CHALMERS
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# Mapping, Evaluation and Improvements of Simple Stormwater Measures

## A Case Study in Gothenburg

Master’s Thesis in the Master’s Programme of Infrastructure and Environmental Engineering

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Master’s Thesis ACEX30-18-29
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Examensarbete ACEX30-18-29/ Institutionen för arkitektur och samhällsbyggnadsteknik,
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Cover:
Example of existing grass ditch along road in an industrial area in Gothenburg (photograph by authors).

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ABSTRACT

Stormwater management is of importance since urban drainage may cause flooding and transport pollutants from for example roads to receiving waters. There is a lack of mapping of existing, simple traffic-related stormwater drainage measures, which provide pollutant treatment of stormwater. This thesis investigated the drainage to and pollution treatment efficiency of existing measures in selected sub-catchments in Gothenburg. Included measure were grass ditches, swales and filter strips. The possibility to improve these measures regarding treatment efficiency and drainage capacity, and implementing new simple measures were studied. The project included a literature study, data collection, a field study, and stormwater quality modelling in StormTac. The results showed that simple traffic-related stormwater measures existed in two of five studied sub-catchments. Areas closer to the city centre did not contain any simple measures while several simple measures were mapped in areas further from the city centre and mainly in the land-uses "open land", "industrial area", and "nature". The percentage of traffic surface drained to these measures varied largely between the studied sub-catchments. The result from the field study suggests relatively limited potential for implementing improvements and new simple measures in the studied sub-catchments. Performed simulations suggested that the existing measures reduce the traffic-related pollutants to a noticeable degree in the areas where measures were mapped. However, the implementation of improvements of these measures and new simple measures showed low potential for large reductions of traffic-related pollutions from the sub-catchments to the receiving waters. Considering the low potential to implement improvements, it is important to include better stormwater management in the planning process of new areas.

Key words: Gothenburg, pollutant reduction, quality modelling, road runoff, simple stormwater management, stormwater

Kartering, Utvärdering och Förbättringar av Enkla Dagvattenåtgärder

En Fallstudie i Göteborg

*Examensarbete inom mastersprogrammet infrastruktur och miljöteknik*

JESPER ERIKSSON

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Institutionen för Arkitektur och samhällsbyggnadsteknik

Avdelningen för Vatten miljö teknik

Chalmers tekniska högskola

## SAMMANFATTNING

Dagvattenhantering är av stor vikt eftersom avrinning i städer kan orsaka översvämningar och föroreningar transporteras från till exempel vägar ut till recipienter. Det saknas kartläggning av befintliga, enkla dagvattenåtgärder som reducerar föroreningar i trafikrelaterat dagvatten. Detta examensarbete undersöker avrinningen till och föroreningsreduktionen i dessa dagvattenåtgärder i valda studerade avrinningsområden i Göteborg. Även möjligheten att förbättra föroreningsreduktionen och öka tillrinningen till åtgärderna undersöktes. Projektet innehöll en litteraturstudie, insamling av data, en fältstudie och modellering av dagvattenkvalité i StormTac. Resultatet visade att enkla dagvattenåtgärder återfanns i två av de fem studerade avrinningsområdena. Områden närmre stadskärnan innehöll inte några befintliga åtgärder, medans flertalet åtgärder hittades i områden längre från centrum, främst inom markanvändningarna ”öppen mark”, ”industriområde” och ”natur”. Andelen av trafikytan som avvattnades till enkla dagvattenåtgärder varierade markant mellan de studerade avrinningsområdena. Resultatet från fältstudien antydde en relativt begränsad potential till förbättringar och implementering av nya enkla dagvattenåtgärder i de studerade områdena. De utförda simuleringarna visade att de befintliga dagvattenåtgärdernas föroreningsreduktion var märkbar i de avrinningsområden där befintliga åtgärder återfanns. Däremot var potentialen för minskade trafikrelaterade föroreningsmängder genom förbättringar och implementering av nya enkla dagvattenåtgärder begränsad. Detta antyder att det är av betydelse att hållbar dagvattenhantering blir en del av processen när nya områden planeras.

Nyckelord: Dagvatten, enkel dagvattenhantering, föroreningsmodellering, föroreningsreduktion, Göteborg, vägdagvatten

# Contents

# Preface

This was a Master's Thesis written in the Department of Architecture and Civil Engineering and the Division of Water Environment Technology, at Chalmers University of Technology in Gothenburg. The project was initiated by a collaboration between Kretslopp och Vatten (Sustainable Waste and Water) and Miljöbron. The thesis covered 30 credits and was performed during the spring of 2018.

We would like to express gratitude to our examiner Mia Bondelind and our supervisor at Chalmers, Karin Björklund, for the great support and guidance throughout the project. Also, we would like to acknowledge our supervisors at Kretslopp och Vatten, Helen Galfi and Jenny Lindh, for the inputs and share of knowledge. We are thankful to everyone at Kretslopp och Vatten that have helped us get access to the needed software, vehicle for the field study and answered to our questions that have occurred during this project. Especially, we want to thank the GIS engineer Johan who have been very supporting with the collection of the needed data. You have all been important to make this project possible.

Gothenburg June 2018

Jesper Eriksson and Theo Wilkås

# 1 Introduction

Water is an essential resource for society, contributing to economic and social wealth, and is the core of natural ecosystems (European Commission, 2018). Europe's water resources are under large stains from changed water cycles and increased pollutant loads from human activity. Runoff from urban areas effects receiving waters through discharge of contaminated stormwater, increased erosion and risk of flooding (Butler & Davies, 2010). In urban areas, surface runoff is increased and infiltration into the ground is decreased due to impervious areas such as roads and roofs. Since traffic occupies large spaces in the urban area, the traffic-related stormwater is of importance (Gunawardena, Liu, Egodawatta, Ayoko, & Goonetilleke, 2018). Traffic is also a main contributor to contamination of urban surfaces; this contamination is transported to receiving waters with stormwater.

The City of Gothenburg has the vision to be "The best city in the world when it's raining" (City of Gothenburg, 2017). Knowledge and examples on sustainable and creative stormwater management should be implemented, showing that the city is going in the right direction at the time of the 400 years jubilee in 2021.

The municipality of Gothenburg experience a lack of mapping of existing traffic-related stormwater drainage measures, such as swales, grass ditches, and filter strips. These measures provide pollutant treatment, reduce peak flows and the total volume of stormwater runoff. This leads to reduction of the impact of contamination on receiving waters by less discharge of contaminated stormwater and less combined sewer overflows. In addition, already existing drainage and storage measures could potentially store, drain, and treat the stormwater more efficient by the implementation of low cost improvements.

## 1.1 Aim and objectives

The aim of this project was to obtain knowledge about simple traffic-related stormwater treatment, drainage, and storage measures – for example swales, grass ditches and filter strips – and how these affect the quality of the discharged stormwater through pollution treatment efficiency of stormwater. The thesis investigated the pollution treatment efficiency in and drainage to existing measures in Gothenburg and the possibility to improve these regarding treatment efficiency and drained traffic surfaces. In addition to the improvements of existing measures, the possibility of implementing new simple measures were investigated. The study also compared the total discharge of pollutants from traffic-related stormwater before and after the improvements and implementation of new measures.

The project aimed at answering the following research questions:

1. What drainage and treatment measures exist today? How much of the traffic-related surface are drained to these measures?
2. How can the total treatment and drainage of these measures be improved by small adjustments and implementation of new simple measures?
3. How much of the annual load of pollutants from traffic surfaces is reduced in existing simple measures?
4. If improvements of these measures or new measures are implemented, how much is the annual load of pollutants from traffic surfaces reduced?

## 1.2 Limitations

The focus in this thesis was on simple stormwater measures. These were defined in this study as elements in the urban traffic environment that were primarily constructed to convey stormwater, not to delay, store or provide treatment. The specific measures included in this study were grass ditches, swales and filter strips.

The included improvements were limited to smaller adjustments with low investment costs and which do not significantly increase the need for maintenance. Included improvements were removing curb stones, covering or throttling storm drains, and lowering grass surfaces through excavating.

This project included roads and traffic-related areas managed by the municipality within the urban area of Gothenburg. Consequently, smaller private roads and larger national road were excluded from this study. This limitation was done since it is the municipal roads that are of interest for future possible improvements. Private roads are managed by the private sector and national roads are manage by the Swedish Traffic Administration.

Estimations of quality of stormwater discharge and treatment was performed with the stormwater and recipient model StormTac. This model uses standard values of water quality parameter for different types of land-uses and treatment efficiencies for different treatment facilities. No field water samples for quality of the stormwater were collected.

# 2 Theoretical background

In order to gain knowledge about traffic-related stormwater, a literature study was conducted. The study included information about stormwater management in general, contaminants in traffic-related stormwater, stormwater measures, possible improvements of the measures, and modelling of stormwater.

## 2.1 Urban drainage

The need of the urban drainage system is caused by the alteration of the natural water cycle by human activities, both wastewater and stormwater (Butler & Davies, 2010). Wastewater is defined as water processed and used for domestic and industrial purposes and stormwater is defined as water that origins in precipitation that falls on impervious areas (Svenskt Vatten, 2016).

The conventional method of draining the stormwater from urbanized areas has been through underground pipe networks, optimized to prevent local flooding by conveying water from the area as fast as possible (Woods-Ballard et al., 2007). These systems have not been designed with sustainability in mind and has led to for example risk of flooding and insufficient water quality. In recent years, the focus on sustainably within stormwater management has increased and new developments should consider implementing local disposal, delay and treatment of the stormwater in for example open stormwater systems and facilities (Svenskt Vatten, 2011).

### 2.1.1 Urban pipe drainage systems

Most of the urban drainage systems in Sweden consist of separated sewer systems. However, the combined system can still be found in some older urban districts (Svenskt Vatten, 2016). The combined system was built in Sweden from the late $19^{th}$ century until around 1940-1950. As the name suggest, both wastewater and stormwater are conveyed in the same conduit in the combined system. Since it is not economically possible to convey and treat all collected sewer and stormwater during heavy rains, the systems are not designed with the capacity for more extreme rain events that only occurs every 10, 20 or 30 years. When the capacity of the combined system is reached during heavy rains, the pipe network may be relieved by a combined sewer overflow (CSO), which is a structure that release some of the water into a nearby water course. These structures prevent the water in the combined sewer system from flooding in more inconvenient locations in the system (Butler & Davies, 2010). The CSOs can result in high concentrations of contaminants being released to the recipients, even though the wastewater is diluted with a large proportion of stormwater (Bengtsson Sjörs, 2014). However, these CSOs caused by hydraulic overload should not be confused with emergency outflow caused by for example operation error or power failure in pump stations, which also can also occur in separated sewer systems (Svenskt Vatten, 2016).

The separated sewer system is the standard for new development in Sweden (Svenskt Vatten, 2016). The principle applied is that the wastewater and the stormwater are separated in different pipes, most often placed next to each other in the same trench (Butler & Davies, 2010). One advantage with the separated system is that CSOs are avoided. Another advantage is that the "polluted" wastewater and "cleaner" stormwater is not mixed, which allow the stormwater to be discharged to a nearby water course while the wastewater can be conveyed to the wastewater treatment plant in smaller pipes. A disadvantage with the separated system is the increased investment cost for two pipe systems and that the discharged stormwater to the recipients usually is polluted to some degree. The stormwater can be polluted both by surface pollutants from the catchment and from wastewater incorrectly connected to the stormwater network.

Urban pipe drainage systems can also be a hybrid between the two systems (Svenskt Vatten, 2016). These combinations can exist for example in areas which are in a transition phase between an old combined system being transformed into a separated system.

### 2.1.2 Stormwater

During urbanisation, more surfaces becomes impervious (Butler & Davies, 2010). This causes less precipitation to drain through infiltration. This consequently increases the runoff (Figure 2.1). Runoff water need to be managed in order to not create damages or other inconveniences. This is usually solved by leading the water through pipes to a nearby waterbody, the receiving water. Surface runoff generally transport the water much faster to the receiving water compared to groundwater flow. Consequently, the change of waterflow from infiltration to surface runoff can have large effects on the flow variation in the receiving waters. In addition, the anthropological influence on the water cycle also result in more transport of contaminants to the receiving waters.

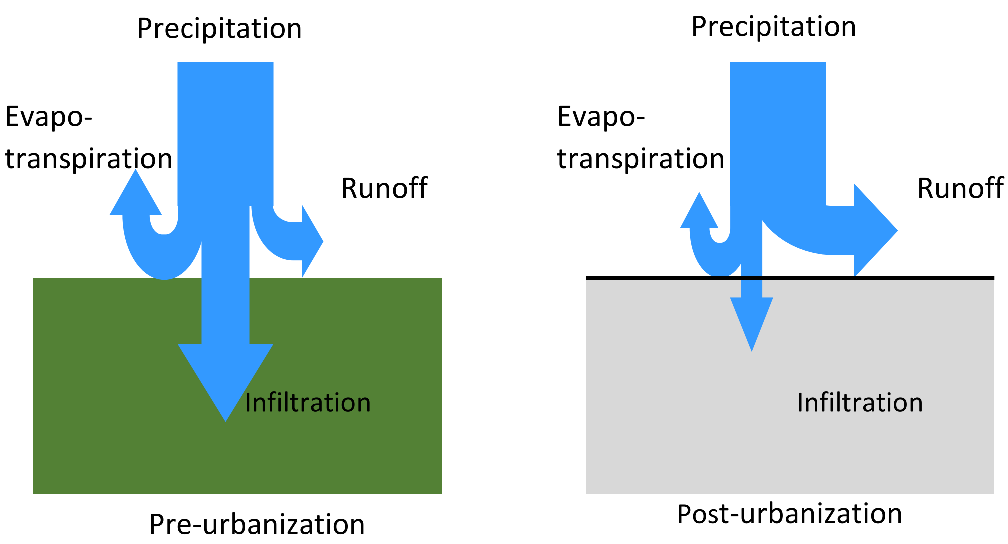



*Figure 2.1* *Effect on water cycle by urbanization. (Modified from* (Butler & Davies, 2010).*)*

As can be seen in Figure 2.1, not all rainfall becomes surface runoff. The runoff is affected by losses such as wetting losses, depression storage, infiltration and evapotranspiration, and the runoff coefficient of the surface (Butler & Davies, 2010). Calculation of the runoff can be performed with different models (Vägverket, 2008). All are based on the calculation of the design flow with Equation (2.1).

$$Q_{design} = i \cdot A_r \tag{2.1}$$

$Q_{design}$ design flow [l/s]
$i$ rain intensities [l/(s*ha)]
$A_r$ reduced area, $A_r = A * \varphi$ [ha],
$A$ surface area [ha]
$\varphi$ surface runoff coefficient [-]

Statistically, shorter rain events have higher rain intensities. The intensities varies during the event, generally with higher intensities during first half of the rain (Butler & Davies, 2010). The rain intensity depends on the return period and the duration of the studied rain (Vägverket, 2008). The return period for rain events is used to describe the probability for different rain intensities. It can also be used as a safety factor in the design of new stormwater systems (SMHI, 2018). The length of the return period is a rate of how often the rain occurs on average. For example, a rain event with a return period of 100 years occurs on average once during 100 years, which means that the probability is 1 % each year. However, the accumulated probability over a longer time span is considerably larger (Table 2.1).

*Table 2.1 Probability for an event during different time spans for different return periods. (Modified from* (Svenskt Vatten, 2016).*)*

| Return period | Probability for 5 years | Probability for 10 years | Probability for 20 years | Probability for 50 years | Probability for 100 years |
|---|---|---|---|---|---|
| **5 years** | 67 % | 89 % | 99 % | 100 % | 100 % |
| **10 years** | 41 % | 65 % | 88 % | 99 % | 100 % |
| **20 years** | 23 % | 40 % | 64 % | 92 % | 99 % |
| **50 years** | 10 % | 18 % | 33 % | 64 % | 87 % |
| **100 years** | 5 % | 10 % | 18 % | 39 % | 63 % |
| **500 years** | 1 % | 2 % | 4 % | 10 % | 18 % |
| **1000 years** | < 1 % | 1 % | 2 % | 5 % | 10 % |

The duration of a studied rain event is selected from the time of concentration within an area (Vägverket, 2008). The time of concentration is the longest time required for the runoff from one part of the catchment to the studied point and is used for determining how much of the surface that is contributing to the flow at a specific time. This time can be estimated from the distance and approximated runoff velocities for different surface materials (Table 2.2).

*Table 2.2 Approximated runoff velocities for different surfaces. (Modified from* (Svenskt Vatten, 2016).*)*

| Surface material | Runoff velocity [m/s] |
|---|---|
| General conduit/pipe | 1.5 |
| Tunnel and larger conduit/pipe | 1.0 |
| Ditch and gutter | 0.5 |
| Open land | 0.1 |

According to the Swedish Water and Wastewater Association, rain intensities should be adjusted for future probable climate change when designing new stormwater facilities (Svenskt Vatten, 2016). This is suggested to be performed by multiplying the rain intensity by 1.25 for rains shorter than one hour and by 1.2 for rain longer than one hour.

To calculate the runoff, the area of the catchment needs to be calculated (Vägverket, 2008). As mentioned, not all precipitation over the area will be converted into runoff. Therefore, the area is reduced by multiplying it with a runoff coefficient, $\varphi$. It represents the expected share of the precipitation that will be turned into runoff. The runoff coefficient is a number between 0 and 1, and depends both on the losses and the inclination of the surface. In addition, the surface material can get saturated during long and intensive rains, which will affect the runoff coefficient.

There are different calculation methods for estimating the generated stormwater flows from urban areas, for example the net area method, the rational method, and the time-area method (Vägverket, 2008). The net area method is a highly simplified method and only includes impervious surfaces, which are assumed to be of highest importance. This assumption makes the method only applicable for highly impervious areas such as roofs, roads, and other paved areas. The rational method is a relatively fast method for making rough estimations of flows from homogenous areas with a high degree of impervious and fast contributing areas (Vägverket, 2008). The time-area method is the most used in Sweden for more complex calculations according to Blomquist et al. (2016). The method is suitable for areas of larger and more heterogenous nature, inclination and runoff coefficients, than can be calculated with the rational method (Vägverket, 2008). For calculations of flows in pipe network, a computerized model software should be used.

### 2.1.3 Flow in ditches

Studying flowing stormwater, three different kinds of energy needs to be considered: pressure, velocity and potential (Häggström, 2009). This can be described by Bernoulli's Equation (2.2).

$$H = \frac{p_1}{\rho g} + \frac{v^2}{2g} + z \tag{2.2}$$

| | |
|---|---|
| $H$ | total head |
| $z$ | potential head |
| $\frac{p_1}{\rho g}$ | pressure head, $p$=pressure, $\rho$=density, $g$=gravitational acceleration |
| $\frac{v^2}{2g}$ | velocity head, $v$=mean velocity over the cross section, $g$=gravitational acceleration |

When the level of the water surface can vary, in a not full pipe, stream, or ditch, the concept of open channel flow can be applied (Butler & Davies, 2010). The free water surface has a pressure equal to the atmospheric pressure and the cross-section area varies with the flow. The Bernoulli Equation (2.2) applied for open channels gives Equation (2.3).

$$H = h + x + \frac{v^2}{2g} \tag{2.3}$$

| | |
|---|---|
| $H$ | total head |
| $h$ | level of lowest bottom point |
| $x$ | depth from water surface to lowest bottom point |
| $\frac{v^2}{2g}$ | velocity head |

Frictional losses for liquid flows in open channels are calculated with Manning's formula (Equation (2.4) (Häggström, 2009).

$$h_f = \frac{v^2 L}{M^2 R^{4/3}} \tag{2.4}$$

| | |
|---|---|
| $h_f$ | frictional loss [m] |
| $v$ | mean velocity over the cross section [m/s] |
| $L$ | length of open channel [m] |
| $M$ | Manning's number [$m^{1/3}$/s] |
| $R$ | hydraulic radius, $R=A/P$ [m] |
| $A$ | area of cross section [$m^2$] |
| $P$ | wetted perimeter, length of cross section of channel in in contact with water [m] |

Manning's number M is a material constant of roughness between the flowing water and the studied surface (Häggström, 2009). Higher M-values indicates smoother surfaces and consequently less frictional losses and higher velocities in the open channels. The value M is experimentally derived and some examples for different surface material can be seen in Table 2.3.

*Table 2.3 Description of different surface characteristic classes and an interval of Manning's number, M. (Modified from* (Johannesson & Vretblad, 2011) *and* (Vägverket, 2008).*)*

| Surface characteristic | M rough | M smooth |
|---|---|---|
| **Paved channel** | | |
| Asphalt/concrete | 70 | 85 |
| Smooth stone | 60 | 75 |
| Rough stone | 45 | 60 |
| **Dug channel** | | |
| Straight smooth surface | 40 | 60 |
| Stony soil or some vegetation | 25 | 35 |
| **Natural channel** | | |
| Smooth surface, soil or sand, no shallows or ponds | 30 | 45 |
| Stony soil or some bottom vegetation | 25 | 35 |
| Stony till with shallows and ponds | 20 | 30 |
| Much vegetation, shallows and ponds | 12 | 20 |

The M-value also varies between open channels with the same vegetation cover but with different hydraulic flows (Vägverket, 2008). As seen in Figure 2.2, a channel with a lower hydraulic flow compared to the height of the vegetation, has a lower M-value.

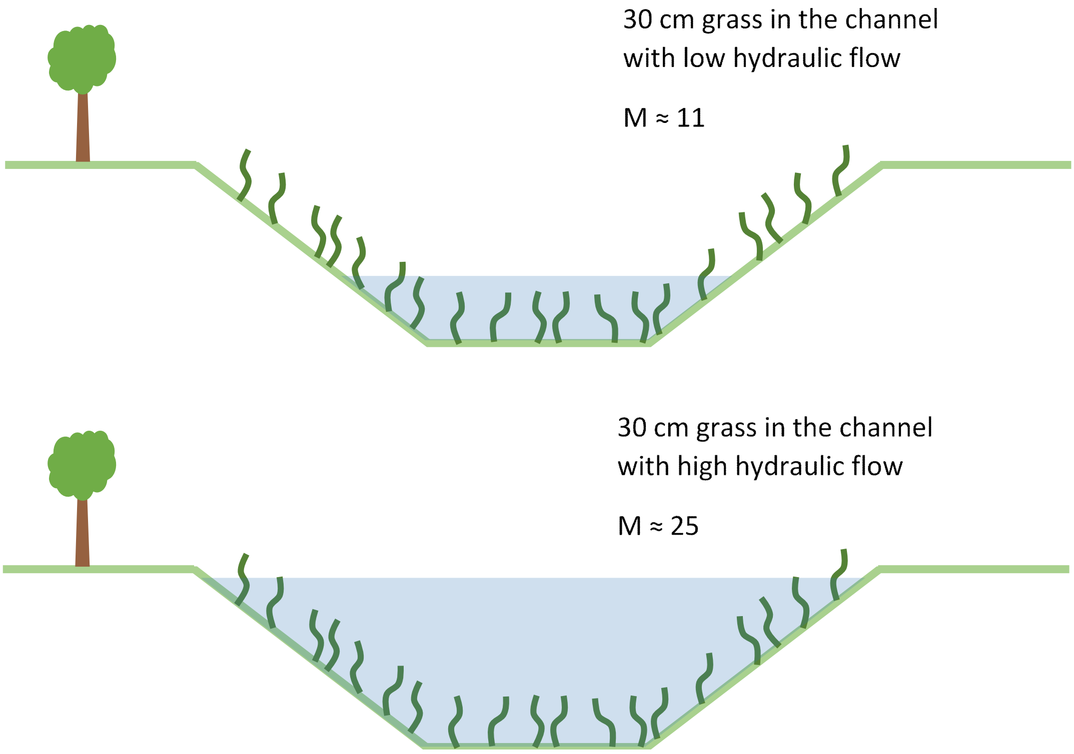



*Figure 2.2 Example on how Manning's number, M, can vary in the same channel. (Modified from* (Vägverket, 2008)*.)*

If the flow in a channel is under constant roughness, constant inclination, and constant cross section shape for a long distance, an equilibrium depth is reached, the natural depth. Under this condition, it is an equilibrium between the friction loss and the fall along the channel. This can be described by the Equation (2.5).

$$S_b = \frac{h_f}{L} = \frac{v_n^2}{M^2 R_n^{4/3}} \tag{2.5}$$

$S_b$ inclination of channel bottom
$h_f$ frictional loss [m]
$L$ length of open channel [m]
$v_n$ mean velocity over the cross section at natural depth [m/s]
$M$ Manning's number [$m^{1/3}$/s]
$R_n$ hydraulic radius at natural depth [m]

In conclusion, larger ditches with low inclinations result in lower flows, which is beneficial if the stormwater is to be delayed in the system. In addition, more vegetation and therefore higher M-values will also decrease the flow velocity in the ditches.

### 2.1.4 Contaminations in traffic-related stormwater

Even though stormwater often is consider unpolluted compared to wastewater, urban stormwater can still be heavily contaminated with several different polluting substances (Butler & Davies, 2010) and stormwater is considered the main pollution source to lakes and water courses within or close to urban areas (Alm, Agata, & Larm, 2010). Stormwater origins from the pure precipitation and is contaminated by particles and pollutants from the atmosphere and urban surfaces. Hence, stormwater acts as a transport medium for pollutants from both point and diffuse sources. The contaminations can vary widely for different areas and different times (Butler & Davies, 2010). Consequently, standard values of pollutant concentrations in stormwater should be handed with caution.

In cases where waterbodies have been classified as below "good water status", it has not been proven that stormwater is the responsible source of pollutants (Vattenmyndigheterna i samverkan, 2016). However, stormwater contain high concentrations of prioritized compounds as lead, cadmium, mercury, nickel, PAHs, octylphenol, nonylphenols, copper, chromium, zinc, arsenic and PCB.

#### 2.1.4.1 Sources of traffic-related contaminants

It is important to identify the sources of the contaminants in the stormwater in order to estimate concentrations and to develop methods for treatment (Malmqvist, 1983). In addition, knowledge about the sources of contaminants can assist in decision making in the planning and construction of urban areas in order to reduce these pollutant sources. There are many different sources of particles in the urban area and these are mainly related to the land-use (Naturvårdsverket, 2017). Traffic is one significant source of pollutants in stormwater (Opher & Friedler, 2010) and contributes with pollutants from many different sources (Table 2.4).

The metals are pollutants of great interest due to their extensive presence in stormwater, their potential toxic effect on aquatic organisms, and since they cannot be chemically transformed or destroyed (Davis et al., 2001). Traffic is a major source of metals in stormwater, including for example lead, copper, zinc, cadmium, chromium and nickel. Lead contamination has decreased rapidly since the ban of lead added to gasoline, but can still be found in high concentrations (Hwang et al., 2016). Lead has also been used as balancing weight in wheels, but this has been banned in new cars in the European Union (EU) since 2005. Copper and zinc are two major trace metals from traffic. Copper is released from breaking pads and this has been shown to be one of the main origin of copper entering receiving waters and is today one of the greatest threats to aquatic organisms in urban waterbodies. Zinc is released through wear of tyres since it corresponds to approximate 1.5 % of the weight of the tyre.

Organic pollutants are frequently found in road dust and can be harmful to animals and human health (Markiewicz et al., 2017). PAH16 (Polycyclic Aromatic Hydrocarbons) is a group of organic pollutants, including for example Benzo(a)pyrene (BaP). PAH16 is released to the environment mainly from vehicles exhausts, wear of tyres, motor lubricant oils, wear of asphalt and wear of breaks. In a study performed by Markiewicz et al. (2017), PAHs were identified as the highest prioritized organic pollutants from traffic and roads.

Nutrients such as phosphorous and nitrogen are also important quality parameters to study in traffic runoff. They exist naturally in the environment, but increased concentrations due to human activities have caused issues with over-fertilization of waterbodies (Havs och Vattenmyndigheten, 2017). Regarding phosphorus, a study showed that roads and surrounding grass surfaces contributed with up to 80 % of the total phosphorous in the stormwater (Washbusch et al., 1999). In 1999, the US Environmental Protection Agency estimated that the traffic sector in America contributed with 55 % of nitrogen oxides emissions (Frey & Unal, 2002). Gaseous compounds can settle on the traffic surfaces and be washed off to the receiving water by stormwater runoff.

Suspended solids are important to study in traffic-related stormwater since they transport several micro-pollutants to the receiving waters (Shinya et al., 2000). A study by Shinya et al. (2000) showed a strong correlation between suspended solids and metals, and that PAHs are related to suspended solids. In addition, nutrients are most often attached to solid particles (Vaze & Chiew, 2002). In Melbourne, Australia, a study showed that 75 % of the total phosphorus and 90 % of the total nitrogen was attached to particles, mostly to particles of smaller fractions.

*Table 2.4 Sources of pollution and pollutants in traffic-related stormwater. (Modified from* (Naturvårdsverket, 2017).*)*

| Specific source | Pollutant |
|---|---|
| Exhaust gas | PAHs, benzene, alkylphenol, nitrogen |
| Engines | chromium, nickel, copper |
| Brake lining | copper, antimony, zinc, lead, cadmium |
| Car tires | zinc, lead, chromium, copper, PAHs, alkylphenol, particles, phthalates |
| Pavement material | particles, PAHs, several metals |
| Winter road maintenance | particles (sand and gravel), sodium chloride |
| Car-care products | phthalates, alkylphenol, fluorinated substances, phosphorus |
| Tunnel washing | PAHs, metals (zinc, copper, lead, chromium etcetera), particles |

As can be seen in Table 2.4, there are many different contaminants in traffic-related stormwater. However, the Swedish Transport Administration consider the concentration of phosphorous, copper, and cadmium in the traffic-related stormwater and the receiving waters as good indicators to get an understanding of the total loads of pollutants in the environment (Trafikverket, 2011).

#### 2.1.4.2 Build-up of contaminants

Pollutant load are build-up on the surface over time and are eventually washed off by precipitation (Figure 2.3).

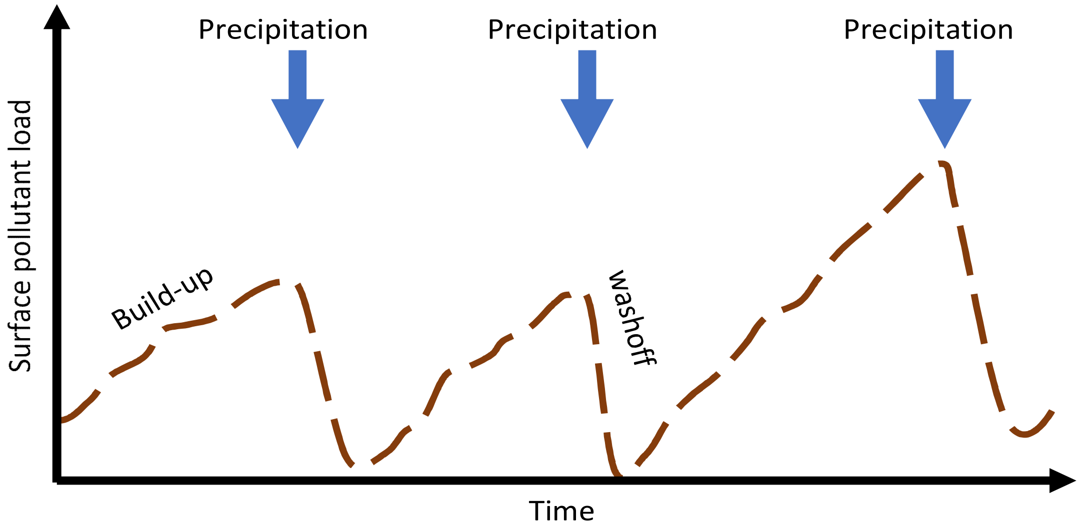



*Figure 2.3 Schematic characterization of surface pollutant load over time, build-up and washoff of pollutants. (Modified from* (Vaze & Chiew, 2002).*)*

As previously mentioned, there are many different factors that influence the accumulation of pollution. Some example for pollution build-up on impervious surfaces are: land-use, population, traffic intensity, impact of street sweeping, season, meteorological conditions, previous dry period, and type and condition of road surface (Butler & Davies, 2010). According to Butler & Davies (2010), the build-up can be described by Equation (2.6).

$$\frac{dM_s}{dt} = aA - bM_s \tag{2.6}$$

$M_s$ mass of pollutant on surface [kg]
$a$ surface accumulation rate constant [kg/(ha*day)]
$A$ catchment area [ha]
$t$ time since the last rainfall or street sweeping [day]
$b$ removal constant [1/day]

#### 2.1.4.3 Transport of contaminants

The stormwater collects large amounts of particles when it is transported over different types of surfaces in the urban environment (Naturvårdsverket, 2017). The amount of particles transported with the stormwater depends on the flow and energy of the water. When the flow and energy decreases, for example when discharged to the recipient, the particles can settle to the bottom. The particle bound pollutants are buried in the sediment, while the suspended solids are more portable and easily spread in the waterbody.

Handling generation and transport of pollutant from urban surfaces, the concept of “first flush” is of significance (Zoppou, 2001). The concept relates to that the initial part of a rain event often contains higher concentrations of pollutants compared to the end of the rain events. Many studies have shown the presence of the phenomena, while some studies found it for some or no samples (Naturvårdsverket, 2017). However, the first flush effect is most frequently occurring for particles in runoff from smaller areas with mainly impervious areas, such as roads and parking lots.

## 2.2 Management of traffic-related stormwater

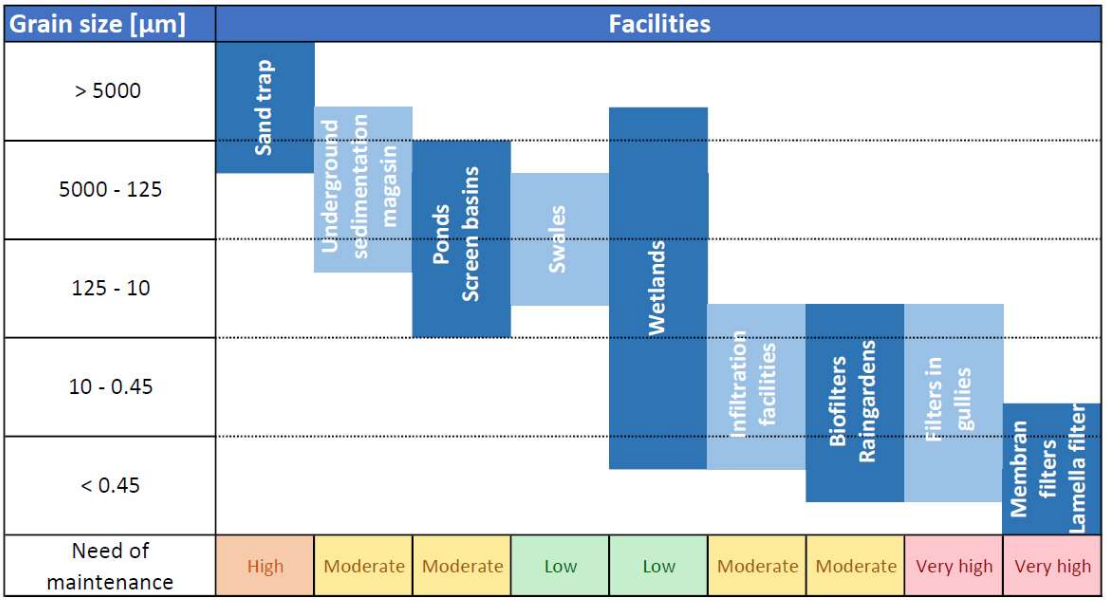
Stormwater management differs from wastewater management in the way it requires to deal with sediments containing non-biodegradable particles, short residence time in the treatment facilities and irregular flow patterns with long dry periods (Blecken, 2016). In addition, stormwater treatment facilities should often provide ecological services and be a part of recreation areas.

Stormwater management is regulated by laws, guidelines and norms on local, national and EU level (City of Gothenburg, 2017). According to Swedish law 2006:412, about common water services, the municipality has the responsibility to ensure that water, wastewater and stormwater services are provided for urban developed areas if needed, considering human health or the environment (LAV SFS 2006:412). However, this does not include road ditches, storm drains, gullies or pipes connecting gullies to the stormwater network. The services provided should be paid by the property owners, and the fee should cover the costs for the treatment needed to protect human health and the environment. Damages caused by flooding of water that should have been drained by the responsible authority’s drainage network should be compensated. The county administrative boards have the responsibility to supervise that the law is obeyed, and lawsuits are heard by the Land and Environment Court.

During the process of new developments, the municipality requires that the management of stormwater is considered and that guidelines are complied (Göteborgs Stad, 2010). However, in existing areas, the stormwater management may sometimes be inadequate. The City of Gothenburg requires that stormwater should be managed locally or as close to the source as possible, in order to reduce flow and transportation of contaminants from the area. Stormwater from impervious areas should be detained, and treated if required, before it is discharged to a ditch, recipient, or pipe network. The requirements for treatment of stormwater from the local Environmental Administration are derived from The Swedish Environmental Code and Water Framework Directive (Göteborgs Stad, 2017). The extent of treatment required for different areas depends on both the contamination load from the studied area and the sensitiveness of the receiving water. Pedestrian and bicycle paths do not have any requirements for stormwater treatment.

Depending on the requirement for treatment of the stormwater, various facilities can reduce contaminants with different grain size (Table 2.5) (Blecken, 2016). In addition, the need of maintenance varies between the different facilities which will also affect the selection of treatment facilities for different cases.

*Table 2.5 Schematic shows the grain size different facilities can treat and the need of maintenance for these facilities. (Modified from* (Blecken, 2016).*)*




Stormwater management with open conveys can contribute to additional values such as green recreation areas and biodiversity concurrently as a detention and treatment of the water is achieved (Vattenmyndigheterna i samverkan, 2016). Open stormwater management is also considered good for educational purposes and increased awareness for the citizens (City of Gothenburg, 2017).

There are only two sources providing guidelines for stormwater control measures according to Rujner (2018): the Swedish Transport Administration and the Swedish Water and Wastewater Association. The Swedish Transport Administration have guidelines for how to drain the national roads and even if this study does not include national roads, the guidelines are included since the Swedish Transport Administration has the responsibility to provide knowledge to other road authorities, such as the municipalities (Vattenmyndigheterna i samverkan, 2016).

This study includes municipal roads in Gothenburg, which are managed by the municipal Traffic and Public Transport Authority. A schematic figure of the typical drainage process of urban traffic surfaces can be seen in Figure 2.4.

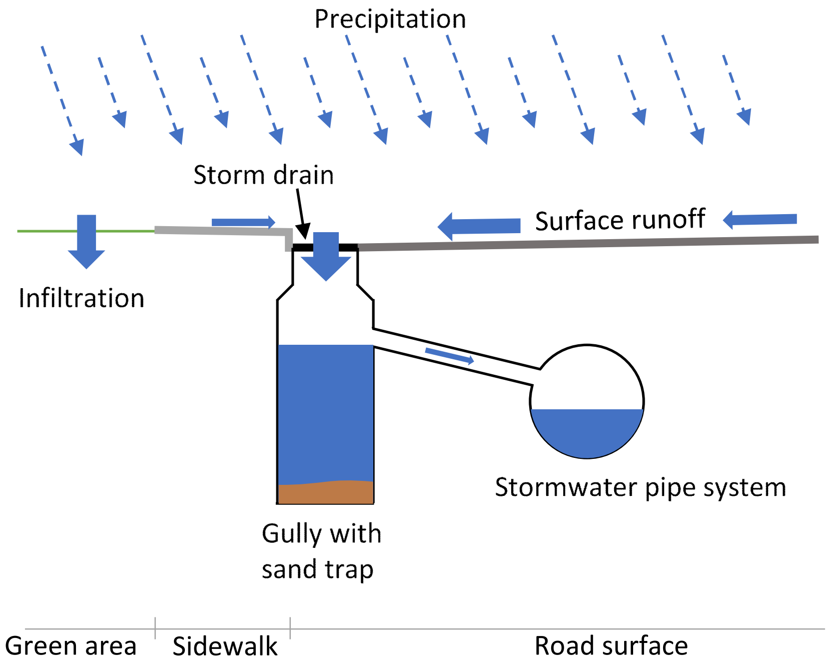



*Figure 2.4* *Example of stormwater drainage for urban traffic surfaces. (Modified from* (Butler & Davies, 2010).*)*

Roads are often designed with drainage through gullies to the pipe network. The Traffic and Public Transport Authority demands that the gullies should be installed with maximum distance from each other of 60 m or with maximum 300 m$^2$ impervious area drained (Trafikkontoret, 2018). If flooding due to a clogged gully risks damaging the surroundings, two gullies should be installed. Pollutants are usually building up in the gullies during dry weather and pollutants in the water in the sand trap are washed out by smaller rain events (Butler & Davies, 2010). However, deposits of heavier solids are only discharge from the gully to the pipe network during heavier rain events. According to Bennerstedt (2005), the sand trap in the gullies should be emptied at least once per year in order to minimize the risk of stirring up the trapped sediments during intensive rains. Bennerstedt also found that the gullies with sand traps seems to reduce the studied heavy metals (lead, cadmium, cupper, chrome, and zinc) by 10 %. Especially the larger particles, larger than 0.5 mm, were found to be trapped in the sand trap.

The Traffic and Public Transport Authority in Gothenburg has provided "General provisions" which include their demands for the design and drainage of their roads (Trafikkontoret, 2018). They state that the roads must be built to prevent any local bodies of water. The stormwater must not be led to other surrounding properties or other areas not included in the traffic area, if no special agreements are applied. Expected development should also be taken into consideration.

The Traffic and Public Transport Authority also states that the inclination of the road are chosen with consideration of the drainage, surface material in the pavement, risks of settlement, wear on vehicles, and driving comfort (Trafikkontoret, 2018). The road is therefore constructed with a cross fall, a slope perpendicular to the longitudinal direction, in order to drain the road surface, prevent hydroplaning, and ice formations during cold periods (Mannering & Washburn, 2012). On straight sections of the road, this cross fall should according to The Traffic and Public Transport Authority normally be 2.5 – 3 % double cross fall, called camber (Figure 2.5). Single sided cross fall, super-elevated, can be used on straight section smaller than 5.0 meters (Trafikkontoret, 2018). In curve sections, the road is usually design with a super-elevated cross section, tilting into the curve, and the stormwater is consequently drained to one side.

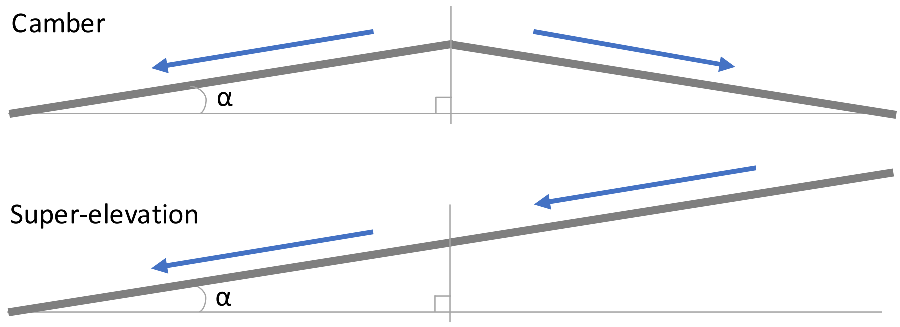



*Figure 2.5 Different cross-sections of roads and runoff direction.*

According to Swedish Transport Administration, the pavement and adjacent road area has to be drained to ensure traffic safety, bearing capacity and frost heave resilience (Vägverket, 2008).

### 2.2.1 EU regulations and water administration

The EU Water Framework Directive states that all waters should have a good ecological and good chemical status (European Commission, 2016). In addition, stricter objectives can be set for specific areas. The EU also want the citizens to be more involved and a survey have shown that 47 % of Europeans in EU25 are worried about water pollution. The definition of good ecological status refers to the presence of aquatic plants, fish fauna, nutrient supply and some other aspects (European Commission, 2018). Good chemical status refers to environmental quality standards, regarding 53 chemical compounds, and is also supported by other European laws.

The EU Water Framework Directive is adapted by Swedish law since 2004 and thereby, Sweden is committed to implement all parts of it (Havs och Vattenmyndigheten, 2016). The work with the water administration is divided into cycles of six years, where 2016-2021 is the on-going. A cycle starts with data of the waters being compiled to define the status and identify required provisions. When a cycle has ended it is reported to the EU (Havs och Vattenmyndigheten, 2014). In Sweden, the Swedish Agency for Marine and Water Management is responsible for the review that is based on information from the five Water Authorities, one for each Water District. Gothenburg is located in the Water district of Västerhavet and it is the County Administrative Board of Västra Götaland that is the responsible Water Authority (Vattenmyndigheterna, n.d.).

The Water Authority of Västerhavet has an intervention programme of provisions that needs to be implemented by the authorities and municipalities to achieve the environmental quality standards (in Swedish: miljökvalitetsnormer) (Vattenmyndigheterna i samverkan, 2016). One of the Swedish Transport Administration's provisions are to provide knowledge to other road authorities, as the municipalities, about strategies to lower the environmental impacts of traffic-related runoff. This also aims to create a co-operation between different actors and ensure that the most efficient provisions are prioritized. A provision that the municipalities should implement is to practise supervision of activities that affects the waters to an extent that the environmental quality standards are not achieved and make demands of provisions. The municipalities should also operate to lower the risks of CSOs that have a significant impact on the receiving waters. Another provision for the municipalities is to produce a stormwater plan regarding quantity and quality of urban runoff before 2019.

All proposed provisions from the Water Authority of Västerhavet have an estimated additional administrative cost for the society of 14.1 billion SEK for the cycle 2016-2021 (Vattenmyndigheterna i samverkan, 2016).

### 2.2.2 Existing simple measures for traffic-related stormwater

As previously mentioned, existing simple measures already exist in the urban environment today and may not been constructed primarily to delay, store, or treat stormwater.

The term “ditch” is used in this thesis as an umbrella term for swales and grass ditches. Differences and further descriptions of these simple measures are provided in this section.

#### 2.2.2.1 Grass ditch

A grass ditch is defined as a ditch that has steeper side slopes, for example between 1:2 and 1:3 (Figure 2.6) (City of Gothenburg, 2017). It can also drain the pavement of a road by having a bottom elevation at least 30 cm below the base of the pavement. A grass vegetated ditch is a cheaper method to treat traffic-related stormwater compared to for example sedimentation ponds and infiltration ponds (Vägverket, 2003). The treatment is especially effective for rain events with low intensity and long durations. However, more treatment steps are needed to control the high concentration of pollutants at the first flush after a longer dry period.

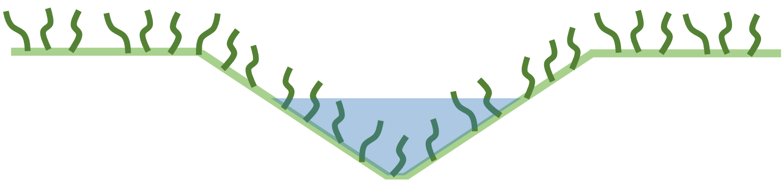


*Figure 2.6 Schematic figure of a grass ditch.*

According to the Swedish Transport Administration, the inclination along the ditch should be at least 0.5 %, or 0.2 % if it is designed under harder restrictions for the design and maintenance (Vägverket, 2005). A ditch with too small inclination can cause issues with clogging (Vägverket, 2003). It is also stated that the depth of the ditch should be at least 0.5 m below the road surface (Vägverket, 2005).

A ditch along a national road in Sweden should be dimensioned for a 5-10 year rain event with 10 minutes duration to avoid erosion, according to the guidelines for simple stormwater treatment facilities from 1998 (Vägverket, 1998). In addition to drainage, the ditch also has a function to store stormwater at extreme rain events and control traffic pollutants (Vägverket, 2008).

According to the Swedish Transport Administration it is recommended that a ditch should be at least 60 m long, be trapezoid or parabolic shaped and have a bottom width of 0.5 to 3 m (Vägverket, 2003). To achieve better treatment of stormwater and minimize the risk of erosion, the ditch should be vegetated with dense grass that is mowed and removed once a year. De-icing salt can damage vegetation if it reaches the roots.

Open ditches can be beneficial in cold climates compared to closed pipe systems since the open system is more resilient against frost and the surfaces can be used for storage of snow (Viklander & Bäckström, 2008).

If there is risk for erosion, the ditch slopes, centre, inlets and outlets must be provided with erosion protection (Vägverket, 2008). In addition, it is of importance to keep the border between the road and the ditch lowered to prevent waterbodies at the road (Blecken, 2016). This concerns swales as well.

#### 2.2.2.2 Swales

Grass swales or shallow grass-lined channels are simple techniques to conveying, treat, and reduce the stormwater runoff volume by infiltration and storage (Butler & Davies, 2010). Swales can, in similarity with ditches, be constructed parallel to roads to receive stormwater along the entire length of the measure. The stormwater is detained either until it is infiltrated or until it is conveyed further downstream in the stormwater system. The gradient along the swale should preferably be low, less than 5 %, and pervious soils with high draining properties are recommended. The sides of the swale are usually less steep than 1:3, which simplifies the maintenance consisting of cutting of the grass (City of Gothenburg, 2017). In contrast to grass ditches, swales are shallower, for example 30-50 cm, and therefore not constructed to drain the pavement of roads (Figure 2.7).

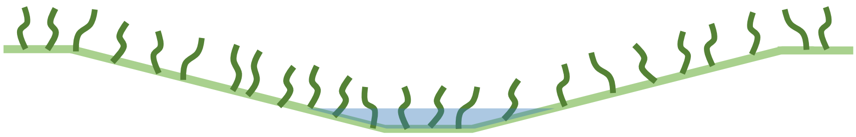


*Figure 2.7 Schematic figure of a swale.*

A field study in Maryland, USA, have shown that the stormwater runoff volume from a highway was completely reduced in the grass swales during smaller rain events (Davis, Stagge, Jamil, & Kim, 2012). Larger rain events showed a partial volume reduction while for the largest, it was much smaller and the swales preformed as an impervious channel. The infiltration rate and capacity for swales are thereby reduced when the soil is saturated. The total volume reduction was significant for rain events smaller than 30 mm.

From a study in Luleå, Sweden, 4 to 32 % of a 2-month rain event was estimated to be temporally stored in a grass swale's top soil (Rujner, 2018). During tests in Minnesota and Wisconsin, USA, roadside swales showed an infiltration rate varying between 0.75 cm/h and 15.5 cm/h (Ahmed, Gulliver, & Nieber, 2015). This was higher than expected and Ahmed et al. suggest that it can be due to roots in the soil close to the surface, creating macro-pores. The test also showed that the hydraulic conductivity was not reduced in the centre of the swale due to sediments.

Swales alone are generally not sufficient as treatment to achieve good water quality, but can be a choice for pre-treatment to other facilities, since sedimentation in swales perform well (Blecken, 2016). In addition, swales and ditches can have an advantage in cold climate since there are possible snow deposits. Nevertheless, ice can cause issues at inlets and outlets. The removal capacities for dissolved pollutants and small particles are low in ditches and swales (Bäckström & Viklander, 2000).

Trimming of the vegetation is important to both retain flow capacity and improve the removal of particles (Blecken, 2016). To obtain a high flow capacity, the grass should be short, but the ideal length for removal of particles are 50 to 150 mm, this can result in a conflict of interests.

#### 2.2.2.3 Filter strips

In combination with swales, filter stripes are often constructed (Blecken, 2016). Filter strips, vegetative filter strips, or vegetative buffer strips are ground surface with a low inclination designed to promote sheet flow for the stormwater, which decrease the runoff velocities and favor infiltration (Figure 2.8) (Butler & Davies, 2010). The inclination of the filter strip should be between 2 and 5 % (City of Gothenburg, 2017). Filter strips have shown to have a moderate efficiency compared to grass swales (Davis et al., 2012). However, the performance of a swale can be significantly improved by implementing filters strip in combination with check dams (Chapter 2.2.3.4). In similarity to swales, the preferred height of the grass for removal of particles is between 50 and 150 mm (Blecken, 2016).

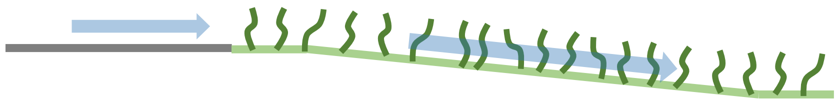


*Figure 2.8 Schematic figure of a filter strip with the runoff from the road.*

### 2.2.3 Improvements of existing measures

The theory behind the suggested possible improvements are described briefly below. It should be noted that many of the improvements can be implemented together in order to optimize the effect.

#### 2.2.3.1 Throttle or cover storm drains

The load on stormwater pipes that are filled during rains can be eased by throttling or covering the inlets to the storm drains (Svenskt Vatten, 2011). However, this requires that no inconvenient areas are flooded and that the water can be drained downstream. The throttling can be performed by covering the storm drains with steel plates with only smaller holes.

#### 2.2.3.2 Raise the outlets from ditches and swales

By raising the outlets in a ditch or swale, a storage volume can be created which improve retention and sedimentation (Blecken, 2016). To prevent stagnant water, it is of importance that the water can be infiltrated.

#### 2.2.3.3 Remove curb stone

A measure suggested by the Swedish Water and Wastewater Association is removing curb stones along roads to allow the water to drain to a lower situated grass surface which can be existing or be created (Svenskt Vatten, 2011). This can preferably be implemented in combination with for example throttling storm drains. According to the City of Gothenburg, removing curb stones can be a substitute to storm drains (City of Gothenburg, 2017).

#### 2.2.3.4 Check dams

To improve the infiltration and detention in a swale, check dams can be installed (Davis et al., 2012). Check dams are barriers that detain and slows down the flow at low to moderate flows, but the water can flow over the barriers at high flows (Figure 2.9). In similarity to raising the outlets, a storage volume is created which increase the sedimentation and retention.

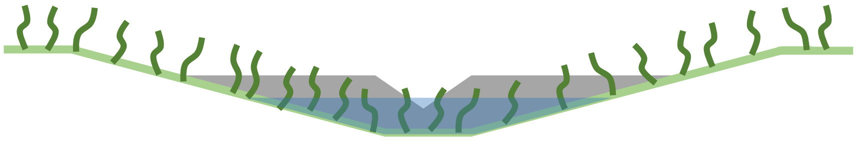


*Figure 2.9 Schematic figure of a check dam in a swale.*

#### 2.2.3.5 Two-stage ditches

A two-stage ditch is an alternative to the traditional ditch that has a narrower channel in the centre of a larger channel (Figure 2.10).

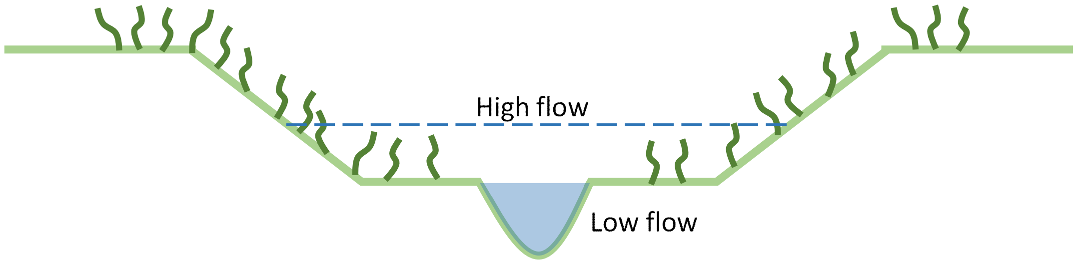



*Figure 2.10 Two-stage ditch. (Modified from* (Länsstyrelsen Västra Götalands Län, n.d.)*.)*

This design achieves lower velocity at higher flows which is beneficial both regarding erosion issues and treatment efficiency (Lindmark, 2013). However, large masses of soil must be removed to convert traditional ditches to a two-stage and more land is needed. According to the County Administrative Board, the vegetated benches improve biodiversity and stability, resulting in decreased demand of maintenance (Länsstyrelsen Västra Götalands Län, n.d.). A conversion to two-stage ditches are suitable for ditches that:

- have erosion issues.
- are flooded at moderate to high flows.
- are shallow.
- are lacking trees.
- are not affected by damming in a large extent.
- are located in areas with intensive agriculture.
- are located upstream nutrient sensitive receiving waters.
- are not located upstream wetlands.
- are longer than approximately 1 km.
- have surroundings suitable for deposition of the removed masses.

#### 2.2.3.6 Filters in gullies

Filters installed in gullies to capture contaminants from the traffic-related stormwater runoff were evaluated in study in Stockholm (Bennerstedt, 2005). The result showed that both filters installed in gullies and manholes downstream the gullies reduce the studied contaminants by 3 % each. However, to not reduce the hydraulic capacity, the filters need to be changed every third month. This, together with lack of possibilities for the water to bypass the filter if it becomes clogged, resulted in that the author states that this type of filter should not be used if its performance is not improved.

Another study of filters was performed in Stockholm 2012, in which the filters did not have any effect on most of the studied substances (Alm, Agata, & Rennerfelt, 2015). However, the result indicated that older filters were more effective than new, which seemed to release contaminants. The authors conclude that for larger areas it is more feasible to treat the water in an end-of-pipe facility.

#### 2.2.3.7 Smart trap

Smart trap is a development of the original sand traps that prevent sediments to be flushed out during larger rain events (City of Gothenburg, 2017). In addition, the Smart trap also improves the sedimentation.

## 2.3 Stormwater modelling tools

Models are tools where the processes in reality are described in a simplified and reliable way for the purpose (Wennberg, 1997). Hence, the purpose of the model is important and is also what sets the demand of the input data, which can be general approximations or detailed measurements for long time-series. The result from a model can never be more detailed than the quality of the input data (Blomquist, Hammarlund, Härle, & Karlsson, 2016). To be reliable, a model should be calibrated and validated with measured data (Wennberg, 1997).

The stormwater modelling tools used in this study, SCALGO Live and StormTac Web, are presented in this section of the report.

### 2.3.1 SCALGO Live

SCALGO, short for Scalable Algorithmics, is a static model developed in collaboration between the Center for Massive Data Algorithms (MADALGO) at Aarhus University in Denmark, the Duke University in USA, experts within application of environmental GIS, and the LIDAR industry (SCALGO, 2018). The model uses algorithms to process large amount of topological data for flood mapping. The SCALGO product studied in this project is the browser-based application SCALGO Live.

The input data for the model are elevation models which are used to create workspaces in SCALGO Live. Originally, the national elevation model with a mesh grid 2x2 m is used. To get a higher resolution, an own DTM (digital terrain model) or DEM (digital elevation model) can be imported to the application. The elevations in this workspace can later be edited with simple tools within the programme in order to evaluate effects of different scenarios and measures. When a new elevation model is created, a hydrological analysis can be run on the model to study sea-level rise, flash flood mapping, flow accumulation and watersheds for different rainfalls. In the flash flood map, water trapped in depressions can be investigated in order to study the water depth, the volume of the depression and the volume of water stored in the depression from a specific rainfall. However, it is important to emphasize that the model considers all surfaces as completely impervious and is not connected to any underground pipe network.

### 2.3.2 StormTac Web

StormTac is a static stormwater and recipient model created by Thomas Larm (Alm et al., 2010). The model can be used for calculating pollution loads and reduction efficiencies by using standard values for runoff coefficients, pollutant loads for specific land-uses, and degree of pollutant removal for different stormwater measures. Calculations of flows and detention can also be performed in the model from precipitation, runoff coefficients, and areas for each land-use. However, flow variations and effect on sedimentations processes by high flows cannot be analysed since it is not a dynamic model (Larm & StormTac AB, 2017). The model boundary is the boundary of the studied watershed (Larm, 2000).

The model was originally excel-based, but is now browser-based, see print screen of user interface in Figure 2.11. The user interface is divided into the five boxes: Runoff, Pollutants transport, Pollutants treatment, Receiving water, and Transport and flow detention.

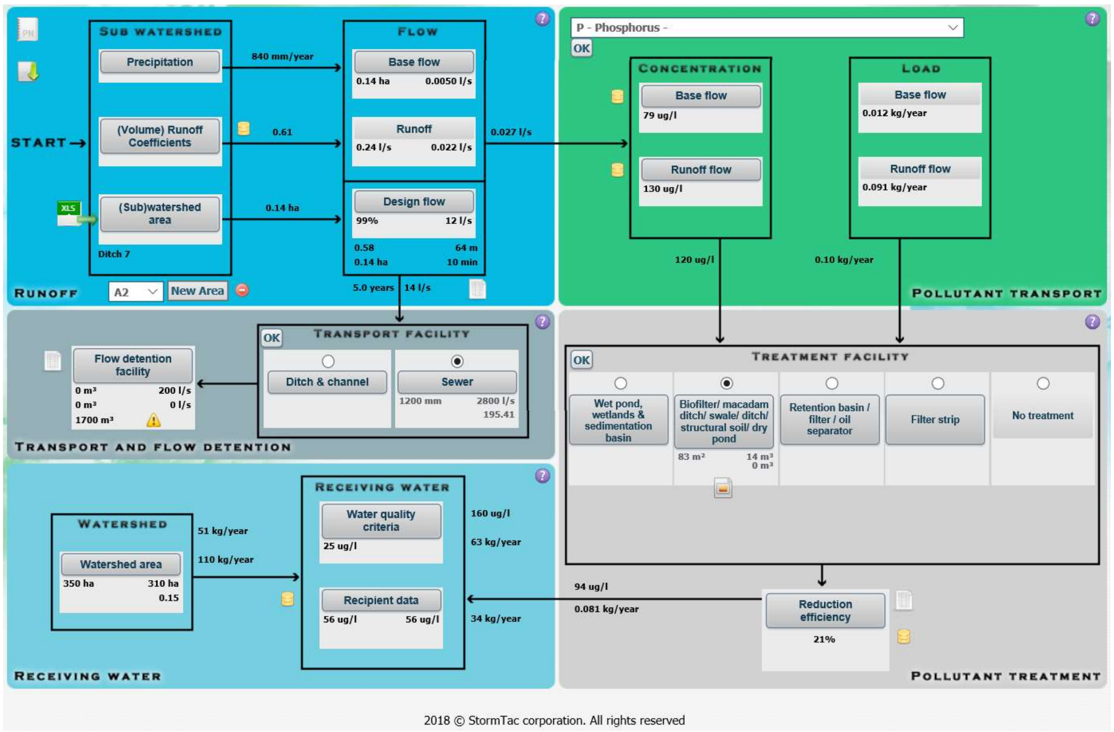



*Figure 2.11 Print-screen of the user interface of StormTac-web* (StormTac AB, 2018).

A disadvantages of using the model is that the standard values are not based on only Swedish studies and may not reflect the studied conditions in Sweden (Göteborgs Stad, 2017). According to the model author, the model can be used for calculations on different scales, from smaller sub-areas within a new zoning area to entire municipalities or catchments of receiving waters (Larm, 2018b).

The method used in StormTac Web for calculating the yearly pollution loads from the watershed is based on the product of the yearly concentrations from the different land-uses and yearly flows (Equation (2.7)).

$$L_j = \frac{\sum_{i=1}^{N} Q_i C_{ij}}{1000} \tag{2.7}$$

$L_j$ mass load rate (mass flux) [kg/year]
$j$ substance
$Q$ runoff water flow [m$^3$/year]
$C$ standard concentration [mg/l]
$i$ land-use $i$=1, 2, … N

This method allows direct calibration of flow and pollution content (Larm, 2000). The yearly flow is calculated with the rational method (Chapter 2.1.2) with the yearly precipitation, area, and runoff coefficients (Equation (2.8)) (Larm, 2018b). Case studies were used to calibrate the runoff model (Larm, 2000).

$$Q = 10p \sum_{i=1}^{N} (\varphi_i A_i) \tag{2.8}$$

| | |
|---|---|
| $Q$ | runoff water flow [$m^3$/year] |
| $p$ | precipitation intensity [mm/year] corrected for systematical errors |
| $A_i$ | size [ha] of land-use $i$ |
| $\varphi_i$ | yearly runoff coefficient for land-use $i$ |
| $i$ | land-use $i$=1, 2, … N |

The standard concentrations used in Equation (2.7) are depending on different land-uses, which is the conventional method for classification of stormwater properties (Larm, 2018b). The concentrations are presented as yearly average concentrations and are most often based on flow-weighted sampling performed over long time series. Some land-uses do not have any sampling result to be based on. These are instead based on other considerations such as calibration with a case study or comparison with similar land-uses. The database with standard concentrations used by the model is continuously updated when new reliable data are available.

In the model, the standard values can be chosen from a range from minimum to maximum for example regarding runoff coefficients and standard concentrations (Larm, 2000). The values should be chosen from this range depending on the specific characteristics of the studied area. For example, a slanted area should be given a value for the runoff coefficient closer to the maximum and a denser residential area should be given a value of standard concentrations closer to the maximum and vice versa. The model can also relate the pollution concentration to the traffic intensities for larger roads (Larm, 2018b).

Base flow, the dry-weather flow including groundwater and connected drainage water, is estimated in the model with Equation (2.9), (2.10), and (2.11).

$$Q_b = 10 K_x K_{inf} p A \tag{2.9}$$

$$K_{inf} = \frac{p - p\varphi - E}{p} \tag{2.10}$$

$$E = 1000(0.50 - 0.55\varphi) \tag{2.11}$$

| | |
|---|---|
| $Q_b$ | base flow [$m^3$/year] |
| $K_{inf}$ | fraction of yearly precipitation that is infiltrated (assuming that surface water storage is neglected or included in the parameter values φ and E) |
| $K_x$ | share of $K_{inf}$ that reaches the base flow |
| $p$ | precipitation intensity [mm/year] corrected for systematical errors |
| $A$ | size of land-use [ha] |
| $\varphi$ | surface runoff coefficient [-] |
| $E$ | (potential) evaporation intensity [mm/year] |

The pollutant load from the base flow is then calculated with Equation (2.12) using the base flow from Equation (2.9).

$$L_b = \frac{Q_b C_b}{1000} \tag{2.12}$$

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

One of the main purposes of the StormTac model is its simulations of pollutant reduction efficiencies for different treatment facilities (Larm, 2018a). The calculations of these reduction efficiencies (RE) are based on large amounts of flow-weighted samples from case studies and area assumed to follow logarithmic relationships between the reduction efficiency and the size of the facility compared to the reduced watershed of the facility (Larm, 2000). These are also adjusted to more site-specific properties by including factors regarding for example the inlet concentration and the irreducible concentration. These factors can however be turned off if desirable.

For biofilter, macadam ditches, swales, grass ditches, and dry ponds, the pollutant reduction efficiency is calculated with Equation (2.13)(StormTac AB, 2018).

$$RE = [k_1 ln(n_0) + k_2] * f_{C_{in}} * f_{C_{irr}} * f_{bypass} \tag{2.13}$$

$RE$ reduction efficiency [%]
$k_1$ regression coefficient 1, specific for each substance and facility
$n_0$ share facility area of reduced watershed area [%]
$k_2$ regression coefficient 2, specific for each substance and facility
$f_{C_{in}}$ factor, inlet concentration
$f_{C_{irr}}$ factor, irreducible concentration, lowest possible outflow concentration
$f_{bypass}$ factor, bypass

For filter strips, the model calculates the reduction efficiency with Equation (2.14).

$$RE = k_1 ln(A_{SF}/\varphi A) + k_2 \tag{2.14}$$

$RE$ reduction efficiency [%]

$k_1$ regression coefficient 1, specific for each substance and facility

$A_{SF}$ stormwater facility area [$m^2$]

$\varphi$ volume runoff coefficient

$A$ watershed area [ha]

$k_2$ regression coefficient 2, specific for each substance and facility

# 3 Methodology

To fulfill the aim of the project, the project included a literature study, data collection, a field study, modelling, and analysis of results. The literature study gave an in-depth knowledge and understanding of the field of stormwater, and resulted in examples of possible improvements according to Research question 2: “How can the total treatment and drainage of these measures be improved by small adjustments and implementation of new simple measures?”. To answer Research question 1, “What drainage and treatment measures exist today?”, a field study was performed by mapping existing measures. However, before the field study, data was collected about the stormwater system in different areas in Gothenburg in order to select study areas and to prepare the field study. To answer Research question 3 and 4, modelling was performed both for the current system and with implemented improvements to increase the treatment of the stormwater. These results were compared to evaluate the potential benefits. Since the entire urban area of Gothenburg could not be mapped, five sub-catchments were selected to be studied more closely. These were selected in order to get a representative picture of the entire city.

## 3.1 Field study preparations

Firstly, data were collected about Gothenburg in order to select study areas. General information was gathered for the entire area of Gothenburg, such as land-uses, division of sub-catchments, etcetera. When the study areas were selected, detailed data about the stormwater system were collected for these specific studied sub-catchments. A description of the collected geographical data can be seen in Table 3.1. For data processing, the Geographical Information System (GIS) tools ArcGIS and QGIS were used throughout the project.

*Table 3.1 Collected data for the study. Abbreviations: TPTA (Traffic and Public Transport Authority), SWW (Sustainable Waste and Water), SCB (Sweden Statistics).*

| Data | Comment | Source | Received |
|---|---|---|---|
| **Sub-catchments** | Shape-file | SWW | 2018-01-25 |
| **Land-use** | Shape-file | SWW | 2018-01-22 |
| **Administration map** | Shape-file, Separation of public and private land | SWW | 2018-01-30 |
| **Orthophoto** | TIF-file, 0.06m | SWW | 2018-01-30 |
| **Digital elevation model** | DEM, 0.5m | SWW | 2018-01-30 |
| **Impervious surfaces** | Shape-file, roofs, roads, paved surfaces | SWW | 2018-01-30 |
| **Ditches** | Shape-file | SWW | 2018-01-22 |
| **Streams** | Shape-file | SWW | 2018-01-22 |
| **Water-course** | Shape-file | SWW | 2018-01-22 |
| **Urban area borders** | Shape-file | SCB | 2018-02-20 |
| **Traffic intensities** | Shape-file | TPTA | 2018-03-26 |
| **Storm drains, ditch drains, pipes own by TPTA** | Shape-file | SWW | 2018-01-30 |
| **Stormwater sewer network** | Shape-file | SWW | 2018-01-30 |
| **Combined sewer network** | Shape-file | SWW | 2018-01-30 |

### 3.1.1 Included types of measures and improvements

From the literature study, it was identified what to expect and should be observed during the field study. The following existing simple measures were to be mapped in the field:

- Ditches: grass ditches and swales
- Vegetated filter strips

The literature study also resulted in examples of possible improvements which was mapped in the field study. Possible improvements included: (a) improving existing measures; and (b) improving the stormwater management in the area by implementing new simple measures. The improvements to be mapped in the field study were:

a) improve existing measures by:
    1 increase drained traffic surface by:
        i. removing curb stones
        ii. covering or throttling storm drains
    2 increase efficiency of measures by:
        i. deepen grass surface by excavation
        ii. adjust height of inlets to pipe network in ditches
        iii. delay stormwater with screens in ditches
b) implement new measures.
    1 Areas suitable for swales
    2 Areas suitable for grass ditches
    3 Areas suitable for filter strips

### 3.1.2 Screening with SCALGO Live

The stormwater modelling tool SCALGO Live was used for studying flow directions and stored volumes in the studied areas. The received Digital Elevation Models, DEM, with resolutions of 0.5×0.5 m for the selected study areas did not include the elevation of buildings. Therefore, the elevation models were modified by rising the model surface by 10 m at the location of all buildings. This was performed to make the water flow simulations more realistic. The modified DEM-models were imported into SCALGO to analyse depression areas, runoff flows and watersheds. The SCALGO models were also used as a tool to identify possible improvements, described in Chapter 3.3.2.

The model treats all surfaces as completely impervious, which is not true for all surfaces in the studied areas. This assumption is more applicable for very heavy rainfalls and flooding when more surfaces can be considered impervious due to saturated ground conditions. However, since this study mainly focus on traffic surfaces, which are highly impervious, this simplification does not have a large effect on the flow directions on the road surfaces.

## 3.2 Study Areas

This section describes the case study area, the municipality of Gothenburg. General information about the municipality is provided as well as more detailed information about selected sub-catchments studied more in-depth.

### 3.2.1 City of Gothenburg and selection of study areas

Gothenburg is located on the west coast of Sweden at the outlet of the Göta River and is Sweden's second largest city, with more than half a million inhabitants (City of Gothenburg, n.d.). The urban area of Gothenburg is shown in Figure 3.1. The city is characterized by its hills of bedrock and valleys with clay (Nationalencyklopedin, n.d.). In the areas closest to the river, the soil layers are mostly filling materials with contaminants that risk to spread if stormwater is infiltrated (City of Gothenburg, 2017). Clay, bedrock, and filling materials limit the possibility to infiltrate stormwater. However, in the outskirts of the municipality, corresponding to 10 % of the total surface of the city, areas are found with permeable materials suitable for infiltration. In these areas, ditches can be found as a part of the stormwater system.

Sustainable Waste and Water is the municipal department responsible for the common water, wastewater and stormwater services (Göteborgs Stad, n.d.). There are 871 km pipes and 12 km tunnel beneath the city dedicated for stormwater. In addition, 499 km pipes are used in the combined sewer system where stormwater and wastewater is led to the wastewater treatment plant, Ryaverket. Until 1955, combined wastewater system was constructed in Gothenburg. Since then, separated system has been implemented when reconstructing and extending the network (City of Gothenburg, 2017). In 2009, 4.05 $Mm^3$ wastewater was released through CSOs with little or no treatment (Göteborgs Stad, n.d.).

Gothenburg has 1 626 km of municipality owned roads and the total area of all roads in the municipality is 1 722 ha, corresponding to 3.8 % of the total land area of the municipality of 4 507 100 ha (Statistics Sweden SCB, 2013).

The average precipitation per year in Gothenburg used for stormwater quality simulations is 840 mm/year (Kretslopp och Vatten, 2015). This can be compared to the average precipitation in Gothenburg during 1961-1990 of 748 mm/year (Statistics Sweden SCB, 2014).

The catchments in Gothenburg are, in the document “Stormwater treatment requirements” by the municipality, divided into 22 receiving waters (Göteborgs Stad, 2017):

- Coastal areas
- Delsjöbäcken
- Finngösabäcken
- Göta River, downstream the inlet to drinking water treatment plant
- Göta River, upstream the inlet to drinking water treatment plant
- Haga Å
- Hamnkanaler/Fattighusån
- Hovåsbäcken
- Krogabäcken
- Kvibergsbäcken
- Kvillebäcken
- Kvillen
- Låssbybäcken
- Lärjeån
- Madbäcken
- Mölndalsån
- Osbäcken
- Ottebäcken
- Stora Ån
- Säveån
- Vitsippsbäcken
- Wastewater treatment plant, Ryaverket

Each receiving water has a catchment, which is divided into smaller sub-catchments. Five of these sub-catchments are evaluated in this study (Table 3.2) (Figure 3.1). The five areas cover different land-uses and both central areas and areas near the outskirts of the city. The selection of sub-catchments was based on the gathered information about the entire municipality of Gothenburg. Sub-catchments that include national roads were excluded which heavily limited the selection.

*Table 3.2 Overview of general information about the studied sub-catchments.*

| Sub-catchment | Type of area | Total size [ha] | Residential [%] | Harbour [%] | Industrial [%] | Nature [%] | Park [%] | Open land [%] |
|---|---|---|---|---|---|---|---|---|
| Ringön | Industrial | 78.4 | 0 | 6 | 94 | 0 | 0 | 0 |
| Stigberget | Residential, blocks | 105.4 | 71 | 0 | 0 | 2 | 20 | 7 |
| Lillhagen | Spare developed | 237.0 | 39 | 0 | 12 | 42 | 3 | 5 |
| Örgryte | Residential, detached housed | 63.7 | 69 | 0 | 0 | 25 | 0 | 6 |
| Dag Hammarskjöldsleden | Residential, industrial, highway | 391.3 | 37 | 0 | 24 | 25 | 1 | 14 |

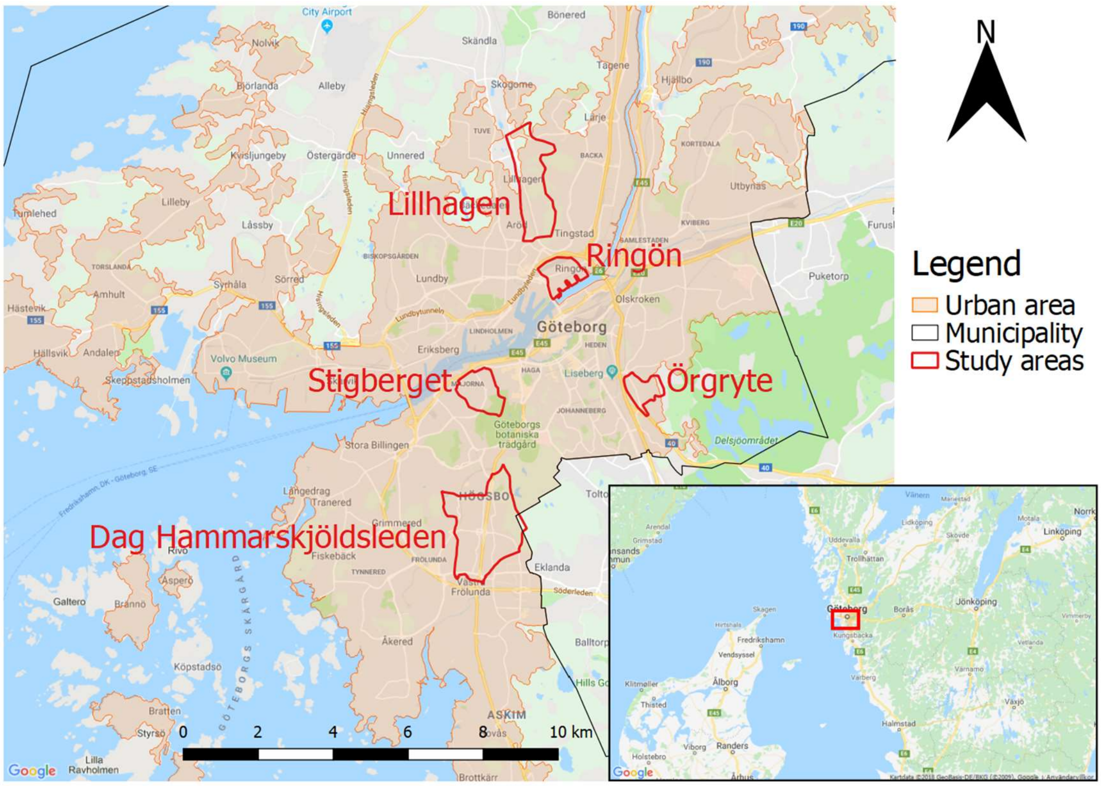



*Figure 3.1 Overview of Gothenburg with the location of the studied sub-catchments in red. The orange indicates the urban area and the black line is the border of the municipality of Gothenburg. Background map from Google open source layer in QGIS (Map data ©Google 2018).*

### 3.2.2 Ringön

Ringön is an industrial area located near the city centre and its receiving water Göta River, downstream the raw water inlet of the drinking water treatment plant. The sub-catchment is shown in Figure 3.2 and the land-uses are presented in Table 3.3. The catchment also includes the area Frihamnen, but this was excluded in this study due to the future development plans of the area. The pipe network is a separate system in Ringön.

Göta River is seen as a less sensitive receiving water (Göteborgs Stad, 2017). Since the river is modified to a large extent, the classification is based on the ecological potential, not the ecological status. The classification of the ecological potential is unsatisfying and the river does not achieve a good chemical status. Environmental problems include: environmental toxins, changed flow conditions, morphological changes, and foreign species (Vattenmyndigheterna, Länsstyrelserna, & Havs och Vattenmyndigheten, 2017a).

The area consists of 5.9 ha traffic surfaces, which corresponds to 7.5 % of the total area.

*Table 3.3 The different land-uses in Ringön and the percentage of the total area.*

| Land-use | Area [ha] | Percentage of the total area [%] |
|---|---|---|
| Residential | 0.0 | 0 |
| Harbour | 4.5 | 6 |
| Industrial | 73.9 | 94 |
| Nature | 0.0 | 0 |
| Park | 0.0 | 0 |
| Open land | 0.0 | 0 |
| **Total** | **78.4** | **100** |

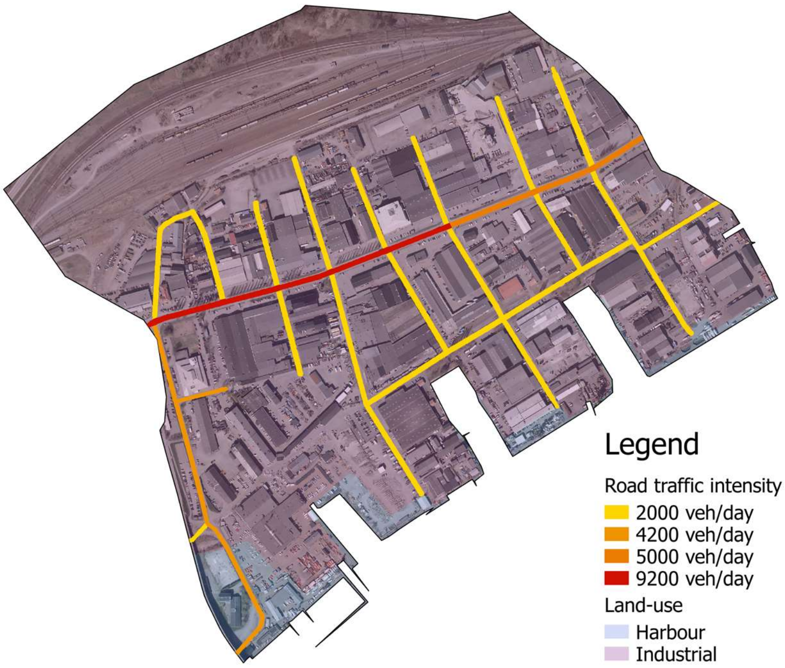



*Figure 3.2 Map of the land-use and road network in Ringön. Purple is industrial area and blue is harbor area. Roads with higher traffic intensities are red.*

### 3.2.3 Stigberget

Stigberget is a dense residential area with blocks. The sub-catchment is shown in Figure 3.3 and the land-uses are presented in Table 3.4. Stigberget is a sub-catchment of Göta River, downstream the raw water inlet of the drinking water treatment plant. The area has a combined sewer network which conveys stormwater from the sub-catchment to the wastewater treatment plant, Ryaverket. The CSOs, caused by high load on the combined sewers system from stormwater, are discharged into Göta River. The conversion into a separate system has begun in the area.

The area consists of 11.9 ha traffic surfaces, which corresponds to 11.3 % of the total area.

*Table 3.4 The different land-uses in Stigberget and the percentage of the total area.*

| Land-use | Area [ha] | Percentage of the total area [%] |
|---|---|---|
| Residential | 74.8 | 71 |
| Harbour | 0.0 | 0 |
| Industrial | 0.0 | 0 |
| Nature | 2.1 | 2 |
| Park | 20.9 | 20 |
| Open land | 7.6 | 7 |
| **Total** | **105.4** | **100** |


*Figure 3.3 Map of the land-use and road network in Stigberget. Orange is residential area, dark green is nature area, light green is park area and grey is open land. Roads with higher traffic intensities are red.*

### 3.2.4 Lillhagen

The receiving water of Lillhagen is the stream Kvillebäcken and the pipe network is separated. The area is located on the eastern side of the stream, in the outskirt of the city and contains residential areas with detached and semi-detached houses and an industrial area. The sub-catchment is shown in Figure 3.4 and the land-uses are presented in Table 3.5.

Kvillebäcken is classified as a sensitive receiving water with moderate ecological status and does not achieve good chemical status (Göteborgs Stad, 2017) (Vattenmyndigheterna, Länsstyrelserna, & Havs och Vattenmyndigheten, 2017b). The environmental issues are eutrophication, morphological changes, and environmental toxins.

The area consists of 16.2 ha of traffic surfaces, which corresponds to 6.7 % of the total area.

*Table 3.5 The different land-uses in Lillhagen and the percentage of the total area.*

| Land-use | Area [ha] | Percentage of the total area [%] |
|---|---|---|
| Residential | 92.2 | 39 |
| Harbour | 0.0 | 0 |
| Industrial | 27.5 | 12 |
| Nature | 99.0 | 42 |
| Park | 6.3 | 3 |
| Open land | 12.0 | 5 |
| **Total** | **237.0** | **100** |


*Figure 3.4* *Map of the land-use and road network in Lillhagen. Orange is residential area, purple is industrial area, dark green is nature area, light green is park area and grey is open land. Roads with higher traffic intensities are red.*

### 3.2.5 Örgryte

Örgryte is a residential area with mainly detached houses located in eastern Gothenburg, near the city centre. The sub-catchment is shown in Figure 3.5 and the land-uses are presented in Table 3.6. The original receiving water is Mölndalsån, but since the area mostly consist of a combined sewer system the actual receiving water is the wastewater treatment plant, Ryaverket. However, CSOs in the area are discharged into Mölndalsån, as do the separate stormwater pipe network in the south end of the area.

Mölndalsån is a sensitive receiving water with moderate ecological status and is not achieving good chemical status (Göteborgs Stad, 2017) (Vattenmyndigheterna, Länsstyrelserna, & Havs och Vattenmyndigheten, 2017c). The environmental issues are eutrophication, morphological changes, and environmental toxins.

The area consists of 6.7 ha of traffic surfaces, which corresponds to 10.4 % of the total area.

*Table 3.6 The different land-uses in Örgryte and the percentage of the total area.*

| Land-use | Area [ha] | Percentage of the total area [%] |
|---|---|---|
| Residential | 43.7 | 69 |
| Harbour | 0.0 | 0 |
| Industrial | 0.0 | 0 |
| Nature | 15.9 | 25 |
| Park | 0.0 | 0 |
| Open land | 4.1 | 6 |
| **Total** | **63.7** | **100** |

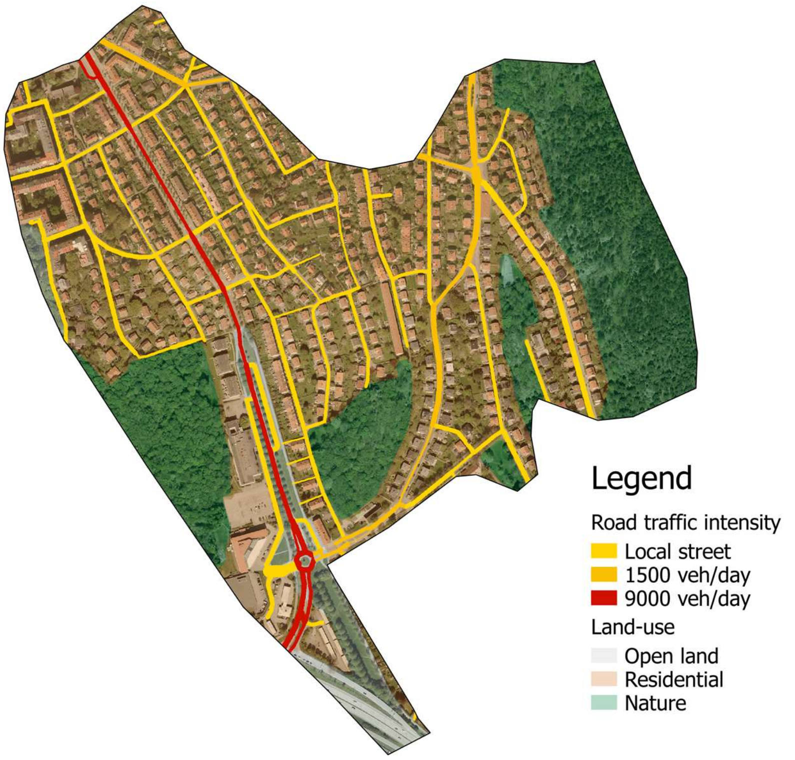



*Figure 3.5 Map of the land-use and road network in Örgryte. Orange is residential area, dark green is nature area and grey is open land. Roads with higher traffic intensities are more red.*

### 3.2.6 Dag Hammarskjöldsleden

Dag Hammarskjöldsleden is an area next to a large traffic route with the same name. The area consists of industrial areas and residential areas with multi-family, detached and semi-detached houses. The sub-catchment is shown in Figure 3.6 and the land-uses are presented in Table 3.7. The pipe network is separate and the receiving water is Stora Ån, which is a very sensitive water (Göteborgs Stad, 2017).

The ecological status of Stora Ån is moderate and it does not achieve good chemical status (Vattenmyndigheterna, Länsstyrelserna, & Havs och Vattenmyndigheten, 2017d). Environmental issues are eutrophication, morphological changes, and environmental toxins.

The area consists of 36.7 ha of traffic surfaces, which corresponds to 9.4 % of the total area.

*Table 3.7 The different land-uses in Dag Hammarskjöldsleden and the percentage of the total area.*

| Land-use | Area [ha] | Percentage of the total area [%] |
|---|---|---|
| Residential | 143.2 | 37 |
| Harbour | 0.0 | 0 |
| Industrial | 94.1 | 24 |
| Nature | 98.2 | 25 |
| Park | 2.6 | 1 |
| Open land | 53.2 | 14 |
| **Total** | **391.3** | **100** |

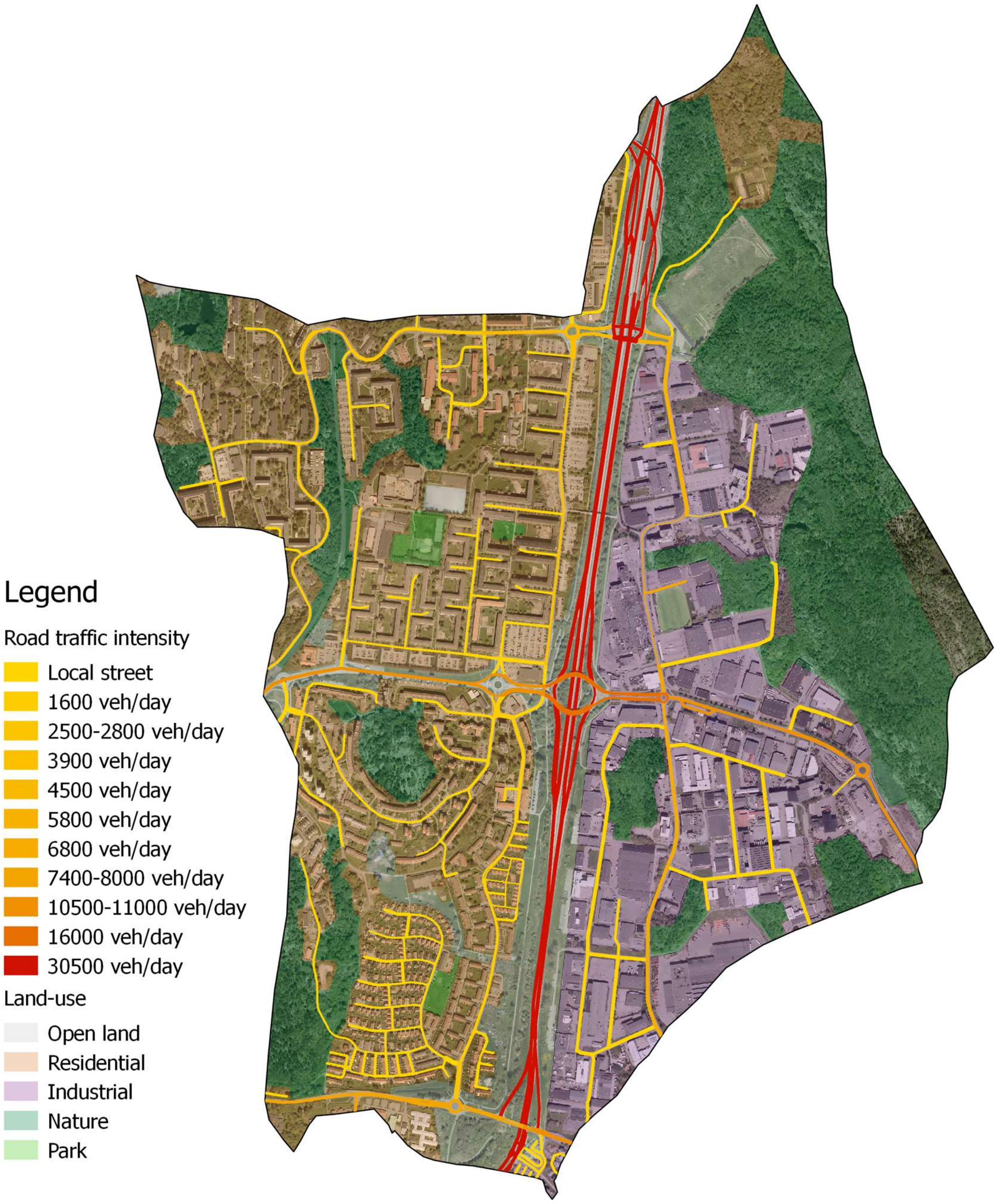



*Figure 3.6* *Map of the land-use and road network in Dag Hammarskjöldsleden. Orange is residential area, purple is industrial area, dark green is nature area, light green is park area and grey is open land. Roads with higher traffic intensities are red.*

## 3.3 Field study

A field study was performed to investigate the presence of simple traffic-related stormwater measures, possible improvement of existing measures, and possible new simple measures (Research questions 1 & 2). The field study was a visual inspection executed by driving on all roads within the selected sub-catchments. The inspection was performed during the time-period 5$^{th}$ to 15$^{th}$ of February 2018. During this period, the weather was shifting between snowing to fair weather with temperatures around 0 °C, this sometimes resulted in snow covering the studied surfaces.

Notes were taken on maps produced for the specific purpose. The maps included the road network, buildings for orientation, the position of storm drains, water-courses, streams and already known ditches. In addition, pictures were taken of some relevant situations and details as a complement to the notes.

### 3.3.1 Existing measures

When a measure was observed, the relevant features were noted on the maps. The features registered for grass ditches and swales were:

- approximate location. More detailed information regarding the geographical position was collected from orthophotos and elevation models.
- dimension of cross section; depth, width of bottom, width of top. Measured with folding rule and measuring tape.
- surface characteristics related to Table 2.3.
- possible connection to pipe network.

If the properties of the grass ditch or swale varied largely along the stretch, the measure was divided into smaller segments with separate properties. Additionally, it was registered where traffic-related stormwater was led neither to the stormwater system nor directly to a grass ditch or a swale. At these locations, the water flowed over green areas and thereby being filtered to some extent. The locations of these filter strips were noted on the maps together with comments on the surface characteristics. Due to the large extension of these measures, properties regarding their dimensions were gathered later from orthophotos and elevation models.

Due to the very high number of storm drains and gullies within the areas, no explicit method of inventory was applied. To study whether all storm drains found in the field study, existed in the collected data layer and vice versa, would be far outside the time frame of this project. Instead, notes were taken when the existence or absence of storm drains affected the runoff to the studied measures. If there was any uncertainty about the existence or absence of storm drains, this was controlled in orthophotos.

### 3.3.2 Localizing improvements and new simple measures

Places where improvements of current measures were possible and available areas where new simple measures (Chapter 3.1.1) could be implemented were noted. Improvements that would require more comprehensive adjustments were not considered. For the improvements, the following nine restrictions were set:

1. The inclination of the road must be to the desired direction (unreasonable to change the inclination of road surface).
2. Only municipal areas, not private.
3. Exclude areas separated from the road by a sidewalk.
4. Must not increase the risk of flooding of roads or other properties.
5. Must not create road drainage problems.
6. Must not promote erosion of ditches and filter strips.
7. Preferably, no trees should be damaged by the increased amount of water.
8. The filter strips must not be too steep.
9. The present function of the area should not be lost.

## 3.4 Data processing

After the field study, notes from the visual survey were processed and digitalized. These notes and information from previously collected data were then used to calculate results and inputs for further simulations.

### 3.4.1 Digitalizing existing measures

The notes of the existing measures were processed into GIS shape-files. Grass ditches and swales were drawn as polylines in GIS-layers and other measures such as filter strips were drawn as polygons. The specific position of the measure was based on field observations, orthophotos, taken pictures, and elevation models.

For grass ditches and swales, the digitalized information, in addition to the spatial location, was the:

- depth.
- width at top.
- width at bottom.
- surface characteristics.
- connection to pipe network.

For filter strips, the following data was included:

- Location and extension
- Surface characteristics
- Connection to pipe network

### 3.4.2 Digitalizing possible improvements and new simple measures

Available areas noted for possible new simple measures were drawn as polygons in shape-layers. Comments were added regarding what the improvement would include. For example: removing curb stones; throttling or covering storm drains; and/or excavation to create a ditch. In addition, notes were included regarding:

- surface characteristics.
- connection to pipe network.
- comprehensiveness of implementing improvement.

In addition to new areas that can be used to improve the stormwater system, comments were also included regarding possible improvements on the already existing measures. For example, if more water can be drained to the measure from the road by removing curb stones and/or throttling storm drains, and improving the storage or treatment efficiency of the measure by rising outlets and excavating more soil.

### 3.4.3 Data processing

QGIS was then used to calculate results and inputs for further simulations. Calculated properties were the:

- length of ditches.
- side slopes of ditches.
- surface area of measures.
- surface area of improvements.

### 3.4.4 Determining flow paths

To evaluate the mapped existing measures, the flow paths from road surface to receiving water had to be determined. The method for determining the surface flow on the roads is described in Chapter 3.4.6. Flow directions in stormwater conduits were determined by studying the elevation of the bottom of the manholes. To determine the flow direction in the ditches, SCALGO Live was used to study the elevation of the bottom of the ditches.

### 3.4.5 Traffic intensities

In this study, the roads are divided into different classes related to the traffic intensities since this is highly correlated with pollutant concentrations from the road surface. Traffic intensities were collected from the Traffic and Public Transport Authority, which was the most updated and reliable data source. Roads with traffic intensity higher than 1000 vehicles per day (veh/day) were assigned its specific intensity and the smaller local roads were all considered "local streets". These local streets were all assigned the same traffic intensity. This limitation was performed due to lack of data about the traffic intensities on these small roads. However, this limitation was considered insignificant due to the lower impact from these smaller roads. In addition, some assumptions regarding the traffic intensities on the larger roads had to be made where data was lacking. In these cases, roads were assigned the traffic intensities based on connecting roads and study of the surroundings. Some sub-stretches of roads were merged to single stretches with only one average traffic intensity. This was made in order to simplify the data handling.

### 3.4.6 Calculation of road surfaces

To evaluate the pollutant reduction efficiencies of the studied measures, drained traffic surfaces were estimated. Road surface areas were estimated using SCALGO Live, field study results, and collected data about storm drains and pipe network. The areas were drawn as polygons in a GIS-layer and were based on:

- flow paths extracted from SCALGO Live.
- locations of storm drains, based on: maps from the Traffic and Public Transport Authority, field study data, and orthophotos.
- divided according to measure.
- divided for each road and parking lot.

These polygons were connected to the specific ID of the measure and given the specific traffic intensity according to the data from the Traffic and Public Transport Authority.

## 3.5 Simulations of stormwater quality in StormTac

To evaluate the pollutant treatment efficiency of the simple measures (Research questions 3 & 4), the StormTac Web model was used. The main use of StormTac is to achieve data for design of new measures, not evaluate the measures investigated in this study. Nevertheless, the model was considered the best available tool for the purpose of this investigation.

As stated in the literature study (Chapter 2.3.2, Equation (2.1)), the estimation of pollutant reduction efficiency in StormTac is based on, among other factors, the inlet concentration: a higher inlet concentration results in a higher reduction efficiency. Since the ditches collect stormwater from not only the road surfaces, all areas within the watershed of the measure have to be included in the model. Otherwise, if only traffic surfaces are included in the model, the inlet concentrations would be overestimated. Thus, also the reduction efficiency would be overestimated. In conclusion, the StormTac models must include all stormwater in the traffic environment, not only road runoff.

To study the pollutant reduction efficiency of the studied measure, 12 of the 13 standard substances in the StormTac model was used (Table 3.8). The excluded substance, mercury (Hg), was not studied since the pollutant has an exemption to the allowed concentrations in the receiving waters. In addition, the concentrations are mostly affected by the atmospheric deposition and not the traffic intensity (Göteborgs Stad, 2017; Vattenmyndigheterna et al., 2017a).

*Table 3.8 List of the 12 substances used in this study.*

| Abbreviation | Substance | Type |
|---|---|---|
| **P** | Phosphorus | Nutrient |
| **N** | Nitrogen | Nutrient |
| **Pb** | Lead | Metal |
| **Cu** | Copper | Metal |
| **Zn** | Zinc | Metal |
| **Cd** | Cadmium | Metal |
| **Cr** | Chromium | Metal |
| **Ni** | Nickel | Metal |
| **SS** | Suspended solids | Particles |
| **Oil** | Oil | Oil |
| **PAH16** | Polycyclic aromatic hydrocarbons 16 | Organic pollutant |
| **BaP** | Benzo(a)pyrene | Organic pollutant |

### 3.5.1 Simulations of current situation

To begin with, the total loads of contaminants from the entire sub-catchment were estimated. All roads were split into different categories related to their specific traffic intensity. Areas were gathered from the GIS-layers and used as input in StormTac. Each road category was assigned different road land-use types and a specific factor was set related to the traffic intensity. The total pollutant load was then extracted from the model. After this, the existing measures were evaluated for the different study areas. The areas were divided into smaller sub-watersheds according to the presence of the existing measures, flow paths, and pipe network. Each measure was then assigned an individual sub-watershed area in StormTac.

If the outflow from one measure was flowing into another measure, the outflow concentrations from the first measure were used as input to the second measure. This second measure had to be handled in another model file. This caused a lot of data extraction and implementation between the files which could be a source of error.

The simulations in StormTac are described according to the different boxes in the flow chart user interface. The boxes “Runoff”, “Pollutant transport” and “Pollutant treatment” was used in this project.

#### 3.5.1.1 Runoff

In the model, a yearly average rainfall was selected. This parameter was set to 840 mm/year according to recommendation from Sustainable Waste and Water and was the same for all areas. The sub-watershed area of each measure was investigated to find the size of different land-uses and traffic intensities. As mentioned in Chapter 2.3.2, StormTac can be used for both larger scales; entire catchments with input such as residential areas, multifamily area etcetera; or smaller scales such as zoning plans with input such as roofs, grass areas, and roads. Since the aim of this project is to evaluate the effect of individual measures, a smaller scale was selected. The land-uses that was used in the study are described in Table 3.9 together with motivation of their usage. For areas in series, the volume runoff coefficients were assigned manually according to the results from the area upstream.

*Table 3.9 Motivations of selected land-uses in the StormTac models.*

| Land-use category in StormTac | Description/Motivation of usage |
|---|---|
| Forest | Forest areas. |
| Grass area | Green areas with almost exclusively grass |
| Highway road ditch | Ditches along roads with highway standard |
| Industrial area | Industrial properties. |
| Local streets with curb stone | Smaller residential streets where road runoff is conveyed to storm drains. |
| Mixed green area | Mixed green areas including trees, grass and parks. |
| Parking | Parking lots. |
| Park ground | Green areas including paths etcetera. |
| Residential area, excluding road | Residential areas, used for both single family house areas and multi-family house areas. Roads and ditches excluded and handled separately. |
| Roads 1-10 | Roads, given factor according to traffic intensity |

#### 3.5.1.2 Pollutant transport

In the pollutant transport box, the factors, *f*, for the road categories were assigned according to the relationship described in the Equation (3.1).

$$f = \frac{I_t}{1000} \tag{3.1}$$

$f$ factor describing the traffic intensity in StormTac
$I_t$ traffic intensity [veh/day]

Sub-watersheds upstream in series had to be implemented as "own areas" in the areas downstream. For these, concentration of the different pollutants had to be entered manually from the result from the modelled area upstream.

#### 3.5.1.3 Pollutant treatment

In the pollutant treatment box, the evaluated treatment facility was designed. The used values selected to simulate the ditches, grass ditches and swales, are described in Table 3.10 and for filter strips in Table 3.11.

*Table 3.10 Description of selected parameters for simulation of grass ditches and swales in StormTac.*

| Parameter | StormTac's recommendation Standard (min-max) | Used values | Comment |
|---|---|---|---|
| **Design outflow** | From flow detention facility box | - | Not considered for the quality simulations |
| **$n_0$ (Share facility area of reduced watershed area)** | 5.0-12 (2.5-80) % | 0.1-100 | Measured from GIS |
| **$h_1$ (depth)** | ≥ 100 mm | 100-2000 mm | Measured in field study |
| **$h_2$ (filter media)** | 150 (100-1000) mm | 150 mm | Standard value in StormTac used |
| **$h_3$ (coarse sand)** | 0 mm | 0 mm | Not existing in measure |
| **$h_4$ (macadam)** | 0 mm | 0 mm | Not existing in measure |
| **$h_5$ (structural soil)** | 0 mm | 0 mm | Not existing in measure |
| **$h_6$ (subsoil)** | 1000 (0-unlimited), mm<br>Thickness to max groundwater level | 1000 mm | Standard value in StormTac used |
| **Dry pond** | - | No | Not a dry pond |
| **$h_7$ (drainage pipe to subsoil)** | Sum of $h_2$-$h_5$, mm | 150 mm | No drainage pipe |
| **$h_8$ (raised bypass)** | 0 mm | 0 mm | No raised bypass |
| **$n_2$ (filter media)** | Share of drained pore volume<br>0.25 (0.15-0.40) | 0.25 | Standard value in StormTac used |
| **$k_2$ (filter media)** | 200 (50-300) mm/h | 200 mm/h | Standard value in StormTac used |
| **$k_6$ (subsoil)** | 8.0 (1.3-13) mm/h | 8.0 mm/h | Standard value in StormTac used |
| **z (slide slope, 1:X)** | 0-10 | 0.3-5.4 | Measured in field study |
| **L (facility length)** | - | 11-658 m | Measured length from GIS |
| **Polluted ground** | - | No | Only concerning waterproof layer around facility |
| **Biochar** | - | No | Biochar not included |

*Table 3.11 Description of selected parameters for simulation filter strips in StormTac.*

| Parameter | StormTac's recommendation Standard (min-max) | Used value | Comment |
|---|---|---|---|
| **Regression constant** | 1150 (800-2500) | Measured from GIS, $m^2/ha_{red}$ | Facility area's part of reduced watershed area |

In the simulations of the treatment facilities, some values were selected outside the suggested range. This could increase the uncertainty (Larm, 2018a) but had to be done to simulated the existing measures. One reason that the values fall outside the suggested range could be that StormTac was developed for designing new facilities, while this study evaluates already existing measures that were not constructed with consideration of requirements regarding treatment and detention. The parameters are shown in Figure 3.7.

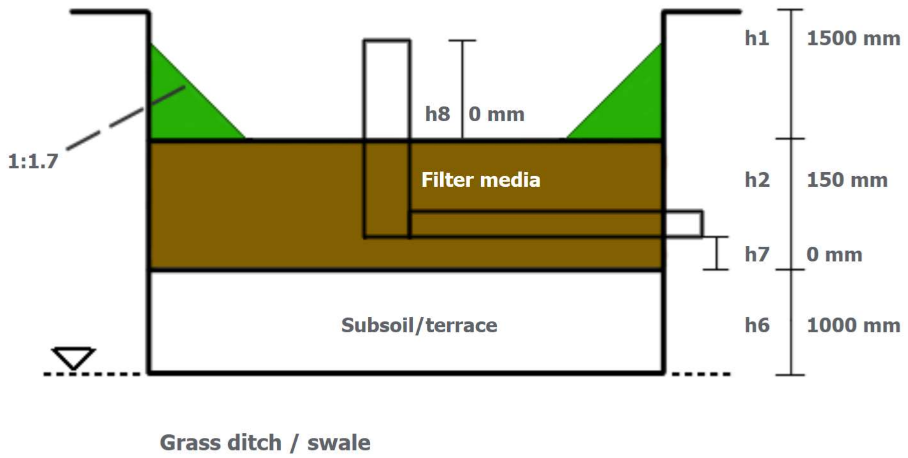



*Figure 3.7 Description of parameters used for designing grass ditches and swales (StormTac AB, 2018).*

In addition, parameters regarding the calculation of the reduction efficiency was adjusted in the pollutant treatment box. Here it could be selected if the parameter would be included or excluded in the calculation.

### 3.5.2 Simulations of possible improvements

Studying and learning the modelling tool resulted in knowledge about which improvements that could or could not be implemented in the model. The following improvements could not be accounted for in the model:

- Rising the outlets in the grass ditches was excluded since it does not increase the reduction efficiency in the StormTac model (Larm, 2018a).
- Two-stage ditches were not found possible to simulate in the StormTac model.
- Check dams were not found possible to simulate in the StormTac model.

New models were set up for the simulation of the situation with possible improvements implemented, following the same procedure as described in Chapter 3.5.1. Included in these models where:

1. Existing measures with larger drained road surface. Simulated by adding the new road area and eventual new areas.
2. New measure found during field study which could receive traffic-related stormwater. Simulated with the same method as existing measures.

The result from the simulation with the implemented improvements was then compared with the simulation of the current situation in order to evaluate the treatment efficiency of the improvements.

# 4 Results

This chapter presents the results of the project. First, results from the field study are presented. Thereafter, results from the simulations are presented.

## 4.1 Results from the field study

In this section, the results from the field study are presented, that aim to answer Research question 1 and 2. The results are presented for each studied sub-catchment, both existing measures and possible improvement measures, followed by general observations. Some pictures taken during the field study are included in Appendix I.

### 4.1.1 Ringön

#### 4.1.1.1 Existing measures

No existing measures were found within the area. All road surfaces were drained to the pipe network and the area was characterised by a large degree of impervious area.

#### 4.1.1.2 Suggested improvements or implementation of new measures

Since no measures were mapped, no adjustments to existing measures could be implemented to improve pollutant reduction or increase the area of drained surfaces. Instead, implementation of new measures was investigated. Considering the restrictions described in Chapter 3.3.2, one area was identified where a new swale could be implemented (Figure 4.1).


*Figure 4.1 Identified improvement within Ringön. Green colour indicates the area where a new measure can be implemented. Red indicates the road surface that would be drained to this new measure.*

The swale would drain 316 $m^2$ traffic surface and would require removal of 125 $m^3$ of soil (Table 4.1). The area of the suggested new measure was located in the industrial land-use category, along a road with traffic intensity 4200 veh/day.

*Table 4.1 Possible improvement measure found in Ringön during field study and the increased traffic surface drained to the measure.*

| # | Improvement measure | New drained road surface |
|---|---|---|
| **1** | Create ditch by excavating 125 $m^3$ of soil | 316 $m^2$ (4200 veh/day) |
| **Total** | Removing curb stone: 0 m<br>Covering storm drains: 0<br>Removing grass layer: 0 $m^2$<br>Removing soil volume: 125 $m^3$ | 316 $m^2$ |

Since the total traffic-related municipal surface within Ringön was 5.9 ha, the suggested new drained area of 316 $m^2$ was only 0.5 % of the total area.

Several green areas were located within the area close to the roads. However, sidewalk, bicycle paths and trees prohibit any simple implementation of measures in these areas.

The stormwater pipe network in Ringön was divided into six branches with discharges to the receiving water, the Göta River. Two of these outlets were located near green areas where larger end-of-pipe solutions may be possible. Simple measures were not considered suitable for this area, larger measures such as detention basins with filters could be investigated.

## 4.1.2 Stigberget

### 4.1.2.1 Existing measures

In the area, no existing measures were found, and all road surfaces were drained to the pipe network.

### 4.1.2.2 Suggested improvements or implementation of new measures

Since no measure were mapped, no adjustments to improve the pollutant reduction or increase the drained surfaces could be implemented on existing measures. Therefore, areas for the implementation of new measures were investigated. Green areas, which could be used for implementation of new simple stormwater measures, were disconnected from the roads by sidewalks or the inclination of the road was leaning to the opposite direction. In addition, old trees also limited the possible improvements in the area. However, one area was mapped where a new swale could be implemented (Figure 4.2). The area was located in the residential land-use category, in a five-way roundabout.

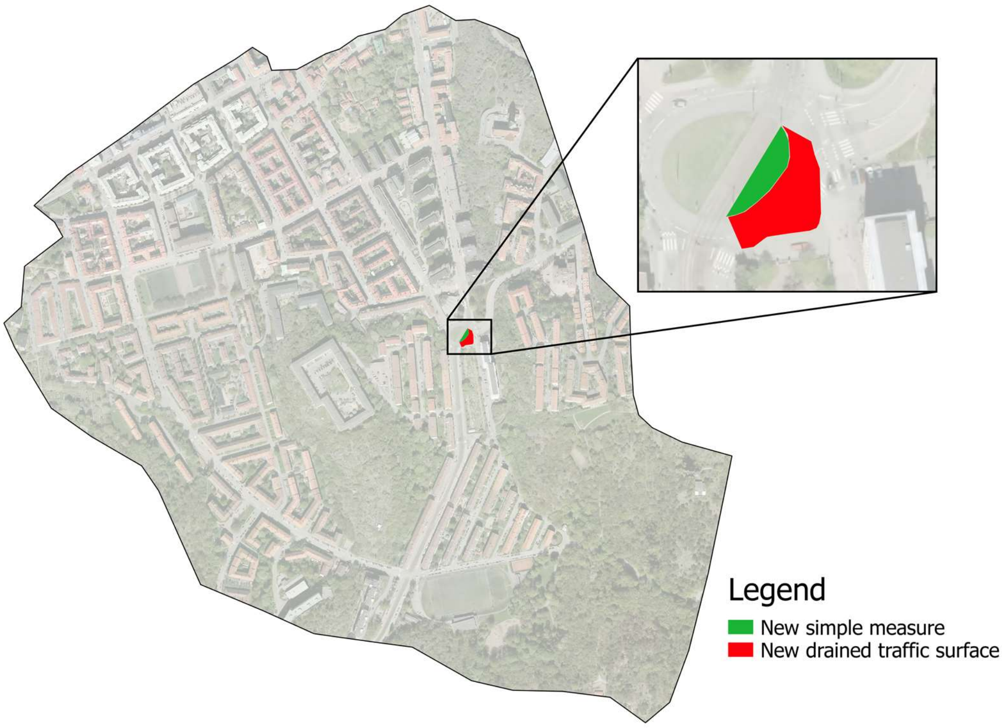



*Figure 4.2* *Identified improvement within Stigberget. Green colour indicates area where the new measure can be implemented. Red indicates the road surface that would be drained to this new measure.*

The suggested new measure would drain 399 $m^2$ traffic surface and the workload needed to implement the measure is described in Table 4.2.

*Table 4.2* *Possible improvement measure found in Stigberget during field study and resulting traffic surface drained to the measure.*

| # | Improvement measure | New drained road surface |
|---|---|---|
| **1** | Create ditch by excavating 54 $m^3$ soil, removing 33 m curb stone, and 33 $m^2$ grass layer | 399 $m^2$ (4200 veh/day) |
| **Total** | Removing curb stone: 33 m<br>Covering storm drains: 0<br>Removing grass layer: 33 $m^2$<br>Removing soil volume: 54 $m^3$ | 399 $m^2$ |

Since the total traffic-related municipal surface within Stigberget was 11.9 ha, the suggested drained area of 399 $m^2$ was only 0.3 % of the total area. Considering the workload described in Table 4.2 and the limited new drained traffic surface, the potential of implementation of new simple measures in Stigberget was considered low.

### 4.1.3 Lillhagen

#### 4.1.3.1 Existing measures

The sub-catchment of Lillhagen was the least developed of the five catchment areas in this study. The area had a lot of grass and forest areas and several existing ditches were mapped (Figure 4.3). Some road surfaces were directly drained to a nearby ditch, but most of the stormwater was first collected in the stormwater pipe network, which was conveyed to ditches before reaching the receiving water Kvillebäcken.

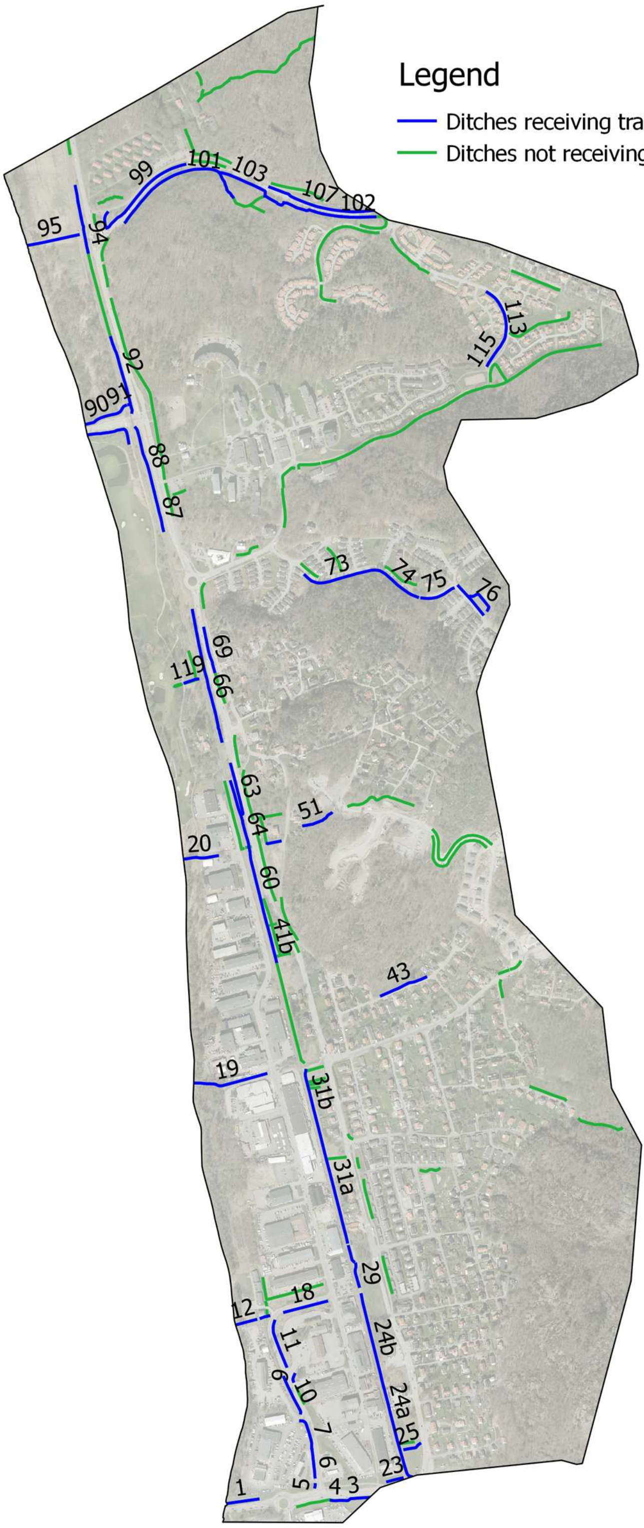



*Figure 4.3* *Map of measures in Lillhagen where blue lines indicate ditches that receive traffic-related stormwater. Green lines indicate mapped ditches which do not currently receive traffic-related stormwater. The numbers correspond with Figure 4.4.*

The ditches were also connected to each other, creating networks. This is described in the flowchart seen in Figure 4.4. The complexity of the ditch network made the area difficult to investigate.

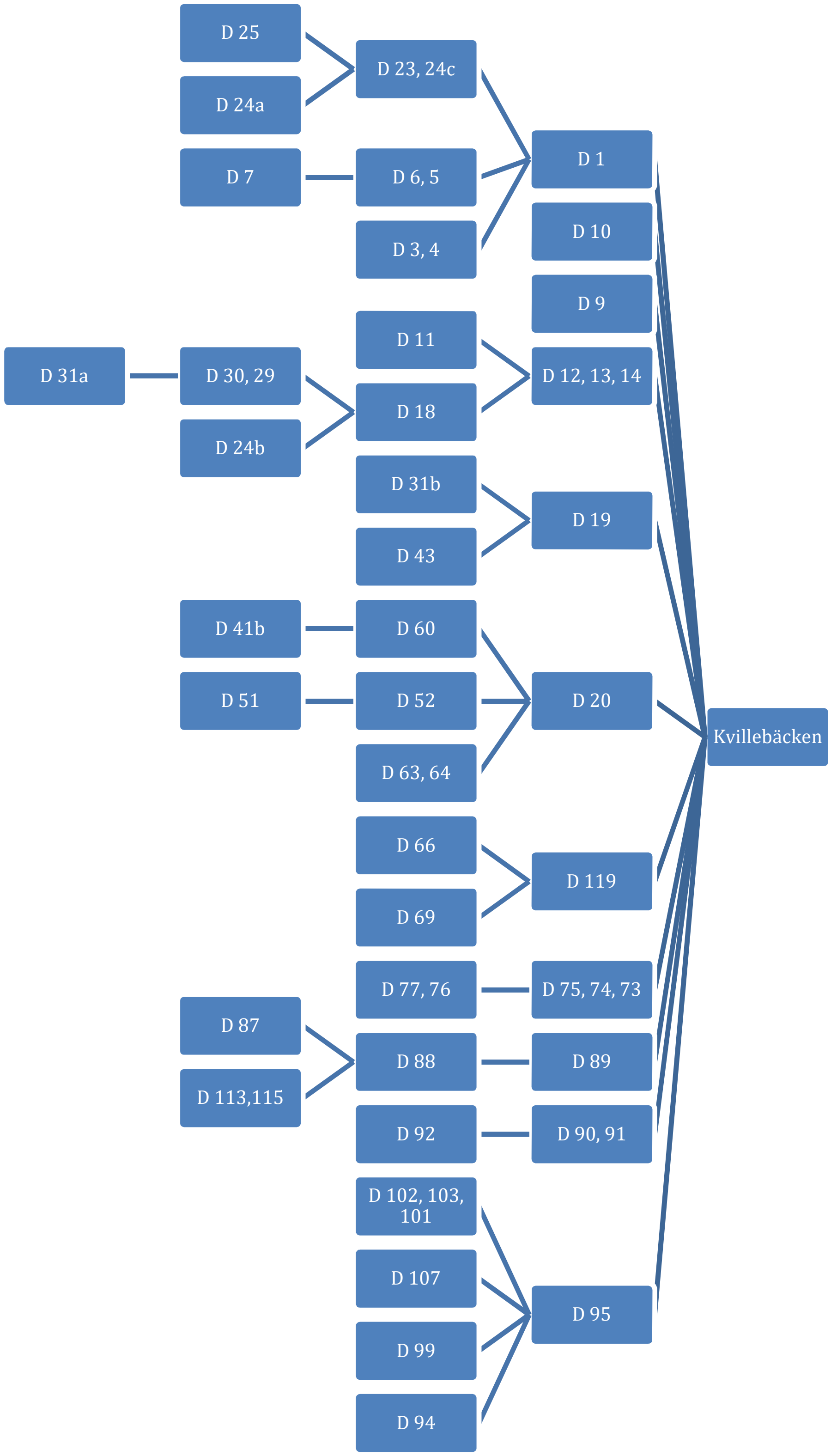



*Figure 4.4 Flow-chart of ditches that receives traffic-related stormwater in sub-catchment Lillhagen. The numbers correspond to the ditches in Figure 4.3.*

As can be seen in Table 4.3, most of the roads in the area were drained to a simple measure, either directly or indirectly. Only 13 % of the traffic surface was conveyed directly to the receiving water Kvillebäcken.

*Table 4.3 Traffic-related surface areas (ha, percentage of the total traffic-related surface) in Lillhagen drained directly and indirectly to measures. The roads are categorized according to the traffic intensity.*

| Category [veh/day] | Total surface [ha] | Directly to measure [ha] | % | Indirectly to measure [ha] | % | Total to measure [ha] | % |
|---|---|---|---|---|---|---|---|
| **Local road** | 10.5 | 0.50 | 5 % | 8.57 | 82 % | 9.08 | 87 % |
| **5200** | 1.47 | 0.48 | 32 % | 0.89 | 60 % | 1.37 | 93 % |
| **5500** | 2.09 | 0.65 | 31 % | 1.07 | 51 % | 1.71 | 82 % |
| **7600** | 0.70 | 0.63 | 90 % | 0.06 | 8 % | 0.69 | 98 % |
| **8800** | 0.53 | 0.37 | 69 % | 0.00 | 0 % | 0.37 | 69 % |
| **16300** | 0.54 | 0.03 | 5 % | 0.51 | 94 % | 0.54 | 99 % |
| **Parking lots** | 0.52 | 0.05 | 11 % | 0.43 | 83 % | 0.49 | 94 % |
| **Total** | **16.3** | **2.71** | **17 %** | **11.5** | **71 %** | **14.2** | **87 %** |

"Local road" was the largest category within the area, but only 5 % of its runoff was led directly to measure. However, 82 % of the runoff from the local roads was indirectly conveyed to a measure. The indirectly drained local roads were mostly found within the residential land-use (Figure 4.5) (Figure 3.4). Some local roads were drained directly to measures, these were found in relatively new residential areas, in proximity to the land-uses "open land" or "nature".

Most of the larger roads were drained to measures, directly or indirectly. The roads that were drained directly to simple measure were mostly found within the land-uses "nature", "industrial", and "open land".

The reason why a large share of the traffic-related stormwater is conveyed to the simple measure in sub-catchment Lillhagen could be the sparse development and the large share of land-uses such as "nature", "open land", and "industrial". These land-uses are probably more likely to contain these simple measures also in other parts of Gothenburg.


*Figure 4.5 Road surfaces in Lillhagen drained to measures. Dark blue areas were drained directly to measures and light blue were indirectly drained to measures via the pipe network.*

#### 4.1.3.2 Suggested improvements or implementation of new measures

During the field study, six possible improvements were found within sub-catchment Lillhagen (Figure 4.6). The numbers in Figure 4.6 correspond to the ones in Table 4.4.

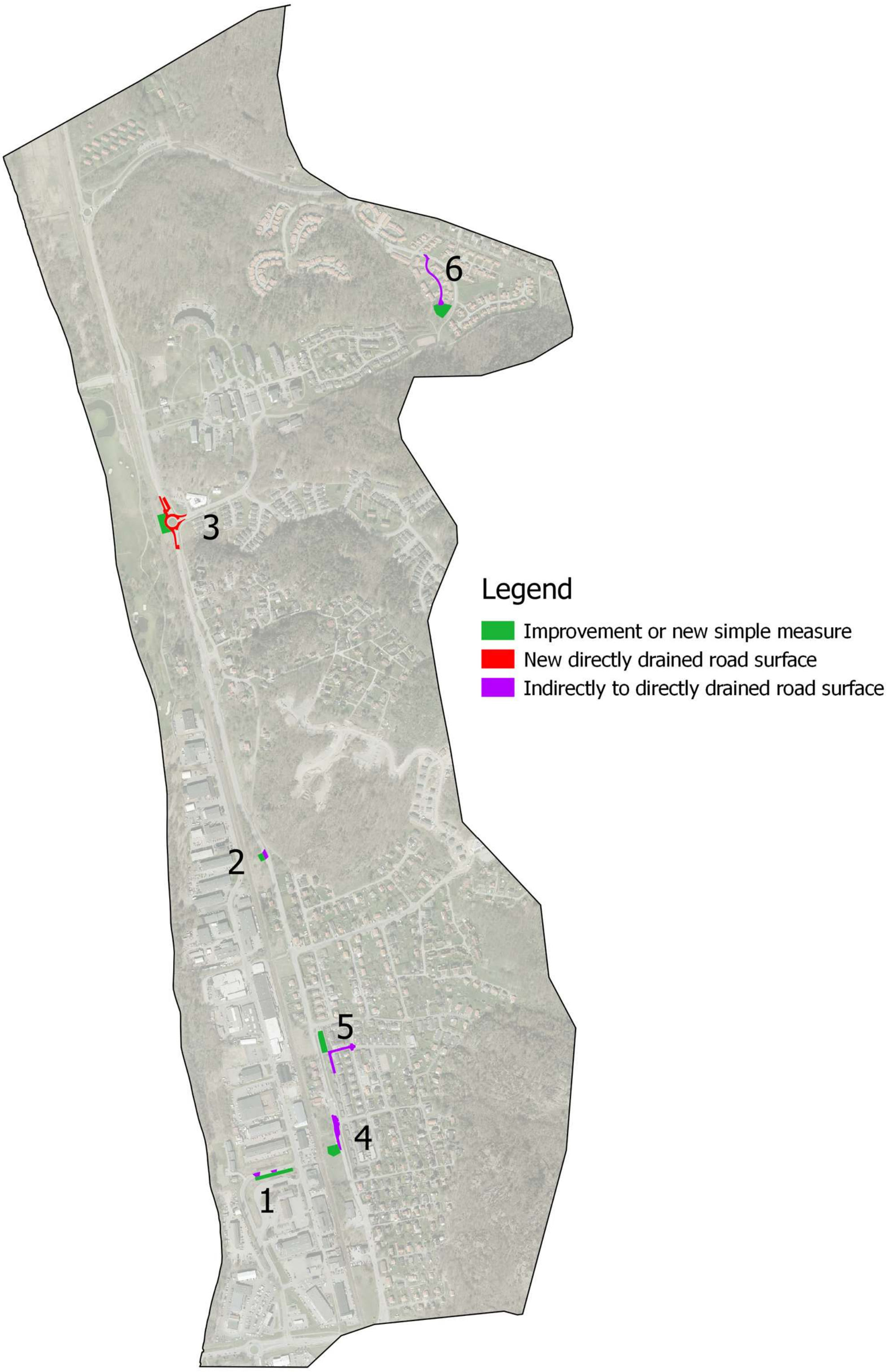



*Figure 4.6 Identified improvements within Lillhagen (numbers corresponding with Table 4.4). Green colour indicates areas where new measures can be implemented. Red indicates new road surface that would be drained to these new measures. Purple indicates road surfaces that would change from being indirectly led to a measure, to direct led to measures.*

Improvement #3 (Table 4.4) would lead to runoff being conveyed directly to a simple measure, which is currently conveyed directly to the receiving water. The remaining five improvements would transfer traffic runoff from indirect to direct discharge to a simple measure (Table 4.4). Managing stormwater higher up in the system would result in longer flow paths in measures and supposedly higher pollutant reductions.

*Table 4.4 Possible improvement measures identified in Lillhagen during field study and resulting traffic surfaces drained to each measure. The numbers of the improvements correspond with Figure 4.6.*

| # | Improvement measure | New drained road surface |
|---|---|---|
| **1** | Convey more stormwater to ditch higher up in system by covering 2 storm drains | D 18: +205 m$^2$ (5200 veh/day)<br>D 12,13,14: -205 m$^2$ (5200 veh/day) |
| **2** | Convey more stormwater to ditch higher up in system by removing 19 m curb stone | D 41b: +172 m$^2$ (5500 veh/day)<br>D 19: -172 m$^2$ (5500 veh/day) |
| **3** | Convey larger road surface to ditch by covering 3 storm drains and removing 45 m curb stone and 45 m$^2$ grass layer | D 87: +1414 m$^2$ (5500 veh/day) |
| **4** | Convey stormwater to new filter strip by removing 10 m curb stone and 90 m$^2$ grass layer | F 1: +762 m$^2$ (5500 veh/day)<br>D 31a: -762 m$^2$ (5500 veh/day) |
| **5** | Convey stormwater to unused ditch by covering 2 storm drains and excavating 6 m$^3$ soil | D 36: +735 m$^2$ (local street)<br>D 31a: -735 m$^2$ (local street) |
| **6** | Convey more stormwater to ditch higher up in system by covering 3 storm drains and excavating 10 m$^3$ soil | D 113, 115: +716 m$^2$ (local street)<br>D 88: -716 m$^2$ (local street) |
| **Total** | Removing curb stone: 74 m<br>Covering storm drains: 10<br>Removing grass layer: 135 m$^2$<br>Removing soil volume: 16 m$^3$ | Direct: +4004 m$^2$<br>Indirect: -2590 m$^2$ |

The total increased traffic surface drained to simple measures would be 0.14 ha if all improvement measures were implemented. However, due to the relatively large effort needed, it could be questioned if it is reasonable. Nevertheless, it can be noticed that the effectiveness of the improvements, i.e. increased road surface compared to the effort, varies and some improvement could be excluded to increase the total effectiveness of all the improvements. For example, improvement #1 and #2 (Table 4.4) demand a low effort compared to other suggested improvements that requires removing grass and soil.

Lillhagen has relatively high potential for improvement compared to other studied catchments. Four of the improvements were found along the larger roads and two were found along local streets (Figure 4.6) (Figure 3.4). Two improvements were located within the land-use “nature”, one within “industrial”, and three within “residential”.

The traffic surface drain directly to the measures, due to the improvements, increased by 4004 m$^2$. However, 2590 m$^2$ were previously drained indirectly to measures.

Therefore, only 1414 $m^2$ is new traffic surface drained to measures. With the implemented improvements and new simple measures, the surface drained directly to measures was increased from 17 % to 19 % of the total traffic surface (Table 4.5).

*Table 4.5 Surface areas (ha, percentage of the total traffic-related surface) in Lillhagen drained directly and indirectly to measures, before and after implementation of suggested improvements.*

| Case | Directly to measure [ha] | % | Indirectly to measure [ha] | % | Total to measure [ha] | % |
|---|---|---|---|---|---|---|
| **Before improvements** | 2.71 | 16.6 % | 11.5 | 70.6 % | 14.2 | 87.2 % |
| **After improvements** | 3.11 | 19.0 % | 11.3 | 69.0 % | 14.4 | 88.0 % |

The total runoff to simple measures was increased by only 0.8 percentage point (Table 4.5). However, the improvements increased the direct runoff and decreased the indirect runoff to simple measures. Figure 4.7 illustrates the network of measures after the implementation of improvements and new measures. The numbers of the affected measures in the flow-chart correspond to the numbers in Table 4.4, which gives further description of the improvement. In Figure 4.7, the measures market with green would receive more direct traffic-related stormwater, and the measures marked with orange would receive less indirect traffic-related stormwater. As can be seen in the flow-chart, the suggested adjustments result in more direct drainage high up in the system and less indirect drainage further down in the system. Consequently, the length of the flow paths for the stormwater in the measures were increased.

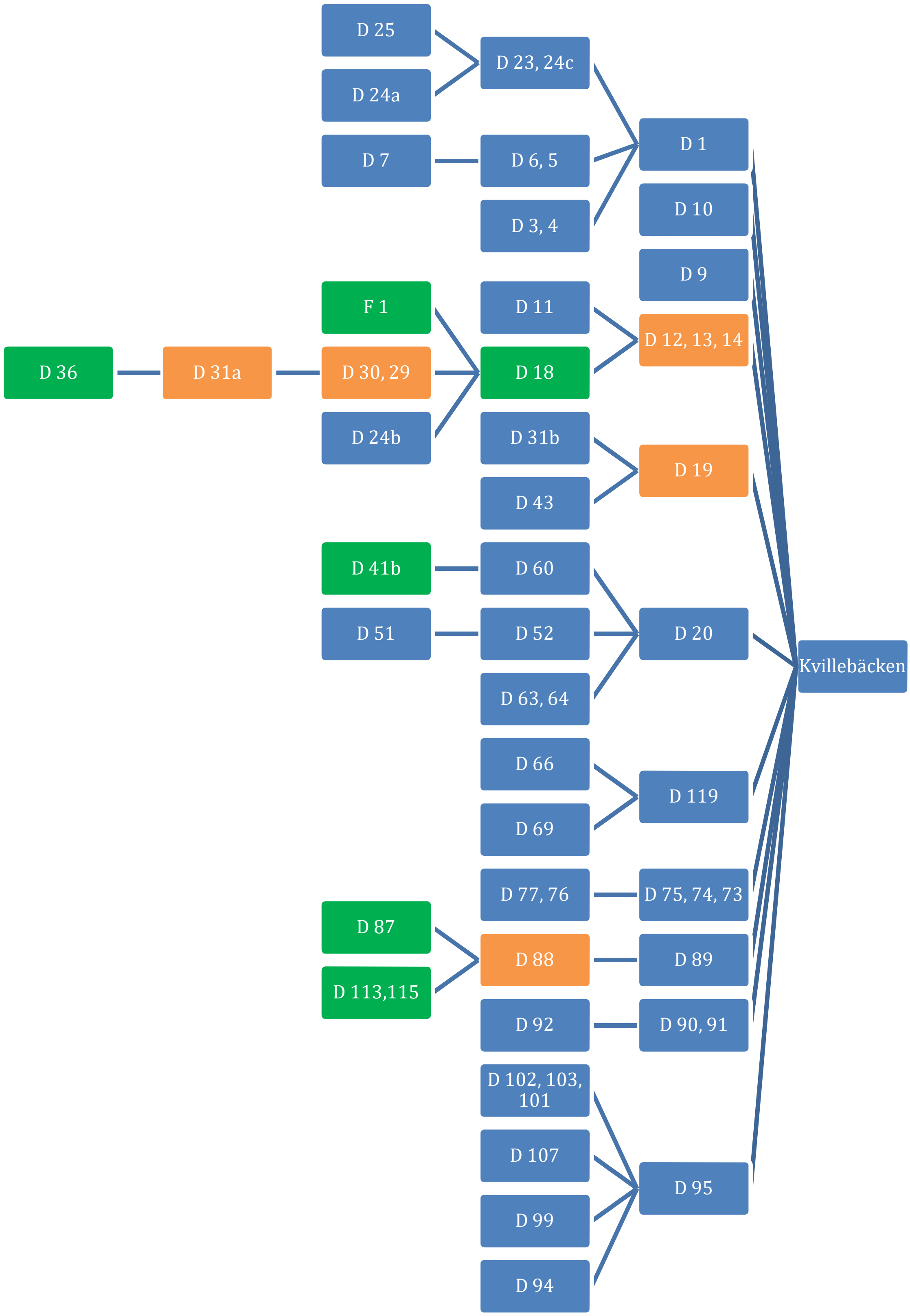



*Figure 4.7* *Flow-chart of ditches and filter strips that receive traffic-related stormwater in sub-catchment Lillhagen with implemented improvements and new measures. Green colour indicates measures with increased directly drained surface. Orange indicates measures with decreased indirect drained surface.*

### 4.1.4 Örgryte

#### 4.1.4.1 Existing measures

In sub-catchment Örgryte, no existing measures were found. All mapped road surfaces were drained to the pipe network, probably due to the dense development in the area and the proximity to the city centre.

#### 4.1.4.2 Suggested improvements or implementation of new measures

Since no measures were mapped, no adjustments to improve the pollutant reduction or increase the drained surfaces could be implemented on existing measures. Therefore, areas for the implementation of new measures were investigated. During the field study in Örgryte, six areas were located where new simple measure could be implemented (Figure 4.8) (Table 4.6).

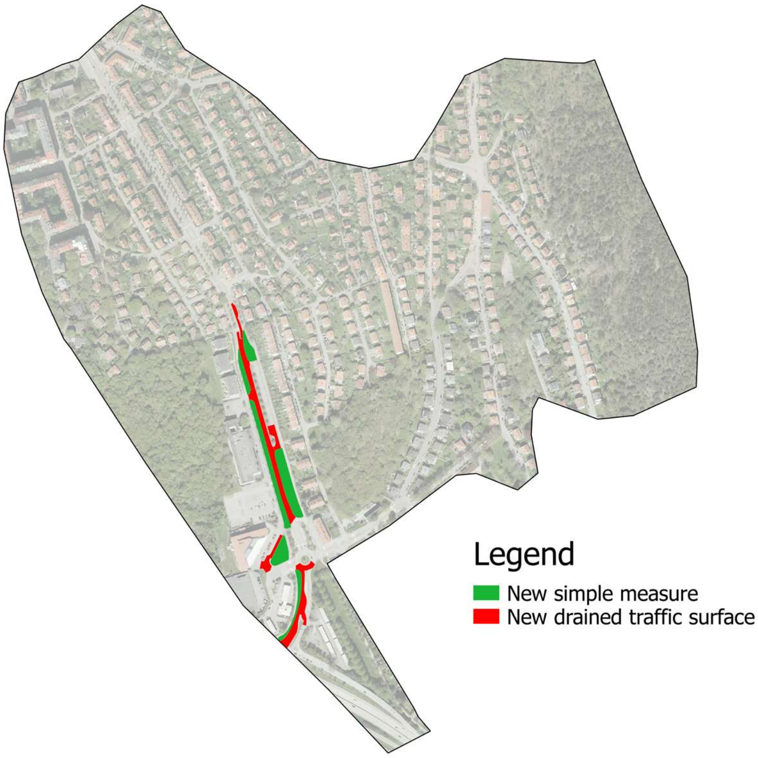



*Figure 4.8 Identified improvements within Örgryte. Green colour indicates areas where new measures can be implemented. Red indicates road surfaces that would be drained to these new measures.*

Since the total traffic-related municipal surface within Örgryte was 6.7 ha, the suggested new drained area (4728 $m^2$) corresponds to 7.1 % of the total area. This was considered a rather large increase. However, considering a large effort is needed for the implementation of the improvements, the potential of small adjustments in Örgryte was considered low. The suggested improvements were found in the land-use "open land" along the large road in the area.

*Table 4.6 Possible improvement measures identified in Örgryte during the field study and the increased traffic surface drained to these measures.*

| # | Improvement measure | New drained road surface |
|---|---|---|
| **1** | Create ditch by excavating 109 $m^3$ soil, removing 13 m curb stone, and covering 2 storm drains | 224 $m^2$ (9000 veh/day) |
| **2** | Create ditch by excavating 33 $m^3$ soil, removing 67 m curb stone, 67 $m^2$ grass layer, and covering 2 storm drains | 663 $m^2$ (9000 veh/day) |
| **3** | Create ditch by excavating 107 $m^3$ soil, removing 207 m curb stone, 195 $m^2$ grass layer, and covering 8 storm drains | 1701 $m^2$ (9000 veh/day) |
| **4** | Create ditch by excavating 29 $m^3$ soil, removing 2 m curb stone, and covering 2 storm drains | 328 $m^2$ (parking lot) |
| **5** | Create ditch by excavating 22 $m^3$ soil, removing 40 m curb stone, 120 $m^2$ grass layer, and covering one storm drains | 452 $m^2$ (local street) |
| **6** | Create ditch by excavating 32 $m^3$ soil, removing 65 m curb stone, 177 $m^2$ grass layer, and covering 3 storm drains | 1360 $m^2$ (9000 veh/day) |
| **Total** | Removing curb stone: 394 m<br>Covering storm drains: 18<br>Removing grass layer: 559 $m^2$<br>Removing soil volume: 332 $m^3$ | 4728 $m^2$ |

### 4.1.5 Dag Hammarskjöldsleden

#### 4.1.5.1 Existing

During the field study in the sub-catchment Dag Hammarskjöldsleden, 30 ditches and two filter strips, which receive traffic-related stormwater, were identified. These measures were mainly found along the larger roads (Figure 4.9). In addition, several ditches were found that did not currently receive any traffic-related stormwater.

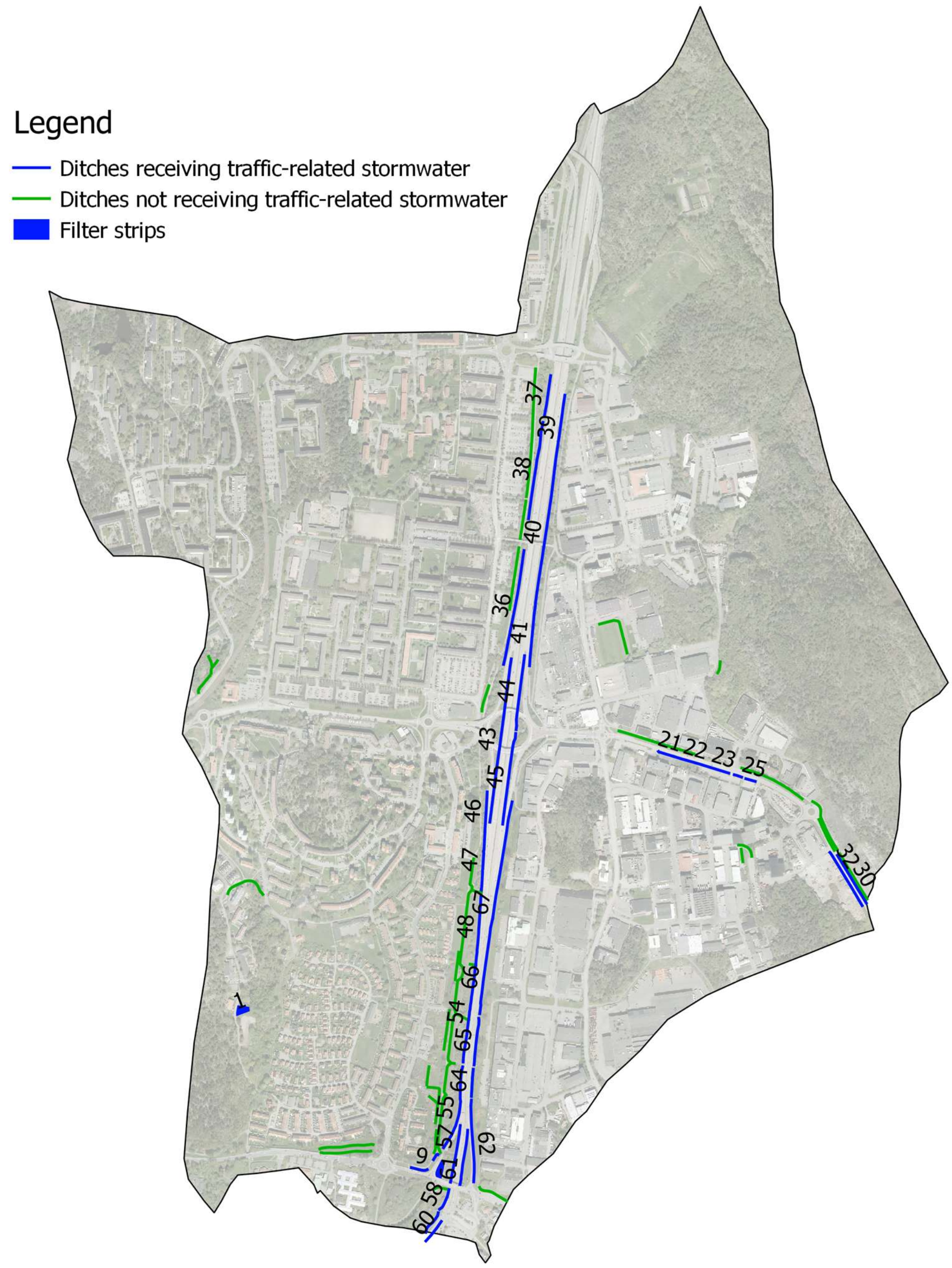



*Figure 4.9 Map of measures in Dag Hammarskjöldsleden where blue lines indicate ditches that receive traffic-related stormwater and blue areas indicate filter strips.*

The traffic surfaces connected to these measures were estimated to 6.0 ha, which is 17 % of the total traffic surface area in the sub-catchment (Table 4.7).

*Table 4.7 Traffic-related surface areas (ha, percentage of the total traffic-related surface) in Dag Hammarskjöldsleden drained to measures. The roads are categorized according to their traffic intensity.*

| Traffic category [veh/day] | Total surface within sub-catchment [ha] | Surface drained to studied measures [ha] | % |
|---|---|---|---|
| **Local streets** | 13.6 | 0.02 | 0 % |
| **1500** | 1.38 | 0.00 | 0 % |
| **2500** | 0.85 | 0.00 | 0 % |
| **4000** | 1.05 | 0.00 | 0 % |
| **6000** | 1.44 | 0.00 | 0 % |
| **8000** | 1.11 | 0.22 | 20 % |
| **9500** | 0.00 | 0.00 | 0 % |
| **10500** | 0.96 | 0.17 | 18 % |
| **11500** | 0.87 | 0.00 | 0 % |
| **16500** | 0.71 | 0.00 | 0 % |
| **30500** | 8.49 | 5.62 | 66 % |
| **Parking lots** | 6.22 | 0.24 | 4 % |
| **Total** | **36.7** | **6.03** | **17 %** |

The mapped simple measures were found mainly along the large roads (Table 4.7) and the surface drained to these measures were found mainly in the land-use categories “open land” and “industrial area” (Figure 4.10) (Figure 3.6). These results suggest that simple measures can be expected along larger roads in the land-use category “open land” also in other parts of Gothenburg.


*Figure 4.10 Map showing traffic surfaces drained to measures in Dag Hammarskjöldsleden.*

#### 4.1.5.2 Suggested improvements or implementation of new measures

During the field study, eight possible improvement measures were found within sub-catchment Dag Hammarskjöldsleden (Table 4.8). The total increased traffic surface drained to simple measure would be 6890 $m^2$ if all improvement measures were implemented. However, due to the relatively large effort required, it could be questioned whether it is reasonable. Nevertheless, it can be noticed that the effectiveness of the improvements, i.e. increased road surface compared to cost, varied and some improvement should be excluded to improve the total effectiveness of all the improvement measures.

*Table 4.8 Possible improvement measures found in Dag Hammarskjöldsleden during the field study and the increased traffic surface drained to these measures.*

| # | Improvement measure | New drained road surface |
|---|---|---|
| **1** | Convey road runoff to unused ditch by removing 160 m curb stone and 425 $m^2$ grass layer | 3024 $m^2$ (10500 veh/day) |
| **2** | Convey road runoff to unused ditch by removing 25 m curb stone, 50 $m^2$ grass layer, and covering one storm drain | 210 $m^2$ (10500 veh/day) |
| **3** | Convey road runoff to unused ditch by removing 27 $m^2$ grass layer | 518 $m^2$ (10500 veh/day) |
| **4** | Create ditch by removing 230 m curb stone, covering 6 storm drains, and excavate 126 $m^3$ soil and 460 $m^2$ grass layer | 1000 $m^2$ (10000 veh/day) |
| **5** | Create ditch by removing 68 m curb stone, covering one storm drain, and excavating 67 $m^3$ soil and 68 $m^2$ soil layer | 250 $m^2$ (10500 veh/day) |
| **6** | Create ditch by removing 60 m curb stone, covering 3 storm drains, and excavating 72 $m^3$ soil and 300 $m^2$ grass layer | 1570 $m^2$ (30500 veh/day) |
| **7** | Increase length of existing ditch by excavating 9 $m^3$ soil | - |
| **8** | Convey road runoff to unused ditch by removing 39 m curb stone, covering one storm drain, and removing 35 $m^2$ grass layer | 324 $m^2$ (10500 veh/day) |
| **Total** | Curb stone: 582 m<br>Storm drains: 12<br>Grass layer: 1365 $m^2$<br>Soil volume: 274 $m^3$ | 6890 $m^2$ |

The total new traffic surface drained to simple measures through improvements was estimated to 1.9 % of the total traffic surface (36.7 ha) within Dag Hammarskjöldsleden. The new total traffic surface drained to simple measures was 6.7 ha, corresponding to 18.3 % of the total traffic surface.

The location of these improvements was along the larger roads (Figure 4.11). Comparing Figure 4.11 with Figure 3.6, it can be seen that the possible improvements were found within the land-use categories “open land” and “industrial area”.

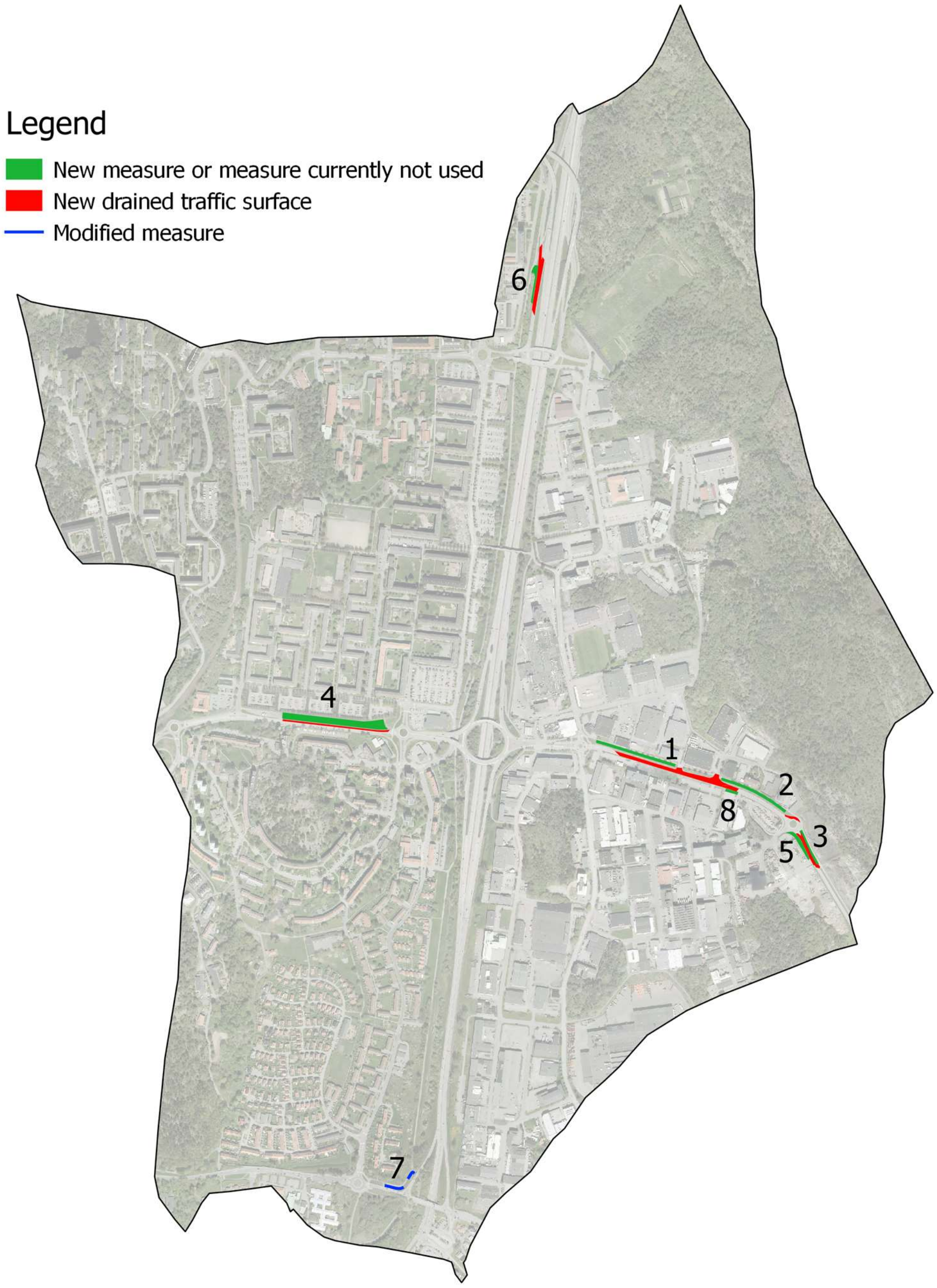



*Figure 4.11 Identified improvements within Dag Hammarskjöldsleden (numbers corresponding to Table 4.8). Green colour indicates areas where new measures can be implemented or existing unused measures that start receiving traffic-related stormwater. Red indicates road surface that would be drained to these new measures. Blue indicates measures that were modified to be more efficient.*

### 4.1.6 Summary and general observations from field study

The results from the field study suggest that areas located near the city centre generally do not have simple measures for stormwater treatment and the possibilities for improvements and implementing new simple measure are limited. However, areas located further away from the city centre which includes land-uses such as "industrial area", "open land" and "nature", are likely to have existing simple measures and possibilities for improvements to a larger extent.

#### 4.1.6.1 Existing measures

During the field study, it was noticed that measures were mostly found along larger roads. The land-use categories "open land", "industrial", and "nature" were especially common which can be seen by comparing Figure 4.3 with Figure 3.4., and Figure 4.9 with Figure 3.6. It was also within these land-uses where the possible improvements were found. This indicates that the probability to find existing measure in other areas in Gothenburg would be greater within these land-uses.

During the field study, it was also observed that most of the smaller roads had sidewalks with storm drains on both sides, draining the road surface. This prevented implementation of small improvements to increase drainage to simple measures and treatment of traffic-related stormwater (Appendix I, Figure A.8). Also, on roads with sidewalk on only one side of the road, runoff was often drained towards the sidewalk and the storm drains to the pipe-network, because of the inclination of the road (Appendix I, Figure A.7). This was also the case along a street built during the last decade.

Often, existing ditches did not appear to be constructed to handle and treat traffic-related stormwater, but to drain surrounding areas and the pavements that can be damaged by stormwater. In the cases where road runoff was drained to ditches, the ditches seemed to be shaped for fast drainage to the pipe-network instead of using the opportunity to reduce the flow in the ditch by increasing the width. This would prevent extreme peak flows and increase the treatment efficiency. However, in most cases, the traffic-related stormwater was instead drained to the stormwater pipe-network through storm drains and gullies.

The ditches were not only located in direct proximity of roads. Several ditches received traffic-related stormwater collected in a conventional pipe network and then released to a ditch. This was especially apparent in Lillhagen and could probably be found in similar areas in Gothenburg. In addition, traffic-related stormwater was in some areas conveyed through several ditches in series connected with culverts.

#### 4.1.6.2 Suggested improvements or implementation of new measures

General observations from all studied sub-catchments were that few simple and possible improvements were found. Large available surfaces were found. However, the inclination of the roads makes it hard or impossible to drain the road surface to these areas. Instead, the water was drained to the storm drains. Another main cause to few identified improvements was the risk of compromising the drainage of the road. Another observation made was that if the restriction for the improvements in Chapter 3.3.2 had been less restrictive, more improvements would be possible. For example, if the road runoff could be conveyed through the sidewalk, many areas could be included which could receive traffic-related stormwater. However, the scope was to investigate simple measures and therefore these were excluded.

## 4.2 Results from StormTac simulations

In this section, to answer Research question 3 and 4, the results from the simulations in StormTac are presented and analysed. For each studied area, two scenarios were investigated: (1) current situation and (2) with implemented improvements and new simple measures.

### 4.2.1 Ringön

#### 4.2.1.1 Simulations of existing measures

Since no existing simple measures were mapped in Ringön, no simulations of pollutant reduction were performed for the current situation.

#### 4.2.1.2 Simulations of improvements or implementation of new measures

To investigate suggested improvement, one new simple measure was modelled in StormTac and the pollutant reduction efficiencies were derived (Appendix II, Table A.1). The pollutant reduction efficiencies were consider high compared to evaluated measures in other areas, for example Lillhagen (Appendix II, Table A.3). The performance of the swale was high due to its large size compared to drained surface and the high inlet concentrations, since it only received traffic-related stormwater.

Less than 1 % of the total loads from the different pollutants reached the new simple measure (Table 4.9). The reduced traffic-related pollution loads were all below 0.5 % of the total loads within the area (Table 4.9). However, the effort needed for implementing the suggested new simple measure in Ringön was considered relatively low and it can therefore be seen as relatively effective. Nevertheless, no large effects on contaminant reduction were expected in the area since no more improvements could be located during the field study. In order to increase the total pollutant reduction from Ringön to the receiving water, a larger share of the traffic surfaces needs to be drained to measures.

*Table 4.9 Results from the StormTac simulations of sub-catchment Ringön with implemented improvements and new simple measure.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic [kg/year] | 6.2 | 100 | 0.44 | 1.3 | 3.9 | 0.014 | 0.43 | 0.31 | 3600 | 34 | 0.035 | $9.3*10^{-4}$ |
| Total loads from traffic to measures [kg/year] | 0.050 | 0.70 | $1.8*10^{-3}$ | $7.7*10^{-3}$ | 0.023 | $8.1*10^{-5}$ | $2.3*10^{-3}$ | $1.5*10^{-3}$ | 19 | 0.19 | $7.0*10^{-5}$ | $3.7*10^{-6}$ |
| Percentage of total traffic loads that reach measures | 0.8 % | 0.7 % | 0.4 % | 0.6 % | 0.6 % | 0.6 % | 0.5 % | 0.5 % | 0.5 % | 0.6 % | 0.2 % | 0.4 % |
| Traffic loads reduced in measures [kg/year] | 0.012 | 0.38 | $1.1*10^{-3}$ | $4.8*10^{-3}$ | 0.016 | $3.8*10^{-5}$ | $1.7*10^{-3}$ | $7.8*10^{-4}$ | 13 | 0.15 | $5.3*10^{-5}$ | $1.7*10^{-6}$ |
| Percentage of total traffic loads reduced in measures | 0.2 % | 0.4 % | 0.2 % | 0.4 % | 0.4 % | 0.3 % | 0.4 % | 0.3 % | 0.4 % | 0.4 % | 0.2 % | 0.2 % |

### 4.2.2 Stigberget

#### 4.2.2.1 Simulations of existing measures

Since no existing simple measures were mapped in Stigberget, no simulations of pollutant reduction were performed for the current situation.

#### 4.2.2.2 Simulations of improvements or implementation of new measures

In similarity with Ringön one new simple measure was modelled in StormTac and the pollutant reduction efficiencies were relatively high (Appendix II, Table A.2). This could be explained by the relatively high regression constant and high inlet concentration.

Only about 0.5 % of the total loads of each pollutant reached the implemented measure (Table 4.10). The reduced traffic-related loads were all below 0.5 % of the total loads within the area (Table 4.10). The results from Stigberget were similar to Ringön and indicates that the traffic surface drained to simple measures needs to be increased to achieve a larger total pollutant reduction in the sub-catchment.

*Table 4.10 Results from the StormTac simulations of sub-catchment Stigberget with implemented improvements and new simple measure.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic [kg/year] | 13 | 150 | 0.98 | 2.6 | 7.0 | 0.022 | 0.42 | 0.34 | 6100 | 37 | 0.041 | $1.2*10^{-3}$ |
| Total loads from traffic to measures [kg/year] | 0.051 | 0.78 | $2.0*10^{-3}$ | $8.7*10^{-3}$ | 0.026 | $9.0*10^{-5}$ | $2.7*10^{-3}$ | $1.8*10^{-3}$ | 22 | 0.23 | $8.1*10^{-5}$ | $4.2*10^{-6}$ |
| Percentage of total traffic loads that reach measures | 0.4 % | 0.5 % | 0.2 % | 0.3 % | 0.4 % | 0.4 % | 0.6 % | 0.5 % | 0.4 % | 0.6 % | 0.2 % | 0.4 % |
| Traffic loads reduced in measures [kg/year] | 0.017 | 0.38 | $1.2*10^{-3}$ | $5.2*10^{-3}$ | 0.018 | $5.3*10^{-5}$ | $1.9*10^{-3}$ | $1.0*10^{-3}$ | 15 | 0.20 | $5.5*10^{-5}$ | $2.3*10^{-6}$ |
| Percentage of total traffic loads reduced in measures | 0.1 % | 0.3 % | 0.1 % | 0.2 % | 0.3 % | 0.2 % | 0.4 % | 0.3 % | 0.3 % | 0.5 % | 0.1 % | 0.2 % |

### 4.2.3 Lillhagen

#### 4.2.3.1 Simulations of existing measures

The simple measures mapped in Lillhagen had lower reduction efficiencies than measures in other areas (Appendix II, Table A.3). The pollutant reduction efficiencies of the studied measures were in a range between 0 to 84 % for the different substances. In general, a trend can be seen that swales with high regression constants have higher efficiencies than grass ditches with low regression constants. In addition to the regression constant and type of measure, the calculations of pollutant reduction efficiencies were also based on the pollutant concentrations into the measures. Hence, it can be noticed that ditches further down in the system have lower pollutant reduction efficiencies, due to more water and lower inlet concentrations.

The results showed that a relatively large share of the pollutants in Lillhagen was reduced in the simple stormwater measures (Table 4.11). Since 87 % of all traffic-related stormwater in Lillhagen was drained to simple measures, the percentages of the traffic-related pollutants that reached measures were high in Lillhagen (80-88 %) compared to other studied areas. However, the percentages that were reduced in the measures varied between the studied substances, between 8 % and 61 % of the total traffic-related load within the sub-catchment. For example, 88 % of the phosphorus from traffic-related land-uses reached the measures, but only 8 % was reduced. The same numbers for oil were 85 % and 61 % respectively. Even if the percentages of pollutants reaching the measures were high, the reduction efficiencies were relatively low for some substances. Consequently, it could be beneficial to increase the efficiency of these measures in order to improve the system.

*Table 4.11 Results from the StormTac simulations in sub-catchment Lillhagen with existing measures.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic [kg/year] | 18 | 210 | 1.4 | 3.8 | 11 | 0.029 | 0.54 | 0.43 | 8200 | 47 | 0.044 | $1.4*10^{-3}$ |
| Total loads from traffic to measures [kg/year] | 16 | 180 | 1.2 | 3.2 | 9.4 | 0.025 | 0.46 | 0.36 | 7000 | 40 | 0.035 | $1.2*10^{-3}$ |
| Percentage of total traffic loads that reach measures | 88 % | 85 % | 83 % | 84 % | 85 % | 85 % | 84 % | 84 % | 85 % | 85 % | 80 % | 84 % |
| Traffic loads reduced in measures [kg/year] | 1.5 | 34 | 0.64 | 1.1 | 3.5 | $9.2*10^{-3}$ | 0.17 | 0.14 | 3500 | 29 | $7.8*10^{-3}$ | $2.4*10^{-6}$ |
| Percentage of total traffic loads reduced in measures | 8 % | 16 % | 46 % | 30 % | 32 % | 32 % | 31 % | 32 % | 43 % | 61 % | 18 % | 17 % |

#### 4.2.3.2 Simulations of improvements or implementation of new measures

The improvements and the new simple measures were implemented in the models and new reduction efficiencies of pollutants were derived (Appendix II, Table A.4). For some measures, the efficiencies were decreased due to the lowered regression constants and decreased incoming concentrations. However, the total pollutant reduction in the measures was increased due to the increased amount of pollutants reaching the measures by implementation of the improvements.

The pollution loads from traffic reaching the measures increased between 0.3-2.2 % when the new and the improved measures were implemented (Table 4.12). The reduction of traffic-related pollutants increased with 1-24 %. The highest increase was observed for organic pollutants. The modifications made in the system resulted in a reduced pollutant load leaving the system and reaching the receiving water. However, the reductions of pollutants achieved by the implemented improvements were low, seen to the total load in the sub-catchment. Consequently, the potential for increasing the treatment by improving simple measures was considered low. The implemented improvements mostly added new traffic surface or moved the surface higher up in the system. For a larger reduced pollutant load in Lillhagen, it would probably be more effective to increase the efficiencies of the existing measures since most of the water is already conveyed to measures. This could however not be simulated in StormTac but it is recommended to be further investigated.

Considering the relatively low effort needed to implement the improvements and the new measures, the suggested adjustments were relatively effective compared to improvements within other studied areas. The adjustments could be worth implementing even though they would not have a significant effect on the total traffic-related pollutant loads from the sub-catchment.

*Table 4.12 Results from the StormTac simulations in sub-catchment Lillhagen with implemented improvements and new simple measures.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic to measures [kg/year] | 16 | 180 | 1.2 | 3.2 | 9.5 | 0.025 | 0.47 | 0.37 | 7000 | 41 | 0.035 | $1.2*10^{-3}$ |
| Difference compared to no improvements | 0.7 % | 1.6 % | 0.3 % | 0.8 % | 1.2 % | 1.4 % | 2.2 % | 1.4 % | 1 % | 1.4 % | 1.1 % | 1.2 % |
| Percentage of total traffic loads that reach measures | 88 % | 86 % | 83 % | 85 % | 86 % | 86 % | 86 % | 85 % | 86 % | 86 % | 80 % | 85 % |
| Traffic loads reduced in measures [kg/year] | 1.6 | 36 | 0.66 | 1.2 | 3.9 | 0.01 | 0.19 | 0.14 | 3600 | 29 | $9.3*10^{-3}$ | $3.0*10^{-4}$ |
| Difference compared to without the improvements | 5 % | 3 % | 3 % | 8 % | 10 % | 10 % | 12 % | 3 % | 4 % | 1 % | 19 % | 24 % |
| Percentage of total traffic loads reduced in measures | 9 % | 17 % | 47 % | 33 % | 35 % | 35 % | 35 % | 33 % | 44 % | 61 % | 21 % | 21 % |

### 4.2.4 Örgryte

#### 4.2.4.1 Simulations of existing measures

Since no existing simple measures were mapped in Örgryte, no simulations of pollutant reduction were performed for the current situation.

#### 4.2.4.2 Simulations of improvements or implementation of new measures

The six new simple measures in Örgryte modelled in StormTac showed higher reduction efficiencies than the measures in Lillhagen and Dag Hammarskjöldsleden (Appendix II, Table A.5). The high pollutant reduction efficiencies are explained by the measures' large size compare to the drained surface and since the measures only receive traffic-related stormwater, which result in high incoming concentrations.

The suggested new simple measures in Örgryte were estimated to receive between 8 % and 17 % of the total traffic-related pollutant loads from the different substances (Table 4.13). This increase in drained traffic surfaces was large compared to other studied sub-catchment areas. However, the efforts for implementing the measures were by far the largest and it can be questioned if these can be considered small adjustments. If the new measures would be constructed, the reductions for the studied substances were estimated to between 3 % and 12 % of the total traffic-related pollutant loads (Table 4.13). Since there was no pollutant reduction in the area before the improvements, this can be considered a noticeable change.

*Table 4.13 Results from the StormTac simulations of sub-catchment Örgryte with implemented improvements and new simple measures.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic [kg/year] | 7.2 | 82 | 0.59 | 1.5 | 4.1 | 0.012 | 0.22 | 0.18 | 3400 | 19 | 0.024 | $6.5*10^{-4}$ |
| Total loads from traffic to measures [kg/year] | 0.72 | 9.45 | 0.046 | 0.14 | 0.53 | $1.3*10^{-3}$ | 0.037 | 0.028 | 318 | 2.7 | $2.3*10^{-3}$ | $7.4*10^{-5}$ |
| Percentage of total traffic loads that reach measures | 10 % | 12 % | 8 % | 9 % | 13 % | 11 % | 17 % | 16 % | 9 % | 14 % | 9 % | 11 % |
| Traffic loads reduced in measures [kg/year] | 0.2 | 4.1 | 0.029 | 0.081 | 0.37 | $6.9*10^{-4}$ | 0.026 | 0.015 | 210 | 2.1 | $1.5*10^{-3}$ | $4.3*10^{-5}$ |
| Percentage of total traffic loads reduced in measures | 3 % | 5 % | 5 % | 5 % | 9 % | 6 % | 12 % | 9 % | 6 % | 11 % | 6 % | 7 % |

### 4.2.5 Dag Hammarskjöldsleden

#### 4.2.5.1 Simulations of existing measures

The simple measures mapped in Dag Hammarskjöldsleden were estimated to have higher pollutant reduction efficiencies compared to the existing measures in Lillhagen (Appendix II, Table A.6). The pollutant reduction efficiencies of the studied measures were in a range between 0 and 90 % for the different substances. It was observed that Ditch 58, which received the outflow from Ditch 59, had lower reduction efficiencies compared to the other measures. The low reduction efficiencies in Ditch 58 can be explained by the lower inlet concentrations of pollutants due to the low outflow concentrations from Ditch 59.

The existing measures received between 27 and 55 % of the substances generated by traffic in the sub-catchment (Table 4.14). This can be compared to that only 17 % of the road surface in the area was drained to measures. The explanation can be that the highway Dag Hammarskjöldsleden, with higher traffic intensity than the other roads in the area, was to a larger extent drained to ditches. This suggest that simple measures located along the largest roads are beneficial since the roads generate more pollutants and require more treatment.

Due to the relatively large reduction efficiencies of the measures in Dag Hammarskjöldsleden, compared to for example Lillhagen (Appendix II, Table A.3) (Appendix II, Table A.6), a relatively large amount of the pollutants is reduced in these measures. Although only 17 % of the traffic-related surfaces were drained to the measures, 11 % to 36 % of the total traffic-related pollutant load was estimated to be reduced in the measures. Consequently, results from the simulations of existing measures in Dag Hammarskjöldsleden suggest that the pollutant load to the receiving water from traffic is less due to the simple measures.

Compared to Lillhagen, which was the other studied area with mapped existing measures, Dag Hammarskjöldsleden had a relatively small percentage of pollutants discharged to measures. Consequently, to improve the performance of pollutant reduction in Dag Hammarskjöldsleden, it would be beneficial to increase the traffic surface drained to measures in the sub-catchment.

*Table 4.14 Results from the StormTac simulations of existing measures in sub-catchment Dag Hammarskjöldsleden.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic [kg/year] | 35 | 480 | 3.2 | 8.2 | 35 | 0.074 | 2.5 | 2 | 20000 | 160 | 0.21 | $5.6*10^{-3}$ |
| Total loads from traffic to measures [kg/year] | 13 | 140 | 1.4 | 3.4 | 19 | 0.023 | 0.93 | 0.76 | 6600 | 43 | 0.068 | $2.0*10^{-3}$ |
| Percentage of total traffic loads that reach measures | 36 % | 28 % | 45 % | 41 % | 55 % | 31 % | 37 % | 38 % | 33 % | 27 % | 32 % | 35 % |
| Traffic loads reduced in measures [kg/year] | 4 | 51 | 0.86 | 1.8 | 13 | 0.013 | 0.55 | 0.42 | 4500 | 35 | 0.031 | $8.9*10^{-4}$ |
| Percentage of total traffic loads reduced in measures | 11 % | 11 % | 27 % | 21 % | 36 % | 17 % | 22 % | 21 % | 23 % | 22 % | 15 % | 16 % |

#### 4.2.5.2 Simulations of improvements or implementation of new measures

The improved existing measures and the implementation of new simple measures resulted in new, and relatively high, pollutant reduction efficiencies (Appendix II, Table A.7).

According to the StormTac simulations, the eight improvements increased the traffic-related loads to measures by 5-10 % for the different studied pollutants (Table 4.15). The pollutant reduction in the measures increased by 7-14 %. Due to the relatively small effort needed to implement the improvements and new measures compared to the gained traffic surface, the potential of implementing the improvements in Dag Hammarskjöldsleden was relatively high compared to other studied sub-catchments. However, since the range of total reduced pollutant load only changed from 11-36 % to 12-38 % with all mapped improvements implemented, no large potential for reducing the pollutants from traffic was considered by implementing the improvements. If large changes are wanted, other measures need to be taken. Nevertheless, the suggested improvements still reduce the loads by a noticeable amount and could therefore be beneficial to implement. Even though it would not improve the pollutant reduction in the entire area by a substantial amount.

*Table 4.15 Results from the StormTac simulations in sub-catchment Dag Hammarskjöldsleden with implemented improvements and new simple measures.*

| | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total loads from traffic to measures [kg/year] | 14 | 150 | 1.5 | 3.6 | 21 | 0.025 | 1.0 | 0.81 | 7100 | 47 | 0.071 | $2.1*10^{-3}$ |
| Difference compared to no improvements | 8 % | 9 % | 6 % | 7 % | 6 % | 8 % | 7 % | 7 % | 7 % | 10 % | 5 % | 6 % |
| Percentage of total traffic loads that reach measures | 39 % | 31 % | 47 % | 44 % | 59 % | 34 % | 40 % | 40 % | 36 % | 30 % | 34 % | 37 % |
| Traffic loads reduced in measures [kg/year] | 4.4 | 58 | 0.92 | 1.9 | 13 | 0.014 | 0.6 | 0.45 | 4900 | 38 | 0.034 | $1.0*10^{-3}$ |
| Difference compared to without the improvements | 8 % | 14 % | 7 % | 9 % | 7 % | 9 % | 9 % | 7 % | 8 % | 10 % | 8 % | 8 % |
| Percentage of total traffic loads reduced in measures | 12 % | 12 % | 29 % | 23 % | 38 % | 18 % | 24 % | 23 % | 25 % | 24 % | 16 % | 17 % |

### 4.2.6 Summary and evaluation

#### 4.2.6.1 Existing measures

The results from the simulations varied largely between the different areas. In sub-catchment Ringön, Stigberget, and Örgryte no reduction of traffic-related pollutants was simulated, since no simple measures were mapped. In the two sub-catchments with mapped simple measures, the results from the simulations showed noticeable pollutant reduction. In Lillhagen, 8 % to 61 % of the traffic-related pollutants were reduced in measures, while these numbers were 11% to 36 % for Dag Hammarskjöldsleden. Although the load to measures was substantially larger in Lillhagen, the reduction efficiency was lower. One reason for this difference could be that the simple measures in Dag Hammarskjöldsleden mainly received runoff from traffic surfaces which resulted in high concentrations and therefore high reduction efficiencies. In Lillhagen, the measures in general received more stormwater relatively their size and they also received stormwater from other sources, such as gardens and roofs, and stormwater from the nature. These resulted in substantially reduced reduction efficiencies.

#### 4.2.6.2 Suggested improvements or implementation of new measures

The simulations of sub-catchments Ringön and Stigberget showed very limited potential for improved reduction of traffic-related pollutant loads in simple measures. The suggested new measures were found to be efficient, but the limited area of drained traffic-surface, compared to the entire sub-catchment, made the total impact very low.

Simulations of suggested measures in Örgryte resulted in noticeable reductions of the total traffic-related pollutant loads. However, due to the large effort needed to implement the suggested measures, the potential of the improvements was still considered to be limited.

The areas with existing measures also showed limited potential for implementing the improvements and new simple measures. The simulated pollutant reduction was still increased. However, due to the limited amount of improvements mapped, the overall potential of increasing the pollutant reduction from the entire sub-catchment was not considered to be substantial. Hence, it can be expected that other areas that are similar to Lillhagen and Dag Hammarskjöldsleden (i.e. have a larger share of the land-uses “industrial”, “nature” or “open land” and are located further from the city centre) have the potential to a higher reduction of pollutant loads from traffic by simple stormwater measures and improvements of these.

# 5 Discussion

In addition to the analysis of the results in Chapter 4, this chapter presents further evaluations of the methods, discussions about the feasibility of simple measures, and suggestions for future studies.

## 5.1 Evaluation of the field study and data processing

The field study was performed in a way that should ensure that all existing measures receiving stormwater from traffic-related surfaces were mapped. This, since all areas along the roads in the selected sub-catchments were investigated by systematically driving on every road. However, snow sometimes caused problems since it made it difficult to visually inspect the surfaces and see if curb stones or grass prevented the road surface to be drained to a nearby measure. The snow also made it hard to identify ditch outlets. Nevertheless, for the cases when the snow layer was very thick, a complementary mapping was performed another day. Consequently, the weather conditions were not considered to affect the outcomes and the conclusions from the results in this study.

During the field study, it was apparent that previously collected data were not always updated or correct. Specifically, it was commonly seen that gullies indicated on the map did not exist in reality, and vice versa. Hence, storm drains and ditch outlets were checked. Together with the issues with snow, covering measures and surfaces, this may have resulted in errors in the mapping procedure.

A potential improvement of the used mapping method could be to perform it during rain, to easier investigate the direction of the stormwater flow. This should also solve the issues with snow-covered measures and surfaces, as mentioned earlier. Nevertheless, a field study performed during the summer season could make it harder to investigate vegetated areas as they tend to overgrow. If the field study was redone, having maps of the pipe network during the mapping of the simple measures would have helped to quickly get an overview of the measure's catchment.

When processing the notes from the field study, it was sometimes difficult to classify the road drainage according to the measures identified in the literature. The literature most often describes how the measures are supposed to be constructed, but the reality did not always reflect the theory. For example, along several roads, it was uncertain whether the road runoff was conveyed to a filter strip or directly to a ditch (Appendix I, Figure A.3). This also affected the modelling of the stormwater system in StormTac, since the stormwater management system had to be described with the available parameters in the model. In this study, filter strips were not inserted between the roads and the ditches because it could lead to overestimations of the pollutant reductions. However, excluding filter strips in these cases could also mean that the reductions were underestimated, and further investigations are needed to know which way is the most correct to imitate the reality.

The processed results from the field study include some errors in estimated traffic surfaces from collected data. For the SCALGO simulations, the resolution of the elevation model was 0.5x0.5 m. This resolution was considered sufficient for studying the flow paths on the surfaces. However, lower and narrower objects such as curb stones could be missed, but these could be corrected by the observations from the field study. In addition, the SCALGO model treats all surfaces as completely impervious. The model was mainly used to study the flow directions on the surfaces which are not largely affected by the perviousness. Hence, this limitation is not considered to affect the results from the model.

## 5.2 Evaluation of the StormTac simulations

The StormTac models built in this project have not been validated using experimental data. Since no stormwater measurements were available, standard values have been used in the models. These data are based on measurements of stormwater worldwide and may not entirely correspond to the Swedish conditions (Göteborgs Stad, 2017). In addition, the StormTac model does not account for seasonal variations. However, the data are based on annual values which includes all different seasons. The winter period, during which the pollutant reduction efficiencies could be lower, is longer in Sweden compared to some other countries where the measured data have been collected, which can lead to overestimated treatment efficiencies in this study.

Since StormTac uses standard values, the results differed considerably depending on whether the simulated ditch was defined as a grass ditch or a swale (Figure 5.1): if the ditch has a side slope of 1:2.1, it is defined as a swale; if the slope is 1:1.9, it is defined as a grass ditch. In one comparison, the average reduction efficiency of all pollutants changed from 31 % to 50 % when the slope was changed from 1:1.9 to 1:2.1. For single pollutants, the reduction efficiency changed from 12 % to 52 %. It can be questioned if this reflects the reality. Consequently, small errors in the measurement of the ditch slope can affect the results both by underestimating or overestimating the treatment efficiencies. However, when combining the results from several ditches in an area, the total reduction can still be seen as a good estimation. Although, evaluation of single measures should be performed with caution.

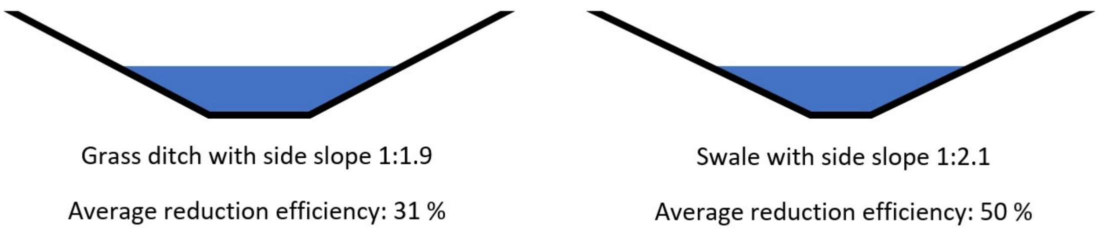



*Figure 5.1 A comparison of the reduction efficiency when the only parameter that differs is the side slope, defining one as a grass ditch and one as a swale.*

Since the measure type was defined by the side slope, improvements that change the shape of the simple measures were not evaluated in this study. In StormTac, an optimization of the measures would have been to excavate all ditches to have side slopes exceeding 1:2 to achieve a larger pollutant reduction. However, it is questioned if these improved reduction efficiencies would occur in reality.

Another limitation is that StormTac cannot estimate the treatment improvements of check dams in ditches, raised ditch outlets, two-stage ditches, or sedimentation in gully sand traps. Therefore, it was not possible to evaluate all measures and improvements mentioned in Chapter 2.2. A future study, that uses a new alternative modelling tool or if StormTac is upgraded with these functions, could lead to a more comprehensive comparison of different measures and improvements. This comparison is of importance since, for example, if the removal efficiencies in sand traps is higher than in ditches, throttling gullies should not be suggested as an improvement.

The simulations in StormTac indicated possibilities of development of the software, particularly regarding areas in series. Each time a change in the model was made, new results had to be extracted and included as inlet concentrations in the areas downstream, which was time-consuming. If the model would allow linking areas in series, these kinds of studies would be easier to perform, hence lower the risk of errors.

Due to the many simplifications, the results from the StormTac simulations should be evaluated with caution and the outcomes should be considered rough indications. Nevertheless, model results can be used to study the magnitude of pollutant concentrations and reduction efficiencies, which was the aim of this project.

## 5.3 Feasibility of simple measures

In similarity with other studies, the results of this thesis showed that existing traffic-related stormwater measures can provide a significant reduction of pollutant (Ingvertsen et al., 2012). Therefore, we find simple measures good in areas where they have been implemented during the development of the areas. However, considering the results, we see limited potential to solve issues with stormwater pollution by implementing improvements and new simple measures. Areas in need of more stormwater treatment, more extensive measures could have a larger potential. Nevertheless, during the development of new areas and larger reconstructions, the potential of improving the stormwater quality by simple measures is considered larger if stormwater management is prioritized from the beginning.

A disadvantage with simple measures are their need of maintenance, to avoid them being over grown, with a lower capacity as a consequence (Blecken, 2016). For example, filter strips tend to grow higher than the road surface, preventing stormwater to be drained. At the same time, the vegetation can provide a lower manning's number, M, which is important to slow down the flow, and the vegetation can also provide treatment of stormwater. Planning of maintenance is therefore central and mowing and removing the grass frequently once a year, as the Swedish Transport Administration suggests (Vägverket, 2003), should preserve the treatment of the stormwater. It cannot be confirmed that the simple measures in this study are maintained properly. If that is the case, the treatment efficiencies could have been overestimated in the StormTac simulations.

As Viklander and Bäckström (2008) stated, open ditches have the advantage in cold climates due to the resilient against frost and possibility to be used for storage of snow. Consequently, simple measures are feasible in Sweden and in Gothenburg.

The existing measures, suggested improvements and new simple measures all have a potential to also provide detention and therefore a decreased load on the pipe network. The detention can be extensive, especially for smaller rain events, as was found in the studies performed by Davis et al. (2012), Ahmed et al. (2015) and Rujner (2018). Consequently, the total benefits are underestimated when only the pollutant reduction is considered. The flow detention can be estimated in a dynamic hydraulic model that require more time, data and measurements to set up and calibrate. A dynamic model can also investigate the risk of flooding. With flow detention, simple measures have the potential to decrease the peak flows and thereby the risk of flooding. To estimate the total benefits of the studied measures and improvements, the benefits of decreased flow and volumes in the pipe network should also be included.

Curb stone removal is a stormwater solution, suggested by the Swedish Water and Wastewater Association, to increase overland drainage of traffic-related stormwater to the simple measures (Svenskt Vatten, 2011). This study showed that this solution was possible to implement in the studied areas and it increased the surface drained to simple measures to various extent. However, the results suggested that the effect on the pollutant reduction to the receiving water would be limited. In addition, the removal of curb stones needs to be discussed with traffic engineers and city planners, to prevent any unwanted consequences for the road users or the esthetical characteristics of the city. An alternative could be to only lower the curb stones to allow stormwater to pass.

In the cases where the improvements led to an increased drained area, resulting in larger flows in the ditch, it is important to investigate if the adjustment may cause erosion damages. If issues with erosion emerge, one solution is to widen the ditch, which simultaneously leads to improved treatment. Larger flows can also be caused by climate change with shorter and more intensive rain events. Therefore, larger flows are expected in the future. Since the results from this study showed that measures receiving much water compared to their size are less effective to remove pollutants, it can be expected that the pollutant reduction in simple measures will become lower in the future. This can be prevented if the dimensions of these measures are increased.

A common issue that prevented implementation of simple measures was the inclination of the road, which tilts away from the existing ditch or area for a possible new measure, even in areas built during the last decade (Appendix I, Figure A.7). This indicates that there is a need to improve the planning process to avoid that new roads are built in this way. Consequently, the study has also shown that it is important to have stormwater management in mind when planning new areas since it is costly to change the inclination of the road surface afterwards.

## 5.4 Future studies

Due to the limited time-frame of this thesis, several aspects could not be covered and are therefore subjects for future studies. For example, future studies should focus on the cost efficiency of the simple measures mentioned in this report, compared with larger and more advanced measures such as stormwater detention and infiltration ponds. For a proper comparison, the improvements of the simple measures mentioned in this study, but not possible to simulate in StormTac, should be included. As previously mentioned, even if the improvements would not be found profitable in terms of pollutant removal, the improvements could still be profitable if the benefits of flow detention were included. Therefore, investigations regarding the flow detention is also needed to get the whole picture of the benefits of the simple measures.

Because only traffic surfaces owned by the municipality were investigated, privately owned traffic areas such as parking lots and petrol stations have been excluded. These could be included in future studies to gain a more complete understanding of the total pollution load on the receiving waters. A greater knowledge and more general trends about the presence, performance and possible improvement of simple measures could be obtained by studying more sub-catchment areas and by comparing two similar areas to each other. However, this would be time-consuming and was not done within this project. With a deeper understanding about general trends, it would also be possible to extrapolate the result for the entire urban area of Gothenburg to estimate the existence, performance and possibilities for improvement of simple stormwater measures in the municipality.

### 5.4.1 Recommendations for further research

In conclusion, to gain further understanding of the simple measures investigated in this thesis and increase the reliability, the recommendations for further research are summarized in the list below.

- To get a better estimation of the existence of simple measure and possible improvements in the entire urban area of Gothenburg, more sub-catchments should be investigated. With more knowledge about where the simple measures are expected to be found, an extrapolation of the result could be performed over the urban area of Gothenburg.
- The flow detention of mapped measures could be evaluated by using a dynamic hydraulic model. The benefits of flow detention in the mapped measures could be added to the pollutant reduction to fully evaluate the performance of the measures. In addition, a dynamic model could investigate the simple measures' effect on the combined sewer network and CSOs.
- More extensive improvement measures could be included in the study to investigate their effect on the pollutant reduction.
- The suggested improvements in this thesis could be compared to the effect of implementing more extensive measures in the sub-catchments.

# 6 Conclusions

The study showed that simple traffic-related stormwater measures existed in two of the five studied sub-catchments. Areas closer to the city centre did not contain any simple measures while several simple measures were mapped in areas further from the city centre and mainly in the land-uses “open land”, “industrial area” and “nature”. The percentage of traffic surface drained to these measures varied largely between the studied sub-catchments, from 0 % to 87 %.

Results from the field study suggest relatively limited potential for implementing improvements and new simple measures in the studied sub-catchments. In some areas, the mapped improvements were barely noticeable. While in some areas, traffic surfaces could be drained by implementing relatively extensive measures. The areas with the largest potential for implementing improvements or new simple measures, were the areas that already contained existing simple measures.

Performed simulations suggested that the existing measures reduce the traffic-related pollutants to a noticeable degree in the areas where measures were mapped. However, the implementation of improvements of these measures and new simple measures showed low potential for large reductions of traffic-related pollution from the sub-catchments. Nevertheless, the mapped improvements and new measures reduced the pollutants to some extent.

It is also concluded that simple measures which mainly receive traffic-related stormwater generally have higher pollutant reduction efficiency. Consequently, measures receiving both polluted stormwater from traffic surfaces and less polluted stormwater have a lower pollutant reduction efficiency. Hence, the lower total pollutant reduction would increase the pollutant load reaching the receiving waters.

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# Appendix I – Pictures from the field study

This appendix presents some representative pictures taken during the field study. Included pictures show existing measures, possible improvements and other relevant observations.


*Figure A.1* *Ditch within the land-use "open land" along the highway in the sub-catchment Dag Hammarskjöldsleden that received traffic-related stormwater from the road. (Photo by authors.)*


*Figure A.2* *Ditch in an industrial area in Lillhagen. The traffic-related stormwater not led to the pipe network through the storm drain, was drained to the ditch. (Photo by authors.)*

Figure A.3 Along a larger road within an industrial area in Dag Hammarskjöldsleden. Curb stones prevented the runoff from the traffic surface from draining to the possible ditch at left side of picture. (Photo by authors.)

Figure A.4 Ditch along a larger road within an industrial area in Dag Hammarskjöldsleden. Curb stones prevented the runoff from the traffic surface from draining to the existing ditches at left side of picture. (Photo by authors.)


*Figure A.5* *Along a larger road in Lillhagen. Curb stones prevented the traffic-related stormwater from being drained to the green area. Instead, the water was led to the storm drain. (Photo by authors.)*

*Figure A.6* *Roundabout in Lillhagen, within the land-use nature, where curb stones prevented the stormwater from the road surface from being drained to the nearby green area. (Photo by authors.)*

*Figure A.7 In some areas in Lillhagen, the inclination of the roads tilted towards the sidewalk and the storm drains. Instead, the traffic-related stormwater could have been led to the ditch by using a super-elevated inclination tilting against the ditch on the left side. (Photo by authors.)*

*Figure A.8 The sidewalk prevented the traffic-related stormwater to reach the nearby ditch in Lillhagen. (Photo by authors.)*

# Appendix II – Results from StormTac simulations

This appendix contains the pollutant reduction efficiencies for the studied measures derived from the StormTac simulations. The tables also describe if the measures are grass ditches, swales or filter strips. In addition, the regression constants of the measures are presented, which are the area of the measures divided by the reduced watersheds of the measures (area multiplied by runoff coefficient).

*Table A.1 Simulated pollutant reduction efficiencies [%] of the new measure in Ringön. The reduction efficiencies of the measures are graded by colour, where green indicates high reduction efficiency and red low efficiency.*

| Improvement number | Type of measure | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Swale | 100 | 35 | 66 | 68 | 71 | 78 | 55 | 80 | 57 | 78 | 81 | 80 | 51 |

*Table A.2 Simulated pollutant reduction efficiencies [%] of the new measure in Stigberget. The reduction efficiencies of the measures are graded by colour, where green indicates high reduction efficiency and red low efficiency.*

| Improvement number | Type of measure | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Swale | 26 | 35 | 66 | 68 | 71 | 78 | 55 | 80 | 57 | 78 | 81 | 80 | 51 |

*Table A.3 Simulated pollutant reduction efficiencies [%] of the studied existing measures in Lillhagen. The reduction efficiencies of the measures are graded by colour, where green indicates high reduction efficiency and red low efficiency.*

| Measure number | Type of existing measure | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 25 | Swale | 26 | 14 | 47 | 68 | 59 | 71 | 49 | 66 | 57 | 69 | 70 | 69 | 69 |
| D 7 | Grass ditch | 9.9 | 21 | 21 | 42 | 26 | 42 | 35 | 33 | 41 | 53 | 79 | 16 | 16 |
| D 24a | Grass ditch | 69 | 37 | 42 | 49 | 43 | 78 | 41 | 54 | 58 | 74 | 82 | 33 | 33 |
| D 3, 4 | Grass ditch | 13 | 24 | 23 | 37 | 25 | 44 | 34 | 31 | 15 | 48 | 65 | 18 | 11 |
| D 10 | Swale | 18 | 36 | 44 | 63 | 59 | 68 | 61 | 67 | 54 | 67 | 84 | 65 | 60 |
| D 9 | Grass ditch | 5 | 15 | 14 | 36 | 20 | 29 | 32 | 25 | 32 | 44 | 73 | 9.7 | 9.7 |
| D 11 | Swale | 31 | 36 | 53 | 65 | 63 | 74 | 55 | 72 | 58 | 72 | 81 | 72 | 52 |
| D 24b | Grass ditch | 61 | 27 | 38 | 45 | 37 | 53 | 26 | 45 | 0.73 | 61 | 51 | 32 | 1.1 |
| D 31a | Grass ditch | 4.9 | 14 | 13 | 35 | 17 | 28 | 31 | 20 | 29 | 37 | 59 | 9.6 | 9.6 |
| D 31b | Grass ditch | 9.8 | 0 | 19 | 37 | 22 | 40 | 4.3 | 24 | 24 | 40 | 27 | 16 | 16 |
| D 43 | Grass ditch | 3.8 | 0 | 9.8 | 32 | 14 | 23 | 0 | 15 | 18 | 30 | 21 | 7.3 | 7.3 |
| D 41b | Grass ditch | 32 | 0 | 30 | 41 | 29 | 29 | 0 | 36 | 0 | 32 | 32 | 26 | 0 |
| D 51 | Grass ditch | 1.8 | 2.7 | 5.7 | 31 | 15 | 12 | 14 | 11 | 18 | 27 | 31 | 5 | 5 |
| D 63, 64 | Swale | 15 | 0 | 38 | 58 | 51 | 64 | 31 | 58 | 40 | 56 | 69 | 63 | 27 |
| D 66 | Grass ditch | 19 | 28 | 27 | 41 | 30 | 53 | 36 | 37 | 44 | 55 | 74 | 21 | 21 |
| D 69 | Swale | 10 | 27 | 33 | 59 | 52 | 61 | 58 | 57 | 46 | 59 | 80 | 57 | 51 |
| D 77, 76 | Grass ditch | 0.44 | 0 | 32 | 48 | 54 | 40 | 0 | 52 | 0 | 37 | 5.4 | 40 | 0 |
| D 87 | Swale | 17 | 28 | 42 | 60 | 55 | 66 | 45 | 61 | 46 | 61 | 74 | 64 | 40 |
| D 113, 115 | Swale | 18 | 6.8 | 40 | 64 | 56 | 66 | 28 | 46 | 0 | 61 | 24 | 65 | 0.51 |
| D 92 | Swale | 35 | 39 | 55 | 67 | 65 | 77 | 57 | 74 | 62 | 74 | 80 | 73 | 59 |
| D 102, 103, 101 | Grass ditch | 9.1 | 0 | 19 | 37 | 22 | 39 | 13 | 25 | 28 | 41 | 45 | 15 | 15 |
| D 107 | Swale | 27 | 38 | 51 | 66 | 63 | 73 | 58 | 71 | 59 | 71 | 81 | 70 | 59 |
| D 99 | Grass ditch | 91 | 26 | 41 | 47 | 39 | 41 | 16 | 45 | 0 | 53 | 34 | 35 | 0 |
| D 94 | Grass ditch | 21 | 30 | 29 | 44 | 33 | 57 | 37 | 41 | 48 | 61 | 82 | 22 | 22 |
| D 6,5 | Grass ditch | 17 | 19 | 26 | 42 | 30 | 51 | 36 | 37 | 44 | 54 | 64 | 20 | 20 |
| D 23, 24c | Grass ditch | 0.50 | 0 | 11 | 53 | 27 | 23 | 21 | 22 | 31 | 46 | 45 | 9.8 | 9.8 |
| D 30, 29 | Grass ditch | 1.4 | 4.6 | 5.4 | 31 | 15 | 12 | 9.1 | 12 | 17 | 7.2 | 0.5 | 5 | 5 |
| D 19 | Grass ditch | 0.53 | 4.7 | 5.8 | 34 | 16 | 13 | 30 | 14 | 20 | 30 | 65 | 5 | 5 |
| D 60 | Grass ditch | 25 | 0 | 27 | 38 | 26 | 15 | 0 | 32 | 0 | 18 | 15 | 24 | 0 |
| D 52 | Swale | 0.55 | 0 | 7.1 | 47 | 36 | 42 | 1.7 | 29 | 6.7 | 32 | 5.3 | 40 | 19 |
| D 119 | Swale | 0.55 | 6 | 7.2 | 49 | 37 | 43 | 17 | 31 | 27 | 34 | 34 | 40 | 32 |
| D 75, 74, 73 | Grass ditch | 13 | 0 | 22 | 38 | 23 | 45 | 5.7 | 27 | 28 | 42 | 30 | 18 | 18 |
| D 88 | Grass ditch | 1.1 | 0 | 5.7 | 31 | 14 | 12 | 12 | 11 | 18 | 26 | 31 | 5 | 5 |
| D 90, 91 | Grass ditch | 23 | 0 | 27 | 39 | 27 | 31 | 0 | 33 | 1 | 27 | 0 | 23 | 0 |
| D 95 | Swale | 2.2 | 0 | 7.1 | 47 | 36 | 42 | 15 | 33 | 26 | 32 | 27 | 40 | 32 |
| D 1 | Grass ditch | 1.2 | 4.6 | 5.7 | 31 | 15 | 12 | 29 | 13 | 18 | 27 | 64 | 5 | 5 |
| D 18 | Grass ditch | 0.50 | 4.8 | 5.8 | 34 | 16 | 13 | 30 | 15 | 20 | 30 | 65 | 5 | 5 |
| D 20 | Grass ditch | 0.69 | 4.7 | 5.8 | 34 | 16 | 13 | 30 | 14 | 20 | 29 | 65 | 5 | 5 |
| D 89 | Grass ditch | 0.52 | 0 | 5.7 | 30 | 14 | 12 | 1.8 | 11 | 12 | 25 | 5.7 | 5 | 5 |
| D 12, 13, 14 | Grass ditch | 0.33 | 4.7 | 5.8 | 33 | 16 | 13 | 30 | 14 | 20 | 28 | 65 | 5 | 5 |
| Min | | | 0 | 5.4 | 30 | 14 | 12 | 0 | 11 | 0 | 7.2 | 0 | 5 | 0 |
| Max | | | 39 | 55 | 68 | 65 | 78 | 61 | 74 | 62 | 74 | 84 | 73 | 69 |
| Average | | | 13 | 24 | 45 | 33 | 41 | 26 | 35 | 27 | 44 | 50 | 29 | 19 |

*Table A.4 Simulated pollutant reduction efficiencies of the new and modified measures in Lillhagen. Improvement number corresponds with Table 4.4. The reduction efficiency of the measures [%] are graded by colour, where green indicates high reduction efficiency and red low efficiency.*

| Measure number | Improvement number | Measure type | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 31a | 4, 5 | Grass ditch | 3.8 | 11 | 10 | 33 | 15 | 23 | 30 | 17 | 27 | 34 | 57 | 7.3 | 7.3 |
| F 1 | 4 | Filter strip | 8646 | 38 | 41 | 74 | 59 | 59 | 77 | 77 | 69 | 83 | 83 | 80 | 58 |
| D 36 | 5 | Swale | 8.1 | 23 | 28 | 59 | 49 | 57 | 41 | 41 | 0 | 53 | 35 | 55 | 0 |
| D 41b | 2 | Grass ditch | 30 | 0 | 29 | 41 | 29 | 35 | 0 | 36 | 1.8 | 37 | 38 | 25 | 0 |
| D 87 | 3 | Swale | 8.3 | 25 | 29 | 57 | 50 | 58 | 54 | 55 | 43 | 56 | 78 | 55 | 51 |
| D 113, 115 | 6 | Swale | 11 | 18 | 32 | 62 | 53 | 61 | 34 | 42 | 0 | 57 | 28 | 59 | 8.5 |
| D 30, 29 | 4, 5 | Grass ditch | 1.4 | 4.6 | 5.8 | 31 | 15 | 12 | 9.1 | 12 | 17 | 26 | 0.49 | 5 | 5 |
| D 19 | 2 | Grass ditch | 0.53 | 4.7 | 5.8 | 34 | 16 | 13 | 30 | 14 | 20 | 30 | 65 | 5 | 5 |
| D 60 | 2 | Grass ditch | 25 | 0 | 27 | 38 | 26 | 15 | 1.8 | 33 | 3.2 | 18 | 15 | 24 | 0 |
| D 88 | 3, 6 | Grass ditch | 1.0 | 0 | 5.7 | 31 | 14 | 12 | 12 | 12 | 18 | 26 | 31 | 5 | 5 |
| D 18 | 1, 4, 5 | Swale | 0.50 | 7.1 | 7.3 | 53 | 40 | 44 | 65 | 39 | 30 | 38 | 65 | 40 | 40 |
| D 20 | 2 | Grass ditch | 0.69 | 4.7 | 5.8 | 34 | 16 | 13 | 30 | 14 | 20 | 29 | 65 | 5 | 5 |
| D 89 | 3, 6 | Grass ditch | 0.52 | 0 | 5.7 | 30 | 14 | 12 | 1.8 | 11 | 12 | 25 | 5.6 | 5 | 5 |
| D 12, 13, 14 | 1, 4, 5 | Grass ditch | 0.30 | 4.7 | 5.8 | 32 | 15 | 12 | 29 | 14 | 19 | 28 | 65 | 5 | 5 |

*Table A.5 Simulated pollutant reduction efficiencies [%] of the new measures in Örgryte. The measures are graded by colour, where green indicates high reduction efficiency and red low reduction efficiency.*

| Improvement number | Measure type | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Swale | 80 | 38 | 65 | 70 | 73 | 83 | 55 | 80 | 61 | 78 | 79 | 80 | 57 |
| 2 | Swale | 30 | 42 | 53 | 68 | 66 | 76 | 63 | 75 | 62 | 75 | 84 | 71 | 67 |
| 3 | Swale | 37 | 42 | 57 | 69 | 68 | 78 | 62 | 77 | 64 | 77 | 83 | 74 | 65 |
| 4 | Swale | 13 | 0 | 36 | 65 | 53 | 63 | 60 | 61 | 52 | 63 | 74 | 61 | 61 |
| 5 | Swale | 30 | 35 | 51 | 69 | 64 | 73 | 42 | 51 | 0 | 71 | 34 | 71 | 18 |
| 6 | Swale | 15 | 34 | 41 | 64 | 59 | 67 | 65 | 66 | 54 | 67 | 84 | 63 | 63 |
| Min | | | 0 | 36 | 64 | 53 | 63 | 42 | 51 | 0 | 63 | 34 | 61 | 18 |
| Max | | | 42 | 65 | 70 | 73 | 83 | 65 | 80 | 64 | 78 | 84 | 80 | 67 |
| Average | | | 32 | 51 | 68 | 64 | 73 | 58 | 68 | 49 | 72 | 73 | 70 | 55 |

*Table A.6* *Simulated pollutant reduction efficiencies [%] of the studied existing measures in Dag Hammarskjöldsleden. The measures are graded by colour, where green indicates high reduction efficiency and red low reduction efficiency.*

| Measure number | Type of existing measure | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 9, 10 | Swale | 16/6 | 1 | 54 | 81 | 65 | 66 | 44 | 77 | 33 | 67 | 64 | 79 | 0 |
| F 2 | Filter strip | 5860 | 38 | 42 | 78 | 63 | 60 | 78 | 80 | 72 | 87 | 87 | 80 | 70 |
| D 25 | Swale | 23 | 40 | 49 | 68 | 65 | 73 | 66 | 73 | 60 | 73 | 85 | 68 | 68 |
| D 32 | Swale | 34 | 42 | 55 | 69 | 67 | 77 | 62 | 76 | 63 | 75 | 83 | 72 | 67 |
| D 30 | Swale | 88 | 32 | 66 | 72 | 74 | 84 | 61 | 82 | 68 | 80 | 81 | 80 | 59 |
| D 60 | Swale | 59 | 53 | 66 | 79 | 81 | 88 | 70 | 90 | 78 | 90 | 86 | 80 | 80 |
| D 59 | Grass ditch | 4.8 | 11 | 13 | 36 | 18 | 28 | 31 | 22 | 30 | 38 | 62 | 9 | 9 |
| D 57 | Swale | 36 | 42 | 56 | 73 | 70 | 80 | 63 | 78 | 67 | 78 | 78 | 74 | 74 |
| D 55 | Grass ditch | 33 | 24 | 33 | 48 | 37 | 66 | 38 | 45 | 53 | 65 | 68 | 26 | 26 |
| D 54 | Grass ditch | 15 | 26 | 25 | 44 | 31 | 52 | 36 | 38 | 46 | 57 | 74 | 19 | 19 |
| D 48 | Grass ditch | 18 | 29 | 27 | 47 | 34 | 56 | 37 | 42 | 50 | 63 | 82 | 21 | 21 |
| D 47 | Swale | 6.7 | 18 | 17 | 42 | 25 | 37 | 34 | 30 | 39 | 51 | 76 | 12 | 12 |
| D 46 | Grass ditch | 8.1 | 20 | 19 | 43 | 27 | 41 | 34 | 33 | 42 | 54 | 77 | 14 | 14 |
| D 45 | Swale | 29 | 44 | 53 | 73 | 71 | 79 | 68 | 79 | 67 | 79 | 84 | 71 | 71 |
| D 44 | Swale | 19 | 38 | 45 | 71 | 67 | 73 | 67 | 73 | 61 | 74 | 84 | 66 | 66 |
| D 43 | Swale | 27 | 43 | 51 | 73 | 71 | 78 | 68 | 78 | 66 | 79 | 84 | 70 | 70 |
| D 41 | Swale | 17 | 36 | 43 | 69 | 64 | 71 | 67 | 70 | 58 | 70 | 82 | 64 | 64 |
| D 40 | Swale | 21 | 39 | 47 | 70 | 66 | 74 | 67 | 72 | 61 | 73 | 81 | 67 | 67 |
| D 39 | Swale | 15 | 34 | 41 | 68 | 63 | 70 | 67 | 69 | 57 | 69 | 83 | 63 | 63 |
| D 38 | Grass ditch | 16 | 28 | 27 | 47 | 35 | 56 | 37 | 43 | 51 | 64 | 84 | 20 | 20 |
| D 37 | Swale | 12 | 31 | 36 | 68 | 62 | 68 | 67 | 68 | 55 | 69 | 81 | 60 | 60 |
| D 36 | Grass ditch | 11 | 30 | 35 | 67 | 62 | 66 | 67 | 67 | 54 | 68 | 81 | 59 | 59 |
| D 61 | Swale | 42 | 49 | 59 | 74 | 73 | 82 | 65 | 81 | 69 | 81 | 80 | 75 | 75 |
| D 62 | Swale | 41 | 29 | 57 | 72 | 69 | 81 | 55 | 77 | 66 | 76 | 72 | 75 | 69 |
| D 63 | Grass ditch | 24 | 9 | 29 | 45 | 32 | 59 | 37 | 39 | 47 | 58 | 56 | 24 | 24 |
| D 64 | Grass ditch | 12 | 25 | 24 | 46 | 32 | 49 | 36 | 39 | 47 | 60 | 81 | 18 | 18 |
| D 65 | Grass ditch | 28 | 33 | 32 | 49 | 38 | 65 | 38 | 47 | 55 | 68 | 80 | 25 | 25 |
| D 66 | Grass ditch | 23 | 30 | 29 | 48 | 36 | 60 | 38 | 44 | 53 | 67 | 82 | 23 | 23 |
| D 67 | Grass ditch | 27 | 33 | 31 | 50 | 39 | 64 | 39 | 48 | 56 | 69 | 84 | 24 | 24 |
| F 1 | Filter strip | 34580 | 38 | 42 | 70 | 58 | 56 | 78 | 76 | 67 | 84 | 86 | 80 | 50 |
| D 22, 21 | Swale | 8.8 | 0 | 46 | 86 | 75 | 82 | 67 | 81 | 72 | 84 | 80 | 79 | 79 |
| D 58 | Swale | 6.5 | 7 | 6 | 34 | 17 | 16 | 29 | 15 | 24 | 32 | 63 | 5 | 5 |
| Min | | | 0 | 6 | 34 | 17 | 16 | 29 | 15 | 24 | 32 | 56 | 5 | 0 |
| Max | | | 53 | 66 | 86 | 81 | 88 | 78 | 90 | 78 | 90 | 87 | 80 | 80 |
| Average | | | 30 | 39 | 61 | 53 | 64 | 53 | 60 | 56 | 69 | 78 | 50 | 45 |

*Table A.7 Simulated pollutant reduction efficiencies [%] of the new and modified measures in Dag Hammarskjöldsleden. Improvement number corresponds with Table 4.8. The measures are graded by colour, where green indicates high reduction efficiency and red low reduction efficiency.*

| Measure number | Improvement number | Measure type | Regression constant | P | N | Pb | Cu | Zn | Cd | Cr | Ni | SS | Oil | PAH16 | BaP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 9, 10 | 7 | Swale | 16/15 | 1 | 63 | 84 | 65 | 66 | 44 | 82 | 33 | 67 | 64 | 79 | 0 |
| D 25 | 8 | Swale | 13 | 32 | 38 | 64 | 59 | 66 | 66 | 66 | 53 | 66 | 82 | 61 | 61 |
| D 26 | 1 | Swale | 36 | 32 | 56 | 69 | 66 | 78 | 60 | 75 | 63 | 75 | 81 | 74 | 59 |
| D 27 | 2 | Swale | 63 | 0 | 63 | 67 | 61 | 62 | 41 | 71 | 26 | 63 | 57 | 74 | 0 |
| D 31 | 3 | Swale | 20 | 37 | 46 | 66 | 61 | 71 | 63 | 69 | 57 | 69 | 83 | 66 | 65 |
| D 68 | 4 | Swale | 71 | 36 | 66 | 69 | 71 | 80 | 56 | 80 | 59 | 79 | 81 | 80 | 53 |
| D 69 | 5 | Swale | 100 | 39 | 65 | 71 | 73 | 84 | 55 | 80 | 62 | 78 | 78 | 80 | 58 |
| D 70 | 6 | Swale | 22 | 40 | 48 | 73 | 70 | 76 | 68 | 77 | 65 | 77 | 86 | 67 | 67 |