) and #2 (2035, no stormwater measures), it is observed that the pollutant concentrations in stormwater decrease with an increased precipitation, due to dilution of the pollutants. However, the stormwater pollutant concentrations for all investigated pollutants (Table 17Table 20) are above the target concentrations before including the planned treatment techniques in the simulation. This shows that additional treatment than the existing swales is necessary.

The pollutant concentrations in stormwater reach the target concentrations for P, Zn and Cu if all planned treatment measures, and 50 % of the proposed ponds are implemented (scenario #4). On the other hand, the target load, and the concentration of BaP in the stream Kvillebäcken are not reached in any simulated scenario. It seems that it is not technically possible to reach these targets due to other sources of pollutants than stormwater, and irreducible concentration.

The efficiency analysis shows that gravel-filled swales are the most area-effective treatment technique for all investigated pollutants. In addition, gravel-filled swales are the most cost-effective technique for treatment of P. For Zn, Cu and BaP, swales are the most cost-effective measure.

Worth noting is that even though the catchment area of Kvillebäcken is highly exploited, and will be even more exploited in the future, the stormwater quality does not seem to deteriorate much in the future. However, the planned treatment is still necessary, since the EU goal of good ecological and chemical status in receiving waters should be met.

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APPENDIX

A. A LIST OF THE 45 PRIORITY AND PRIORITIZED HAZARDOUS SUBSTANCES IN SURFACE WATERS, FROM WATER FRAMEWORK DIRECTIVE (2008/105/EC)

LIST OF PRIORITY SUBSTANCES IN THE FIELD OF WATER POLICY

Number	CAS number (1)	EU number (2)	Name of priority substance (3)	Identified as priority hazardous substance
(1)	15972-60-8	240-110-8	Alachlor	
(2)	120-12-7	204-371-1	Anthracene	X
(3)	1912-24-9	217-617-8	Atrazine	
(4)	71-43-2	200-753-7	Benzene	
(5)	not applicable	not applicable	Brominated diphenylethers	X (4)
(6)	7440-43-9	231-152-8	Cadmium and its compounds	X
(7)	85535-84-8	287-476-5	Chloroalkanes, C_{10-13}	X
(8)	470-90-6	207-432-0	Chlorfenvinphos	
(9)	2921-88-2	220-864-4	Chlorpyrifos (Chlorpyrifos-ethyl)	
(10)	107-06-2	203-458-1	1,2-dichloroethane	
(11)	75-09-2	200-838-9	Dichloromethane	
(12)	117-81-7	204-211-0	Di(2-ethylhexyl)phthalate (DEHP)	X
(13)	330-54-1	206-354-4	Diuron	
(14)	115-29-7	204-079-4	Endosulfan	X
(15)	206-44-0	205-912-4	Fluoranthene	
(16)	118-74-1	204-273-9	Hexachlorobenzene	X
(17)	87-68-3	201-765-5	Hexachlorobutadiene	X
(18)	608-73-1	210-168-9	Hexachlorocyclohexane	X
(19)	34123-59-6	251-835-4	Isoproturon	
(20)	7439-92-1	231-100-4	Lead and its compounds	
(21)	7439-97-6	231-106-7	Mercury and its compounds	X
(22)	91-20-3	202-049-5	Naphthalene	
(23)	7440-02-0	231-111-4	Nickel and its compounds	
(24)	not applicable	not applicable	Nonylphenols	X (5)
(25)	not applicable	not applicable	Octylphenols (6)	
(26)	608-93-5	210-172-0	Pentachlorobenzene	X
(27)	87-86-5	201-778-6	Pentachlorophenol	
(28)	not applicable	not applicable	Polyaromatic hydrocarbons (PAH) (7)	X
(29)	122-34-9	204-535-2	Simazine	
(30)	not applicable	not applicable	Tributyltin compounds	X (8)

Number	CAS number ([1])	EU number ([2])	Name of priority substance ([3])	Identified as priority hazardous substance
(31)	12002-48-1	234-413-4	Trichlorobenzenes	
(32)	67-66-3	200-663-8	Trichloromethane (chloroform)	
(33)	1582-09-8	216-428-8	Trifluralin	X
(34)	115-32-2	204-082-0	Dicofol	X
(35)	1763-23-1	217-179-8	Perfluorooctane sulfonic acid and its derivatives (PFOS)	X
(36)	124495-18-7	not applicable	Quinoxyfen	X
(37)	not applicable	not applicable	Dioxins and dioxin-like compounds	X ([9])
(38)	74070-46-5	277-704-1	Aclonifen	
(39)	42576-02-3	255-894-7	Bifenox	
(40)	28159-98-0	248-872-3	Cybutryne	
(41)	52315-07-8	257-842-9	Cypermethrin ([10])	
(42)	62-73-7	200-547-7	Dichlorvos	
(43)	not applicable	not applicable	Hexabromocyclododecanes (HBCDD)	X ([11])
(44)	76-44-8/ 1024-57-3	200-962-3/ 213-831-0	Heptachlor and heptachlor epoxide	X
(45)	886-50-0	212-950-5	Terbutryn	

([1]) CAS: Chemical Abstracts Service.

([2]) EU-number: European Inventory of Existing Commercial Substances (EINECS) or European List of Notified Chemical Substances (ELINCS).

([3]) Where groups of substances have been selected, unless explicitly noted, typical individual representatives are defined in the context of the setting of environmental quality standards.

([4]) Only Tetra, Penta, Hexa and Heptabromodiphenylether (CAS -numbers 40088-47-9, 32534-81-9, 36483-60-0, 68928-80-3, respectively).

([5]) Nonylphenol (CAS 25154-52-3, EU 246-672-0) including isomers 4-nonylphenol (CAS 104-40-5, EU 203-199-4) and 4-nonylphenol (branched) (CAS 84852-15-3, EU 284-325-5).

([6]) Octylphenol (CAS 1806-26-4, EU 217-302-5) including isomer 4-(1,1',3,3'-tetramethylbutyl)-phenol (CAS 140-66-9, EU 205-426-2).

([7]) Including benzo(a)pyrene (CAS 50-32-8, EU 200-028-5), benzo(b)fluoranthene (CAS 205-99-2, EU 205-911-9), benzo(g,h,i)perylene (CAS 191-24-2, EU 205-883-8), benzo(k)fluoranthene (CAS 207-08-9, EU 205-916-6), indeno(1,2,3-cd)pyrene (CAS 193-39-5, EU 205-893-2) and excluding anthracene, fluoranthene and naphthalene, which are listed separately.

([8]) Including tributyltin-cation (CAS 36643-28-4).

([9]) This refers to the following compounds:
7 polychlorinated dibenzo-p-dioxins (PCDDs): 2,3,7,8-T4CDD (CAS 1746-01-6), 1,2,3,7,8-P5CDD (CAS 40321-76-4), 1,2,3,4,7,8-H6CDD (CAS 39227-28-6), 1,2,3,6,7,8-H6CDD (CAS 57653-85-7), 1,2,3,7,8,9-H6CDD (CAS 19408-74-3), 1,2,3,4,6,7,8-H7CDD (CAS 35822-46-9), 1,2,3,4,6,7,8,9-O8CDD (CAS 3268-87-9)
10 polychlorinated dibenzofurans (PCDFs): 2,3,7,8-T4CDF (CAS 51207-31-9), 1,2,3,7,8-P5CDF (CAS 57117-41-6), 2,3,4,7,8-P5CDF (CAS 57117-31-4), 1,2,3,4,7,8-H6CDF (CAS 70648-26-9), 1,2,3,6,7,8-H6CDF (CAS 57117-44-9), 1,2,3,7,8,9-H6CDF (CAS 72918-21-9), 2,3,4,6,7,8-H6CDF (CAS 60851-34-5), 1,2,3,4,6,7,8-H7CDF (CAS 67562-39-4), 1,2,3,4,7,8,9-H7CDF (CAS 55673-89-7), 1,2,3,4,6,7,8,9-O8CDF (CAS 39001-02-0)
12 dioxin-like polychlorinated biphenyls (PCB-DL): 3,3',4,4'-T4CB (PCB 77, CAS 32598-13-3), 3,3',4',5-T4CB (PCB 81, CAS 70362-50-4), 2,3,3',4,4'-P5CB (PCB 105, CAS 32598-14-4), 2,3,4,4',5-P5CB (PCB 114, CAS 74472-37-0), 2,3',4,4',5-P5CB (PCB 118, CAS 31508-00-6), 2,3',4,4',5'-P5CB (PCB 123, CAS 65510-44-3), 3,3',4,4',5-P5CB (PCB 126, CAS 57465-28-8), 2,3,3',4,4',5-H6CB (PCB 156, CAS 38380-08-4), 2,3,3',4,4',5'-H6CB (PCB 157, CAS 69782-90-7), 2,3',4,4',5,5'-H6CB (PCB 167, CAS 52663-72-6), 3,3',4,4',5,5'-H6CB (PCB 169, CAS 32774-16-6), 2,3,3',4,4',5,5'-H7CB (PCB 189, CAS 39635-31-9).

([10]) CAS 52315-07-8 refers to an isomer mixture of cypermethrin, alpha-cypermethrin (CAS 67375-30-8), beta-cypermethrin (CAS 65731-84-2), theta-cypermethrin (CAS 71697-59-1) and zeta-cypermethrin (52315-07-8).

([11]) This refers to 1,3,5,7,9,11-Hexabromocyclododecane (CAS 25637-99-4), 1,2,5,6,9,10- Hexabromocyclododecane (CAS 3194-55-6), α-Hexabromocyclododecane (CAS 134237-50-6), β-Hexabromocyclododecane (CAS 134237-51-7) and γ- Hexabromocyclododecane (CAS 134237-52-8).'.

B. A LIST OF THE 45 PRIORITY AND PRIORITIZED HAZARDOUS SUBSTANCES IN SURFACE WATERS, FROM WATER FRAMEWORK DIRECTIVE (2008/105/EC) AND THEIR TARGET CONCENTRATIONS.

ENVIRONMENTAL QUALITY STANDARDS FOR PRIORITY SUBSTANCES AND CERTAIN OTHER POLLUTANTS

PART A: ENVIRONMENTAL QUALITY STANDARDS (EQS)

AA: annual average.

MAC: maximum allowable concentration.

Unit: [μg/l] for columns (4) to (7)

[μg/kg wet weight] for column (8)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
No	Name of substance	CAS number (1)	AA-EQS (2) Inland surface waters (3)	AA-EQS (2) Other surface waters	MAC-EQS (4) Inland surface waters (3)	MAC-EQS (4) Other surface waters	EQS Biota (12)
(1)	Alachlor	15972-60-8	0,3	0,3	0,7	0,7	
(2)	Anthracene	120-12-7	0,1	0,1	0,1	0,1	
(3)	Atrazine	1912-24-9	0,6	0,6	2,0	2,0	
(4)	Benzene	71-43-2	10	8	50	50	
(5)	Brominated diphenylethers (5)	32534-81-9			0,14	0,014	0,0085
(6)	Cadmium and its compounds (depending on water hardness classes) (6)	7440-43-9	≤ 0,08 (Class 1) 0,08 (Class 2) 0,09 (Class 3) 0,15 (Class 4) 0,25 (Class 5)	0,2	≤ 0,45 (Class 1) 0,45 (Class 2) 0,6 (Class 3) 0,9 (Class 4) 1,5 (Class 5)	≤ 0,45 (Class 1) 0,45 (Class 2) 0,6 (Class 3) 0,9 (Class 4) 1,5 (Class 5)	
(6a)	Carbon-tetrachloride (7)	56-23-5	12	12	not applicable	not applicable	
(7)	C10-13 Chloroalkanes (8)	85535-84-8	0,4	0,4	1,4	1,4	
(8)	Chlorfenvinphos	470-90-6	0,1	0,1	0,3	0,3	
(9)	Chlorpyrifos (Chlorpyrifos-ethyl)	2921-88-2	0,03	0,03	0,1	0,1	
(9a)	Cyclodiene pesticides: Aldrin (7) Dieldrin (7) Endrin (7) Isodrin (7)	309-00-2 60-57-1 72-20-8 465-73-6	Σ = 0,01	Σ = 0,005	not applicable	not applicable	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
No	Name of substance	CAS number (5)	AA-EQS (2) Inland surface waters (3)	AA-EQS (2) Other surface waters	MAC-EQS (4) Inland surface waters (3)	MAC-EQS (4) Other surface waters	EQS Biota (12)
(9b)	DDT total (7), (9)	not applicable	0,025	0,025	not applicable	not applicable	
	para-para-DDT (7)	50-29-3	0,01	0,01	not applicable	not applicable	
(10)	1,2-Dichloroethane	107-06-2	10	10	not applicable	not applicable	
(11)	Dichloromethane	75-09-2	20	20	not applicable	not applicable	
(12)	Di(2-ethylhexyl)-phthalate (DEHP)	117-81-7	1,3	1,3	not applicable	not applicable	
(13)	Diuron	330-54-1	0,2	0,2	1,8	1,8	
(14)	Endosulfan	115-29-7	0,005	0,0005	0,01	0,004	
(15)	Fluoranthene	206-44-0	0,0063	0,0063	0,12	0,12	30
(16)	Hexachlorobenzene	118-74-1			0,05	0,05	10
(17)	Hexachlorobutadiene	87-68-3			0,6	0,6	55
(18)	Hexachlorocyclohexane	608-73-1	0,02	0,002	0,04	0,02	
(19)	Isoproturon	34123-59-6	0,3	0,3	1,0	1,0	
(20)	Lead and its compounds	7439-92-1	1,2 (13)	1,3	14	14	
(21)	Mercury and its compounds	7439-97-6			0,07	0,07	20
(22)	Naphthalene	91-20-3	2	2	130	130	
(23)	Nickel and its compounds	7440-02-0	4 (13)	8,6	34	34	
(24)	Nonylphenols (4-Nonylphenol)	84852-15-3	0,3	0,3	2,0	2,0	
(25)	Octylphenols ((4-(1,1′,3,3′-tetramethyl-butyl)-phenol))	140-66-9	0,1	0,01	not applicable	not applicable	
(26)	Pentachlorobenzene	608-93-5	0,007	0,0007	not applicable	not applicable	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
No	Name of substance	CAS number [1]	AA-EQS [2] Inland surface waters [3]	AA-EQS [2] Other surface waters	MAC-EQS [4] Inland surface waters [3]	MAC-EQS [4] Other surface waters	EQS Biota [12]
(27)	Pentachloro-phenol	87-86-5	0,4	0,4	1	1	
(28)	Polyaromatic hydrocarbons (PAH) [11]	not applicable	not applicable	not applicable	not applicable	not applicable	
	Benzo(a)pyrene	50-32-8	$1,7 \times 10^{-4}$	$1,7 \times 10^{-4}$	0,27	0,027	5
	Benzo(b)fluor-anthene	205-99-2	see footnote 11	see footnote 11	0,017	0,017	see footnote 11
	Benzo(k)fluor-anthene	207-08-9	see footnote 11	see footnote 11	0,017	0,017	see footnote 11
	Benzo(g,h,i)-perylene	191-24-2	see footnote 11	see footnote 11	$8,2 \times 10^{-3}$	$8,2 \times 10^{-4}$	see footnote 11
	Indeno(1,2,3-cd)-pyrene	193-39-5	see footnote 11	see footnote 11	not applicable	not applicable	see footnote 11
(29)	Simazine	122-34-9	1	1	4	4	
(29a)	Tetrachloro-ethylene [7]	127-18-4	10	10	not applicable	not applicable	
(29b)	Trichloro-ethylene [7]	79-01-6	10	10	not applicable	not applicable	
(30)	Tributyltin compounds (Tributyltin-cation)	36643-28-4	0,0002	0,0002	0,0015	0,0015	
(31)	Trichloro-benzenes	12002-48-1	0,4	0,4	not applicable	not applicable	
(32)	Trichloro-methane	67-66-3	2,5	2,5	not applicable	not applicable	
(33)	Trifluralin	1582-09-8	0,03	0,03	not applicable	not applicable	
(34)	Dicofol	115-32-2	$1,3 \times 10^{-3}$	$3,2 \times 10^{-5}$	not appli-cable [10]	not appli-cable [10]	33
(35)	Perfluorooctane sulfonic acid and its derivatives (PFOS)	1763-23-1	$6,5 \times 10^{-4}$	$1,3 \times 10^{-4}$	36	7,2	9,1
(36)	Quinoxyfen	124495-18-7	0,15	0,015	2,7	0,54	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
No	Name of substance	CAS number [1]	AA-EQS [2] Inland surface waters [3]	AA-EQS [2] Other surface waters	MAC-EQS [4] Inland surface waters [3]	MAC-EQS [4] Other surface waters	EQS Biota [12]
(37)	Dioxins and dioxin-like compounds	See footnote 10 in Annex X to Directive 2000/60/EC			not applicable	not applicable	Sum of PCDD+PCDF+ PCB-DL 0,0065 $\mu g.kg^{-1}$ TEQ [14]
(38)	Aclonifen	74070-46-5	0,12	0,012	0,12	0,012	
(39)	Bifenox	42576-02-3	0,012	0,0012	0,04	0,004	
(40)	Cybutryne	28159-98-0	0,0025	0,0025	0,016	0,016	
(41)	Cypermethrin	52315-07-8	8×10^{-5}	8×10^{-6}	6×10^{-4}	6×10^{-5}	
(42)	Dichlorvos	62-73-7	6×10^{-4}	6×10^{-5}	7×10^{-4}	7×10^{-5}	
(43)	Hexabromo-cyclododecane (HBCDD)	See footnote 12 in Annex X to Directive 2000/60/EC	0,0016	0,0008	0,5	0,05	167
(44)	Heptachlor and heptachlor epoxide	76-44-8/1024-57-3	2×10^{-7}	1×10^{-8}	3×10^{-4}	3×10^{-5}	$6{,}7 \times 10^{-3}$
(45)	Terbutryn	886-50-0	0,065	0,0065	0,34	0,034	

(1) CAS: Chemical Abstracts Service.

(2) This parameter is the EQS expressed as an annual average value (AA-EQS). Unless otherwise specified, it applies to the total concentration of all isomers.

(3) Inland surface waters encompass rivers and lakes and related artificial or heavily modified water bodies.

(4) This parameter is the EQS expressed as a maximum allowable concentration (MAC-EQS). Where the MAC-EQS are marked as "not applicable", the AA-EQS values are considered protective against short-term pollution peaks in continuous discharges since they are significantly lower than the values derived on the basis of acute toxicity.

(5) For the group of priority substances covered by brominated diphenylethers (No 5), the EQS refers to the sum of the concentrations of congener numbers 28, 47, 99, 100, 153 and 154.

(6) For Cadmium and its compounds (No 6) the EQS values vary depending on the hardness of the water as specified in five class categories (Class 1: < 40 mg $CaCO_3$/l, Class 2: 40 to < 50 mg $CaCO_3$/l, Class 3: 50 to < 100 mg $CaCO_3$/l, Class 4: 100 to < 200 mg $CaCO_3$/l and Class 5: ≥ 200 mg $CaCO_3$/l).

(7) This substance is not a priority substance but one of the other pollutants for which the EQS are identical to those laid down in the legislation that applied prior to 13 January 2009.

(8) No indicative parameter is provided for this group of substances. The indicative parameter(s) must be defined through the analytical method.

(9) DDT total comprises the sum of the isomers 1,1,1-trichloro-2,2 bis (p-chlorophenyl) ethane (CAS number 50-29-3; EU number 200-024-3); 1,1,1-trichloro-2 (o-chlorophenyl)-2-(p-chlorophenyl) ethane (CAS number 789-02-6; EU Number 212-332-5); 1,1-dichloro-2,2 bis (p-chlorophenyl) ethylene (CAS number 72-55-9; EU Number 200-784-6); and 1,1-dichloro-2,2 bis (p-chloro-phenyl) ethane (CAS number 72-54-8; EU Number 200-783-0).

(10) There is insufficient information available to set a MAC-EQS for these substances.

(11) For the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo(a)pyrene, on the toxicity of which they are based. Benzo(a)pyrene can be considered as a marker for the other PAHs, hence only benzo(a)pyrene needs to be monitored for comparison with the biota EQS or the corresponding AA-EQS in water.

(12) Unless otherwise indicated, the biota EQS relate to fish. An alternative biota taxon, or another matrix, may be monitored instead, as long as the EQS applied provides an equivalent level of protection. For substances numbered 15 (Fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs. For the purpose of assessing chemical status, monitoring of Fluoranthene and PAHs in fish is not appropriate. For substance number 37 (Dioxins and dioxin-like compounds), the biota EQS relates to fish, crustaceans and molluscs, in line with section 5.3 of the Annex to Commission Regulation (EU) No 1259/2011 of 2 December 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for dioxins, dioxin-like PCBs and non-dioxin-like PCBs in foodstuffs (OJ L 320, 3.12.2011, p. 18).

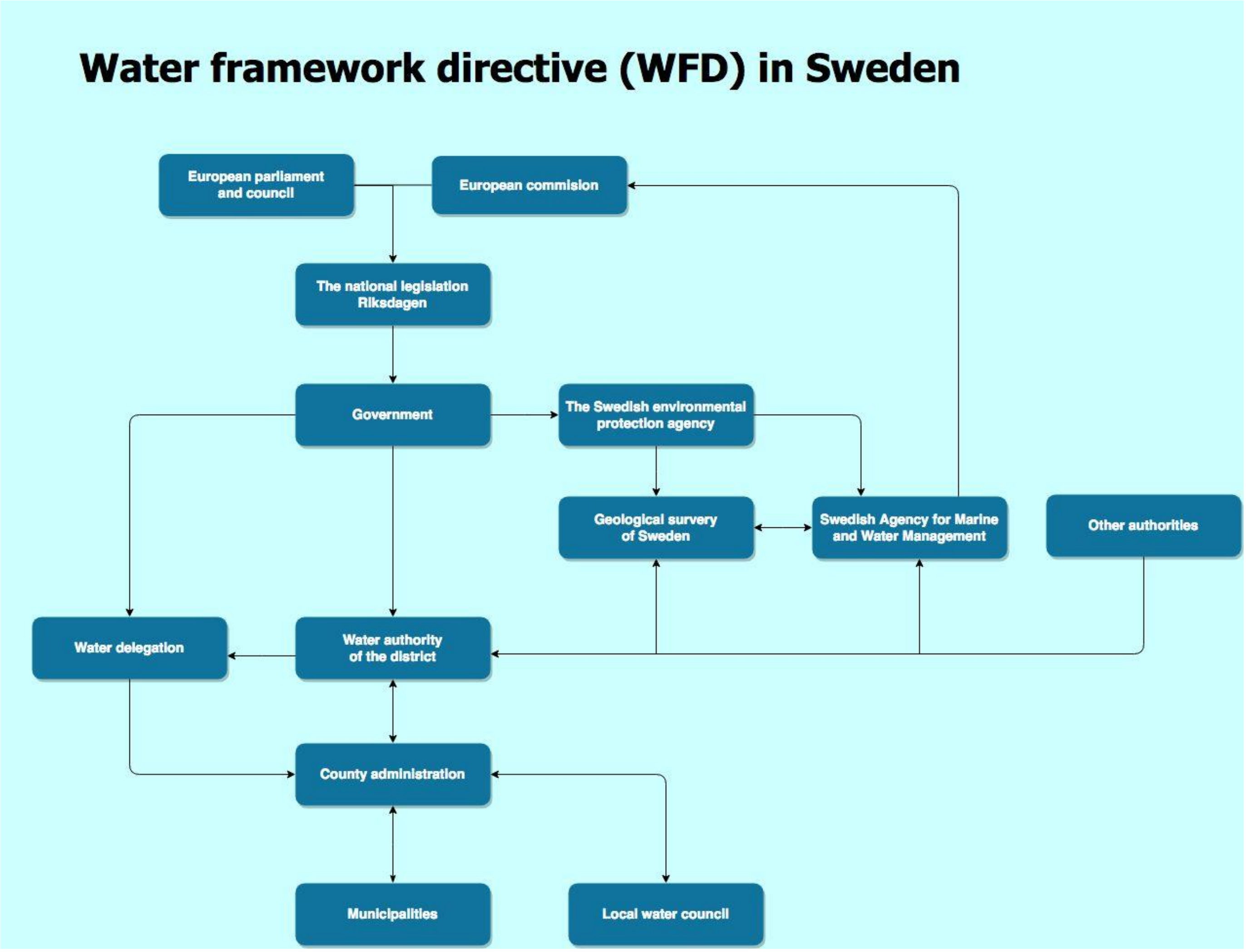
(13) These EQS refer to bioavailable concentrations of the substances.

(14) PCDD: polychlorinated dibenzo-p-dioxins; PCDF: polychlorinated dibenzofurans; PCB-DL: dioxin-like polychlorinated biphenyls; TEQ: toxic equivalents according to the World Health Organization 2005 Toxic Equivalence Factors.'

C. 14 ELEMENTS WHICH ARE USED TO DETERMINE THE STATUS OF A WATER BODY ACCORDING TO WFD

Elements	Lakes	Streams	Coastal water
Biological			
Benthnic	X	X	X
Macroalgae			X
Diatom	X		
Macrophytes	X	X	
Phytoplankton	X		X
Fish	X	X	
General chemical and physiochemical			
Nutrients	X	X	X
Light conditions	X		X
Oxygen conditions	X		
Acidification	X	X	
Synthetical substances	X	X	X
Hydromorphological			
Connectivity	X	X	X
Hydrological conditions	X	X	
Morphological conditons	X	X	X

D. Flow scheme of how the stormwater legislation is connected between EU and local Swedish county administrations.



E. THE 16 SWEDISH NATIONAL ENVIRONMENT OBJECTIVES DECIDED BY THE GOVERNMENT TO SERVE AS GUIDELINES FOR ENVIRONMENTAL ACTIONS.

F. STORMWATER OUTLET CONCENTRATIONS INTO A WATER BODY SET BY ENVIRONMENTAL AGENCY OF THE CITY OF GOTHENBURG.

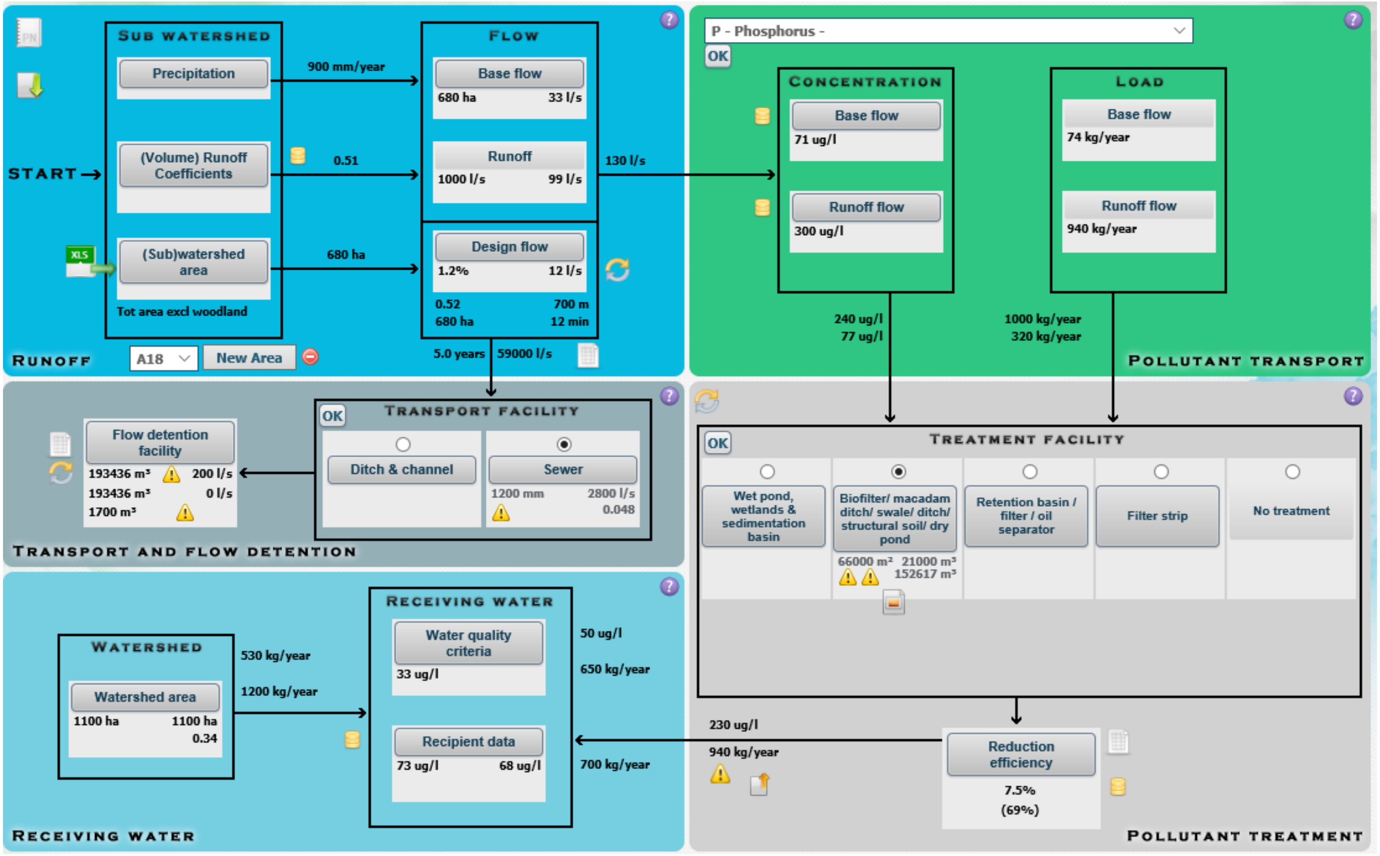
Riktvärden

Riktlinjerna styr hur riktvärdena ska tillämpas.

Ämne/parameter	Riktvärden i utsläppspunkt
Arsenik (As)	**15 µg/l**
Krom (Cr)	**15 µg/l**
Kadmium (Cd)	**0,4 µg/l**
Bly (Pb)	**14 µg/l**
Koppar (Cu)	**10 µg/l**
Zink (Zn)	**30 µg/l**
Nickel (Ni)	**40 µg/l**
Kvicksilver (Hg)	**0,05 µg/l**
PCB	**0,014 µg/l**
TBT	**0,001 µg/l**
Oljeindex	**1000 µg/l**
Bens(a)pyren	**0,05 µg/l**
MTBE	**500 µg/l**
Bensen	**10 µg/l**
pH	**6-9**
Totalfosfor	**50 µg/l**
Totalkväve	**1250 µg/l**
TOC	**12 mg/l**
Suspenderat material	**25 mg/l**
Partiklar	Krav på minst 90 % avskiljning av partiklar > 0,1 mm om partiklarna kommer från tvätt-processer utomhus eller motsvarande
Flöde	I utsläppspunkt i recipient får utsläppsmängden, som momentanvärde, vara högst 1/10 av recipientens momentanflöde

I första hand ska totalhaltsanalyser användas. Som regel ska metallerna bestämmas enligt SS 02 81 50. Motivering till respektive värde finns i bilaga 1.

G. THE LAYOUT OF SIMULATION SOFTWARE STORMTAC, WITH ITS FIVE SUB-MODELS FOR CALCULATION OF STORMWATER AND RECEIVING WATER QUALITY PARAMETERS. THE SECOND FIGURE SHOWS STANDARD CONCENTRATIONS OF THE DIFFERENT POLLUTANTS FOR DIFFERENT LAND USES, TOGETHER WITH THE RUNOFF COEFFICIENT.



H. STANDARD CONCENTRATIONS OF THE DIFFERENT POLLUTANTS FOR DIFFERENT LAND USES, TOGETHER WITH THE RUNOFF COEFFICIENT (FROM STORMTAC).

Schablonhalter, StormTac, version 2008-04 http://www.stormtac.com/

Standardvärden

Markanvändning	Avr. Koeff.	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	olja	PAH	BaP	COD	Fe	BOD	TOC	Arsenik	DOC
Urban	-	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l
Vägar (5 000 fordon/dygn)	0.85	0.14	1.65	13.5	31	62	0.24	1.0	1.15	0.1	79	0.2	0.672	0.007	25	1.4	5	21	2.4	21
Vägar (10 000 fordon/dygn)	0.85	0.18	1.8	17	51	89	0.28	1.8	1.8	0.1	89	0.3	1.064	0.014	50	3	10	25	2.4	21
Vägar (30 000 fordon/dygn)	0.85	0.24	2.4	31	72	197	0.44	5.0	4.4	0.1	115	1.0	1.504	0.042	100	5	15	30	2.4	21
Vägar (100 000 fordon/dygn)	0.85	0.31	4.5	80	94	575	1	16.2	13.5	0.1	206	3.4	1.985	0.14	225	8	25	47	2.4	21
Parkeringar	0.85	0.1	1.1	30	40	140	0.45	15	4	0.1	140	0.8	1.7	0.06	150	6	1.7	20	2.4	14
Villor	0.25	0.2	1.4	10	20	80	0.5	4	6	0.2	45	0.4	0.6	0.1	65	1.7	9	10	3	7
Radhus	0.32	0.25	1.45	12	25	85	0.6	6	7	0.2	45	0.6	0.6	0.1	75	3	9	12	3	8
Flerfamiljshus	0.45	0.3	1.6	15	30	100	0.7	12	9	0.2	70	0.7	0.6	0.1	85	5.6	9	20	3	14
Fritidshus	0.2	0.2	3.3	5	20	80	0.5	2	5	0.1	50	0.1	0.3	0.05	50	1.7	9	5	3	4
Koloniområden	0.2	0.15	5	5	15	50	0.2	0.2	1	0	38	0	0	0	50	1.7	9	5	3	4
Centrum	0.7	0.28	1.85	20	22	140	1	5	8.5	0.1	100	1.5	0.6	0.1	60	1.6	11	24	2.4	17
Industrier	0.5	0.3	1.8	30	45	270	1.5	14	16	0.1	100	2.5	1	0.15	80	8	9	24	4	17
Park	0.18	0.12	1.2	6	15	25	0.3	3	2	0	49	0.2	0	0	42	1.7	5.4	8	4	6
Atmosfärisk deposition	-	0.03	2.4	3	5	30	0.11	0.17	0.4	0	0	0	1.9	0.01	19	0.05	2.5	4	0.0003	3
Rural																				
Skogar	0.05	0.04	0.75	6	6.5	15	0.2	0.5	0.5	0	34	0	0	0	42	0.8	5.4	11	4	2
Jordbruksmarker	0.11	0.15	5.3	9	14	20	0.1	1	0.5	0	190	0	0	0	42	0.8	10	13	4	9
Gräs- och ängsmarker	0.075	0.2	2	6	15	30	0.3	2	0.5	0	80	0.2	0	0	42	0.8	5.4	9	4	6
Våtmarker	0.2	0.05	0.9	6	7.5	12.5	0.15	0.15	0.5	0	16	0	0	0	42	0.8	7.5	11	4	8
Övrigt																				
Golfbanor	0.18	0.35	2.1	5	15	18	0.3	0.7	2	0	55	0	0	0	42	1.7	16	4	4	8
Fygplatser	0.85	**0.11**	**5.0**	**10**	15	50	0.3	3.0	3	0.1	130	**0.5**	1.7	0.05	**30**	6	1.7	83	2.4	58
Banvall (järnväg)	0.50	0.05	1.0	26.13	48.8	168.8	0.3	2.2	1.6	13	55.5	0.6	2.0	0.05	42	0.8	5.4	10	4	10
Hygge	0.20	0.05	2.00	6	6.5	15	0.2	0.5	0.5	0	40	0	0	0	42	0.8	5.4	11	4	8

blå fet stil: uppdaterad data.

Minvärden

Markanvändning	Avr. Koeff.	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	olja	PAH	BaP	COD	Fe	BOD	TOC	Arsenik	DOC
Urban	-	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l
Vägar (5 000 fordon/dygn)	0.7	0.14	1.65	13.5	31.24	62	0.24	1.0	1.2	0.1	78.7	0.17	0.7	0.007	25	1.4	5	21	2.4	21
Parkeringar	0.7	0.07	0.6	11	25	50	0.2	3	1	0.1	40	0.5	0.4	0.04	100	6	1.7	20	2.4	14
Villor	0.2	0.1	1	2	12	50	0.3	1	2	0.1	20	0.1	0.5	0.03	40	1.7	9	10	3	7
Radhus	0.3	0.1	1	6	12	60	0.3	1	5	0.1	20	0.15	0.5	0.03	40	3	7	12	3	8
Flerfamiljshus	0.35	0.2	1	8	12	73	0.3	5	5	0.1	40	0.2	0.5	0.03	60	5.6	9	20	3	14
Fritidshus	0.05	0.13	1.7	2	5	40	0.15	0.5	2	0.1	20	0.1	0.25	0.015	50	1.7	9	5	3	4
Koloniområden	0.1	0.03	1.7	2	5	10	0.03	0.1	0.4	0	15	0	0	0	50	1.7	9	5	3	4
Centrum	0.4	0.2	1.2	10	17	60	0.5	4	5	0.1	42	0.3	0.5	0.03	57	1.6	5	24	2.4	17
Industrier	0.5	0.28	1.4	20	20	130	0.5	3	5	0.1	50	0.5	0.55	0.04	40	8	8	24	4	17
Park	0	0.09	0.7	1	5	10	0.1	0.4	0.08	0	10	0	0	0	42	1.7	5.4	8	4	6
Atmosfärisk deposition	-	0.01	0.8	2	2.5	6	0.03	0.1	0.1	0	0	0	0.12	0.01	19	0.01	2.5	4	0.0001	3
Rural																				
Skogar	0.05	0.02	0.4	1	4	10	0.1	0.1	0.03	0	10	0	0	0	42	0.8	2.3	11	4	0.7
Jordbruksmarker	0.1	0.05	2.3	1	5	10	0.1	0.1	0.03	0	40	0	0	0	42	0.8	10	13	4	9
Gräs- och ängsmarker	0	0.08	0.7	1	10	15	0.1	0.1	0.03	0	40	0	0	0	42	0.8	5	9	4	6
Våtmarker	0.1	0.01	0.4	0.5	5	5	0.05	0.1	0.015	0	5	0	0	0	42	0.8	7.5	11	4	8
Övrigt																				
Golfbanor	0	0.1	1.3	1	5	10	0.1	0.4	0.08	0	10	0	0	0	42	1.7	5.4	8	4	8
Fygplatser	0.7	**0.02**	0.7	0.5	6.6	**30**	**0.1**	0.7	3	0.1	4.4	**0.1**	1.7	0.05	100	6	1.7	20	2.4	58
Banvall (järnväg)	0.1	0.05	1.0	26.13	48.8	168.8	0.3	2.2	1.6	13	55.5	0.6	2	0.05	42	0.8	5.4	10	4	10
Hygge	0.15	0.03	1.0	1	4	10	0.1	0.1	0.03	0	10	0	0	0	42	0.8	2.3	11	4	8

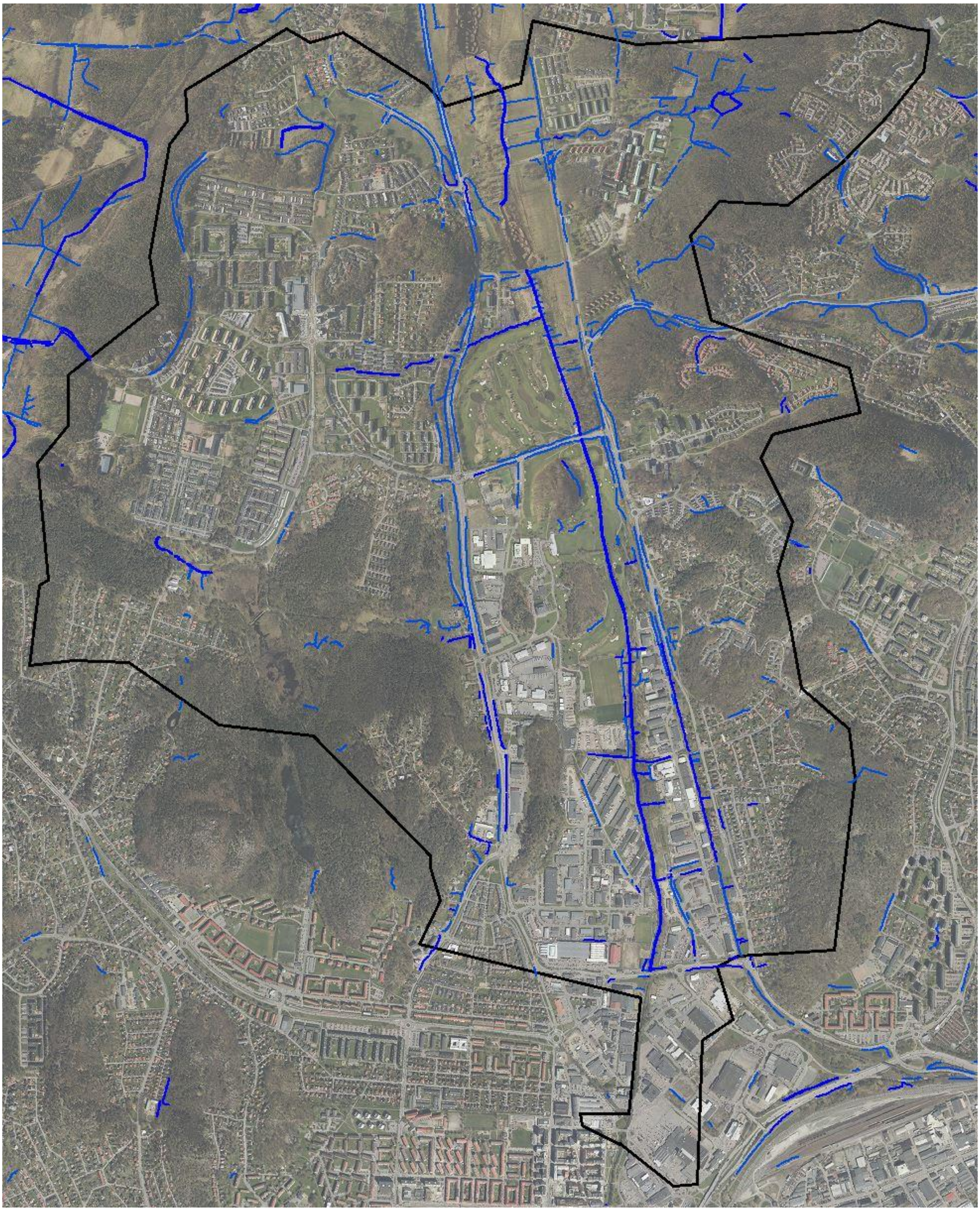
blå fet stil: uppdaterad data.

Maxvärden

Markanvändning	Avr. Koeff.	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	olja	PAH	BaP	COD	Fe	BOD	TOC	Arsenik	DOC
Urban	-	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l
Vägar (100 000 fordon/dygn)	1.0	0.31	4.5	80	94.5	575	1.0	16.2	13.5	0.1	206	3.4	2.0	0.14	225	8	25	47	2.4	21
Parkeringar	1.0	0.16	1.5	50	50	230	1	20	7	0.2	300	1.1	2.1	0.08	200	6	1.7	20	2.4	14
Villor	0.4	0.3	2	50	60	200	1	8	11	0.2	60	0.6	0.8	0.2	80	1.7	9	10	3	7
Radhus	0.5	0.4	2.2	55	80	200	1.2	10	20	0.3	60	0.8	0.8	0.2	120	3	56	12	3	8
Flerfamiljshus	0.6	0.4	2.2	75	315	350	1.5	20	20	0.4	150	1	0.8	0.2	120	5.6	56	20	3	14
Fritidshus	0.5	4	12	50	60	150	1	6	15	0.2	60	0.2	0.4	0.1	50	1.7	9	5	3	4
Koloniområden	0.5	0.4	10	50	30	100	0.2	1.2	3	0.1	80	0.15	0	0	50	1.7	9	5	3	4
Centrum	0.7	0.7	2.5	230	60	400	2	20	20	0.4	840	2	0.8	0.2	160	1.6	23	24	2.4	17
Industrier	0.8	0.6	2.7	300	130	600	3	20	30	0.5	400	4	3	0.3	120	8	12	24	4	17
Park	0.3	0.31	10	50	50	40	0.8	6	5	0.2	150	1.3	0	0	42	1.7	5.4	8	4	6
Atmosfärisk deposition	-	0.16	4.5	40	60	50	0.3	0.3	0.9	0	0	0	6.8	0.011	19	0.09	2.5	4	0.0006	3
Rural																				
Skogar	0.4	0.09	3	40	20	60	0.9	10	6	0.1	70	0	0	0	42	0.8	4	11	4	8
Jordbruksmarker	0.3	0.6	17	60	20	40	0.8	10	10	0.1	240	0	0	0	42	0.8	10	13	4	9
Gräs- och ängsmarker	0.3	0.7	10	40	30	40	0.8	10	5	0.1	340	1.3	0	0	42	0.8	19	9	4	6
Våtmarker	0.4	0.2	1.8	20	15	20	0.4	5	2.5	0.1	20	0	0	0	42	0.8	7.5	11	4	8
Övrigt																				
Golfbanor	0.3	0.9	3.9	50	50	40	0.8	6	5	0.2	240	0	0	0	42	1.7	5.4	8	4	5.6
Fygplatser	1.0	**0.45**	**26**	0.5	**30**	**70**	**2**	0.7	3	0.1	4.4	0.1	1.7	0.05	200	6	1.7	20	2.4	100
Banvall (järnväg)	0.8	0.05	1.0	26.13	48.8	168.8	0.3	2.2	1.6	13	55.5	0.6	2	0.05	42	0.8	11.5	10	4	7
Hygge	0.3	0.07	3.0	40	20	60	0.9	10	6	0.1	70	0	0	0	42	0.8	4	11	4	8

blå fet stil: uppdaterad data.

I. THE EXISTING SWALES AND STREAMS IN THE CATCHMENT AREA OF KVILLEBÄCKEN. THE DARK BLUE LINES REPRESENT STREAMS AND THE LIGHT BLUE LINES REPRESENTS SWALES (FROM ARCMAP)



J. REMOVAL EFFICIENCIES OF DIFFERENT STORMWATER TREATMENT TECHNIQUES FOR COMMON STORMWATER POLLUTANTS ACCORDING TO LITERATURE, TOGETHER WITH REQUIRED IMPERVIOUS AREA FOR IMPLEMENTATION.

	Removal efficiency, Nutrients [%]		Removal efficiency [%] Heavy metals						Removal efficiency, Solids [%]
	Total P	Total N	Zn Total (dissolved)	Cu Total (dissolved)	As Total (dissolved)	Cd Total (dissolved)	Cr Total (dissolved)	Ni Total (dissolved)	
Dry pond	20-45[1]	20-45[1]	58-62 (0-29) [2,3]	42-47 (0-37) [2,3]	19 (0) [3]	21 (-70) [3]	41 (14) [3]	41 (5) [3]	30-66[2,3,4]
Wet pond	50-61[1,3,5]	28-50[1,3,5,6]	60-71 (50-57) [2,3,5]	41-60 (25-36) [2,3,5]	38 (NA) [3]	53-62 (70) [3,5]	67 (15) [3]	51 (-26) [3]	46-98[2,3,4,5,6]
Sand filters	50-80[3,4,5]	23-32[3,4,5]	77 (76)[3]	47 (19)[3]	14 (-17)[3]	48 (10) [3]	Cr[3] 50 (0)	-	50-87[3,4,5]
Infiltration basin	50-80[4,5,6]	45-70[5,6]	Metals[4,5,6,7] Total 50-90 Dissolved 20-35						50-99[4,5,6,7]

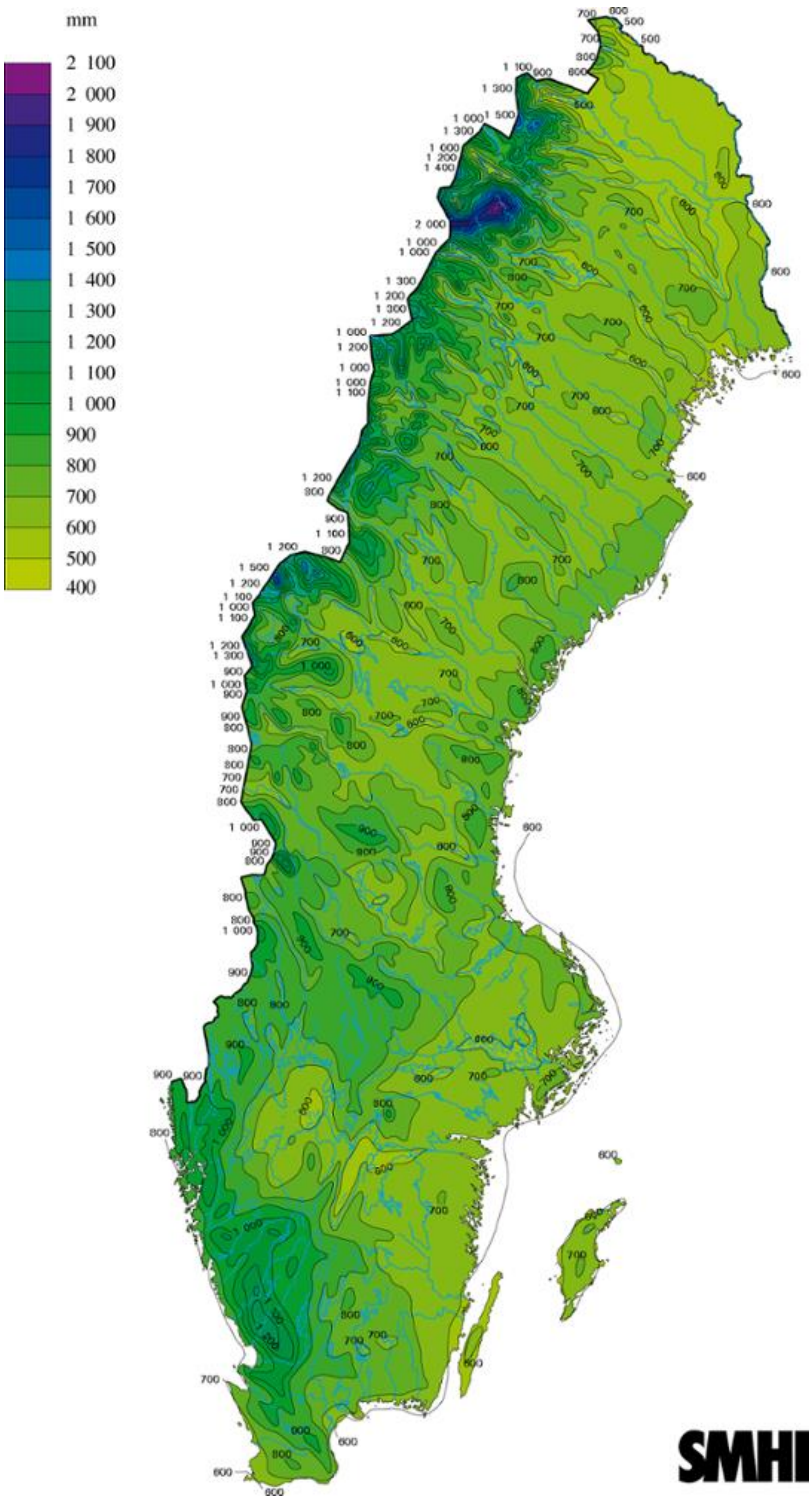
Infiltration Trenches	50-75[5,6]	40-70[5,6]	98 (91) [5]	97 (91) [5]	-	85 (49) [5]	-	-	50-99[4,5,6,7]
Filter strips	20-40[6]	16-40 [3,6]	76 (61) [3]	70 (54) [3]	10 (-5) [3]	65 (31) [3]	50 (21) [3]	46 (22) [3]	50-80[3,4,5]
Swales	20-85[6]	10-35[7]	37 (19) [3]	40 (27) [3]	30 (0) [3]	38 (43) [3]	49 (10) [3]	66 (59) [3]	30-90[3,4,6]
Green roofs	-456[3]	-	40 (79) [3]	-	305 (-265) [2]	22 (NA) [3]	-	-	72[3]
Rain gardens	48-50[3,6]	28-50[3,6]	75 (NA) [3]	55 (NA) [3]	-	-	-	-	75-78[3,6]
Pervious pavemen	30-65[1,3,4]	65-100[4,9]	66-74 (52-61) [3,9]	35-40 (-7-15) [3,9]	-	11-69 (33-60) [3,9]	-4 (-464) [3]	53 (51) [3]	64-100[1,3,4,9,12]
Constructed wetlands	25[6]	20[6]	Metals[4,6] 35-80						40-80[3,4,5,6]

1. (Novotny, Ahern, & Brown, 2010)
2. (Fassman, 2012)
3. (Leisenring, Clary, & Hobson, 2012)
4. (EPA, 1999)
5. (Jotte, Raspati, & Azrague, 2017)
6. (Corson, 2006)
7. (Revitt, Ellis, & Scholes, 2006)
8. (Erickson et al., 2013)
9. (Pagotto, Legret, & Cloirec, 2000)
10. (City of Eugene, 2014)
11. (Davis & McCuen, 2005)
12. (Legret, Colandini, & Le Marc, 1996)

K. A COMPILATION OF THE DIFFERENT TREATMENT TECHNIQUE AND THE TREATMENT PROCESSES THEY UTILIZE.

	Sedimentation	Filtration	Infiltration	Biological	Chemical	Evaporation
Dry pond	X	*	*	X		
Wet pond	X	X	*	X	X	X
Hydrodynamic separators	X					
Soakaways		X	X	X		
Sand filters		X	*	X	X	
Soil filters		X				
Chemical filters		X			X	
Infiltration basins		X	X	X	*	
Infiltration trenches		X	X	X	*	
Filter strips	X	X	*	X		
Filter drains		X		X		
Swales	X	X	*	X		X
Green roofs		X		X	X	X
Rain gardens	X	X	X	X	X	X
Pervious pavement	X	X	X	X		
Constructed wetlands	X	X	*	X	X	X

L. THE MEAN PRECIPITATION IN SWEDEN FOR 1961-1990 [MM].



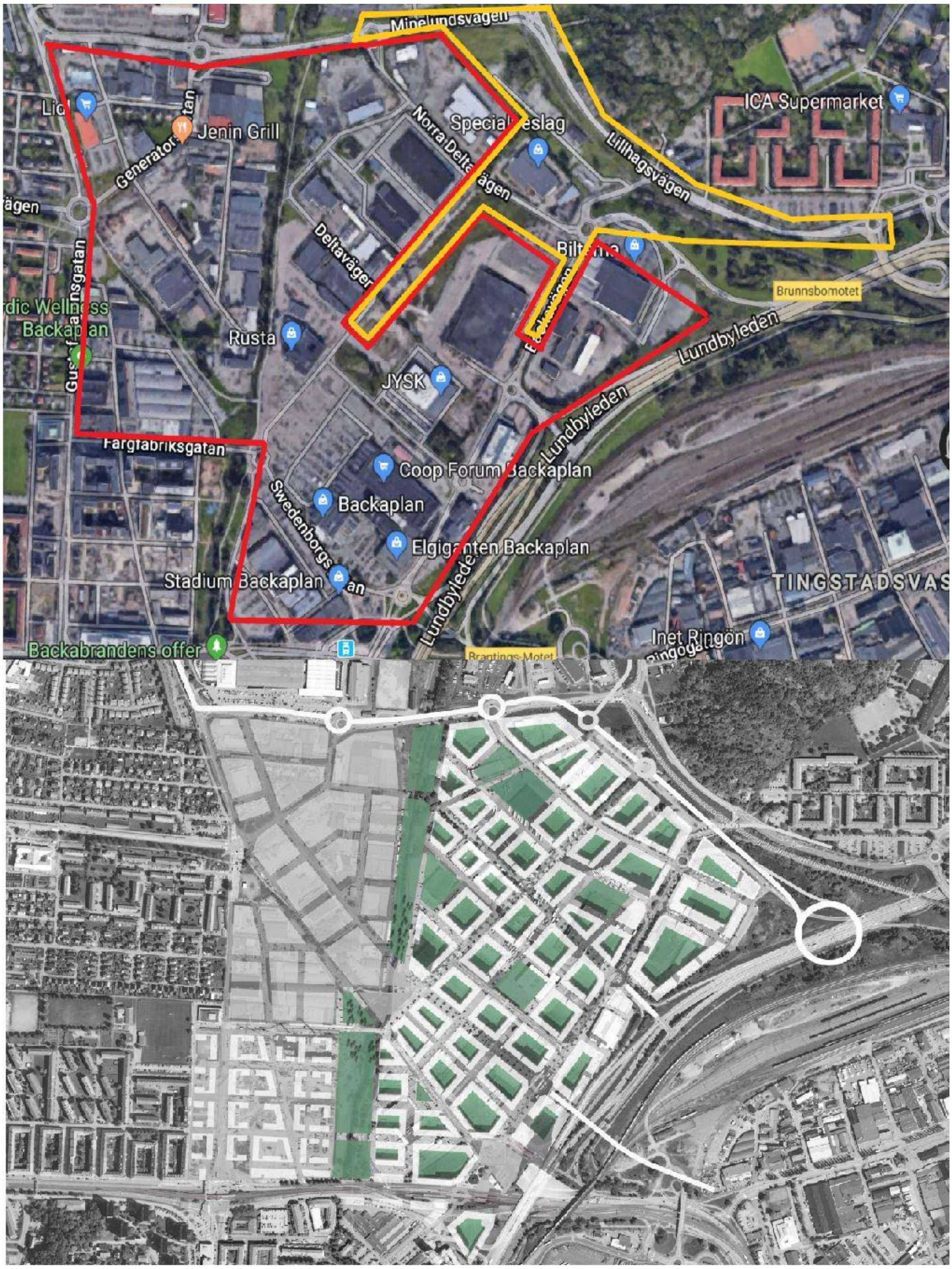
M. GLOBAL CLIMATE MODELS USED TO ANALYZE RCP-SCENARIOS FOR CLIMATE.

De globala klimatmodeller som ingår i ensembleanalysen för RCP-scenarierna

Drivande GCM	Institut, Land	Referenser	Europa + Sverige			Världen + Afrika		Sydvästra Asien + Syd-amerika		Arktis	
			RCP 2,6	**RCP 4,5**	**RCP 8,5**	**RCP 4,5**	**RCP 8,5**	**RCP 4,5**	**RCP 8,5**	**RCP 4,5**	**RCP 8,5**
CanESM2	CCCMA, Kanada	Chylek et al., 2011		X	X	X	X	X	X	X	X
CNRM-CM5	CNRM-CERFACS, Frankrike	Voldoire et al., 2012		X	X	X	X	X	X		
EC-EARTH	EC-EARTH, EU	Hazeleger et al., 2010	X	X	X	X	X	X	X	X	X
IPSL-CM5A-MR	IPSL, Frankrike	Dufresne et al., 2013		X	X	X	X	X	X		
MIROC5	MIROC, Japan	Watanabe et al., 2011		X	X	X	X	X	X		
HadGEM2-ES	Hadley Centre, UK	Collins et al., 2011	X	X	X	X	X	X	X		
MPI-ESM-LR	MPI-M, Tyskland	Popke et al., 2013	X	X	X	X	X	X	X	X	X
NorESM1-M	NCC, Norge	Bentsen et al., 2013		X	X	X	X	X	X	X	X
GFDL-ESM2M	NOAA GFDL, USA	Dunne et al., 2012		X	X	X	X	X	X		
CSIRO-Mk3-6-0	CSIRO, Australien	Gordon et al., 2010						X	X		

N. MAPS OF KVILLEBÄCKEN

Backaplan

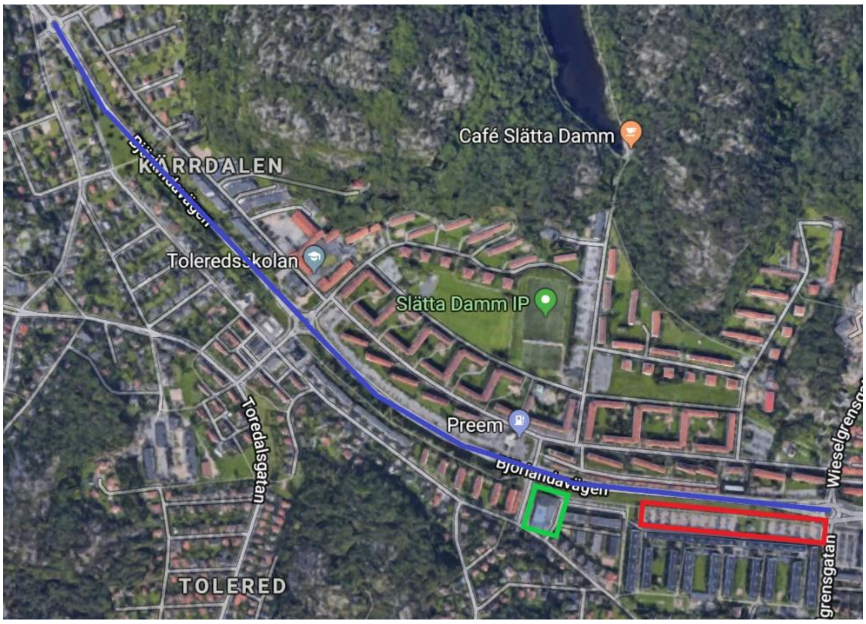


The upper figure shows the Backaplan today divided into areas where projects are planned. In the yellow area, new roads and a junction is planned. The red area is a planned shopping mall, and residence area (Google, 2019). *The lower figure shows the planned buildings in the area* (Stadsbyggnadskontoret et al., 2015).

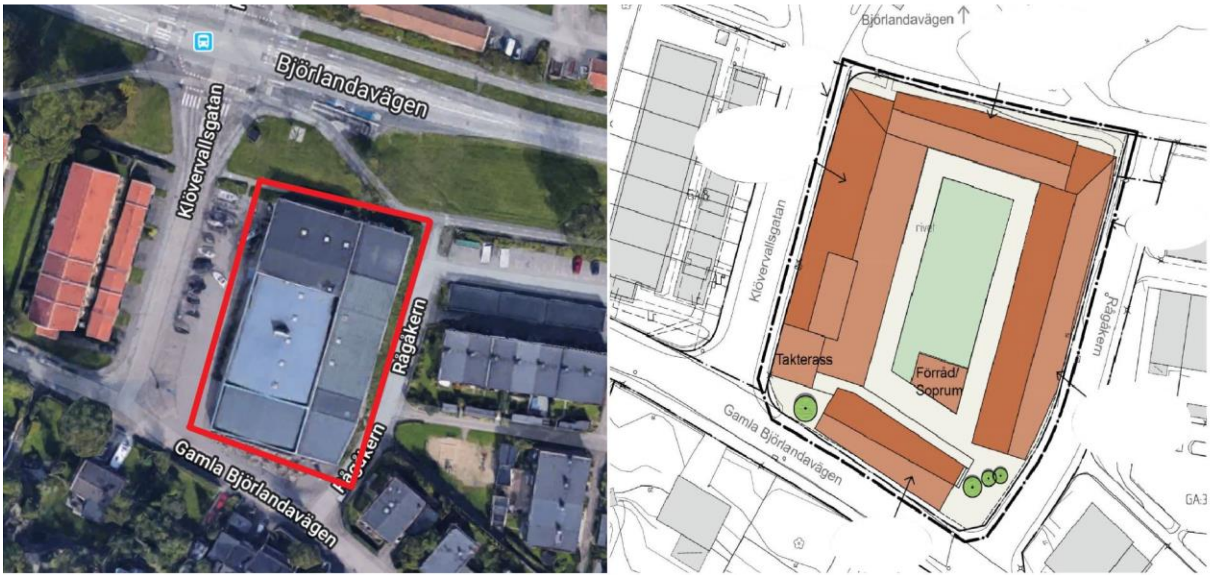
Rambergsstaden

Before and after exploitation of Rambergsvallen. The left figure shows before exploitation with a green area and a football field (Google, 2019)*. The right figure shows after exploitation with four apartment blocks, each with a green courtyard* (Göteborgs Stad, 2014)*.*

Tolered



Location of the planned residence at Klövervallsgatan (green square), the residences at Fyrklövergatan (red square) and the bicycle road and pathway (blue line) (Google, 2019)*.*



The current property at Klöverfallsgatan is seen in the left figure (Google, 2019)*, and the planned property is seen in the right* (Stadsbyggnadskontoret Göteborgs Stad, 2017)*.*

Fyrklövergatan before and after planned exploitation (Google, 2019)*,* (Göteborgs stad, 2016)*. Parking lot converted to properties with green areas.*

Illustration of the bicycle path and walkway planned along Björlandavägen, divided in stage 1 and stage 2 (SDN Lundby, 2019).

Skogome

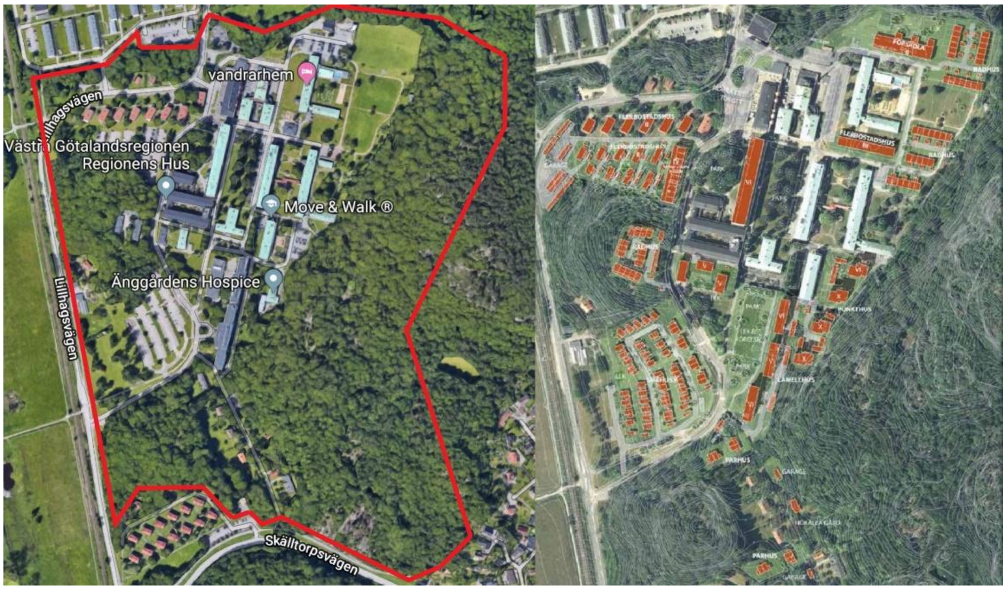
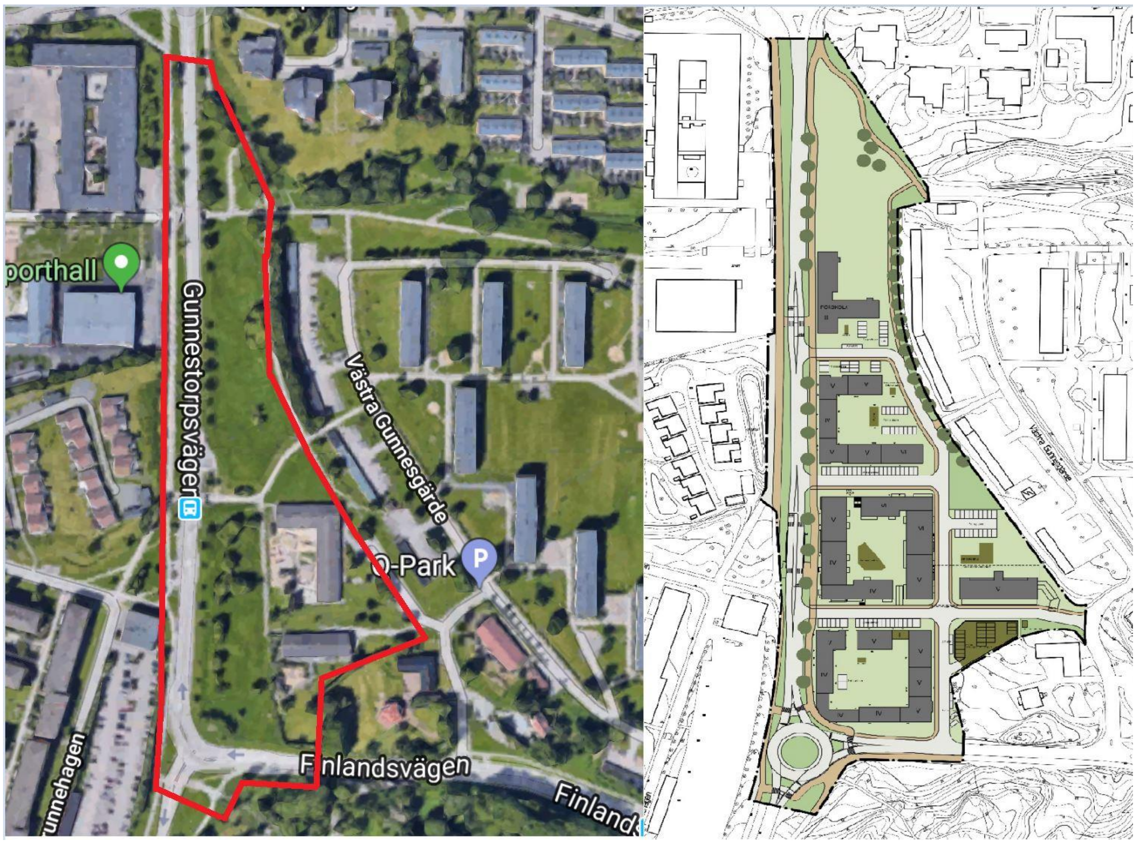


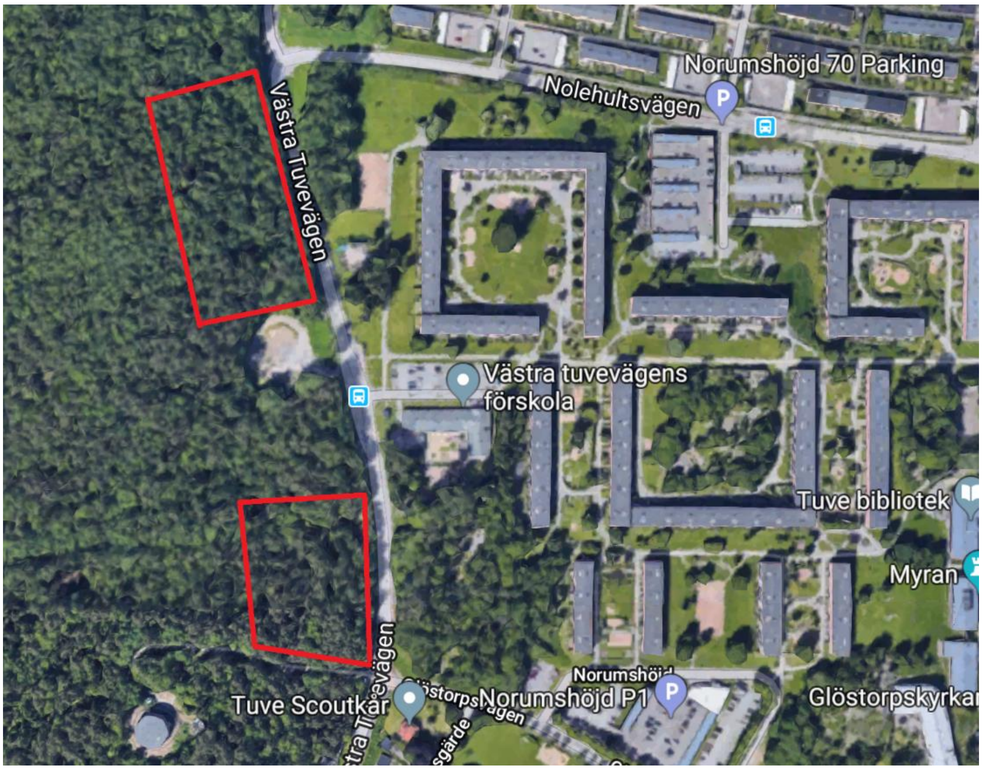
Illustration of Lillhagsparken today (left) (Google, 2019) *and the planned exploitation (right)* (Göteborg Stad, 2013). *The red line represents the zoning plan, but exploitation will not occur in the whole zone. The orange buildings in the planned exploitation represents the new buildings.*

Tuve

Location of the planned exploitation in Gunnetorpsvägen (yellow) and Glötorpsvägen/Västra Tuvevägen (red) (Google, 2019).



Before (left figure) (Google Maps) and after (right figure) exploitation at Gunnestorpsvägen (Stadsbyggnadskontoret Göteborgs Stad, 2016).



The planned areas of exploitation in Tuve marked in red (Google, 2019).

O. REMOVAL EFFICIENCIES (ACTUAL AND FROM STORMTAC) FOR CALCULATION OF IRREDUCIBLE CONCENTRATION

Pollutants	**Actual removal efficiency [%]**	**Removal efficiency from Stormtac [%]**	**Irreducible concentration [%]**
P	81	81	0
Zn	98	95	3
Cu	95	95	0
BaP	97	93	4