Pollutant Removal Efficiencies and Flow Detention of Infiltration Trenches

An investigation of an Infiltration Trench in Kungsbacka

Master of Science Thesis in the Master's Programme Geo and Water Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Sustainable Urban Drainage Systems (SUDS) are today commonly applied when reducing pollutant loads and controlling surface runoff from urban stormwater. Examples of SUDS-techniques are stormwater ponds, infiltration trenches, green roofs and swales. This master thesis aims at contributing to the research on infiltration trenches with a complementary investigation of its pollutant removal efficiencies and flow detention. This is because the research on infiltration trenches is limited compared to other SUDS-techniques, as for example stormwater ponds. The study is carried out by flow weighted sampling at the inlet and outlet of one infiltration trench in Kungsbacka south of Gothenburg, located under the parking lot of the supermarket ICA Maxi. The observations and sampling were conducted during April to June 2012 and the results from five storm events were analyzed. The pollutants; suspended solids, heavy metals, nitrogen and phosphorus were analyzed. Experimental procedures were carried out in the WET laboratory at Chalmers University of Technology. Suspended solids have been analyzed according to standard methods and nitrogen and phosphorous ions were analyzed with ion chromatography and heavy metals were analyzed with ICP-MS. Preparation of ICP-MS samples were made at the WET laboratory and then sent to an external laboratory for analysis. The obtained results have been calculated through cumulative pollutant calculations and presented as Event Mean Concentrations (EMC) and Reductions (R). The results show that the pollutant concentrations of the inlet are in accordance with typical stormwater pollutant concentrations in Gothenburg and the outlet mean concentrations are below the compared discharge guideline values. The results also show that the infiltration trench has an average removal efficiency of 80% for suspended solids, approximately 50% for total inorganic nitrogen and all removal efficiencies for heavy metals were over 50%. Zinc, lead, copper and chromium have removal efficiencies of 70-80% while cadmium and nickel have removal efficiencies of 50-60%. The observed flow hydraulics showed good flow detention since the outflow hydrographs were generally significantly lower than the inflow hydrographs for all storm events. However, the flow detention measurements were not carried out under normal circumstances, since the overflow and choking construction at the outlet had to be removed in order to perform the sampling, which affected the result. The conclusion is that the infiltration trench has good pollutant removal efficiencies, and most likely well-functioning flow detention. In order to obtain a statistically reliable result it is recommended to carry out the observations during a longer period and thereby also determine seasonal variations.

Key words: infiltration trenches, SUDS, urban stormwater drainage, pollutant removal, flow detention, suspended solids, heavy metals, nutrients

Föroreningsreduktion och flödesutjämning i makadamdiken
En undersökning av ett makadamdike i Kungsbacka

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SAMMANFATTNING

Lokalt omhändertagande av dagvatten (LOD) är idag en vanligt förekommande metod för att reducera dagvattnets volym och föroreningsbelastning innan det släpps ut till recipienten. Exempel på vanligt förekommande tekniker för LOD är dagvattendammar och makadamdiken. Detta examensarbete har som syfte att bidra till en ökad kännedom om makadamdikens funktioner, genom en praktisk undersökning av ett makadamdikes föroreningsreduktion och flödesutjämning eftersom makadamdiken inte har undersökts i samma utsträckning som andra LOD tekniker, som exempelvis dagvattendammar. Studien har genomförts med flödesproportionell provtagning i inloppet och utloppet av ett makadamdike, beläget under ICA Maxis parkeringsplats i Kungsbacka, söder om Göteborg. Provtagningarna har skett under en period från april till juni år 2012 och resultatet av fem regn har analyserats. De parametrar som undersökts är suspenderad substans, tungmetaller samt kväve och fosfor. Laborationer har skett på laboratoriet för avdelningen Vatten Miljö Teknik på Chalmers tekniska högskola i Göteborg. Kväve och fosfor har analyserats med jonkromotografi och tungmetaller har analyserats med ICP-MS. Förberedelser av ICP-MS prov har gjorts i laboratoriet och har därefter skickats till ett externt laboratorium för analys. Inkommande dagvatten har jämförts med typiska värden för dagvatten i Göteborg och utgående vatten med riktvärden för utsläpp för dagvatten. Resultatet är presenterat som Event Mean Concentration (EMC) och reduktion (R) och har beräknats genom kumulativ föroreningsberäkning. Resultatet av studien visar att kvaliteten av inkommande dagvatten stämmer överrens med typiska värden för dagvatten i Göteborgsområdet och föroreningshalterna i det utgående vattnet är under de jämförda riktlinjerna. Resultatet visar också att makadamdiket har en genomsnittlig reningsgrad över 80 % för suspenderad substans, cirka 50 % för kväve och samtliga reningsgrader för tungmetallerna var över 50 %. Zink, bly, koppar och krom hade reningsgrader runt 70-80% medan kadmium och nickel hade reningsgrader runt 50-60%. Resultatet för flödesutjämningen är presenterat i hydrografer och visar en god flödesutjämning eftersom utflödeshydrograferna generellt har betydligt lägre toppar än inflödeshydrograferna. Flödesmätningarna utfördes dock inte under normala förhållanden eftersom brädd- och strypfunktionen i utloppsbrunnen togs bort för att genomföra provtagning och mätning. Slutsatsen är att makadamdiket har en god reningsförmåga samt förmodligen god flödesutjämning. För att få ett statistiskt säkrare resultat är det rekommenderat att göra fler mätningar under en längre period, då också årstidsvariationer kan utvärderas.

Nyckelord: Makadamdiken, dagvattenrening, dagvattenhantering, LOD, tungmetaller, suspenderad substans, näringsämnen

Contents

Preface

This master thesis has been initiated by Norconsult AB and carried out from January to August 2012 at the Department of Civil and Environmental Engineering, Division of Water Environment Technology at Chalmers University of Technology, Sweden.

First of all we would like to thank our supervisors, Dr/Assistant professor Thomas Pettersson at Chalmers University of Technology and Emma Nilsson Keskitalo at Norconsult AB. Your support and feedback during this master thesis project has been very valuable for us.

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Finally we would like to express our gratitude towards the co-workers at Team VA-teknik at Norconsult AB for helping us when needed. Especially we would like to Walter Gabrijelcic for your help with installing all measurement devices at the study site.

Göteborg, August 2012

Erika Nilsson and Andrea Stigsson

1 Introduction

Drainage systems are essential in our society and human activities affecting the natural water cycle have created this fundamental need. Urbanisation has resulted in natural land being exploited and covered with impermeable surfaces. Impervious surfaces reduce the natural drainage and increase the stormwater runoff. This can result in many negative consequences if the stormwater is not controlled, as for example flooding and pollution of water-courses. Human health could also be at risk. Well-functioning urban stormwater drainage systems are thereby essential in urban areas today.

Traditionally, urban stormwater has been drained in combined sewer systems, which divert stormwater and wastewater in the same sewers. This was the only constructed solution for stormwater drainage in Sweden until the 1950's (Stahre, 2004). However, combined sewer systems contribute to an increased load on receiving wastewater treatment plants, as well as risks for flooding and discharge of untreated wastewater. When urban areas increase in size and population these risks also increase. Due to that the stormwater runoff increases, there is a great risk that the combined sewer systems get temporarily overloaded during heavy storm events. Therefore, separate stormwater sewer systems, in which only the stormwater is conveyed and directly discharged into nearby surface waters, became the most common solution in Sweden after the 1960's (Stahre, 2004).

In addition to an increased runoff, the stormwater in urban areas usually contains pollutants. These pollutants are accumulated on impermeable surfaces and washed away with the first stormwater flush (Pettersson, 1997). When stormwater is conveyed in separate sewers it is discharged without treatment and an increased concern regarding the impacts that this is causing on receiving waters has thereby been developed. Solutions that control both the stormwater flow and water quality have hereby recently been more and more popular. Different types of on-site solutions have been developed. On-site solutions treat the stormwater by even out peak flows and reduce pollutant concentrations before it is discharged. Today, they are commonly applied when new residential areas and highways are built or rebuilt. These treatment solutions can for example consist of stormwater ponds or infiltration trenches.

Nevertheless, most research has been on stormwater ponds while the research on infiltration trenches has been more limited. The functions of infiltration trenches are therefore not that widely known and the opinions, whether they should be applied for flow detention or pollutant removal, differ. Hitherto, the majority of infiltration trenches have been constructed in the purpose of flow detention. A reason to this is that the research regarding pollutant removal efficiencies shows a wide range of removal rates. The Swedish Road Administration (2011) states, for example, that the removal of metals ranges from 10-90%. Additional investigations on the removal efficiencies of infiltration trenches are therefore needed.

1.1 Background

Infiltration trenches are commonly constructed adjacent to roads and around/under parking lots. The main function of infiltration trenches is to control the stormwater flow even though it is stated that they also can be applied to reduce the pollutant load of the stormwater. Under the parking lot outside the large supermarket ICA Maxi in the city of Kungsbacka three infiltration trenches have been constructed. One of these infiltration trenches has been investigated in this study. The city is located at the coast, approximately 40 kilometres south of Gothenburg. See Figure 1a for location of Kungsbacka and Figure 1b for an overview of the parking lot.

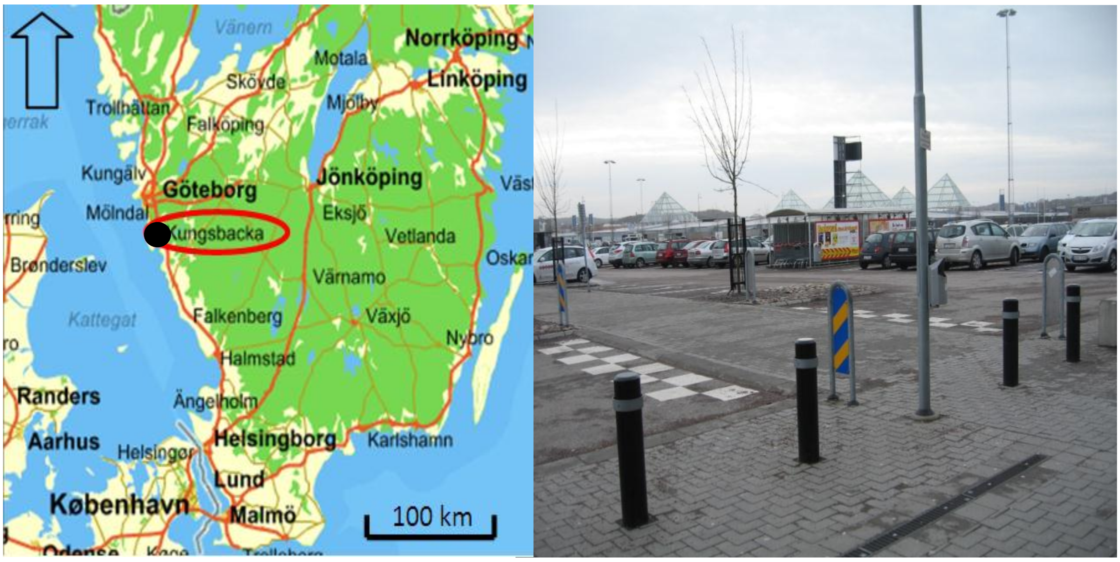

Figure 1: a) Location of Kungsbacka, Sweden (Eniro, 2012) *b) ICA Maxi Parking lot (Nilsson & Stigsson, 2012)*

This Master Thesis project is carried out in cooperation with Norconsult AB, aiming on a more detailed study of removal efficiencies of infiltration trenches as well as their flow detention capacity.

1.2 Aim of Study

This master thesis aims at contributing to the research on infiltration trenches with a complementary investigation of pollutant removal efficiencies and flow detention. Flow detention and removal efficiencies of stormwater pollutants are investigated for one infiltration trench, located under the parking lot of ICA Maxi in Kungsbacka. The obtained results of pollutant concentrations and removal efficiencies are compared with earlier studies as well as stormwater discharge guidelines. The observed flow detention is compared to the design capacity. Finally, the function of the infiltration trench is evaluated.

1.3 Methodology

This master thesis consists of a literature study, an experimental procedure and an analysis of the results. The literature study provides a background to urban drainage, rain characteristics, flow detention and common pollutants in urban stormwater. Furthermore, it also presents the application of sustainable urban drainage systems (SUDS) and different types of stormwater management practices.

The experimental procedure consisted of stormwater sampling at the infiltration trench in Kungsbacka. Five storm events from April to June, in 2012, have been analysed. After sampling, laboratory experiments have been conducted. The laboratory experiments have been carried out at the WET laboratory at Chalmers University of Technology and Alcontrol laboratory in Linköping. Different water quality analyses have been performed; such as heavy metals, total suspended solids (TSS), volatile solids (VS), total inorganic nitrogen (TIN) and phosphate-phosphorous (PO_4^{3-}).

The pollutant removal efficiencies have been determined using a mass balance approach, based on flow-weighted samples collected from the inlet and the outlet of the infiltration trench. Moreover, Event Mean Concentrations (EMC) have been calculated for each storm event. The obtained results have been analysed and compared with results from previous studies on infiltration trenches as well as discharge guidelines. The guideline from Riktvärdesgruppen (2009) have been used since these guideline values are one of the most elaborated ones in the field of stormwater management in Sweden.

The flow detention of the infiltration trench has been measured by flow meter devices installed at the inlet and outlet of the infiltration trench and the results are presented as hydrographs. Based on the observed detention characteristics, the flow detention function has been evaluated and compared to the design capacity.

1.4 Delimitations of Study

The results of the removal efficiencies and flow detention of the infiltration trench are based on five rain events during the period April to June, in 2012. The investigation has only been performed on one infiltration trench, at the study site in Kungsbacka. The main focus is on the removal efficiencies of suspended solids and heavy metals although nutrients also are analysed. Both total and dissolved metals have been analysed but the focus is on total metals. When investigating nitrogen and phosphorous concentrations only total inorganic nitrogen (TIN) and phosphate-phosphorous (PO_4^{3-}) have been evaluated, even though they sometimes are denoted as nitrogen and phosphorus.

2 Urban Stormwater

The natural water cycle describes the continuous movement of water. Stormwater is defined as the surface runoff resulting from precipitation and the ground surface characteristics affect the volume of stormwater runoff that will be generated. Figure 2 illustrates an example of stormwater runoff generation before and after urbanisation.

In natural landscapes, without any built-up surfaces, the stormwater can take different routes. Some infiltrate through the ground and turn into groundwater. Meanwhile some runs on the ground surface, so called surface runoff. In any case, the water moves towards a watercourse. One part of the stormwater returns to the atmosphere by evaporation or by transpiration by plants. The proportion between runoff and infiltration depends on how saturated the ground is, and the runoff flow increases when the ground becomes saturated. The proportions of the different routes also depend on surface type and the duration of the rainfall (Butler & Davies, 2004). This can be observed when natural land is being exploited and built-up surfaces replace natural land. An increase of impervious surfaces results in an increase of stormwater runoff in relation to infiltration. If the amount of impervious surfaces increases considerably the natural water cycle and its processes will be affected.

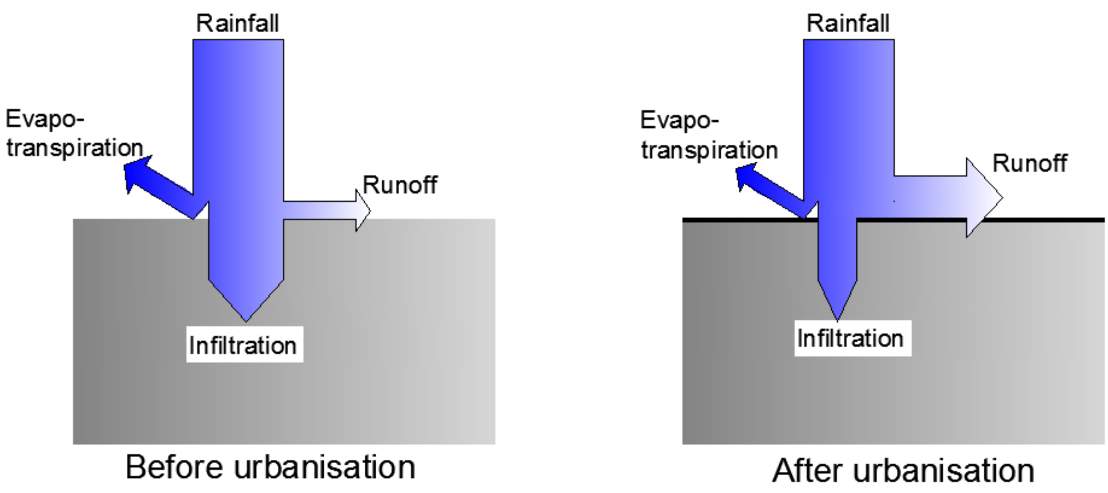

Figure 2: The changes of rate of rainfall due to urbanization (Butler & Davies, 2004). Modified by Erika Nilsson 2012-02-27

The increased runoff contributes to an increase of volume of water reaching the watercourse in a short term perspective, since the runoff on impervious surfaces is transported with a higher speed than runoff on natural surfaces. As a consequence, the flow will both start and decay quicker, which results in greater peak flows (Haestad & Durrans, 2003). In the following subchapters a description of stormwater runoff generation, by rainfall and ground conditions, as well as stormwater water quality is presented. A summary of stormwater quality discharge guidelines are also presented.

2.1 Stormwater Runoff Generation

As described above, stormwater runoff is originated from rainfall characteristics as well as ground conditions of the drainage area. This subchapter presents more detailed descriptions of these characteristics and conditions.

2.1.1 Rainfall Characteristics' Effects on Runoff Generation

The majority of stormwater runoff is a result of rainfall, but other types of precipitation also contributes, as for example snow. However, rainfall normally dominates. Consequently, rainfall modelling and prediction becomes vital in the planning process of drainage systems, as well as when analyzing their function and operation. Storm event properties that are of importance are: intensity, duration, and frequency.

Rainfall *intensity*, also called depth, is expressed as mm/h or l/s*ha, at a specific location. Rainfall *duration* is an expression for the time period of which the rainfall lasts. It does, however, not necessarily express the time period for an entire storm. The storm can be segmented and durations representing different parts can be analysed as a range of durations. Rainfall *frequency* is commonly denoted as the return period of a rainfall, and is the average number of years it takes before another rainfall with a specific magnitude occurs. For instance; a rainfall with a return period of 5 years, will on average occur 20 times in 100 years. (Butler and Davies, 2004)

Rainfall information is generally given in the form of an intensity-duration-frequency relationship, also denoted IDF. Figure 3, illustrates a typical IDF-relationship. As the illustration implicates; intensity reduces as duration increases, which means intensity and duration have a form of inverse relationship (Stahre and Urbonas, 1990). Butler and Davies (2004), explains that this relationship is in line with what is known as common-sense; it feels natural that drizzle goes on during a long period, but heavy storms only last a short time. Furthermore, intensity and frequency are also related; high intensity rains have longer return periods for a given duration.

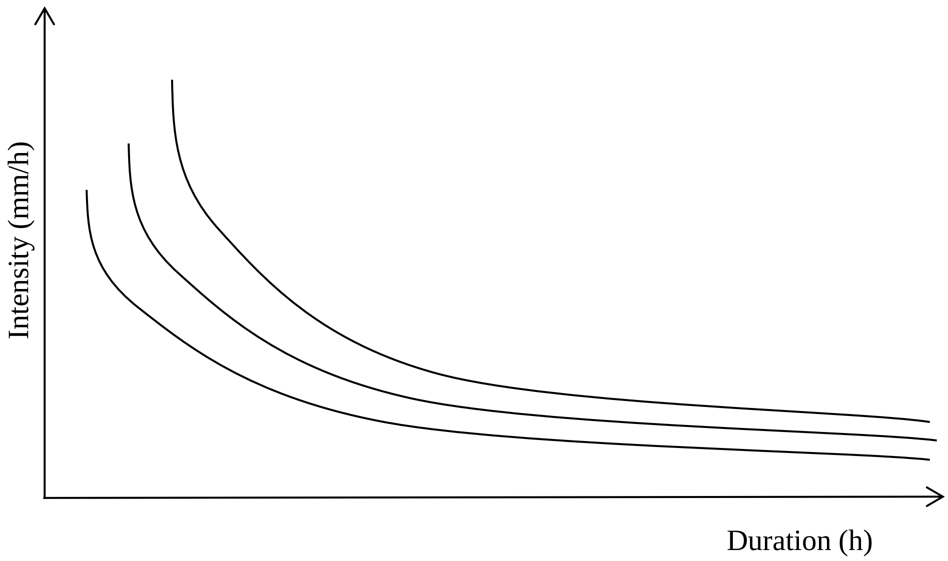

Figure 3: Illustration of an IDF-graph. Intensity in relation to duration for different curves of return periods. (Butler & Davies, 2004) Modified by Andrea Stigsson 2012-02-23

A storm profile can be made with different levels of precision. A simple type is to use a block diagram, which represents the rainfall as a block rainfall, derived directly from an IDF curve. As the name implies, a block rainfall has a rectangular time distribution and thereby the same intensity during its entire duration, which makes it easy to understand and is usually applied in calculation methods.

Generating rainfall data

Different measurement methods can be used to generate up-to-date measurements of rainfall data. Rain gauges are the most common method and a standard type is the tipping bucket. Rain gauges generally measures rain data expressed as intensity, in mm/h, at a specific location in the catchment area (Haestad & Durrans, 2003). This results in point rainfall data, which is representative for that location. Point-rainfall data is, however, not always representative for a larger area and a number of measurement locations could therefore be necessary.

To determine what kind of rainfall characteristics to expect at a site during a time period, as for example a year, time-series of rainfall events have to be observed. Time-series of rainfall events include single events with dry periods in-between and gives information about return periods for different rain characteristics, as for example, peak flow. Critical conditions at a specific site can thereby be identified.

The purpose of the data determines what type and level of detail that is necessary. Data for design and planning are mainly used in the purpose of producing an overview and enabling an overall design of the dimensions of a drainage system and data of peak flow rates are important in this situation. More detailed data are required when checking and evaluating a drainage system, since the performance is assessed during extreme conditions or when the system is heavily loaded. Most detailed data are necessary when analysing a system, due to the fact that it is a case of evaluating a system that already exists. Real flow data and real-time operation data are examples of what can be of interest. (Butler and Davies, 2004)

Seasonal Rainfall Variations in Sweden

Sweden is located in an area called the West Wind Belt, which is an area characterized by western winds and cyclones that are moving along zones, mainly the polar zone. These cyclones are separating warm air from cold air. Due to the proximity to the North Atlantic Sea and strong winds, the climate during the winter season is considered as mild in Sweden. Due the presence of cyclones, the climate is also characterized by precipitation falling all year around. It is during summer and autumn the most precipitation occurs, when the cyclones are coming from areas west or south west of Sweden. The western parts of Sweden are thereby subjected to more precipitation than the rest of the country. However, there can also be long periods of dry weather when the cyclones are blocked by anticyclones and thereby forced to move north or south of Sweden. (SMHI, 2009)

According to Butler and Davis (2004) it has been showed that summer storms are more likely to be more peaked than winter storms and this is also the case in Sweden. The precipitation during the summer season is often occurring as thunderstorms and large amounts of rain or hailstone can precipitate during short storm events with high intensity. During the winter season, the intensity of the storm event is usually lower than in the summer and most precipitation is occurring as snow. In the coastal areas in the south of Sweden it is more common with rain than snow during the winter season (SMHI, 2009).

2.1.2 Ground Characteristics' Effects on Runoff Generation

Only a part of the rainfall that reaches the ground will generate runoff due to losses of varying types. Interception, infiltration, evapotranspiration and depression storage are examples of losses that have to be considered when calculating stormwater runoff. Figure 4 schematically shows the concept of runoff generation.

The types of losses can be divided in to initial losses and continuing losses. In modelling, all initial losses are usually combined and assumed to affect the runoff only at the beginning of the storm event. However, in the case of intense storms in highly urbanized areas, initial losses generally do not affect the runoff generation markedly and can therefore be neglected. Nevertheless, for less severe storms and less urbanized areas the initial losses can affect the generation of runoff noticeably.

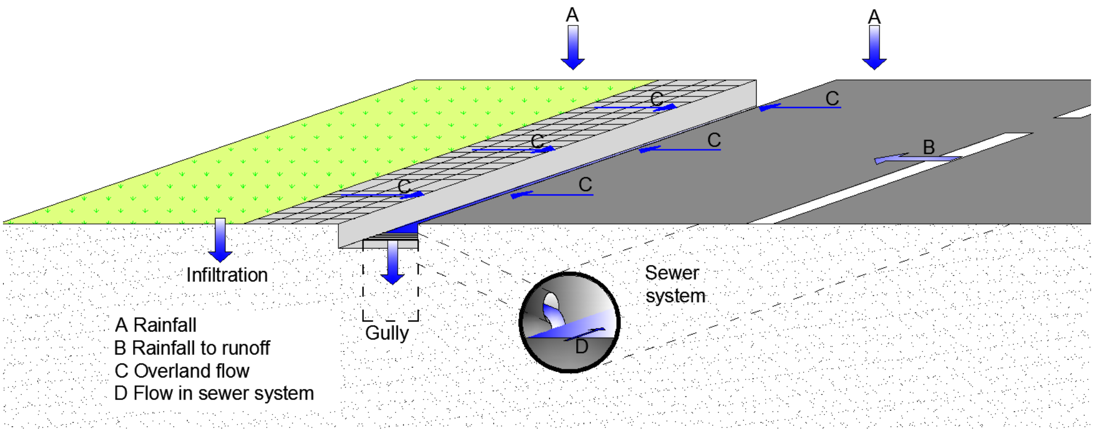

Figure 4: The concept of stormwater runoff generation (Butler & Davies, 2004). Modified by Erika Nilsson 2012-02-22.

Initial Losses

Depression storage is a type of initial loss where the rain water is captured in holes and irregularities in the ground. The volume of the depression storage is depending on ground characteristics as well as rain characteristics. Another type of initial loss is interception, which means that vegetation collects and retains runoff water. Impervious areas only have a small rate of interception; less than 1 mm, and it is therefore commonly negligible compared to the losses from depression storage. (Haestad & Durrans, 2003)

Continuing Losses

Infiltration is a type of continuing loss, and corresponds to the process of rainfall passing through the surface layer of the ground, entering pores of the soil. How much of the rainfall that will infiltrate is decided by the infiltration capacity of the soil, which depends on a number of factors. Firstly, soil characteristics such as type, compaction and structure. Secondly, local water conditions at the time of the rain event, as for example, water depth on the soil and initial moister content of the soil. Finally, the infiltration capacity is affected by the type of surface cover. Typically, the infiltration rate is high initially and decreases exponentially until saturation of the upper zone of the soil is reached and a steady-state capacity is obtained. (Butler & Davies, 2004)

Evapotranspiration is another type of continuing loss where runoff water constantly vaporizes from open water bodies and vegetation. As stated earlier continuing losses always affect the runoff generation but despite this fact evapotranspiration can be neglected in some cases. In the case of short duration rainfalls the effect of evapotranspiration is very small, and therefore it is neglected or classified as an initial loss. (Butler and Davies, 2004)

Effective Rainfall

Continuing losses does, in contrast to initial losses, markedly affect the generation of runoff in urban areas, and the effect is most apparent in areas with large open spaces. They are normally represented by a simplified model based on a constant proportional loss equation, after initial losses have been subtracted. The result is the effective rainfall of the storm event. Ground and rainfall characteristics determine the runoff coefficient, C. The most important characteristics are; soil and vegetation type, slope, land use, rain intensity and duration. It is important to transform effective rainfall by surface routing to an overland flow hydrograph when calculating the runoff. (Butler and Davies, 2004)

2.2 Urban Stormwater Quality and Characteristics

There is a wide range of different substances in urban stormwater, which can be both organic and inorganic, and are to be considered as pollutants. They can be present in dissolved, colloidal or particle forms. The concentrations of pollutants can vary depending on different factors, as for example storm event and site conditions. This subchapter presents common pollutant sources as well as common pollutants in urban stormwater. Table 1 presents average concentrations from Gothenburg 1995-1996 and their ranges of some common pollutants in urban stormwater.

Table 1: Ranges and mean concentrations of pollutants present in urban stormwater (Pettersson, 1996)

Pollutant	**Mean concentration [mg/l]**	**Concentration span [mg/l]**
COD	65	5 - 100
TN	2	1.3 - 3.6
TP	0.3	0.1 – 0.76
TSS	200	30 - 1750
Zinc	0.3	0.005 – 0.95
Copper	0.1	0.0015 – 1.33
Lead	0.2	0.005 – 0.84
Cadmium	0.001	0.0005 – 0.003

2.2.1 Pollutant Sources

The urban atmosphere is classified as a major stormwater pollutant source and the pollutants in the atmosphere are mainly derived from different man-made activities, such as industry, heating, vehicle use or refuse incineration. In Sweden, 20% of the total organic matter, 20% of the total phosphorous and 70% of the total nitrogen in stormwater are assumed to originate from atmospheric fallout. (Butler & Davies, 2004)

There are two types of atmospheric fallout; wet fallout and dry fallout. Wet fallout is absorbed and dissolved by precipitation while dry fallout is transported directly into the stormwater drainage system or settled on land surfaces. These dry fallout particles can also be carried long distances by the wind. The contribution of wet and dry fallout is varying from site to site. In Gothenburg, Sweden, wet fallout is the dominating type of atmospheric fallout. It is accounting for about 60% of nitrogen, phosphorous, lead, zinc and cadmium pollution. (Butler & Davies, 2004)

Vehicles and everyday traffic are another major sources of pollution in many urban areas. The reason for this is firstly due to the heavy concentrations of automobiles in urban areas and secondly due to the difficulty of vehicle exhaust to be diluted (Malmqvist, 1983). There are several forms of vehicle emissions, such as volatile solids and PAHs from unburned fuel, exhaust gases, lead particles from petrol and hydrocarbons from fuels, lubrication and hydraulic systems (Butler & Davies, 2004).

In stormwater there are also particles originating from different types of buildings and roads. Due to erosion there are particles of brick, concrete, asphalt and glass, which mainly are major constituents in stormwater sediments. Pollutants can also be released from roofs, gutters, and paintings. However, the amount of released pollutants depends on the condition of the building or the roads. Roads are also degrading over time, which is a process that releases particles of various sizes. Depending on pavement structure and material, various substances can be released from the wearing of pavement such as bitumen, aromatic hydrocarbons, tar, emulsifiers, carbonates metals and fine sediments (Butler & Davies, 2004) .

Moreover, road surfaces can have varying metal loadings. It has been shown that roads with concrete surfaces can, for example, have high levels of lead and zinc compared to asphalt surfaces. The metal loadings on roads are also depending on hydrological conditions and street cleaning practices. Thus, it has been shown that the municipal street cleaning procedures both reduce the total metal levels and their size distributions due to that metals with particles sizes greater than 250 µm are more efficiently removed with street sweeping (Ellis & Revitt, 1981).

Other stormwater pollutant sources in urban areas are animals, urban debris and spills or leaks. Urine and faeces from animals are sources of high oxygen demand and contain bacteria such as faecal coliforms and faecal streptococci. Street debris, such as litter and organic material are also sources of a high oxygen demand, as well as contributing to elevated solids content. Spills and leaks have varying pollutant content depending on land use and human behaviour. Nevertheless, industrial spills are dominating compared to household spills, which only is a minor pollutant source. (Butler & Davies, 2004)

2.2.2 Suspended Solids

There are four classes of solids that are of concern for stormwater, these are gross, grit, suspended and dissolved solids. Suspended and dissolved solids are the finest sized types of solids and are of major concern regarding the stormwater pollutant characteristics.

Suspended solids (SS) are defined as solid matter, which is maintained in suspension and then retained when a sample is filtered with a 0.45 µm pore size. The solid matter can both be organic and inorganic. Suspended solids that have a size of less than 63 µm in diameter are the most efficient carriers of pollutants. These fine fractions of suspended solids are carrying a significantly high pollutant load compared to other stormwater pollutants. Thus, high concentrations of fine fractioned suspended solids can contribute to various adverse effects on receiving waters such as high turbidity, reduced light penetration and interference with fish and other aquatic organisms. Moreover, after deposition the pollutants attached to the sediment are posing a risk since they may re-suspend at high flows or cause a delayed sediment oxygen demand. (Butler & Davies, 2004)

Fixed solids are defined as the residue of total, suspended or dissolved solids after ignition while volatile solids are defined as the weight loss on ignition (Standard Methods Committee, 1997). Volatile solids can give an approximate indication of the amount of organic content in suspended solids (Butler & Davies, 2004). This is due to that the loss of ignition not only are losses of organic matter but also losses caused by decomposition and volatilization of some mineral salts. For a more precise determination of organic matter it is recommended to utilize other experimental procedures, such as total organic carbon, BOD or COD (Standard Methods Committee, 1997).

Total suspended solids (TSS) are suspended solids, dissolved solids and volatile solids altogether. Many other pollutants have a strong affinity to TSS and therefore many other pollutants present in urban stormwater are removed together with TSS. Nevertheless, there are some pollutants that not are removed together with TSS, which among others are dissolved solids, nitrites and nitrates and soluble phosphorus. (Stahre & Urbonas, 1990)

2.2.3 Heavy Metals

Heavy metals can be defined as metals with densities of or over 5000 kg/m^3 (Malmqvist, 1983). All heavy metals occur naturally in different concentrations in nature. There are some heavy metals, such as iron, manganese, zinc and copper, which are essential for the survival of living organisms. However, in elevated concentrations these metals are toxic. There are also heavy metals that are not essential to living organisms in any concentration, for instance mercury, cadmium and lead (Metcalf & Eddy, 2003). The system of heavy metals in an urban environment is considered as complex and includes accumulation, transport pathways and removal processes. The loads of heavy metals in an urban area vary depending on the characteristics of the contributing source, the chemical composition of the metal, deposition, re-suspension processes and hydrological conditions (Revitt, et al., 1990).

Heavy metals can be sorted into different classes, which are dissolved metals, suspended metals, and total metals. Dissolved metals are defined as metals that in an unacidified sample can pass a 0.45 µm membrane filter while suspended metals are those metals that can be retained on a 0.45 µm membrane filter. Total metals are defined as the sum of dissolved and suspended metals (Metcalf & Eddy, 2003). In urban stormwater, lead is mostly present in the suspended solid phase while metals such as zinc, copper and cadmium are present in their dissolved phase (Morrisson, et al., 1984).

In urban stormwater, heavy metals are mainly attached to suspended solids and the concentrations of heavy metals usually increase with decreasing particle size. The reason for this is that finer particles have a higher capacity for cation ion exchange and that they have relatively large surface areas. (Herngren, et al., 2005)

The main source of lead is mainly considered to be vehicles (Revitt, et al., 1990). Lead can accumulate in the human body and cause lead poisoning and chronic diseases. Therefore, lead can be considered as one of the most severe environmental problems in a public health point of view. There is no other chemical pollutant with the same toxicity and ability to accumulate in nature and that is spread by human activities to the same extent as lead (Odum, 2000).

Zinc is essential in small quantities to all living organisms. However, elevated concentrations of zinc may be toxic even though the human body has proven to be exceptionally resistant to zinc. Zinc present in soil can reduce the growth of plants. Major sources of zinc in urban stormwater are atmospheric fallout and corrosion of building materials. In Sweden the atmospheric fallout of zinc is mainly originated from continental European industries. (Malmqvist, 1983)

Copper is also essential in small quantities but toxic to living organisms in higher concentrations. High concentrations of copper in drinking water may cause acute copper poisoning and copper in soils can decrease the growth or cause death to plants or trees. In urban stormwater the major sources of copper is atmospheric fallout or corrosion of building materials. (Malmqvist, 1983)

2.2.4 Nutrients

Nutrients, which consist of nitrogen and phosphorous, can also be present in stormwater. However, it is more common that stormwater with a high amount of nutrients is found in agricultural areas or areas with grazing cattle. In urban and suburban areas, the levels of nutrients in stormwater are lower. (Monteiro, 2005)

Nitrogen

There are four main forms of nitrogen, these are organic nitrogen, ammonia, nitrite and nitrate. The sum of all four forms of nitrogen altogether is total nitrogen (TN). Organic nitrogen, which analytically can be determined by the Kjeldahl method, includes natural materials such as proteins, peptides, nucleic acids and urea. There is also various synthetic organic material included in organic nitrogen (Metcalf & Eddy, 2003). Ammonia is generated by the breakdown of nitrogenous organic matter. The major part of this ammonia is quickly recycled but there is some ammonia that is released to the atmosphere (Malmqvist, 1983). Ammonia nitrogen is in solution, depending on the pH of the solution, present in two phases, which are the ammonium ion (NH_4^+) and ammonia gas (NH_3) (Monteiro, 2005). The main sources of nitrogen in urban stormwater are atmospheric deposition, animal and bird spilling, decomposition of organic litter in gutters and the utilization of fertilizers on grass surfaces (Monteiro 2005). When the environmental impact of nitrogen is evaluated, all forms nitrogen is contributing and total nitrogen is thereby the important parameter (Malmqvist, 1983). If excessive concentrations of nitrogen are discharged to receiving waters there is a potential of undesirable growth of aquatic plants such as algae and floating macrophytes, which in severe cases can lead to eutrophication (Monteiro, 2005).

In this Master Thesis total inorganic nitrogen (TIN) have been measured, which consist of ammonia gas, ammonium ion, nitrite and nitrate (Metcalf & Eddy, 2003).

Phosphorus

In the natural environment there are no elemental phosphorus existing and there are no stable gaseous phosphorous compounds in the atmosphere. Thus, atmospheric phosphorus only exists when it is absorbed onto particulate matter (Malmqvist, 1983). Instead phosphorous can be present as phosphate ions, inorganic orthophosphate, polyphosphate, complex phosphate or in living or dead organic matter (Metcalf & Eddy, 2003).The presence of phosphorous in urban stormwater has been investigated in numerous of studies and in many cases the studies have shown significantly high phosphorous concentrations (Malmqvist, 1983). The main phosphorus source is domestic sewage, which has entered the stormwater system in some way. Other potential phosphorous sources in urban stormwater are the same as for nitrogen (Monteiro, 2005).

2.2.5 Organic Pollutants

There is a wide range of organic pollutants present in urban stormwater due to the wide use of organic chemicals in different materials and products. Organic substances can also be generated unintentionally in different manufacturing or combustion processes. Many of these substances have never occurred on earth prior to being produced. Today there are thousands of organic substances and most of them are still unidentified. However, the most common groups of organic pollutants are polycyclic aromatic hydrocarbons (PAHs), phthalates and nonylphenol ethoxylates (NPE) and nonylphenols (NP). In general there is a lack of research on organic pollutant although PAHs have been measured to some extent. (Strömvall, et al., 2007)

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic compounds that is widely spread. There are several hundred types of different PAHs. At room temperature PAHs occur as flammable, colorless solids without any significant odor (UK Health Protection Agency, 2008). The most PAHs are in general attached to settled or suspended particles in water due to their affinity for organic carbon and their low solubility. Studies of PAHs in stormwater have shown that the main part of the PAHs are linked to suspended solids and only a minor part of the total PAH content is appearing in dissolved form. (Karlsson & Viklander, 2008)

PAHs originate from natural processes such as forest fires or incomplete combustion of organic material. Another source is industrial activities such as aluminium, iron or steel production, waste generation, mining and oil production (UK Health Protection Agency, 2008). In stormwater the most important sources of PAHs are wearing and leaching of asphalt, wearing of tires and automobile exhausts. The highest concentrations of PAHs are generally measured at the first flush in the beginning of the runoff. Many PAHs are carcinogenic and mutagenic and are therefore included in EU priority pollutants list (Karlsson & Viklander, 2008). They are persistent organic pollutants and therefore degrade slowly in the environment (UK Health Protection Agency, 2008).

Phthalates

Phthalates are a group of industrial chemicals that are used as plasticizers in polyvinyl chloride (PVC) plastics and they are therefore widely used in many consumer products. Examples of products containing phthalates are building materials, clothes, cosmetics, pharmaceuticals, medical devices, toys, food packaging, automobiles, and cleaning materials (Heudorf, et al., 2007). Globally, about 4 million tons of phthalates are annually produced (Björklund, et al., 2009).

Phthalates are not chemically bound to PVC plastics and due to this they can leach, migrate or evaporate into the atmosphere, indoor air, food or other materials. Humans can be directly exposed to phthalates when using products containing phthalates and indirectly when phthalates are leaching into other products. The exposure pathways are through ingestion, inhalation and dermal contact and humans can be exposed through their whole life time, including as foetus. (Heudorf, et al., 2007)

There is no risk for bioaccumulation of phthalates in human bodies (Heudorf, et al., 2007). However, phthalates can have severe adverse effects on humans, mainly on the reproductive system but also on the liver and kidneys (Fromme, 2011). In the environment, phthalates have severe effects on aquatic organisms (Björklund, 2010).

Due to the wide use of phthalates it is likely that these compounds reaches the stormwater systems. In urban stormwater, high amounts of phthalates have been detected. However, the research of phthalates in urban stormwater is not as extensive as for example for nutrients, heavy metals and PAHs (Björklund, 2010). A reason for this can be that the analyses of phthalates are expensive and time consuming (Björklund, et al., 2009).

2.3 Stormwater Discharge Guidelines

As stated above, urban stormwater contains a wide range of pollutants and the pollutant content can vary depending on site specific conditions. To reduce the pollution discharge from urban areas some discharge guidelines are needed, but due to the varying quality of stormwater it is difficult to state general discharge guidelines. The most widely known guidelines are the ones in the EU Water Framework Directive (WFD), which is a common framework for the water management policy within the EU. However, this framework covers all waters (groundwater, inland surface waters, transitional waters and coastal waters) and its main objective is that all water bodies in the EU member states should achieve good status by 2015. The definition of good status is based on the biological, chemical and physical characteristics of the water (Mihaiescu & Mihaiescu, 2009). Each member state is responsible for implementing the legislations in the WFD (Chave, 2001). In Sweden, the Swedish EPA is in charge of the WFD, and is in Swedish called "Vattendirektivet". The main purpose of "Vattendirektivet" is to monitor the water quality in Sweden. The water quality is classified as good or poor quality, where the purpose is to sustain waters with good quality and to improve the water quality for waters with poorer quality (Svenskt Vatten, 2011).

Regarding stormwater pollutant assessment the main utilization of the WFD can be the list of 33 priority substances, which can be seen as an attempt to identify the most hazardous substances in the field of water policy. The objective of this list is to set environmental quality standards and it includes substances among others plants protection products, biocides, metals, PAHs and some selected chemicals (European Commission, 2011). The aim is to eliminate the presence of these substances in natural waters until 2020 (Svenskt Vatten, 2011). However, in Sweden many of the substances in the WFD list of priority pollutants are not relevant when assessing stormwater quality due to the fact that many of these substances have been forbidden to use since a long time. The absence of these substances has been confirmed by several studies. Nevertheless, there is no guarantee that these substances would not appear in a natural environment due to potential long atmospheric transport, unlicensed usage, and leachate and diffuse pollution from imported goods (Alm, et al., 2010).

Furthermore, in Sweden there are no set guidelines for stormwater discharges on a national level. Instead each municipality has their own stormwater management plan which is adapted to the local conditions of their receiving waters. However, many of these stormwater management plans are lacking pollutant threshold values for stormwater discharges to receiving waters. There are national discharge guidelines for surface waters set by the Swedish Environmental Protection Agency but due to the variations of stormwater runoff quantity and quality between different rainfall events is not suitable to apply these guidelines (Riktvärdesgruppen, 2009).

For evaluation of stormwater quality, assessments are performed from case to case depending on the sensitivity of the receiving surface water. However, there is a potential of arbitrary assessments for every case. For this reason, in 2008, Riktvärdesgruppen, which is a network of professionals in the field of stormwater management in municipalities around the city of Stockholm, initiated a project with the purpose to develop proposed guidelines for stormwater discharges in the region. (Riktvärdesgruppen, 2009). These guidelines can be seen in Appendix 1.

3 Urban Stormwater Drainage

As a consequence of stormwater runoff characteristics and water quality there is a need to control and treat stormwater runoff in urban areas. Climate change and increasing population have resulted in that sewer systems tend to reach their limits, and there are different methods to address this problem. This chapter presents a description of how flow regulation by storage facilities and regulation devices is achieved. In addition, a calculation procedure of how to find the design flow and storage volume required for specific area is presented.

3.1 Flow Regulation and Storage

A traditional engineering solution to avoid overloaded sewer systems has been to increase the capacity of the sewer system, and thereby avoid peak flows. This can be achieved by, for example, changing from a combined system to a separate system by constructing new sewers with larger capacities or installing storage facilities (Stahre, 2006). An infiltration trench is a type of storage facility.

Storage facilities can detain stormwater during storm events, and thereby prevent peak flows. The storage volume required is determined mainly by inflow and outflow characteristics of inflow and outflow hydrographs from the storage facility. Figure 5, illustrates how the size of the storage volume varies in relation to inflow and outflow characteristics. The cut off area resulting from the intersection of the inflow and outflow hydrographs represent the storage volume of a storage facility. A large storage volume results in a greater reduction of the peak flow than a small storage volume. It is thereby important that the inflow construction has a considerably higher flow capacity than the outflow construction.

The storage volume of a detention facility is mainly designed based on the maximal volume of stormwater it temporarily has to detain during a storm event. The storage volume has to be sufficient to control peak flows at a given design storm. The design inflow is commonly defined by the selected design storm, and the inflow hydrograph calculated based on that. Equation 1 shows a basic mathematical expression for storage volume calculations, assuming that the storage is empty at the beginning of the storm. The bigger the difference the larger storage volume is needed to detain the peak flow. (Stahre & Urbonas, 1990)

$$V = \int_0^{t_0} (Q_{in} - Q_{out})\,dt \qquad (1)$$

Where:

V = required storage volume

t = time from beginning of storage

t_0 = time when the outflow hydrogrph intersects the recession limb of the inflow hydrograph

Q_{in} = inflow rate

Q_{out} = outflow rate

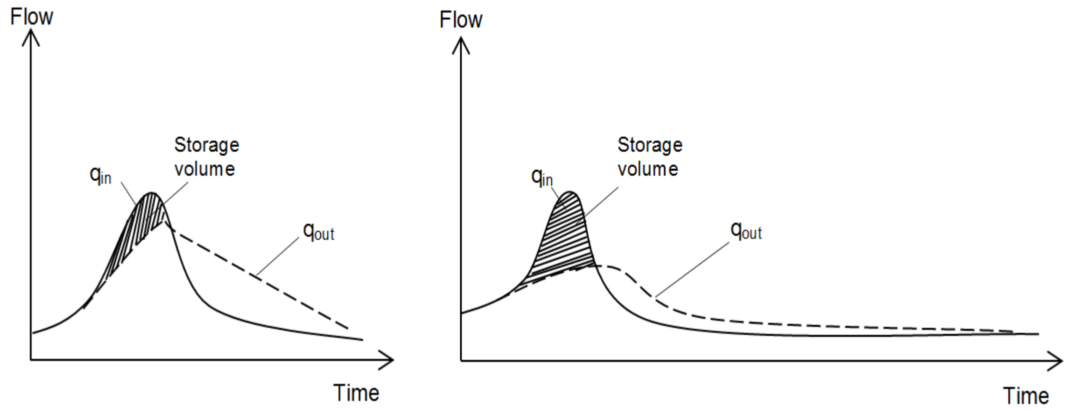

Figure 5: The relation between storage volume, flow and time. (Stahre & Urbonas, 1990) Modified by Andrea Stigsson 2012-02-25.

Since the purpose of storage facilities is to control the stormwater runoff in a specific area the flow capacity of the inflow construction is designed based on the stormwater run-off conditions of its drainage area. The outflow construction has to restrict the outflow volume so that detention of the stormwater is obtained. The flow capacity of the outflow construction is thereby designed based on the size of the inflow construction as well as the required storage volume. However, the outflow construction can also be designed to obtain a specific discharge limit. In that case the inflow construction and storage volume have to be designed based on that.

In addition to the inflow and outflow constructions, it may also be necessary to provide some type of overflow construction. An overflow construction will prevent flooding upstream the storage facility if the capacity is too low, by increasing the outflow. However, if the consequences of exceeding a discharge limit are more severe than flooding upstream the storage facility a by-bass construction may not be suitable. Furthermore, a storage facility is preferably designed to be emptied by a natural gradient. However, this is only achievable if there are elevation differences at the site. If the required storage volume only can be obtained with a deep storage and the site has a relatively flat surface, pumping will be necessary to empty the storage facility. (Stahre & Urbonas, 1990)

3.2 Calculation of Design Flow

As presented earlier storage facilities are designed based on selected design storms and based on the design storm a design flow can be calculated. The design flow represents the total volume of stormwater runoff that will result from the design storm in a specific drainage area, and thereby the required storage volume of a detention facility.

Chapter 2.1 generally describes the generation of stormwater runoff. In order to calculate the stormwater runoff of a specific drainage area in Sweden, the Swedish Water & Wastewater Association (SWWA) has provided different standards. These standards can be found in, for example, Publication P90 by SWWA. Factors included in these standards are; rain intensity, size of drainage area, ground characteristics and slope, type of development, and shape of drainage area.

3.2.1 The Rational Method

According to SWWA (2004), one method to roughly calculate the design flow for small drainage areas is the Rational Method. This method can be used upstream a storage facility, if the stormwater system do not have storage facilities. Downstream storage facilities it cannot be applied in an adequate way, since it will not give a correct estimation of design flow because the stormwater is detained.

The rational method is, as mentioned above, a rough calculation method. Thereby, a number of conditions have to be fulfilled for the method to be accurate. As a start, the area subject for the calculations should be more or less rectangular. Furthermore, drainage coefficients of the same values should be equally represented in the area, and finally, only small differences in time of concentration between parts of the drainage area is preferable. Consequently, the rational method is mostly applicable on relatively small areas with a uniform and even development (Svenskt Vatten, 2004). According to the rational method the design flow can be calculated according to the following Equation 2.

$$q_d = A^* \, C \, ^* \, i(t_r) \tag{2}$$

Where:
q_d =design flow [l/s]
A= Drainage area [l/s]
C = runoff coefficient [-]
i(tr) = design rain intensity [l/s*ha]
t_r = rain duration, equal to time of concentration, t_c, in the Rational Method [s]

The runoff coefficient C, is dimensionless and represents a measurement of the maximal part of a drainage area that contributes to runoff generation. In other words, it is an expression of how much of the rainfall volume that generates stormwater runoff, after all types of losses. Consequently, it is depending on level of development and level of impermeable surfaces in the area, as well as, ground slope and rain intensity; the greater ground slope and rain intensity, the bigger drainage coefficient. (Svenskt Vatten, 2004)

As explained earlier, important information about different rain characteristics in an area could be derived from long time-series of rainfalls. The design rain intensity, $i(t_r)$, is one of these characteristics and nationwide rainfall observations, which include information about daily precipitation, are provided by SMHI. (Svenskt Vatten, 2004)

Defining the design rain intensity also includes a selection of return period. SWWA has summarized guidelines where adequate return periods are given for different types of areas, in the range of urbanized to rural, and different types of conveyance techniques for wastewater, which also includes stormwater pipes. Generally, high level of urbanization results in high return periods, up to 10 years, while return periods in rural areas could be down to 1 year, depending on type of stormwater conveyance. (Svenskt Vatten, 2004)

As presented above, the rain duration, t_r, is assumed to be equal to time of concentration, t_c, when using the Rational Method. Time of concentration is equal to time of entry and time of flow upstream the location in the area which is subject to design calculations. The total time of concentration for a drainage area can be calculated by an empiric relation including length of conveyance path, slope of conveyance construction, contributing drainage area and rain intensity. However, for rough calculations assumed water velocity, for different conveyance constructions, and length of conveyance path can be applied. In general, water running in pipes has a higher velocity than water running over rough surfaces, such as trenches and gutters. (Svenskt Vatten, 2004)

4 Sustainable Development in the Field of Stormwater Management

As an alternative to traditional stormwater drainage such as combined and separate sewers, the development during recent decades has been more on solutions for local disposal of stormwater with the purpose of reducing the runoff rate to the sewer system rather than to detain large volumes. These solutions are characterized as low technology solutions and are less expensive compared to traditional engineering solutions. Nevertheless, both approaches can be used supplementary and the chosen approach is dependent on local conditions. This developmental change can be referred to the expression *Sustainable Development*. The concept of sustainable development has during the recent years also been incorporated in the field of stormwater management. (Stahre, 2004)

This chapter provides a presentation of Sustainable Urban Drainage Systems (SUDS) and its applications. It also provides information on different SUDS practices. The main focus is on infiltration trenches but other SUDS-practices, such as stormwater ponds are also briefly presented.

4.1 Sustainable Urban Drainage Techniques

Although the concept of sustainable development is widely accepted there are some difficulties in putting its principles into practice. Therefore the term Sustainable Urban Drainage has been introduced, which in short terms involves community affordability and social acceptability. The objectives of Sustainable Urban Drainage are according Butler and Davies (2004) to:

- Maintain an effective public health barrier
- Avoid local and distant flooding
- Avoid local or distant pollution of the environment
- Minimize the use of natural resources
- Adapt and rely on long term requirements for the future

These objectives are set for both wastewater and stormwater management. However, most of the objectives can be applied for stormwater.

In order to incorporate sustainable development in the field of stormwater management, different stormwater management strategies have been developed. These strategies have different terminologies in different parts of the world, for instance Sustainable Urban Drainage Systems (SUDS), Best Management Practices (BMPs), Low Impact Development (LID), Integrated Catchment Planning or Ecological Stormwater Management (Stahre, 2006). In Sweden, the term “Lokalt Omhändertagande av Dagvatten” (LOD) is the most frequently used term but internationally SUDS and BMPs are the most used names. They are all aimed to mimic the hydrological processes in nature, which can be through infiltration, percolation, surface runoff, slow drainage in open systems and in stormwater ponds and wetlands (Stahre, 2004). Henceforth, the term SUDS will be used in this report.

All sustainable stormwater management practices can be divided into structural and non-structural practices. A structural practice can for example be an infiltration trench, stormwater pond or a green roof. Non-structural practices are characterized as preventive measures, which for instance can consist of restrictions to use specific building materials, control exhaust emissions, apply street sweeping or have special routines for handling contaminated snow. (Stahre, 2006).

Besides achieving an effective stormwater treatment there is, in SUDS, also a focus on socio-economic factors when designing stormwater management practices (D'Arcy & Frost, 2001). Thus, SUDS can be considered as a holistic approach with multiple purposes on urban drainage. SUDS involve both flood and pollution control in combination with protection of the environment, which means that consideration must be taken to wildlife habitat and aesthetic amenities (Lampe, et al., 2004). When designing SUDS, there is a need for involvement from both landscape architects and ecologists (D'Arcy & Frost, 2001).

The implementation of SUDS in urban areas will generate additional values to the area. These additional values are according to Stahre (2006) technical values, environmental values, economical values, aesthetical values, biological values, recreational values and educational values. A “technical value” of a stormwater management practice means that the selected SUDS practice should meet the technical criteria set by the technical departments in a city and thereby have as high standard as a conventional treatment system. Concerning the “environmental value”, the purpose is to achieve satisfying pollutant removal efficiency. The “economical value” of a SUDS practice means that the involved technical departments should see an economical advantage of installing a SUDS practice. The “aesthetic value” means that the citizens can find the SUDS attractive. However, the aesthetic value is always subjective. The “ecological value” means that a SUDS practice for example can enhance the biological diversity, which may be of interest in dense urban areas. Concerning the “recreational value”, the purpose is to integrate recreational activities, such as walking, biking or riding together with the SUDS practice. Finally, the “educational value” means that a SUDS practice can be utilized for instance to inform children about water related issues. (Stahre, 2006)

However, it is important to keep in mind that although the main purpose of SUDS is to be sustainable in a long term it is not always the most sustainable option. In some cases it is more sustainable to apply conventional stormwater pipe system depending on the site conditions, for example water quality. (Stahre, 2006)

4.2 Infiltration Trenches

Infiltration trenches are one of the most common stormwater facilities for infiltration, and are also known as soakaways. Infiltration trenches can be used both to; control stormwater runoff and reduce the stormwater pollutant load to recipients (Silva, et al., 2010). However, the opinions differ if the main purpose is to control runoff flow or reduce the pollutant load of the stormwater. For instance, Silva et al. (2010) , Sowinski (2005) and Stahre (2004) state that infiltration trenches are most efficient in reducing and absorbing the stormwater runoff while Maniquiz et al. (2010) states that infiltration trenches are not efficient in controlling hydraulic peak flows. On the other hand, US EPA (2006) states that infiltration only should be used in order to treat small storms and that they thereby are applied for improving water quality. Nevertheless, the general assumption is that infiltration trenches should be utilized for flow detention.

Although infiltration trenches have been used for many years and are commonly used today, they are not as widely used as for example stormwater ponds. The reason for this is that there are no general accepted design specifications, which exist for stormwater ponds (Silva, et al., 2010). However, a general design of an infiltration trench constitutes of a linear excavation filled with a coarse stone aggregate, such as single or macadam (Stahre, 2006). The grain size of the macadam should be between 22.4 to 90 mm. (Swedish Road Administration, 2009). Furthermore, the excavation can be lined with a geotextile and covered with for instance topsoil, grass or pavement (Butler & Davies, 2004). See Figure 6 for a schematic illustration.

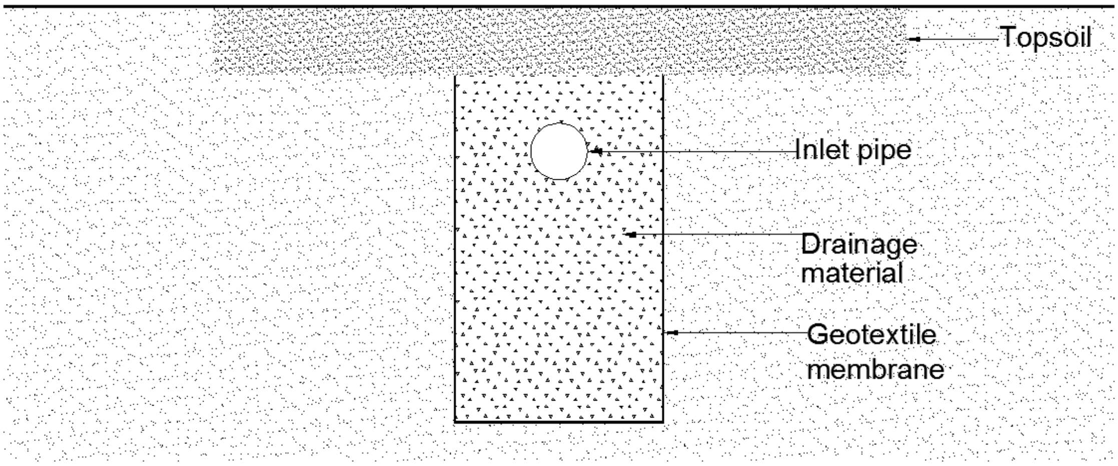

Figure 6: Illustration of an infiltration trench. (Butler & Davies, 2004)

Other construction designs are, however, also applied. Different forms and sizes are common for infiltration trenches (Lampe, et al., 2004). A reason for this can be that consideration must be taken to ground conditions when designing infiltration trenches. The design described above is, primarily, applied for smaller types of infiltration trenches, which are used for draining small catchment areas. The stormwater is then stored in the void space between the aggregates and can infiltrate into the surrounding ground or be released into the stormwater sewer system. (US EPA, 2006a)

Nevertheless, there are other types of designs more suitable for larger catchment areas. An example of this is underground storage facilities filled with macadam, which have a capacity to detain and, thereby, control stormwater peak flows. The stormwater in these types of infiltration trenches do not percolate into the surrounding ground. Instead the stormwater is conveyed in sub-drains, which are perforated pipe systems placed in gravel beds with the purpose to collect and remove infiltrated stormwater. The investigated infiltration trench under the parking lot outside ICA Maxi is of this kind.

4.2.1 Design Considerations and Applicability

Infiltration trenches can be applied in most climates but there is a need for some design modifications in cold and arid climates. Their efficiency is depending on local site conditions, for instance potential groundwater contamination, type of soils and clogging. The main limiting factors for infiltration trenches are the soil and groundwater conditions and topography. Soils should be permeable enough in order to allow the stormwater to infiltrate and minimize the risk of clogging. However, in order to avoid insufficient treatment and groundwater contamination the infiltration rate in soils should not be too quick. Ideally, the infiltration rate should vary between 12.5 and 75 mm per hour. Moreover, the clay content should not be more than 20 percent and clay/silt content should be less than 40 percent. (US EPA, 2006a)

For this reason there are some limitations when applying infiltration trenches in fine graded soils. When infiltration trenches are applied in these soils the percolation of stormwater to underlying ground is very low. There is also the potential that fine-graded material can intrude the stone material and clog the trench. For infiltration trenches in fine-graded soils, it is therefore important to protect the stone material with a geotextile. (Stahre, 2004)

In order to minimize the risk for groundwater contamination, the bottom of the infiltration trench should be separated from the groundwater table. A distance of 60 to 150 cm is recommended between the bottom of the trench and the groundwater table. Seasonal variations in the groundwater table must therefore be taken into when designing an infiltration trench. (US EPA, 2006a)

4.2.2 Pollutant Removal Mechanisms of Infiltration Trenches

The pollutant removal mechanisms in an infiltration trench are mainly caused by adsorption and ion exchange, but there is also microbial degradation (Berndtsson, et al., 1989). Adsorption is defined as:

"*The net accumulation of matter at the interface between a solid phase and an aqueous solution phase*." (Sposito, 1989)

Moreover, according to Sposito (1989) the ion exchange capacity can be defined as:

"*The number of moles of adsorbed ion charge that can be desorbed from unit mass of soil, under given conditions temperature, pressure, soil solution composition, and soil-solution mass ratio*."
(Sposito, 1989)

Nevertheless, there are certain factors affecting the pollutant removal efficiency of an infiltration trench. An important factor influencing both runoff control and pollutant removal efficiencies is climate conditions and especially rainfall patterns. Thus, if a trench is designed at a total rainfall of 10 mm, the trench is able to completely infiltrate a total rainfall that is less than 10 mm. During periods of heavy rainfall when the total rainfall exceeds the design rainfall, the pollutant removal efficiency will be reduced. Other factors influencing the pollutant removal efficiency of an infiltration trench are average daily traffic, catchment area and rate of impervious surfaces. (Maniquiz , et al., 2010)

4.2.3 Previous Studies of Pollutant Removal Efficiencies

There is little data and few studies concerning the pollutant removal efficiency of infiltration trenches (US EPA, 2006; Wyoming Department of Environmental Quality, 1999). Moreover, according to Maniquiz et al. (2010), there are few studies on the long-term performance of infiltration trenches, even though they have been used for a long period of time. A general assumption is, however, that infiltration trenches have very high pollutant removal efficiencies (US EPA, 2006; Wyoming Department of Environmental Quality, 1999).

In Table 2, pollutant removal efficiencies from different studies are presented. As seen in Table 2, the results from the different studies vary. The majority of the studies show a high removal rate of heavy metals, around 90 percent, while the nitrogen and phosphorous removal is varying. The highest phosphorus removal is 100 percent presented by Winer (2000) while the Swedish Road Administration presents the lowest phosphorus removal rate. For nitrogen, the lowest removal rate is found in Winer (2000) while the highest is found in Maniquiz et al (2010). However, it is important to consider the differences in the studies when comparing the results. Nevertheless, the summation of the results shows that more data is needed concerning pollutant removal efficiencies of infiltration trenches.

Table 2: Pollutant removal efficiencies from different studies

Parameter	Removal efficiencies from different studies [%]				
	US EPA (2006)*	(Maniquiz et al., 2010)	Winer (2000)	Wyoming Dep. of Env. Quality (1999)*	Swedish Road Administration (2011)
TSS	75	89			50-90
TP	60-70	82	100	60	10-50
TN	55-60	84	42	60	
Zn	85-90	89-93		90	15-90
Cu	85-90	89-93		90	10-90
Pb	85-90	89-93		90	30-80
Cd	85-90			90	10-50
Oil and grease		100			
BOD, COD, DOC		89-93			
Bacteria	90			90	
NOx			82		

*Not specified what metals that were analyzed

The differences in the studies, primarily, constitute of; incoming water quality, types of infiltration trench, range, and place. The pollutant removal efficiencies have, in some cases, been estimated based on studies of rapid infiltration land in wastewater treatment systems or by modelling. This is the case of the pollutant removal efficiencies presented by Wyoming Department of Environmental Quality (1999). Furthermore, the pollutant removal efficiencies from US EPA (2006) are derived from land disposal of wastewater and are based on the assumption that the infiltration trench is designed to manage the runoff from a 25 mm storm. The studies performed by Maniquiz et al. (2010) and the Swedish Road Administration have, on the other hand, investigated road runoff. In the study by Maniquiz et al. (2010) the pollutant removal efficiencies for an infiltration trench adjacent to a road situated in Yong-in City, Korea, has been investigated. This study was carried out during June 2006 through September 2008 and is based on 22 rainfall events. The Swedish Road

Administration investigated removal efficiencies of trenches treating road runoff, and the study include both infiltration trenches and other trenches such as swales (Swedish Road Administration, 2011). In Table 2 there are also pollutant removal efficiencies presented by Winer (2000). Winer (2000) points out that those results should be considered with carefulness due to difficulties in monitoring infiltration practices and the fact that only a few infiltration practices have been monitored. For infiltration trenches, only 3 different trenches were monitored. Although the removal efficiency of oil and grease was stated as 100 % in the study performed by Manuquiz et al. (2010) it is not suitable to use infiltration trenches for stormwater with high hydrocarbons content due the risk of clogging. This is also the case for stormwater with high sediment content. In order to avoid this problem pre-treatment is required (Maniquiz , et al., 2010).

4.2.4 Maintenance

The lifespan of an infiltration trench can be estimated to a couple of decades if it is maintained normally. After this period the stone material must be changed (Stahre, 2004). An infiltration trench can be designed with the purpose to facilitate and reduce regular maintenance.

Measures to facilitate and reduce regular maintenance can among others be to install observation wells, which allow inspection and monitoring of the drawdown rate. In order to avoid clogging, an underdrain can be installed at the bottom of the infiltration trench. (US EPA, 2006a)

Maintenance and inspection activities can be divided into standard maintenance, semi-annual inspection, five-year maintenance and maintenance upon failure. Standard maintenance includes removing sediment and oil/grease from pre-treatment devices and overflow structures. Semi-annual inspection includes checking observation wells after three days of dry weather, which indicates clogging if a failure to percolate is observed within this period. Pre-treatment devices and conveyance channels are also inspected in order find structural damage and accumulated sediments. The five year maintenance is mainly to check if the bypass capability is functioning. Maintenance upon failure mainly involves excavating the old stone material and replacing it with clean stone material. (US EPA, 2006a)

4.2.5 Costs

Compared to other stormwater management devices infiltration trenches are slightly more expensive regarding the cost per treated area (US EPA, 2006a). The construction costs of infiltration trenches, in Sweden, have been estimated to 700 SEK/m^3 (Norconsult, 2010). Nevertheless, the major costs of an infiltration trench are the maintenance costs due to that infiltration trenches that are improperly maintained have high failure rates. The general estimation is that the maintenance costs are ranging between 5 and 20 percent of the construction costs. However, in order to guarantee a long-term durability of the infiltration trench it is more realistic that the maintenance costs are around 20 percent of the construction costs (US EPA, 2006a).

4.3 Other SUDS Practices

Except for infiltration trenches there are also other SUDS practices such as stormwater ponds, green roofs, swales and wetlands. Green roofs and swales are mainly used reduce the stormwater runoff rate and volume while wetlands are used as an end-of-pipe solution. Stormwater ponds can be considered as the most frequently applied SUDS practice and they are also the most investigated one.

4.3.1 Stormwater Ponds

The original purpose of stormwater ponds was to detain stormwater and thereby reduce peak flows. However, there have been numerous investigations showing that ponds also significantly can improve the water quality. It has been concluded that stormwater ponds can treat most types of stormwater. The pollutant removal efficiency of stormwater ponds varies between studies, but typical removal rates are presented in Table 3.

Table 3: Typical removal rates for stormwater ponds (Pettersson , 1996).

Parameter	**Removal rate [%]**
Total Suspended Solids	55
Volatile Solids	47
Zinc	28
Copper	20
Lead	45
Cadmium	44
Total Nitrogen	8
Phosphate phosphorus	20

The pollutant removal mechanisms in stormwater ponds are of different sorts and a pond's pollutant removal efficiency can be evaluated using three main factors; treatment processes, hydraulics and hydrology (Persson, 1998). Incoming stormwater is treated by two main processes; primarily by settling of particles but also through nutrient uptake by algae (US EPA , 2006b). According to Persson (1998), denitrification processes are also of importance.

Pollutant reduction by particle sedimentation is effective due to the fact that a significant amount of the pollutants in stormwater are attached to solids (Pettersson, 1999). It has been shown that the main proportion of particle-bound pollutants is related to the smallest particles, which aggregate into larger flocs (Pettersson, 1999).

As a consequence, settling velocity is very important and it is affected by particle size distribution in the incoming stormwater and particle behaviour in the pond.

The hydraulic and hydrologic efficiencies are, hereby, very important, since they determine the detention time and flow pattern in a pond, which is essential for an efficient sedimentation and nutrient removal. In order to obtain hydraulic efficiency, the incoming water should be equally distributed in the pond, which could be achieved by designing the water flow path in the pond. The hydrologic efficiency could be measured as the total volume of treated water in relation to the total inflow, during a time period. (Persson, 1998)

Pond design is of importance in order to obtain an effective pond; Pettersson (1999) states that a pond has to be properly designed to maximize the effective pond volume and, thereby, avoid dead and recirculation zones. This could also be concluded from the factors which affect the pollutant removal efficiencies.

5 Site Description

The investigated infiltration trench is located below a parking lot of a large supermarket. The supermarket, ICA Maxi, is situated in the city of Kungsbacka, which is a city located in the south-western part of Sweden, approximately 40 kilometers south of Gothenburg. See Figure 7 for location. It has a size of approximately 10 000 m^2 with room for about 600 vehicles (Conara AB, 2012), and can therefore be considered as a large parking lot. Larger parking lots are classified to have moderate to high pollutant loads and stormwater infiltration and detention are therefore required (City of Stockholm, 2005).

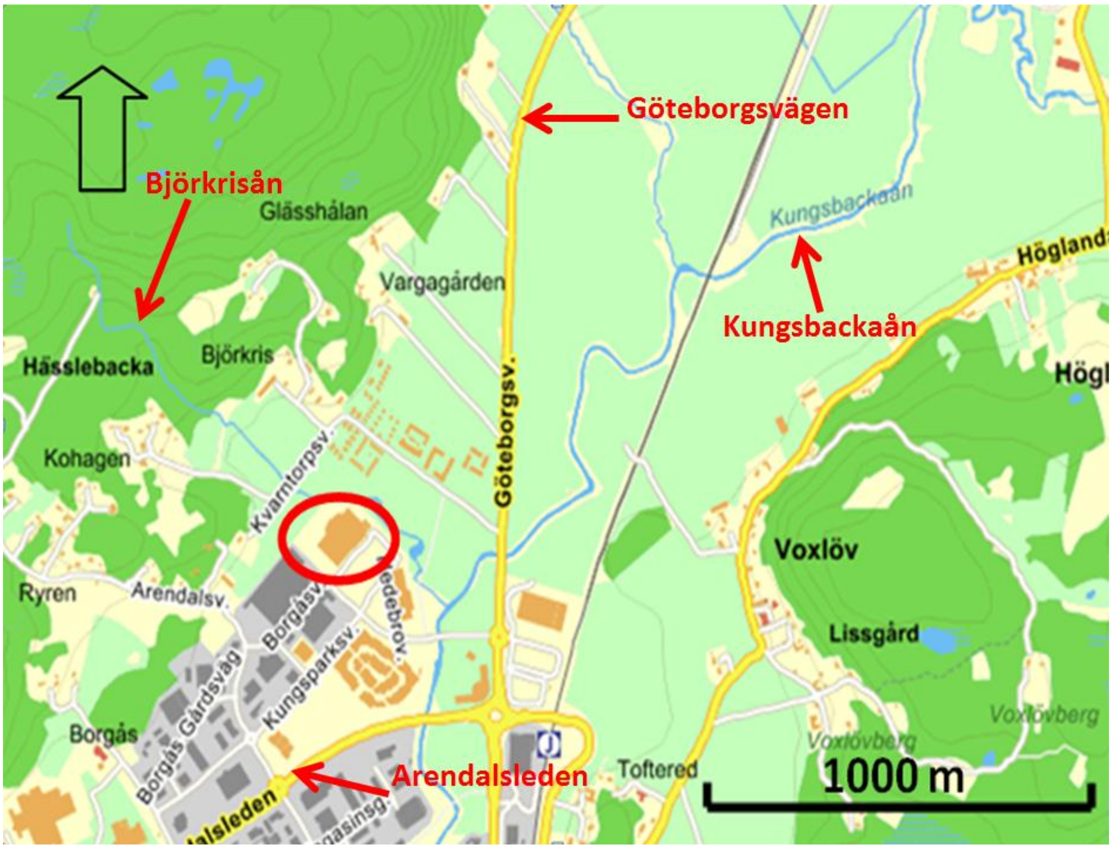

Figure 7: Red circle shows location of ICA Maxi Supermarket. (Eniro, 2012) Modified by Erika Nilsson.

The supermarket is situated in Borgås industrial area, which is and expanding industrial area mostly consisting of different types of commercial buildings, for example a large designer outlet. However, there are also different warehouses and smaller industries. Adjacent to ICA Maxi supermarket, at the Eastern boundary, there is a residential area called Björkris. This area was originally consisting of arable land but is still under construction. Thus, the first dwellings were built in 2010 and the last ones will be initiated in 2013. In total, 450 dwellings will be constructed in this area (Municipality of Kungsbacka, 2006). North-west of the supermarket the surrounding landscape consists of a mixture of forest and arable land. There are also two larger roads in connection to the parking lot, Arendalsleden, which are located south of the area and Göteborgsvägen located east of the area. Arendalsleden has a traffic intensity of approximate 12 000 vehicles/day and the road is thereby classified to have a moderate pollutant load (Municipality of Kungsbacka, 2012).

The reason for choosing the investigated infiltration trench was mainly due to the fact that the pollutant load on the parking lot was assumed to be high. The site was also chosen due to its proximity to Gothenburg. It was feasible to access the infiltration trench and samples could rapidly be collected and transported to laboratory after a storm event. Prior to the investigation, permission to carry out the measurement was given by the municipality of Kungsbacka and ICA Fastigheter, which is a real estate company that acquires, owns and manages ICA stores.

5.1 Hydrological Conditions

The ground in the area is generally flat and mostly consisting of clay. The groundwater level is located approximately 3 meters under the ground surface (GF Konsult, 2007). Adjacent to ICA Maxi, the stream Björkrisån is passing, which is a minor stream originating from the area north of Kohagen, see Figure 8 for location, and fall into the larger stream Kungsbackaån. When the supermarket ICA Maxi was built Björkrisån was partly rerouted and two stormwater ponds were constructed. (Municipality of Kungsbacka, 2006). North-west of the Björkris area, Björkrisån is dewatering an area of approximately 116 ha. (GF Konsult, 2007)

Kungsbackaån has a catchment area of about 300 km^2 originating from the area around Landvetter airport, located north east of Göteborg, and is discharged in the Kungbacka fjord (Kungsbackaåns vattenvårdsförbund, 2012). Both Kungsbackaån and the Kungsbacka fjord are of national interest due to their ecological value and are classified as Natura 2000 areas (Municipality of Kungsbacka, 2006). The municipality of Kungsbacka has classified Kungsbackaån as a sensitive recipient on an assessment scale consisting of “less sensitive”, “sensitive”, and “highly sensitive”. Moreover, Kungsbackaån is habitat for both salmon and sea trout. (Municipality of Kungsbacka, 2012).

However, there is a need for some improvements concerning its water quality. In the more upstream parts of Kungsbackaån there are problems with acidification. In the more downstream parts, near the Björkris area, there have been problems with eutrophication due to that the stream has received large amounts of nutrients originating from arable land and private sanitary treatment plants. Thus, in the Kungsbacka fjord there is therefore a potential of algal blooms (Municipality of Kungsbacka, 2006).

5.2 Description of Stormwater Management at ICA Maxi Kungsbacka

The total size of the ICA Maxi Supermarket, including the rooftop and the parking lot, is 3.1 ha. The area is divided into three drainage areas based on ground levels, which can be seen in Appendix 2a. Drainage area 1 includes the major part of the large parking lot. Drainage area 2 contains the north side of the large parking lot and then includes areas behind the supermarket. Drainage area 3 consists of the area around the access road and a minor part of the northern side of the parking lot. (Tyrens, 2007)

At the ICA Maxi facility there are three infiltration trenches, one in each drainage area, and their locations can be seen in Appendix 2b. After treatment in the infiltration trenches, the stormwater runoff is treated by an oil separator before being discharged to the stormwater ponds, situated between the parking lot and the residential area. The maximal allowed discharge of stormwater from the parking lot and area for loading to the stormwater ponds is 15 l/s of detained flow. (Tyréns, 2007)

5.2.1 Description of Investigated Infiltration Trench

The infiltration trench that is studied in this Master Thesis is infiltration trench 1, and it has been designed according to publication 1990:11 by the Swedish Road Administration. The infiltration trench is designed based on a two-year design rainfall with the duration of 4 hours. Furthermore, it is allowed to discharge 6.17 l/s, of the total 15 l/s allowed to the stormwater ponds. The drainage area is 1.2 ha and consists of asphalt and the reduced drainage area is consequently 0.98 ha (Tyréns, 2007). It has been estimated that the inlet pipe has a drainage area consisting of approximately 10 % of the total drainage, which is 0.12 ha. This minor drainage area can be seen in Appendix 2c.

Moreover, the infiltration trench, which schematically is illustrated in Figure 8, is filled with macadam with a pore volume of 30 %. The result is that a storage volume of 176 m^3 is required to meet the requirements. The dimensions of the infiltration trench are 46x16x0.8 m. The trench is separated from the surrounding soil by a coating geotextile layer. Theoretically, the design and design conditions imply that about 243 m^3 stormwater will enter the infiltration trench in the case of a two-year rain with the duration of 4 hours. (Tyrens, 2007)

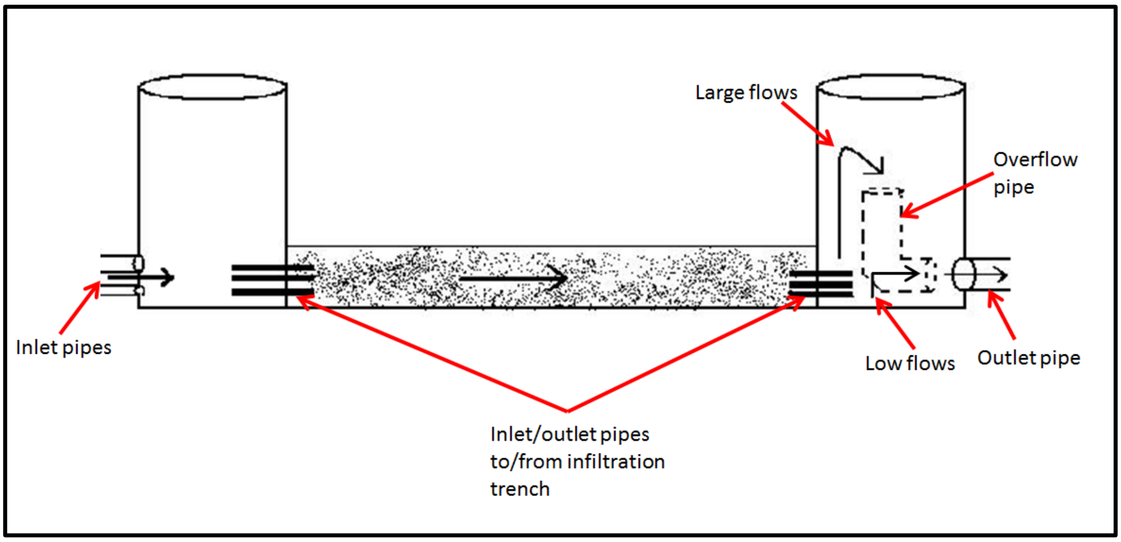

Figure 8: Schematic illustration of the studied infiltration trench (Nilsson & Stigsson, 2012)

As can be seen in Appendix 2a, the infiltration trench has four inlet pipes with the diameters: Ø225mm, Ø160 mm and Ø200 mm. The Ø225 and Ø160 pipes are diverted into the inlet manhole where the sampler and flow meter were placed. In the same manhole there are three pipes leading into the infiltration trench, this can be seen in Figures 9a. There are also three pipes leading out from the infiltration trench into the outlet manhole and the treated stormwater is then diverted to the stormwater pond in a Ø315 mm pipe, as can be seen in Figure 9b.

The outlet manhole is designed with an overflow and choking function, which can be seen in Figure 9b. This overflow function has the purpose to choke the outgoing stormwater volume at normal flows to obtain detention of stormwater inside the infiltration trench. At large flows the water table in the outlet manhole will rise and the stormwater can thereby pass through the overflow function, as illustrated in Figure 8.

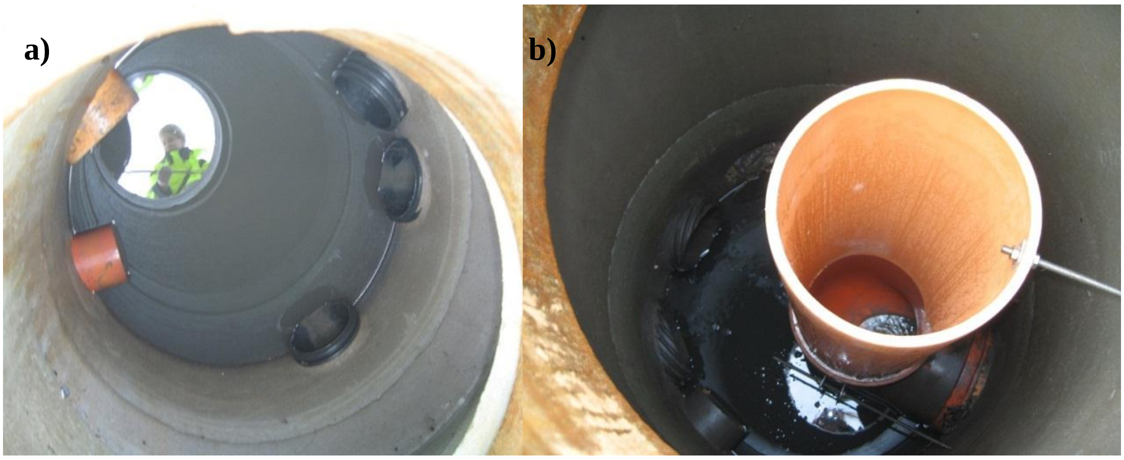

Figure 9: a) Inlet manhole (Nilsson, 2012) b) Outlet manhole. The overflow pipe in the outlet manhole was removed during the measurement period. (Nilsson & Stigsson, 2012)

6 Experimental Procedure

This chapter provides a description of the measurement technique at the study site. It also describes the laboratory experiments that were carried out and the calculation methods.

6.1 Field Measurements at the Parking Lot in Kungsbacka

Stormwater sampling was carried out during five storm events from April to June 2012. The measurement equipment consisted of samplers, flow meters and a rain gauge. See Appendix 3 for photos of measurement equipment at the site.

6.1.1 Measurement Techniques and Methodology

The most common methods for water sampling are flow weighted sampling and time weighted sampling. Flow weighted sampling, which has been applied in this project, means that a flow meter is connected to the sampler and water samples are collected when a certain amount of water has passed. The flow meter is programmed to send pulses which are transformed to a flow in the sampler computer. After a certain amount of water has passed, the sampler collects a predetermined volume of water. The water is pumped to the sampler through a suction line. (Andersson, et al., 2012)

Flow weighted sampling has been proven to minimize the risk of over- and underestimation of pollutant transport and removal efficiency, which often has been the case with time weighted and random sampling. According to Andersson et al. (2012) flow weighted sampling is especially more efficient for transport and removal of particulate matter and phosphorus. Thus, compared with time proportional sampling it has been shown that more than 50 % of particulate matter and approximately more than 40% of phosphorus are detected with flow weighted sampling. The reason to this is that there are often rapid changes in the particle content when the flow is changing. (Andersson, et al., 2012)

According to Pettersson (1999) it is important that the measurements are performed accurately in order to obtain a representative result of the removal efficiency. As stated, flow weighted sampling must be carried out at the inlet and outlet. However, it is also essential that series of flow weighted sampling are conducted during a whole storm event. The obtained samples will then represent the total volume that pass into and out of the treatment facility. Furthermore, it is important to measure several successive storm events in order to estimate the long term removal efficiency. The reason for this is that the pollutant removal efficiency can vary markedly over time, even negative reductions can occur. This is due to differences in rain volumes and dry periods at different storm events (Pettersson 1999; Pettersson 1998).

6.1.2 Site Specific Conditions at Measurement Occasions

Measurements were carried out during spring 2012, see Appendix 4 for specific dates when samples were collected. Two samplers were used in the studied area, one sampler placed in the inlet manhole and one sampler placed in the outlet manhole, see Appendix 2a for location of these manholes. The types of samplers were ISCO 6700 for the inlet and ISC0 3700 for the outlet. Both samplers have mainly the same functions and size. In order to fit the sampler in the outlet manhole during the measurements, the overflow pipe, described in Chapter 5.2.1, was removed. Consequently, the treated stormwater was directly conveyed to the Ø315 outlet pipe at all flow rates. There were also strainers for both samplers, which were connected to the samplers' suction lines. The strainers were able to remove coarse particles and placed in the inlet and outlet pipes. A flow meter was connected to each sampler in order to carry out flow weighted sampling. Both flow meters were of the type NIVUS PCM3 and the flow in the inlet and outlet pipes were registered by sensors that were placed in the pipes. These sensors were placed in the inlet and outlet pipes against the flow direction. Figure 10 shows a schematic illustration of how the sampler, flow meter and car battery were connected in the manhole.

As described earlier, the infiltration trench has four inlet pipes, and the flow measuring was only conducted in one of these. Therefore it was not possible to retrieve a hydrograph of the total inflow directly from the measurements. The total outflow from the infiltration trench was however measured, and it is assumed that the total inflow volume is equal to the total outflow volume. Inflow hydrographs of the total inflow have thereby been estimated by comparing the total accumulated outflow volume during a storm event to the total accumulated inflow volume. The observed inflows were then multiplied by the resulting factor.

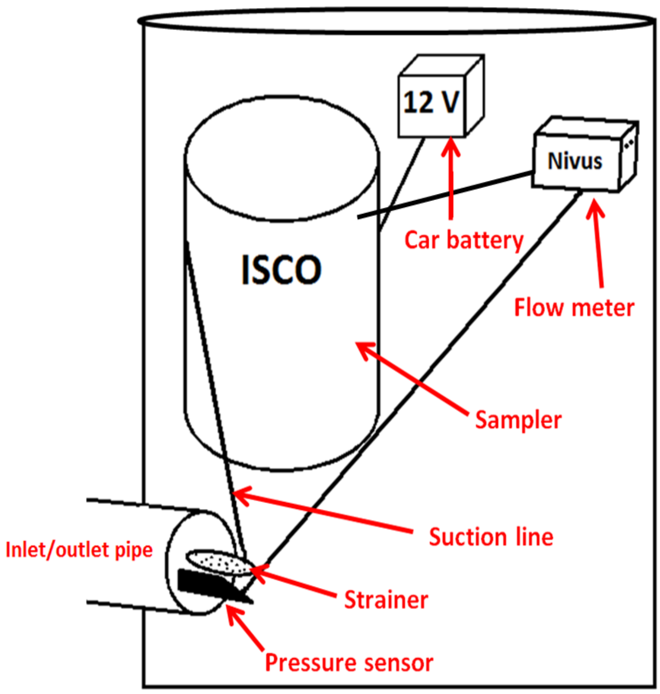

Figure 10: Schematic illustration of measurement equipment in the manhole (Erika Nilsson, 2012)

Prior to each storm event the amount of rain was estimated based on weather forecasts and depending on the amount of rain the flow meters were programmed to send pulses after a certain amount of water had passed. When programming the flow meters it was important that pulses were sent after a suitable flow volume had passed, since it was important that the whole storm was captured and the interval between the pulses could therefore not be too short. In some cases, it was needed to change to new bottles during an ongoing storm event.

Samples were collected as soon as possible after a storm event was finished. The bottles were then sealed and transported to laboratory. The laboratory analysis was conducted, if possible, immediately after the collection of samples. If not, the samples were stored in fridge and analyzed within 24 hours after the collection. However, if the samples were collected on, for example, Friday afternoon, the samples were analyzed the following Monday due the fact it was only possible to be in laboratory at weekdays between 06.00 and 19.00.

Furthermore, rain measurements, which have been described in Chapter 2.1.1, have been carried out during the whole measurement period. A rain gauge has been placed on the rooftop of the supermarket ICA Maxi. The rain gauge has measured the total accumulated rain volume as well as rain intensity and has thereby provided site specific rain characteristics.

6.2 Calculation of Flow Detention

The detained volume of stormwater was retrieved by the hydrographs, as described in Chapter 3.1. The intersections between the inflow and outflow hydrographs were studied and the accumulated inflow volume represented by the cut of area resulting from the intersections has been assumed to represent the detained volume in a storm event. The approximate total volume of runoff entering the infiltration trench during a storm event was also calculated, using the rain depth and the size of the drainage area. This was used to evaluate the observed flow detentions to the designed storage volume.

6.3 Calculation of Pollutant Reduction

The pollutant concentrations and reductions have been calculated by using a mass balance approach based on a cumulative pollutant calculation, in which the total pollutant mass is calculated for the inlet and outlet. Figure 11 illustrates a cumulative pollutant calculation in a hydrograph. The pollutant concentrations were calculated by the Event Mean Concentration (EMC), see Equation 3 (Silva, et al., 2010), and the removal efficiency were calculated by the Reduction (R), see Equation 4 (Pettersson, 1999).

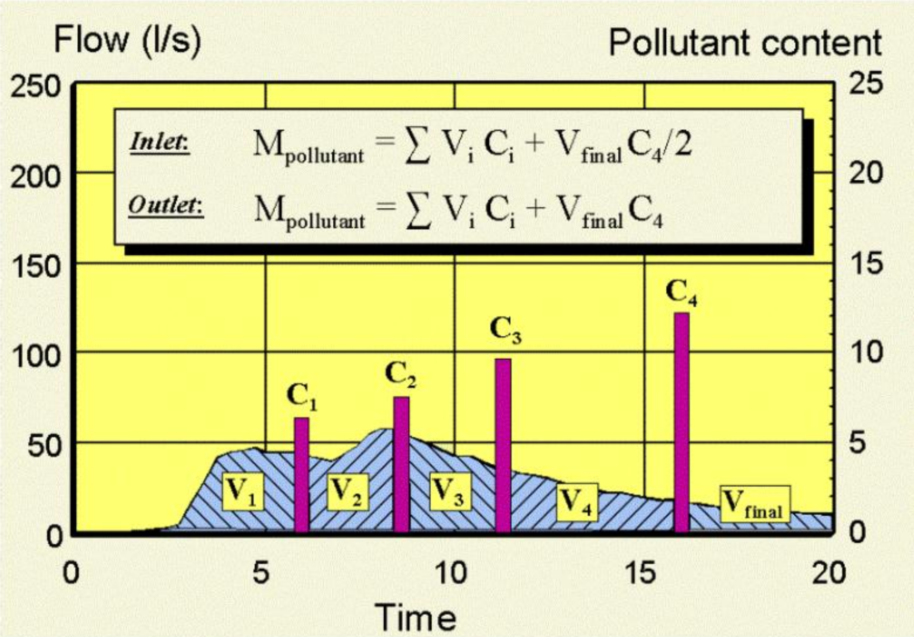

Figure 11: Cumulative pollutant calculation (Pettersson, 1999)

Flow weighted sampling generates pollutant concentrations, C_i, representative for specific volumes, V_i, during the storm event. The pollutant masses, $M_{pollutant}$, is obtained by multiplying the concentrations with the corresponding volumes to get the pollutant mass in that volume. All sub masses and the final mass for the inlet and outlet are then summed up to a total pollutant mass for the storm event (Pettersson, 1999). Flow weighted sampling is required through a whole storm event in order to generate data for such calculations (Pettersson, 1999).

$$EMC = M / V = \sum C_t Q_t \Delta t \;/\; \sum C_t \Delta t \qquad (3)$$

Where:
M = Pollutant masses [mg]
V = Volume [l]
C = concentrations [mg/l]
Q = Flow [l/s]
t = time [s]

and;

$$R = 100(M_{in} - M_{ut}) \;/\; M_{in} \qquad (4)$$

Where:
R = Reduction [%]
M = Pollutant masses [mg]

6.4 Laboratory Analysis

Parameters that were analyzed were heavy metals, total inorganic nitrogen, phosphate and suspended solids. It was believed that the stormwater would contain concentrations of heavy metals since the investigated site was a parking lot with a lot of vehicles. Therefore it was also of interest to measure the concentrations of suspended solids due to that the amount of suspended solids is related to the amount of heavy metals. Moreover, due that some of the surrounding land is or have been arable land it is also interesting to measure the nutrient concentrations in order to evaluate the impact from the surrounding land. The experimental procedures were conducted according to Swedish standard procedures. Table 4 shows the analyzed parameters and their methods.

Table 4: List of analysis methods

Parameter	**Method**
Metals	ICP-MS
Nitrogen and phosphorus	Ion chromatography
Total suspended solids	2540 D. (Standard Methods for the Examination of Water and Wastewater)
Volatile solids	2540 E. (Standard Methods for the Examination of Water and Wastewater)

In order to analyze a whole storm, mixed samples were analyzed. Thus, the first bottles were altogether transferred and mixed in another bottle. The same procedure was conducted for the samples in the middle and in the end. If, for example, all 24 bottles were filled with water, bottle 1 to 8, bottle 9 to 17 and bottle 18 to 24 were mixed. Three different bottles with mixed samples were thereby obtained.

6.4.1 Suspended Solids

According to Standard Methods Committee (1997), the laboratory analysis of suspended solids should be conducted as soon as possible after collection of samples, preferably within 24 hours. This is due to difficulties in preserving the samples and to avoid microbiological decomposition of solids. For wastewater samples, this is especially important to follow. When preserving the samples they should be refrigerated at 4 C. On any account, samples should not be preserved more than seven days. The data from the TSS and VS laboratory experimental can be seen in Appendix 4.

Total Suspended Solids Dried at 103-105 °C

This analysis was carried out according to Method 2540 D in Standard Methods for the Examination of Water and Wastewater by Standard Methods Committee (1997). Prior to filtration, each filter was weighted. Thereafter, the filter was placed on the filtering apparatus with a vacuum suction function. Samples were transferred to a glass flask and stirred with a magnetic stirrer during filtration in order to obtain a more uniform particle distribution. Subsequently, a determined volume was pipetted onto the filter. The pipetting was ongoing until a sufficient amount of particles was observed on the filter or when the filtration rate appeared to be too slow. After filtration, the filter was transferred to an aluminum weighting dish and the filtration apparatus was cleaned with reagent grade water. This procedure was repeated for each sample. After filtration of all samples, filters were dried in oven at 105 °C for 1 hour and thereafter cooled in a desiccator in order to balance temperature and weight. After cooling in desiccator the filter were weighted and the concentration of total suspended solids could be calculated according to Equation 5.

$$\mathrm{TSS}\ [\mathrm{mg/l}] = (\mathrm{A-B})*1000\ /\ \text{sample volume}\ [\mathrm{ml}] \qquad (5)$$

Where:
A = weight of filter + dried residue [mg]
B = weight of filter [mg]

Volatile Solids Ignited at 550 °C
The analysis of volatile solids was conducted according to standard Method 2540 E in Standard Methods for the Examination of Water and Wastewater by Standard Methods Committee (1997). The main principle of this analysis is to ignite the residue obtained from Method 2540 D at 550 °C for 15 minutes and thereby obtain the concentration of volatile solids, which is the weight lost on ignition. Therefore, prior to ignition, the samples were weighted and afterwards cooled in a desiccator. The samples were then weighted and the concentration of volatile solids could be obtained through
Equation 6.

$$\mathrm{VS}\ [\mathrm{mg/l}] = (\mathrm{A-B})*1000\ /\ \text{sample volume}\ [\mathrm{ml}] \qquad (6)$$

Where:
A = weight of filter + residue before ignition [mg]
B = weight of filter + residue after ignition [mg]

6.4.2 Analysis of Metals through ICP-MS

ICP-MS stands for inductively coupled plasma – mass spectrometry and it is a widely used instrument for trace metal analysis. Most of the elements in the periodic table can be quantified by ICP-MS (PerkinElmer, 2012)

The main principle of ICP-MS is the utilization of a high temperature plasma discharge, which generates positively charged ions (Thomas, 2001). Firstly, the sample is pumped into a sample introduction system, which consists of a nebulizer and a spray chamber. The main purpose of the sample introduction system is to break the liquid sample into small aerosol droplets, which then enter the argon plasma. In the plasma, the aerosol droplets are dried and their molecules are dissociated, which means that an electron is removed and single charged ions are thereby formed. These single-charged ions are then introduced to the mass spectrometer, which functions as a mass filter and sorts ions by their mass-.to-charge ratio. A detector counts all ions that are exiting the mass spectrometer since the detector has an active surface on which the ions strike. This active surface is called dynode and each time an ion strikes the dynode an electron is released. The electrons released from this dynode are then striking a second dynode and more electrons are released. Thus, a cascade of electrons is formed and this process continues until it becomes a measureable pulse. The concentration of each element can thereby be determined based on a comparison between the intensities of the measured pulses and the standard ones, which both constitute a calibration curve (PerkinElmer, 2012).

Sample Preparation

It is possible to measure both the total metal concentration and the dissolved fraction of metals in a sample, which has been the case in this master thesis project. For every storm event, three samples with dissolved metals and three samples with total metals have been analyzed both for the inlet and outlet samples.

Therefore, in order to measure the dissolved fraction the samples were filtered with a 0.45 µm cellulose acetate filter. Thereafter, a volume of 9.8 ml from each sample was pipetted to plastic test tubes. In order to preserve the samples, 0.1 ml of HNO_3 was pipetted to each test tube. The same procedure was followed for the preparation of the total metal analysis except the filtration step.

Prior to the ICP-MS analysis 0.1 ml of internal standard solution were added to each test tube. This is necessary in order to avoid and reduce the sources of errors since it compensates and modifies errors caused by matrix effects, instrument drift and dilution errors. If the internal standard solution not is added the result can be very difficult to evaluate

6.4.3 Ion Chromatography

Ion Chromatography is a separation technique applied when analyzing complex mixtures that contain a matrix of many ions. This is mainly the case in liquid samples such as rainwater and river water. There is a wide range of different ions in these samples, for example anions and cations, which both have a simple structure. (Ohio State University, 2012).

However, there are also the more complex structured ions such as proteins and amino acids. Depending on species type, charge and size different ions separate differently and each mixture of ions that are present in a sample can be analyzed by chromatography and the concentration of each species can thereby be calculated. The concentrations of anions such as fluoride, chloride, nitrate, nitrite and sulfate, and cations such as lithium, sodium, ammonium, potassium and calcium can be measured by ion chromatography (Ohio State University, 2012).

In short terms, an ion chromatography machine contains two columns; one column is used for cation separation while the other is used for anion separation (Ohio State University, 2012). There is a charged resin inside the columns in which a stoichiometric chemical reaction is occurring. This reaction is the basic principle of ion chromatography and it is occurring between ions in a solution, also called eluent and a solid phase containing functional groups, for example sulfonic and acid groups in cation chromatography and ammonium groups in anion chromatography. Due to electrostatic forces the solid substance can attract and fix ions from the mobile phase and replace them (Eith, et al., 2001). The mobile phase is run through the system until each ion leave the solid phase. Based on the elution time, which is the time that is needed for the ions to leave the solid phase, the ion concentrations can be detected by measuring the conductivity of the solution. The detected results are presented in graphs (Ohio State University, 2012). The obtained values from the ion chromatography can be seen in Appendix 5.

Experimental Procedure

The purpose of the ion chromatography in this analysis was to obtain to the concentrations of nitrate, nitrite and ammonium in order to calculate total nitrogen and the phosphate concentrations in order to calculate total phosphorus. Samples were transferred in 50 ml HDPE bottles. The samples were immediately stored in freezer until the day of analysis. The filtered water was then transferred to special bottles suited for the ion chromatography machine.

7 Results

The results from the observations of the infiltration trench at the parking lot at ICA Maxi Kungsbacka during April to June in 2012 are presented in this chapter. Five storm events are included in the study and pollutant removal efficiencies as well as flow detention have been examined. The included pollutants are: TSS, VS, heavy metals (As, Pb, Cd, Co, Cu, Cr, Ni, V, Zn), total inorganic nitrogen (TIN) and phosphate-phosphorus (PO_4^{3-}). The measured concentrations of these pollutants can be seen in Appendix 6, which also shows at what accumulated flow the samples were taken. Both dissolved and total concentrations of the heavy metals are included. The flow detention have been investigated by studying inflow and outflow hydrographs, and the detained stormwater volume at each storm event has been compared to the designed storage volume of the infiltration trench. The observations have been made with the overflow construction at the outlet removed, as described in Chapter 6.1.2. The rain characteristics of the five storm events are presented in Table 5.

Table 5: Rain characteristic; return period calculated by DHI software, intensity calculated according to Appendix 2 in P90 by Svenskt Vatten (2004)

Storm event	Date	Duration [h]	Dry period [days]	Rain depth [mm]	Return period [year]	Mean intensity [l/s*ha]	Max intensity [l/s*ha]
Storm 1	2012-04-13	2.3	2	5.2	> 0.08*	6.5	27
Storm 2	2012-04-21	0.7	1	1.8	> 0.08	7.5	13
Storm 3	2012-05-09	15	13	12	0.1	2.1	19
Storm 4	2012-05-10	7	1	22	0.7	4.7	26
Storm 5	2012-06-10	3.5	23	4.9	>0.08	n/a	25

This chapter is divided into two subchapters; Flow Detention and Pollutant Removal Efficiencies. The result from the observed hydraulic behavior is reported in the first subchapter and the removal efficiencies in the second.

7.1 Flow Detention

As also described in Chapter 6.1.2, the inflow to the infiltration trench has been studied by observing the inflow hydrograph at only one of four inlet pipes. Meanwhile the outflow has been observed at the infiltration trench's only outlet pipe. Hence, the total volume of water passing through the infiltration trench at a storm event is known; it has been assumed that the total outflow volume is the same as the total inflow volume at a storm event. Inflow hydrographs of the total inflow have thereby been estimated by comparing the total accumulated outflow volume to the total accumulated inflow volume, since the drainage area to the observed inlet pipe is about 1/10 of the total drainage area of the infiltration trench the factor was initially estimated to 10. In this investigation, the factor has varied between 12 and 6.

Hydrographs of the total inflows have been based on those factors. The hydrographs of all storm events can be seen in Appendix 7. Figure 12 shows the hydrograph of storm event 1 and Figure 13 shows the hydrograph of storm event 4.

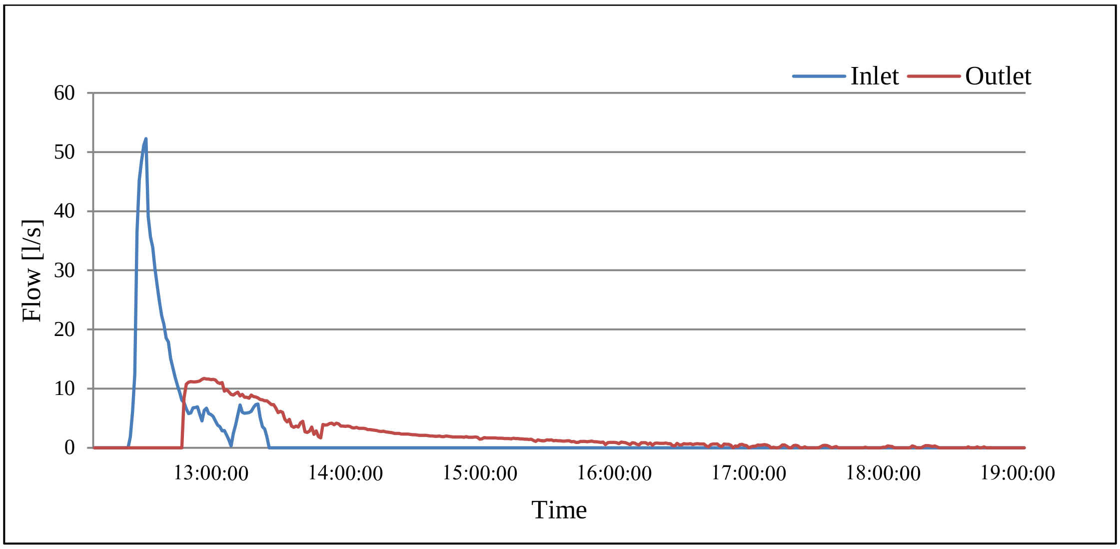

Figure 12: Hydrograph – Storm event 1(Andrea Stigsson, 2012-08-10)

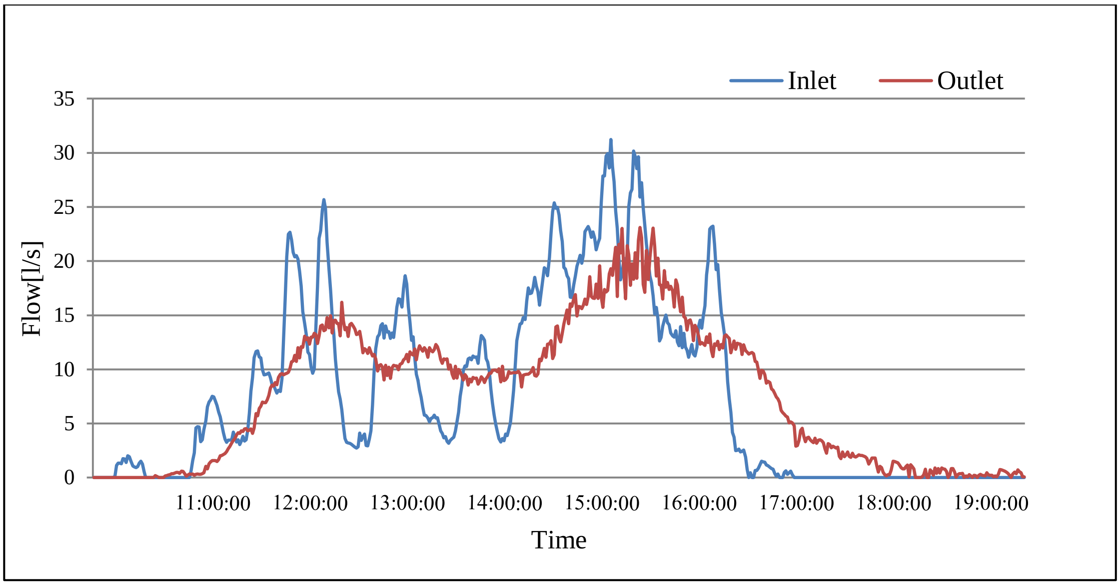

Figure 13: Hydrograph – Storm event 4 (Andrea Stigsson, 2012-08-10)

As the hydrographs shows, the infiltration trench is detaining the stormwater. This is most apparent in storm event 1 and 2, but also obvious in storm event 3 and 5. The outflow hydrographs have markedly lower peak flows than the inflow hydrographs. However, the hydrograph of storm event 4 differ from the others. The detention is not as evident and the peak flow is not evened out as significantly as in the other storm events.

The detained volume of stormwater was retrieved by the hydrographs. The intersections between the inflow and outflow hydrographs were studied and the accumulated inflow volume represented by the cut of area resulting from the intersections has been assumed to represent the detained volume in a storm event.

Table 6 presents the detained volumes and peak outflows for each observed storm event as well as the design storage capacity of the infiltration trench.

Table 6: Detained volumes and peak outflows of storm events

Storm event	Detained Volume [m^3]	Total volume from Drainage area 1 [m^3]	Peak Outflow [l/s]
Storm 1	30	50	12
Storm 2	15	20	5
Storm 3	*	120	12
Storm 4	*	220	22
Storm 5	30	50	12
Design capacity	176	243	6.17

*Detained volumes were difficult to retrieve from the hydrographs

The detained volumes in storm event 3 and 4 were difficult to estimate from the hydrographs, due to that they have more than one peak. However, they are estimated to be in the same magnitude as at the other storm events. None of the detained volumes were close to the designed storage volume. Furthermore, the total volume to enter the infiltration trench during a storm event have been estimated by multiplying the rain depth of the storm event with the size of drainage area 1 (0.98 ha). In Table 6 this is presented as *Total volume to Drainage area 1*. The infiltration trench has a design capacity to detain a total volume of 243 m^3 from the drainage area and only storm event 4 was close to that.

The infiltration trench was also designed to only discharge 6.17 l/s as a maximum. This was a discharge limit based on the maximal allowed discharge to the stormwater ponds in Björkris and thereby to Kungsbakaån. In Table 6 it is however clear that this discharge limit was only achieved at storm event 2. At storm event 1, 3, and 5 the peak outflow was approximately double the allowed flow and at storm event 4 almost the triple. However, since the treated stormwater in the infiltration trench afterwards is detained in stormwater ponds, it is believed that the elevated outflow discharges not significantly will affect the final recipient Kungsbackaån.

7.2 Pollutant Removal Efficiencies

The pollutant concentrations in the water samples collected from the inlet and the outlet of the infiltration trench during the storm events have been used to calculate the pollutant removal efficiency according to the Chapter 6.3. To calculate the total incoming cumulative pollution masses the same factors between the inflow and outflow volumes, as used to create hydrographs of total inflows, have been used. Thereby it is assumed that the inflow of all inlet pipes have the same pollutant content and concentrations.

Cumulative Pollution Masses, Event Mean Concentrations (EMC) and Reductions (R) for all pollutants have been calculated. To evaluate the pollutant removal efficiencies over time, the accumulated masses of the pollutants in all storms have been compiled in graphs. All pollutants have been investigated at all storm events except nitrogen and phosphorus that were not investigated in storm event 5. When investigating phosphorus concentrations, the levels of phosphorus turned out to be very low and phosphorus has therefore not been included in any of the reported results.

The cumulative pollution calculations are based on the graphs in Appendix 7. The concentrations of each pollutants and corresponding volume can be seen in the graphs, for the inflow as well as the outflow. In most cases the incoming pollutant concentrations are higher in the incoming water than in the outgoing water, which indicates an enhanced water quality in the outgoing water.

Event Mean Concentrations

The EMCs of each pollutant at each storm event were calculated based on the cumulative pollution masses. By the EMCs an evaluation of the water quality of the incoming and outgoing water can be made. The retrieved EMCs are presented in Table 7.

Table 7: EMC concentration for inlet and outlet during storm event 1-5, and mean concentrations.

Parameter		**EMC inlet**						**EMC outlet**					
		Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	**Mean Value**	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	**Mean Value**
TSS	[mg/l]	255	267	124	72	30	**150**	46	25	10	15	7.2	**21**
VS	[mg/l]	42	60	26	21	13	**32**	10	7.4	8.1	7.3	5.2	**7.6**
TN	[mg/l]	1.9	2.0	2.0	2.2	-	**2.0**	0.9	2.4	0.76	1.1	-	**1.3**
Zn (total)	[µg/l]	299	560	120	92	55	**225**	68	65	32	30	35	**46**
As (total)	[µg/l]	1.2	2.0	0.5	0.4	0.2	**4.3**	0.3	0.2	0.2	0.2	0.2	**0.2**
Pb (total)	[µg/l]	13	26	3.4	3.9	1.7	**9.6**	2.3	0.6	1.2	1.0	0.8	**1.2**
Cd (total)	[µg/l]	0.2	1.0	0.2	0.8	0.07	**0.4**	0.1	0.2	0.1	0.1	0.1	**0.1**
Co (total)	[µg/l]	5.5	10	1.5	1.6	0.6	**1.9**	1.1	0.4	0.3	0.3	0.3	**0.6**
Cu (total)	[µg/l]	56	127	64	31	15	**59**	12	21	13	12	18	**15**
Cr (total)	[µg/l]	13	22	3.0	4.2	1.7	**8.9**	2.4	0.7	1.0	1.0	1.1	**1.2**
Ni (total)	[µg/l]	10	18	4.5	3.9	2.7	**7.8**	4.4	6.8	2.6	2.0	4.1	**4.0**
V (total)	[µg/l]	18	38	6.9	5.7	4.3	**15**	3.2	1.0	2.0	1.4	2.4	**2.0**

The results show that the mean pollutant concentrations in the incoming water are generally noticeably higher than in the outgoing water. The mean concentrations of the incoming water are quite conformably with the mean and span concentrations in Table 1, which represent typical pollutant concentrations for urban stormwater in

Gothenburg. All of the mean values for the outlet were less than the guideline values for watercourses provided by Riktvärdesgruppen (2009), which can be seen in Appendix 1. However, there were three occasions when the pollutant concentrations exceeded the guidelines. Those values are marked with red in the table.

Pollutant Reduction

The pollutant reduction calculations were also based on the calculated cumulative pollutant masses. The observed reduction rates can be seen in Table 8. The accumulated masses of the pollutants in relation to the accumulated volumes during the storm events give a visual understanding of the reduction rates over time. The graphs can be seen in Appendix 8.

Table 8: Calculated reduction rates at storm event 1-5, and mean values.

Parameter	**Reduction [%]**					
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	**Mean Value**
TSS	75	91	92	80	76	**83**
VS	64	88	69	66	62	**70**
TIN	29	-47	62	50	-	**47***
Zn (total)	70	88	74	68	38	**68**
As (total)	71	91	69	56	13	**60**
Pb (total)	76	98	66	74	54	**74**
Cd (total)	49	69	16	90	-44	**56***
Co (total)	76	96	78	81	54	**77**
Cu (total)	71	83	80	61	-17	**74***
Cr (total)	75	97	67	77	38	**71**
Ni (total)	45	62	41	49	-54	**50***
V (total)	77	88	71	75	44	**71**

*negative reductions are not included

The reduction rates in Table 8 shows that TSS has the overall highest reduction rate and it varies between 76-92% and has a mean value of 83%. The reduction of nitrogen was inconsistent and only analyzed at four storm events. At storm event 2 the concentration of TIN was even higher at the outlet than in the inlet, which resulted in a negative reduction. However, this is as described in Chapther 6.1.1 normal due to differences in rain volumes and dry periods at different storm events. TIN had the lowers mean reduction rate of the pollutants, with lower than 50%.

All mean reduction rates of the metal pollutants were over 50%. Zn, Pb, Co, Cu, Cr, V had mean reduction rates of around 70% up to almost 80%. As, Cd, Ni had lower mean reduction rates of about 60-50%. The reductions of Zn, Pb, Co, Cu, Cr, V was fairly high and consistent through the storm events, besides storm event 5. Ni had an overall slightly lower reduction than the other metals, from 60% to 40%. The reduction of Cd was relatively low compared to the other metals, except in storm event 4 were the reduction was 90%.

Besides TIN, the overall reduction rates at storm event 2 were high. The reduction rates of the metals were generally significantly lower in storm event 5 compared to the other storm events. Ni, Cu and Cd even had negative reduction in storm event 5.

In addition to the results above, reduction rates for dissolved metals have also been looked in to. A complete table of all reduction rates in this study, including dissolved metals, can be seen in Appendix 9. Table 9, below, presents reduction rates for only the dissolved metals.

Table 9: Reduction rates for dissolved metals in the investigated infiltration trench.

Parameter	Reduction [%]				
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5
Zn (dissolved)	21	-25	63	22	-54
As (dissolved)	31	-55	71	-81	-40
Pb (dissolved)	4.8	-44	-135	-93	-35
Cd (dissolved)	-22	-140	-16	-1.3	-66
Co (dissolved)	40	9.7	68	48	48
Cu (dissolved)	46	-39	77	31	-49
Cr (dissolved)	28	-88	2.5	42	29
Ni (dissolved)	-95	-236	16	-7.2	-86
V (dissolved)	57	38	60	27	29

The result shows that the dissolved metals have a bigger portion of negative reduction rates than the other investigated pollutants. In general the positive reduction rates are also lower than for the other pollutants. Dissolved Ni has negative reduction rates in four of five storm events, and only 16% when positive, and dissolved Cd only has negative reduction rates. Dissolved Co and dissolved V have the highest reduction rates with only positive reductions around 30-60%.

8 Analysis

8.1 Flow Detention

The result shows that the investigated infiltration trench successfully detains stormwater flow. This was clearly illustrated in four of five hydrographs. However, the result is not in line with the design capacity of the infiltration trench. But that might be in order, since the overflow and choking construction at the outlet pipe had to be removed in order to carry out the observations. Consequently, the choking mechanism was not in function during the performed observations, and without it the flow detention of the infiltration trench are probably not as designed. That could be one explanation to why the detained volumes never were close to the designed storage volume, even at storm event 4, and why the discharge limit was markedly exceeded at every storm event.

As stated in Chapter 3.1, it is namely essential for a storage facility to have a flow regulating device that is adequately designed at the outlet. Otherwise the requested storage capacity and flow characteristics will not be obtained. An outlet structure that should detain and limit the discharge volume has to be smaller than the inlet structure. The choking construction at the outlet of the investigated infiltration trench made the outlet considerably smaller than the inlet, but without it the size of the inlet and outlet are about the same. Hence, the designed storage volume and discharge limit could not have been expected to be fulfilled in this investigation. Flow measurements with the choking construction in place would therefore probably give a result more in accordance with the design capacity.

The results of this investigation do however indicate that the flow detention works well in the infiltration trench, but the choking construction would probably enhance the detention and limit the outlet flow to the discharge limit. Finally, the observations showed that it primarily were the return period and rain depth of a storm event that affected how well the infiltration trench detained the stormwater. Intensity, duration or dry period did not seem to have the same effects. An increased number of observed storm events would however be necessary to confirm this.

8.2 Pollutant Removal Efficiencies

The result shows that the stormwater runoff from the parking lot outside ICA Maxi Kungsbacka generally has the water quality that can be expected at a parking lot. As stated in Chapter 2.2.3, lead, zinc and copper are common pollutants in stormwater and they usually originate from vehicles. Therefore these heavy metals could be expected in stormwater runoff in this investigation. The result also shows that the stormwater runoff at the parking lot outside of ICA Maxi Kungsbacka contained these metals. In addition, the concentrations of the metals as well as TSS and nitrogen were in accordance with average concentrations for Gothenburg, which is seen in Table 1.

Nevertheless, some concentrations were not as expected. The inlet EMC concentrations for lead were actually lower than expected at a parking lot. It had a mean concentration of about 10 µg/l while the expected mean concentration according to Table 1 is 200 µg/l. 10 µg/l is however within the range of concentrations that were given in the same table. Furthermore, the concentrations of phosphorus were hardly detectable, which implies that the stormwater does not contain domestic sewage. Not all investigated metals were presented in Table 1, so a comparison of those metals was not possible. However the water quality was generally in line with the initial expectations.

Another expected behaviour of the pollutant concentrations at the inlet was that the runoff would have higher pollutant content in the beginning of a storm event than at the end, the so called *first flush*. The first flush in urban stormwater generally contains high pollutant concentrations from accumulated pollutants on the ground surface. The cumulative pollution graphs in Appendix 7 clearly demonstrates higher concentrations at the beginning of the storms in the cumulative pollutant calculation graphs from storm event 1, 2 and 5. It is impossible to observe concentration variation in storm event 3 due to that only one sample was analysed at inlet for that event. Storm event 4 did also not show any pollutant concentrations behaviour in accordance with first flush. Storm event 4 was however closely successive after storm event 3, which could be a possible explanation for lacking a first flush, since pollutants probably did not accumulate on the ground surface between the storm events.

Regarding the outlet pollutant EMC concentrations, they are all meeting the requirements set by Riktvärdesgruppen (2009). The EMC concentrations of total inorganic nitrogen, which all are around 2 mg/L, are somewhat below the set guideline value of 2.4 mg/l for nitrogen. This guideline value is, on the other hand, set for total nitrogen, which in addition contains organic nitrogen and ammonium gas. Organic nitrogen is, as descripted in Chapter 2.2.4, a major part of the nitrogen content in urban stormwater. If organic nitrogen also would have been measured, the nitrogen concentrations would probably have been higher and potentially exceeded the set guideline value.

Pollutant Reduction

In general, the obtained pollutant removal efficiencies can be considered as good. The results in Table 8 show a consistent removal efficiency of about 80-90% for TSS. The removal of VS was also fairly consistent and almost as high as the removal of TSS. Since many other pollutants in urban stormwater have a strong affinity to particles a high removal efficiency of TSS can indicate high removal efficiencies of other pollutants. Examples of pollutants that might be removed together with particles are organic pollutants, such as PAHs and phthalates.

The removal efficiencies of the analysed metals are in a larger span than TSS and VS, which can be seen in Table 9. The highest mean removal efficiencies are observed for lead (74 %), cobalt (77%) and copper (74%) while the lowest average removal efficiencies are observed for nickel with 50 % and cadmium with 56 %. However, the removal efficiencies in Table 9 are for *total* metals only. The removal efficiencies of dissolved metals, which also have been measured, can be seen in Table 10. As it can be seen in Table 10, dissolved metals have significantly lower removal efficiencies and are in many cases negative. A possible explanation for this may be that that most metals are present in their colloidal phase. However, it has been stated in Chapter 2.2.3 that zinc, copper and cadmium mainly are present in their dissolved phase but it is not possible to confirm this based on the data in Appendix 8.

Variations in the Pollutant Reduction

The results in both EMC and reduction rates differ between the storm events. Deviations in pollutant concentrations are however normal in stormwater. Storm events 1-4 have quite similar pollutant concentrations, but the pollutant concentrations as well as reduction rates at storm event 5 differ from the others. Storm event 2 and 5 differed most. The reasons to the deviations can be many. For example chances in local conditions and rain characteristics. A local condition that could have affected the pollutant concentrations in this investigation can have been the amount of traffic at the parking lot at the storm event and during a period before the storm event. Traffic changes have however not been observed during this study. The rain characteristics have on the other hand been studied.

The rain characteristics that have been studied are duration, dry period, rain depth, return period and intensity. The characteristics of the storm event are summed in Table 5. The most obvious difference between storm event 2 and 5 is the number of dry days before the storm event. Storm event 2 had one dry day prior to its start and storm event 5 had 23. This indicates that pollutants to a large extent had accumulated on the surface at the start of storm event 5 than at the start of storm event 2. The inlet EMCs do however not confirm this. The inlet concentrations are higher at storm event 2 than at storm event 5. In general storm event 5 actually had markedly lower inlet concentrations than the other storm events, even though it had the longest dry period. Therefore ground surface accumulation of pollutants most likely is not the explanation to the deviation.

The long dry period prior to storm event 5 could however have contributed to the low reduction rates at storm event 5. During a long dry period no stormwater would enter the infiltration trench and the flow rate would thereby be zero during that period. If there was standing water inside the infiltration trench during that period, particles would have had the time to settle. In that case the pollutant concentrations inside the infiltration trench would have been higher before storm event 5 than before storm event 2. Consequently, this could have had an effect on the outlet concentrations and therefore caused the low reduction rates. However, Storm event 3 had 13 preceding dry days but did not show lower reduction rats than storm event 1, 2 and 4.

Another possibly explanation to the different result from storm event 5 can be that it occurred a month later than the other storms. Storm event 1-4 occurred during one month, 10^{th} of April to 10^{th} of May, and storm event 5 at 10^{th} of June. Seasonal variations have not been considered in this investigations but time of the year might affect the result. A longer investigation period would be necessary to study this.

Pollutant Removal Efficiencies In Relation to Rain Characteristics

In what way rain characteristics affect pollutant removal efficiencies can be observed by comparing the five storm events characteristics and removal efficiencies to each other. Storm event 1 and 5 had the most similar characteristics, only the number of preceding dry days differs. The result shows that storm event 5 in general had lower reduction rates of metals compared to storm event 1. This could imply that long dry periods give lower reduction of metals than short dry periods. However, in the series of observed storm events, storm event 1, 2 and 4 had short preceding dry periods and storm event 3 and 5 had long dry periods, and the reduction of metals cannot be considered as higher in storm 1,2, and 4 than in 3 and 5. Consequently, it is not possible to draw the conclusion that a long dry period results in a low reduction of metals. The inlet concentrations might however affect the reduction of metals. Storm even 1, 2 and 3 had markedly higher inlet concentrations rates than storm event 4 and 5. The reduction rates of metals were also in general higher at storm events 1, 2 and 3 than 4 and 5.

No clear relations between reduction of particles or nitrogen and rain characteristics have been observed in this study. The result does however imply that a storm event with a small rain depth and short duration give better pollutant reduction than a storm event with greater rain depth and longer duration. This can be seen when comparing the smallest storm event, number 2, to the greatest, number 4.

Pollutant Removal Efficiencies Compared to Earlier Studies and Detention Ponds

In Table 2 the results from earlier studies on infiltration trenches are summarized. As presented in Table 2, the removal of TSS has earlier shown to be up to 90%, which is in-line with the results of this investigation. Although, the study by the Swedish Road Administration showed that the removal of TSS can be as low as 50%. The result of TN-removal was however not as accordant to the other studies. The removal of TN varied between the different studies. Winer (2000) stated the removal as low as 42%, while Maniquiz et al. (2010) presented a value as high as 84%. Variations within the same study were, however, only shown by US EPA and it was only a difference of 5% (55-60%). These results are in-line with the results from storm 1, 3 and 4, in this study, which were about 50-80%. The removal of phosphorus was relatively high in the earlier studies. In this investigation were the concentrations of phosphorus in the incoming stormwater too low to measure any removal efficiency.

Regarding metals it is somewhat more difficult to compare with earlier studies due that it many earlier studies only have stated removal efficiencies for metals in general. Moreover, it is also only possible to compare removal efficiencies for lead, zinc, copper and cadmium. However, all measured metal removal efficiencies in this study are below the ones in the studies by Maniquiz et al. (2010), US EPA (2006) and Wyoming Department of Environmental Quality (1999) in which the removal efficiencies were measured to 89-93, 85-90% respectively 90 %. However, in these studies by US EPA (2006) and Wyoming Department of Environmental Quality (1999) the removal efficiencies were stated for metals in general. The removal efficiencies for zinc, copper, cadmium and lead in the study by the Swedish Road Administration (2011) have all large ranges. The result of this master thesis study, however, shows that it might be possible to reduce the ranges of removal efficiencies for metals.

It might also be possible to state that infiltration trenches can be used in the same purpose as detention ponds, in other words, more frequently constructed in the purpose of pollutant reduction. In Table 4 average removal efficiencies for stormwater ponds can be seen. It can be concluded that all removal efficiencies in this master thesis study are higher than the ones for stormwater ponds.

9 Discussion

The investigation of the infiltration trench in Kungsbacka has demonstrated good result for pollutant removal efficiencies, and relatively good results for the flow detention. The observation and laboratory procedures have functioned well during the investigation, however, the limited time period of the investigation as well as some practical issues that occurred during the procedure have probably contributed to some errors. The limited time available restricted the number of storm events that were possible to observe. In addition, technical problems with the measurement and sampling equipment delayed the start of the observations. During the measurements and sampling occasional clogging of the inlet pipe and pressure sensor also contributed to missed samples. These practical problems caused missed storm events in the storm series during April to June 2012.

Observations during a longer time period, with a higher number of successive storm events would make it possible to get a better understanding of the function of the infiltration trench and statistically proven results. If the observations were carried out during a year seasonal variations could be evaluated, and if the observation period would stretch over several years the functions in relation to age and maintenance of the infiltration trench could be investigated.

A necessary assumption that had to be made to evaluate the observations has been that the total inflow volume has been equal to the total outflow volume. This is most likely a fair assumption, but the adjustment of the inflow hydrograph might have affected the result, since definite cumulative calculations have not been possible to perform for the inlet. Furthermore, it has been assumed that the stormwater chemistry has been the same in all four inlets, which do not have to be the case. However, the conditions in the drainage area are fairly consistent and the differences between the inlets are probably negligible.

Despite the fact of few storm events, measured values showed to be fairly consistent during the investigation. This implies reliable results. However, the investigation procedure has generated some sources of error. As stated earlier the measurement and sampling equipment contributed to some missed samples and imperfect flow measuring. Nevertheless, these problems most likely did not considerably affect the results, since the equipment worked well during the storm events included in this study. In the case of technical problems causing major sampling gaps during a storm event, those storm events were refused.

An unavoidable source of error has, on the other hands, been the laboratory experiments, which always contributes to some uncertainties. In this study the detection levels of the Ion Chromatography experiment might have caused that no phosphate was detected, some other method might have been more suitable. Furthermore, handling and mixing of samples expose the sample water to oxygen and room temperature, which might affect the water chemistry. Nevertheless, experiments and sample collection have been performed according to standards and recommendations.

Conclusively, the errors in this study are not considered to be more apparent than errors in any other investigation of the same kind. A factor that cannot be ignored is, however, that the study was not carried out at normal flow characteristics. This might have had an impact on the observed pollutant concentrations at the outlet and thereby also the reduction rates. This is because the pollutant reduction functions in the infiltration trench could be dependent on the flow characteristics.

Storm event 2 was the only event that had an outlet peak flow below the discharge limit and since it can be assumed that the discharge limit is fulfilled at normal conditions, with the overflow and choking construction in place, storm event 2 is probably the storm event that is most similar to normal flow characteristics. Thereby it could be possible that the removal rates of storm event 2 are the most likely. Storm event 2 was the event with the highest pollutant removal rates. This, however, would need further investigations to be confirmed.

As has been mentioned, the stream Kungsbackaån is classified as a sensitive stream and the outgoing stormwater must therefore be of good quality in order to protect the stream. This requirement is considered to be achieved due to the fact that the studied infiltration trench has shown a good pollutant removal. Moreover, the fact that the stormwater also is treated by an oil separator and in the stormwater pond system contributes to an enhanced pollutant removal and dilution of pollutants. Thus, the quality of Kungsbacka is not considered to be affected by the outgoing stormwater. However, a question to ask is what will happen at extremely large storm events with long durations, which may be a possible future scenario due to climate change. The stormwater will probably quickly pass the infiltration trench without treatment and if this happen frequently there is a risk that the water quality in Kungsbackaån may be affected due to that large quantities of stormwater with a high pollutant loads may be discharged to the stream.

10 Conclusion

This master thesis has complemented the research on infiltration trenches with pollutant removal efficiencies for suspended solids, total inorganic nitrogen and heavy metals, of an infiltration trench at a parking lot outside of a supermarket in Kungsbacka, south of Gothenburg, during the spring of 2012. The result showed that the infiltration trench had an average removal efficiency of 80% for suspended solids, about 50% for total inorganic nitrogen, 70-80% for zinc, lead, copper and chromium, and 50-60% for cadmium and nickel. The measurements and sampling had to be performed without the overflow and choking construction, which resulted in lower flow detention than the design capacity and exceeded outflow discharge limit. Flow detention during the storm events was, however, apparent and under normal circumstances it would probably meet the design capacity.

Consequently, the function of the infiltration trench considered to be good. If the reduction rates would be affected by other flow characteristics is unknown. This study has however not showed any indication of reduced pollutant reductions for different flow detentions. The result has been relatively stable at storm events with different flow detentions.

The reduction rates both differ and correspond to earlier studies. The removal efficiencies for zinc, copper, cadmium and lead had very wide ranges in the study by the Swedish Road Administration (2011) and the result of this master thesis study might reduce those ranges of removal efficiencies. It could also be possible to state that infiltration trenches more frequently can be used in the same purpose as detention ponds, in other words, constructed in the purpose of pollutant reduction.

Further Studies

Based on the reasoning in the discussion further studies of the investigated infiltration trench would be interesting, were the effects of seasonal variations, age and maintenance could be studied. To study the infiltration trench during normal flow characteristics could however be difficult. Due to that the overflow construction and the sampler do not fit in the outlet manhole at the same time, but if feasible it most definitely would be interesting. It would also be interesting to study the other infiltration trenches at the parking lot outside of ICA Maxi Kungsbacka to compare with the result from the investigated infiltration trench. The stormwater ponds, which receive the outlet flow from the parking lot, would also be interesting to investigate, since the recently built residential area, Björkris, next to ICA Maxi also discharges the stormwater runoff to the detention ponds. This would give a better understanding of the water quality that is discharged from the area to Kungsbackaån. Finally, a study of organic pollutants such as PAHs and phthalates would be good.

References

Alm, H., Banach, A. & Larm, T., (2010). *Förekomst och rening av prioriterade ämnen, metaller samt vissa övriga ämnen i dagvatten. Rapport Nr 2010-06,* u.o.: Svenskt Vatten .

Andersson, J., Owenius, S. & Stråe, D., (2012). *NOS-dagvatten - Uppföljning av dagvattenanläggningar i fem Stockholmskommuner.* Rapportnummer 2012-02. Svenskt Vatten Utveckling.

Berggren, H et al. (1991). *LOKALT OMHÄNDERTAGANDE AV DAGVATTEN - Erfarenheter och kunskapsuppbyggnad under 1970- och 1980-talen,* Göteborg, Sverige: Chalmers tekniska högskola: Geohydrologiska forskningsgruppen.

Berndtsson, R, Hogland W., Larsson, M., Enell, M. & Wennberg (1989). *Dagvatten från Växjö tätort. Kvantiteter och kvaliteter samt olika belastningar på olika recipienter.* IVL Svenska Miljöinstitutet.

Björklund, K. (2010). *Substance flow analyses of phthalates and nonylphenols*. Water Science & Technology, 62(5), pp. 1154-1160.

Björklund, K., Palm Cousins, A., Strömvall, A.-M. & Malmqvist, P.-A. (2009). *Phthalates and nonylphenols in urban runoff: Occurrence, distribution and area emission factors.* Science of the Total Environment, 407(16), p. 4665–4672.

Butler, D. & Davies, J. (2004). *Urban Drainage.* 2 ed. London, United Kingdom: Spon Press.

Chave, P. (2001). *The EU Water Framework Directive- An Introduction.* London, United Kingdom: IWA Publishing.

City of Stockholm (2005). *Dagvattenstrategi för Stockholm Stad,* Stockholm, Sweden: City of Stockholm.

Conara AB (2012). *Genomföra ICA project.* [Electronic] Available on: http://www.conara.se/referensprojekt/projektledare-och-bestallarombud-ica-maxi-kungsbacka/, accessed 2012-05-19.

D'Arcy, B. & Frost, A. (2001). *The role of best management practices in alleviating water quality problems associated with diffuse pollution.* The Science of the Total Environment, Volume 267, pp. 359-367.

Eith, C. Kolb, M., Seubert, A., Viehweger, K. (2001). *Practical Ion Chromotography - An Introduction,* Herisau, Switzerland: Metrohm Monograph.

Ellis, J. & Revitt, D. (1981). *Incidince of Heavy Metals in Street Surface Sediments: Solubility and Grain Size Studies.* Water, Air and Soil Pollution, Volume 17, pp. 87-100.

Eriksson, E. et al. (2007). *Selected stormwater priority pollutants — a European perspective.* Science of the Total Environment, Volym 383, pp. 41-51.

European Commission. (2010). *Water Framework Directive* [Electronic] Available on:< http://ec.europa.eu/environment/pubs/pdf/factsheets/water-framework-directive.pdf>, Accessed 2012-01-24.

European Commission (2011). *Priority Substances and Certain Other Pollutants according to Annex II of Directive 2008/105/EC.* [Electronic] Available on: http://ec.europa.eu/environment/water/water-framework/priority_substances.htm, accessed 2012-01-24.

Fromme, H. (2011). *Phthalates: Human Exposure*. Encyclopedia of Environmental Health, pp. 298-510.

GF Konsult (2007). *VA-utredning till detaljplan för stadsdel Björkris, Kungsbacka kommun (2007-12-10 ed.*, Göteborg, Sweden: GF Konsult..

Haestad, M. & Durrans, S. (2003). *Stormwater conveyance.* First Edition red. Waterbury: Haestad Press.

Herngren, L., Goonetilleke, A. & Ayoko, G. A. (2005). *Understanding heavy metal and suspended solids relationships in urban stormwater using simulated rainfall*. Journal of Environmental Management, Volym 76, pp. 149-158.

Heudorf, U., Mersch-Sundermann , V. & Angerer, J. (2007). Phthalates: Toxicology and exposure. *International Journal of Hygiene and Environmental Health,* 210(5), pp. 623-634.

Karlsson, K. & Viklander, M. (2008). *Polycyclic Aromatic Hydrocarbons (PAH) in Water and Sediment from Gully Pots.* Water Air Soil Pollut, Volym 188, pp. 271-282.

Kungsbackaåns vattenvårdsförbund, 2012. *Kungsbackaåns vattenvårdsförbund.* [Electronic] Available on: http://www.kbavvf.se/index.htm, accessed 2012-02-08.

Lampe, L., Barret, M. & Woods-Ballard, B. (2004). *Post-Project Monitoring of Bmps/Suds to Determine Performance and Whole-Life Costs.* London, United Kingdom: IWA Publishing.

Malmqvist, P.-A. (1983). *Urban Stormwater Pollutant Sources - An Analysis of Inflows and Outflows of Nitrogen, Phosphorus, Lead, Zinc and Copper in Urban Areas.* Göteborg: Chalmers University of Technology, Department of Sanitary Engineering.

Maniquiz , M., Lee, S.-Y. & Kim, L.-H. (2010). *Long-Term Monitoring of Infiltration Trench for Nonpoint Source Pollution Control.* Water Air Soil Pollut, Volym 212, pp. 13-26.

Metcalf & Eddy, 2003. *Wastewater Engineering, Treatment and Reuse.* 4th red. New York, United States: McGraw-Hill.

Mihaiescu , T. & Mihaiescu, R., 2009. *Review European Union Water Framework Directive.* ProEnvironment, Volym 2, pp. 55-57.

Monteiro, R. (2005). *Pollutant Removal Efficiency in the Välenviken Stormwater Ponds.* Department of Civil and Environmental Engineering, Division of Water Enivronent Technology, Chalmers University of Technology.

Morrisson, G., Revitt, D.M., Ellis, J.B., Svensson, G., Balmer, P. (1984). Variations of dissolved and suspended solid heavy metals through an urban hydrograph. *Environmental Technology Letters* , 5(1-11), pp. 313-318.

Municipality of Kungsbacka (2006). *Detaljplan för Skårby 3:4 m fl i Tölö Handelsetablering,* Kungsbacka, Sweden: Planavdelningen, Kungsbacka kommun..

Municipality of Kungsbacka (2011). *Björkris.* [Electronic] Available on: http://www.kungsbacka.se/sitetemplates/KBInformationPage____14201.aspx, accessed 2012-02-01..

Municipality of Kungsbacka (2012). *Dagvatten - Policy och Riktlinjer.* Municipality of Kungsbcka.

Norconsult (2010). *À-Prislista Markarbeten,* Gothenburg 2010-06-01: Norconsult .

Odum, H. (2000). *Heavy metals in the Enivornment Using Wetlands for Their Removal.* Lewis Publishers.

Ohio State University (2012). *Ion Chromatography Overview* [Electronic] Available on: http://research.chemistry.ohio-state.edu/reel/research-modules/environmental-chemistry/instrumentation/instrument-calibration/, accessed 2012-05-08.

PerkinElmer (2012). *The 30-Minute Guide to ICP-M.* PerkinElmer

Persson, J. (1998). *Utformning av dammar: En litteraturstudie med kommentarer om dagvatten-, polerings- och miljödammar.* Göteborg: Chalmers tekniska högskola.

ersson , T. J. (1996). *Pollution Reduction in Stormwater Detention Ponds. Report 1996:3,* Gothenburg: Chalmers University of Technology: Department of Sanitary Engineering.

Pettersson, T. (1997). *FEM-Modelling o f Open Stormwater Detention Ponds.* Nordic Hydrology, 28(4-5), pp. 339-350.

Pettersson, T. (1998). *Water Quality Improvement in a Small Stormwater Detention Pond.* Water Science Technolgy, 38(10), pp. 115-122.

Pettersson, T. (1999). *Stormwater Ponds for Pollution Reduction,* Gothenburg: Chalmers University of Technology, Department of Sanitary Engineering,.

Revitt, D., Hamilton, R. & Warren, R. (1990). *The transport if heavy metals within a small urban catchment.* The Science of the Total Enivronment, pp. 359-373.

Riktvärdesgruppen (2009). *Förslag till riktvärden för dagvattenutsläpp,* Stockholm: Regionala dagvattennätverket i Stockholms län, Regionplane och trafikkontoret, Stockholms läns landsting .

Silva, A., Nascimiento , N., Seidl, M. & Vieira, L. (2010). *SWITCH in Belo Horisonte, Brazil: infiltration and detention systems for more sustainable stormwater control in Belo Horisonte.* Rev Environ Sci Biorechnol, Volum 9, pp. 7-13.

SMHI (2009). *Sveriges klimat* [Electronic] Available on: http://www.smhi.se/kunskapsbanken/klimat/sveriges-klimat-1.6867, accessed 2012-05-23.

Sowinski, M. (2005). *Reduction of runoff by modified trough - infiltration trench system - a case study of leszno town.* Enhancing Urban Environment by Environmental Upgrading and Restoration, Volume 43, pp. 13-21.

Sposito, G. (1989). *The Chemistry of Soils.* Oxford University Press.

Stahre P. (2006). *Sustainability in urban storm drainage - Planning and examples,* Malmö, Sweden: Svenskt Vatten.

Stahre, P. (2004). *En långsiktig och hållbar dagvattenhantering - Planering och exempel.* Malmö: Svenskt Vatten.

Stahre, P. & Urbonas, B. (1990). *Stormwater detention: for drainage, water quality, and CSO management.* New Jersey, the U.S.: Prentice Hall, Inc.

Standard Methods Committee (1997). *Standard Methods for the Examination of Water and Wastewater*. 20th Ed red. American Public Health Association, American Water Works Association, Water Environment Federation.

Strömvall, A.-M., Norin, M. & Pettersson, T. (2007). *Organic contaminants in urban sediments and vertical leaching in road ditches.* Highway and Urban Environment, 12(3), pp. 235-247.

Svenskt Vatten (2004). *Dimensionering av allmänna avloppsledningar P90.* Svenskt Vatten.

Svenskt Vatten (2011). *Hållbar dag- och dränvattenhantering - Råd vid planering och utformning.* Publikation P105 red. Stockholm, Sweden: Svenskt Vatten.

Swedish Road Administration (2009). *VVK Väg. Publication 2009:120.* Swedish Road Administration.

Swedish Road Administration (2011). *Vägdagvatten - Råd och rekommendationer för val av miljöåtgärd. Report: 2011:112.* Swedish Road Administration.

Thomas, R. (2001). *A Beginner's Guide to ICP-MS*. Spectroscopy, 16(4), pp. 38-42.

Tyréns (2007). *Beräkningar VA-Projektering ICA Borgås.* Tyréns.

UK Health Protection Agency (2008). *HPA Compendium od Chemical Hazards - Polycyclic aromatic hydrocarbons - Benso[a]pyrene.* UK Health Protection Agency.

US EPA (2006a). *Infiltration Trench.* [Electronic] Available on: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=70, accessed 2012-01-20.

US EPA. (2006). *Wet Ponds.* [Electronic] Available on: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=68, accessed 2012-02-20.

Winer, R. (2000). *National Pollutant Removal Database for Stormwater Treatment*, Elliot City, MD, United States: Center for Watershed Protection.

Wyoming Department of Environmental Quality (1999). *URBAN BEST MANAGEMENT PRACTICES FOR NONPOINT SOURCE POLLUTION.* Point and Nonpoint Source Programs, Water Quality Division, Wyoming Department of Environmental Quality

Figures

Figure1: a) Eniro (2012). Kartor. [Electronic] Available on: http://kartor.eniro.se/, accessed 2012-04-24. b) © Nilsson & Stigsson, 2012

Figure 2: Butler, D. & Davies, J. (2004). *Urban Drainage.* 2 ed. London, United Kingdom: Spon Press.

Figure 3: Butler, D. & Davies, J. (2004). *Urban Drainage.* 2 ed. London, United Kingdom: Spon Press.

Figure 4: Butler, D. & Davies, J. (2004). *Urban Drainage.* 2 ed. London, United Kingdom: Spon Press.

Figure 5: Stahre, P. & Urbonas, B. (1990). *Stormwater detention: for drainage, water quality, and CSO management.* New Jersey, the U.S.: Prentice Hall, Inc.

Figure 6: Butler, D. & Davies, J. (2004). *Urban Drainage.* 2 ed. London, United Kingdom: Spon Press.

Figure 7: Eniro (2012). Kartor. [Electronic] Available on: http://kartor.eniro.se/, accessed 2012-03-19

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Figure 9: © Nilsson, 2012

Figure 10: © Nilsson & Stigsson, 2012

Figure 11: Pettersson, T. (1999). *Stormwater Ponds for Pollution Reduction,* Gothenburg: Chalmers University of Technology, Department of Sanitary Engineering,

Figure 12: © Nilsson & Stigsson, 2012

Figure 13: © Nilsson & Stigsson, 2012

Appendix 1: Suggested guidelines for stormwater discharges for Stockholm

Tabell 2. Föreslagna riktvärden för dagvattenutsläpp (årsmedelhalt).
Totala fraktioner avses för näringsämnen och metaller.

		Sjöar, vattendrag, havsvikar		Större sjöar och hav		VU
Ämne	**enhet**	**1a**	**2a**	**1b**	**2b**	
Fosfor (P)	*µg/l*	160	175	200	250	250
Kväve (N)	*mg/l*	2,0	2,5	2,5	3,0	3,5
Bly (Pb)	*µg/l*	10	15	15	20	20
Koppar (Cu)	*µg/l*	18	30	30	40	40
Zink (Zn)	*µg/l*	75	90	90	100	100
Kadmium (Cd)	*µg/l*	0,4	0,7	0,5	0,7	0,7
Krom (Cr)	*µg/l*	10	15	15	25	25
Nickel (Ni)	*µg/l*	15	30	20	30	30
Kvicksilver (Hg)	*µg/l*	0,05	0,07	0,07	0,07	0,07
Suspenderad substans (SS)	*mg/l*	60	100	100	125	125
Oljeindex (olja)	*mg/l*	0,4	0,7	0,5	0,7	1,0
Benso(a)pyren (BaP)	*µg/l*	0,05	0,1	0,07	0,1	0,1

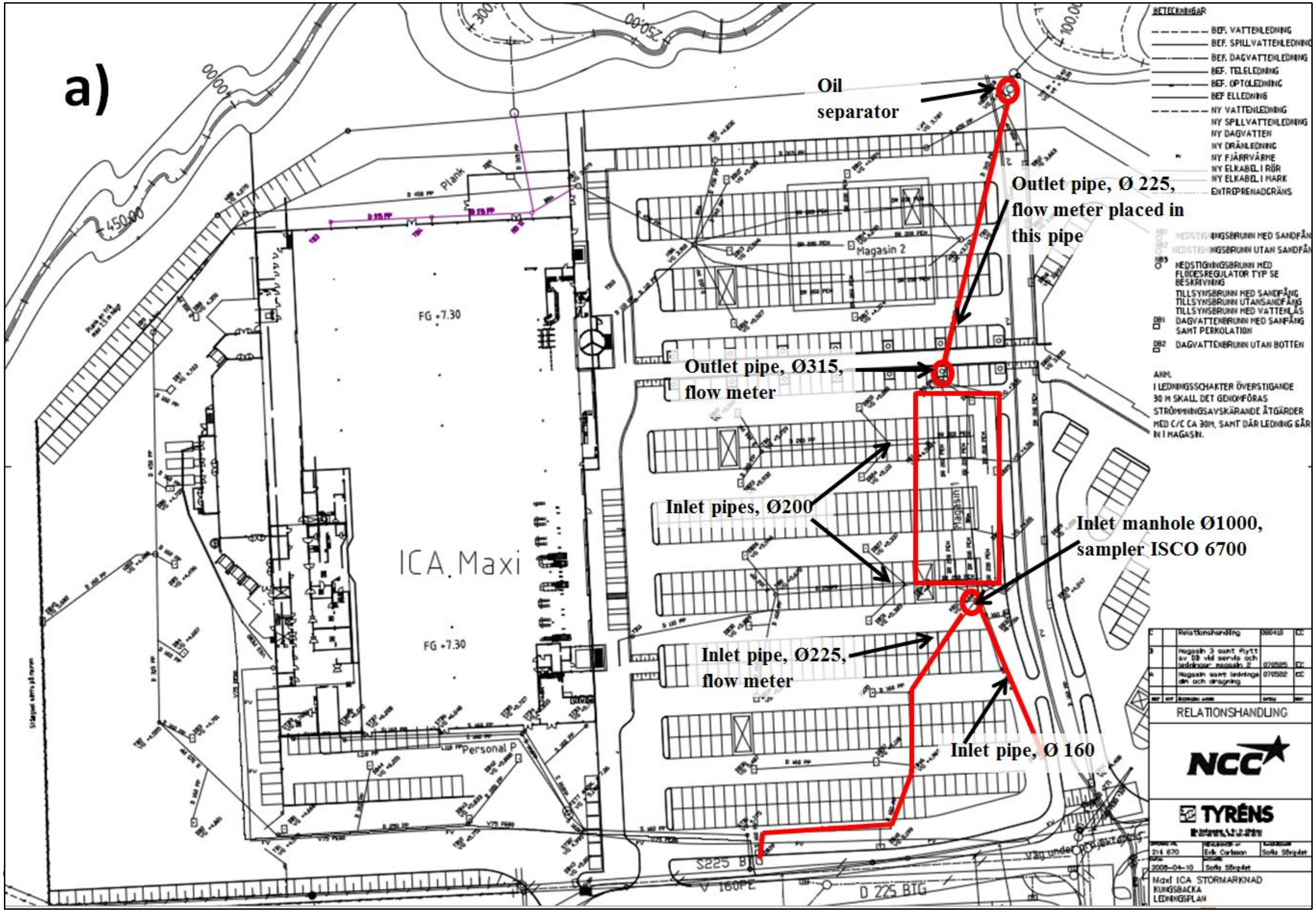
Riktvärdesgruppen (2009).

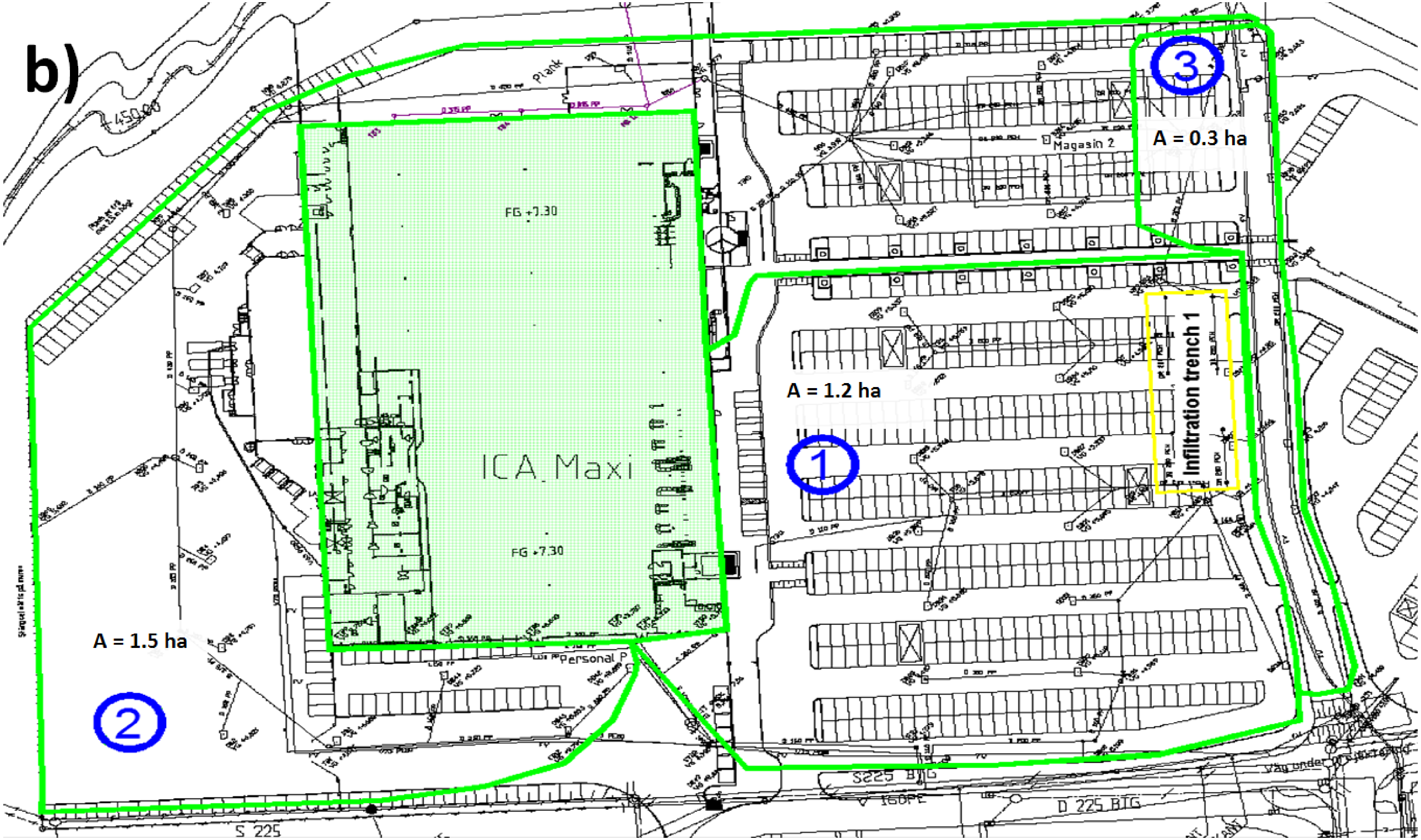
Appendix 2: Plan drawing of the ICA Maxi area with drainage areas.

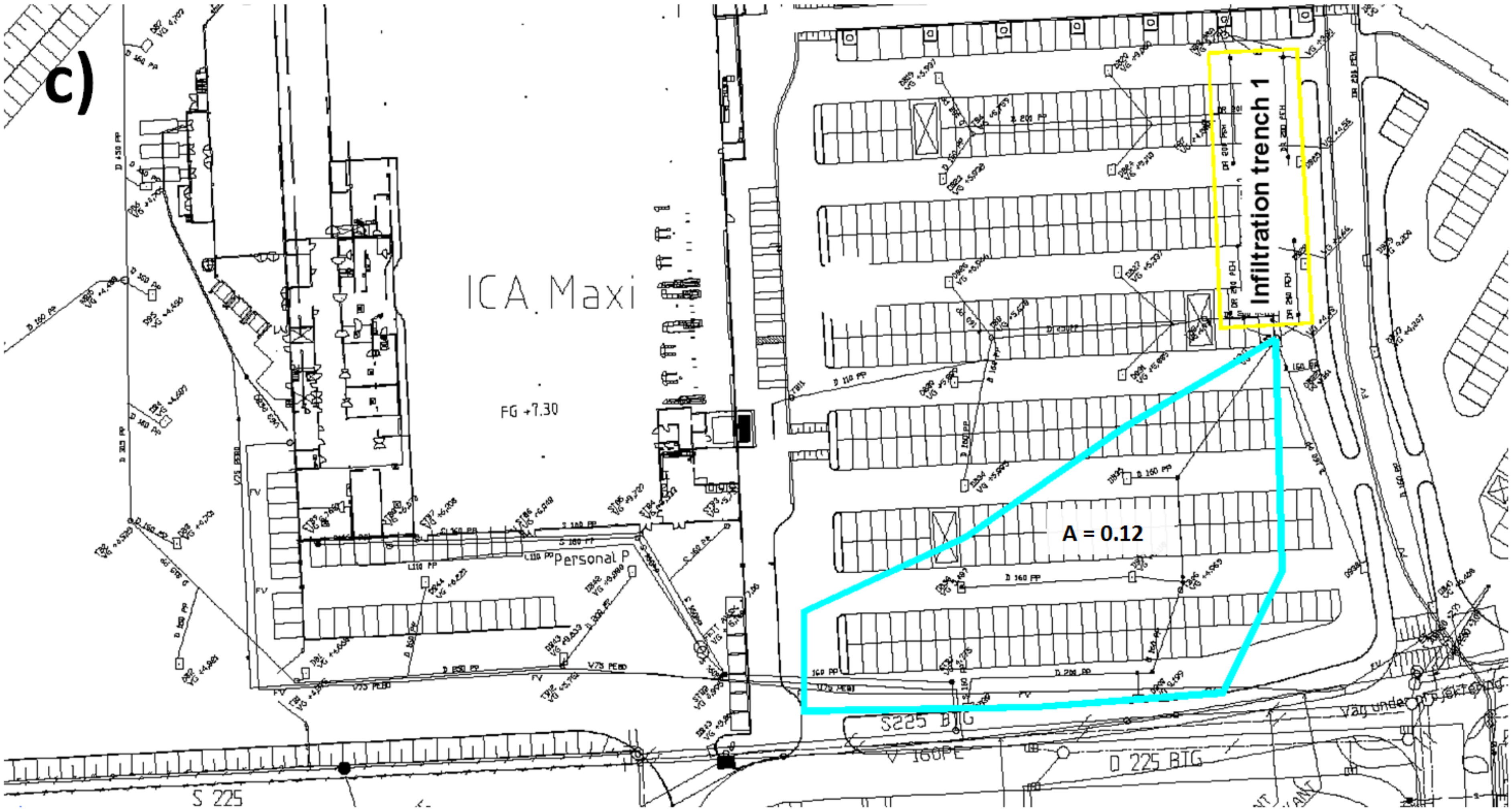
2a) Layout shows location of infiltration trench, inlet and outlet pipes and their dimensions. Layout also shows location of samplers and flow meters.

2b) Layout of drainage areas

2c) Drainage area of the inlet pipe in which flow meter where place


a)
Oil separator
Outlet pipe, Ø 225, flow meter placed in this pipe
Outlet pipe, Ø315, flow meter
Inlet pipes, Ø200
Inlet manhole Ø1000, sampler ISCO 6700
Inlet pipe, Ø225, flow meter
Inlet pipe, Ø 160
ICA Maxi
FG +7.30
FG +7.30
Magasin 2
Magasin 1
Personal P
Plank
S225 B
V 160PE
D 225 BTG
BETECKNINGAR
BEF. VATTENLEDNING
BEF. SPILLVATTENLEDNING
BEF. DAGVATTENLEDNING
BEF. TELELEDNING
BEF. OPTOLEDNING
BEF ELLEDNING
NY VATTENLEDNING
NY SPILLVATTENLEDNING
NY DAGVATTEN
NY DRÄNLEDNING
NY FJÄRRVÄRME
NY ELKABEL I RÖR
NY ELKABEL I MARK
ENTREPRENADGRÄNS
DAGVATTENBRUNN UTAN BOTTEN
ANM.
I LEDNINGSSCHAKTER ÖVERSTIGANDE 30 M SKALL DET GENOMFÖRAS STRÖMNINGSAVSKÄRANDE ÅTGÄRDER MED C/C CA 30M, SAMT DÄR LEDNING GÅR IN I MAGASIN.
RELATIONSHANDLING
NCC
TYRÉNS
Maxi ICA STORMARKNAD
KUNGSBACKA
LEDNINGSPLAN


b)
A = 0.3 ha
A = 1.2 ha
A = 1.5 ha
Infiltration trench 1
ICA Maxi
FG +7.30
Magasin 2
3
1
2


c)
Infiltration trench 1
A = 0.12
ICA Maxi
FG +7.30
Personal P
S225 BTG
D 225 BTG
S 225

Appendix 3: Photos of measurement equipment

Sampler ISCO 6700

Strainer and pressure sensor

Sampler, flow meter and car battery in manhole

Bottles in sampler

Appendix 4: Results from laboratory experiments for TSS and VS

Sample	Date of sample collection	Date of analysis	Filter type	Filtered volume [ml]	Weight before heating in 105 ºC [mg]	Weight after heating in 105 ºC [mg]	Weight after ignition in 550 ºC [mg]	TSS conc. [mg/l]	VS conc. [mg/l]
					Storm 1				
1	2012-04-10	2012-04-17	GF47	130	232.2	311.0	298.2	8.7	3.1
2	2012-04-10	2012-04-17	GF47	225	229.0	242.5	240.3	69.6	16.4
3	2012-04-10	2012-04-17	GF47	300	232.3	240.9	238.8	25.6	6.1
4	2012-04-10	2012-04-17	GF47	205	233.3	261.9	255.7	12.5	3.7
5	2012-04-10	2012-04-17	GF47	200	232.9	246.5	242.9	5.5	2.0
6	2012-04-10	2012-04-17	GF47	300	230.5	242.9	239.7	8.9	3.2
					Storm 2				
7	2012-04-23	2012-04-24	GF47	250	231.2	349.1	324.1	606.2	98.5
8	2012-04-23	2012-04-24	GF47	250	232.0	309.6	291.6	60	9.8
9	2012-04-23	2012-04-24	GF47	275	227.7	275.2	263.7	28.7	7.0
10	2012-04-23	2012-04-24	GF47	500	230.1	235.4	233.6	139.5	30.2
11	2012-04-23	2012-04-24	GF47	400	227.1	241.0	237.2	68.0	18.0
12	2012-04-23	2012-04-24	GF47	500	229.3	241.1	237.3	41.3	10.7

Sample	Date of sample collection	Date of analysis	Filter type	Filtered volume [ml]	Weight before heating in 105 ºC [mg]	Weight after heating in 105 ºC [mg]	Weight after ignition in 550 ºC [mg]	TSS conc. [mg/l]	VS conc. [mg/l]
					Storm 3				
13	2012-05-09	2012-05-11	GF47	250	213.3	244.3	237.9	124	25.7
14	2012-05-10	2012-05-11	GF47	400	231.9	237.5	233.5	14.1	10.1
15	2012-05-10	2012-05-11	GF47	500	231.3	235.1	231.7	7.7	6.9
					Storm 4				
16	2012-05-10	2012-05-11	GF47	350	232.4	256.1	248.2	67.8	22.7
17	2012-05-10	2012-05-11	GF47	350	232.3	253.7	247.1	61.2	19.0
18	2012-05-10	2012-05-11	GF47	350	230.9	263.4	255	93.0	24.1
19	2012-05-12	2012-05-14	GF47	350	230.4	249.7	244.2	55.2	15.8
20	2012-05-10	2012-05-11	GF47	500	230.5	239.0	234.5	17.1	9.1
21	2012-05-12	2012-05-14	GF47	500	231.8	240.7	236.5	17.9	8.5

Sample	Date of sample collection	Date of analysis	Filter type	Filtered volume [ml]	Weight before heating in 105 ºC [mg]	Weight after heating in 105 ºC [mg]	Weight after ignition in 550 ºC [mg]	TSS conc. [mg/l]	VS conc. [mg/l]
Storm 5									
22	2012-06-11	2012-06-12	GF47	250	230.7	243.4	238.5	50.8	19,6
23	2012-06-11	2012-06-12	GF47	350	230.5	237.9	234.2	21.1	10,6
24	2012-06-11	2012-06-12	GF47	400	230.9	235.8	232.2	12.3	9,0
25	2012-06-11	2012-06-12	GF47	500	230.5	237.2	233.7	13,4	7,0
26	2012-06-11	2012-06-12	GF47	500	232.3	234.9	232.5	5,2	4,8
27	2012-06-11	2012-06-12	GF47	500	231.4	233.9	231.5	5,0	4,8

Appendix 5: Results for Ion Chromotography

Sample	Date of sample collection	Date of analysis	Ammonium conc [mmol/l]	Nitrate conc. [mmol/l]	Nitrite conc. [mmol/l]	TIN [mmol/l]	TIN [mg/l]	Phosphate conc. [mmol/l]
					Storm 1			
1	2012-04-10	2012-05-28	0.063	0.022	0.038	0.123	1.8	0
2	2012-04-10	2012-05-28	0.079	0.018	0.048	0.145	2.2	0
3	2012-04-10	2012-05-28	0.082	0.001	0.056	0.139	2.1	0
4	2012-04-10	2012-05-28	0.059	0.001	0.04	0.1	1.5	0
5	2012-04-10	2012-05-28	0.067	0.001	0.049	0.117	1.8	0
6	2012-04-10	2012-05-28	0.038	0.001	0.101	0.14	2.1	0
					Storm 2			
7	2012-04-23	2012-05-28	0.051	0.001	0.062	0.114	1.7	0
8	2012-04-23	2012-05-28	0.052	0.001	0.054	0.107	1.6	0
9	2012-04-23	2012-05-28	0.09	0.001	0.056	0.147	2.2	0
10	2012-04-23	2012-05-28	0.088	0.001	0.048	0.137	2.1	0
11	2012-04-23	2012-05-28	0.083	0.001	0.046	0.13	2.0	0
12	2012-04-23	2012-05-28	0.041	0	0.171	0.212	3.2	n.a.

Sample	Date of sample collection	Date of analysis	Ammonium conc [mmol/l]	Nitrate conc. [mmol/l]	Nitrite conc. [mmol/l]	TIN [mmol/l]	TIN [mg/l]	Phosphate conc. [mmol/l]
				Storm 3				
13	2012-05-09	2012-05-28	0.046	0.001	0.088	0.135	2.0	0
14	2012-05-10	2012-05-28	0.046	0	0.022	0.068	1.0	0
15	2012-05-10	2012-05-28	0.027	0.001	0.012	0.04	0.6	0
				Storm 4				
16	2012-05-10	2012-05-28	0.046	0	0.074	0.12	1.8	n.a.
17	2012-05-10	2012-05-28	0.148	0.001	0.071	0.22	3.3	0
18	2012-05-10	2012-05-28	0.093	0.001	0.046	0.14	2.1	0
19	2012-05-12	2012-05-28	0.058	0.001	0.033	0.092	1.4	0
20	2012-05-10	2012-05-28	0.081	0.001	0.073	0.155	2.3	0
21	2012-05-12	2012-05-28	0.035	0.001	0.017	0.053	0.8	0

Appendix 6: Pollutant characteristics for all storm events

Characteristics of storm event 1

	Sample	Description	Acc. flow [m^3]	Solids [mg/l]		Heavy metals [ug/l]									Nitrogen
				TSS	VS	Zn	Pb	Cd	Cu	Ni	Cr	Co	As	V	
Inlet	1	Bottle 1-8	1.5	606	98.5	680/95	31/0.15	0.34/0.07	120/11	23/2.8	30/0.36	13/0.98	2.9/0.12	43/0.71	1.8
	2	Bottle 8-16	3.1	60	9.8	93/41	2.4/0.18	0.21/0.1	21/12	3.7/1.8	3.2/0.42	1.4/0.38	0.34/0.12	4.6/0.84	2.2
	3	Bottle 16-24	3.6	28.7	7.0	44/38	0.63/0.17	0.08/0.05	14/0.36	2/1.7	0.91/0.59	0.45/0.36	0.14/0.13	1.5/0.96	2.1
Outlet	4	Bottle 1-6	13.7	139	30.2	180/81	6.4/0.26	0.25/0.2	32/7.9	12/8.4	6.4/0.41	2.9/0.62	0.77/0.13	8.8/0.43	1.5
	5	Bottle 7-13	22	68.0	18.0	89/55	2.7/0.18	0.1/0.08	17/7.8	5/3.8	3.1/0.42	1.2/0.08	0.31/0.1	3.7/0.5	1.8
	6	Bottle 14-20	24.6	41.3	10.7										2.1

Characteristics of storm event 2

	Sample	Description	Acc. flow [m³]	Solids [mg/l]		Heavy metals [ug/l]									Nitrogen
				TSS	VS	Zn	Pb	Cd	Cu	Ni	Cr	Co	As	V	
Inlet	7	Bottle 1-4	0.4	472	100	330/72	14/0.28	0.25/0.07	78/17	11/2.6	13/0.32	5.9/0.53	1.3/0.12	21/1.2	1.7
	8	Bottle 7-13	0.9	310	72	1300/160	62/0.31	1.1/0.09	280/14	40/2.3	52/0.32	24/0.39	4.2/0.09	92/1	1.6
	9	Bottle 14-24	1.2	173	42	160/47	6.1/0.29	0.39/0.12	50/18	5.8/2.2	5.4/0.32	2.6/0.3	0.54/0.1	9.4/1.2	2.2
Outlet	10	Bottle 1-10	4.2	10.6	3.6	84/83	0.6/0.38	0.21/0.53	25/26	11/12	0.53/0.46	0.51/0.53	0.22/0.23	0.7/0.54	2.1
	11	Bottle 11-18	12	34.8	9.5	61/62	0.7/0.46	0.17/0.19	22/22	6/5.9	0.94/0.71	0.34/0.27	0.16/0.12	1.2/0.77	2.0
	12	Bottle 18-20	17.1	23.6	7.6	59/53	0.6/0.25	0.15/0.18	15/12	5/4.7	0.63/0.33	0.32/0.22	0.13/0.1	1/0.44	3.2

Characteristics of storm event 3

	Sample	Description	Acc. flow [m^3]	Solids [mg/l]		Heavy metals [ug/l]									Nitrogen
				TSS	VS	Zn	Pb	Cd	Cu	Ni	Cr	Co	As	V	
Inlet	13	Bottle 1-19	11.2	124	25.7	120/56	3.4/0.16	0.16/0.11	64/42	4.5/2.6	3/0.47	1.5/0.35	0.54/0.27	6.9/2.5	2.0
Outlet	14	Bottle 1-3	60	14.1	10.1	39/24	1.4/0.32	0.16/0.13	14/9.9	3.2/2.5	1.2/0.5	0.42/0.14	0.15/0.07	2.4/1.2	1.0
	15	Bottle 4-9	140	7.7	6.9	27/19	1/0.43	0.12/0.13	12/10	2.3/2	0.84/0.44	0.28/0.09	0.2/0.1	1.8/0.9	0.6

Characteristics of storm event 4

	Sample	Description	Acc. flow [m^3]	Solids [mg/l]		Heavy metals [ug/l]									Nitrogen
				TSS	VS	Zn	Pb	Cd	Cu	Ni	Cr	Co	As	V	
Inlet	16	Bottle 1-6	0.4	67.8	22.7	97/36	3.7/0.12	0.11/0.07	40/24	3.9/1.8	3.5/0.62	1.5/0.24	0.36/0.1	5.7/1.3	1.8
	17	Bottle 7-11	0.9	61.2	19.0	83/26	0.38/0.3	0.12/0.09	29/0.6	3.6/1.7	3.4/0.6	1.5/0.15	0.36/0.07	5.1/0.85	3.3
	18	Bottle 12-17	1.2	93.0	24.1	110/24	5/0.16	2.3/0.05	34/9.5	5/1.6	6.1/1.1	2.1/0.14	0.58/0.04	7.6/0.54	2.1
	19	Bottle 1-3	4.2	55.2	15.8	57/28	2.4/0.47	0.13/0.11	11/4.1	2/0.9	3/1.4	0.79/0.12	0.24/0.06	3.1/0.53	1.4
Outlet	20	Bottle 8-11	77.9	17.1	9.1	33/17	1.7/0.52	0.09/0.07	16/9.6	2.5/1.9	1.4/0.63	0.45/0.1	0.17/0.06	2.1/0.69	2.3
	21	Bottle 1-5	178.3	17.9	8.5	37/32	0.97/0.53	0.09/0.1	14/13	2.3/2.1	1/0.6	0.32/0.11	0.24/0.19	1.5/0.76	0.8

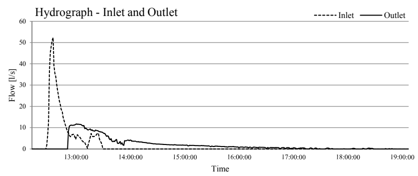
Characteristics of storm event 5

	Sample	Description	Acc. flow [m³]	Solids [mg/l]		Heavy metals [ug/l]								
				TSS	VS	Zn	Pb	Cd	Cu	Ni	Cr	Co	As	V
Inlet	22	Bottle 1-4	2.7	50.8	19,6	84/34	3.1/0.22	0.11/0.06	19/8.6	3.5/2.2	2.6/0.82	1.1/0.22	0.31/0.09	6.4/2.7
	23	Bottle 5-7	4.3	21.1	10,6	29/22	0.66/0.13	0.05/0.04	11/8.5	1.9/1.6	1.1/0.75	0.24/0.09	0.11/0.06	2.7/2
	24	Bottle 8-10	6.0	12.3	9,0	47/31	1/0.18	0.04/0.05	16/13	2.5/2.1	1.3/0.71	0.42/0.17	0.15/0.09	3.4/2.3
Outlet	25	Bottle 1-6	12.6	13,4	7,0	43/29	1.1/0.21	0.1/0.12	25/19	5.5/4.7	1.5/0.56	0.53/0.12	0.25/0.14	3.2/1.9
	26	Bottle 7-13	26.8	5,2	4,8	30/20	0.59/0.12	0.12/0.12	15/12	2.8/2.4	0.88/0.52	0.21/0.06	0.14/0.09	2.3/1.7
	27	Bottle 14-20	40.0	5,0	4,8	38/31	0.88/0.43	0.11/0.1	18/15	4.9/4.5	1.1/0.61	0.21/0.09	0.17/0.12	2.2/16

Appendix 7 – Cumulative Pollution Graphs

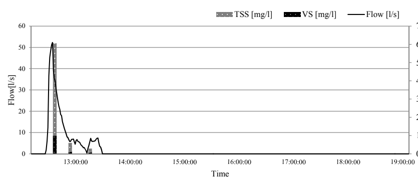
Rain Event 1

Hydrograph - inlet and outlet

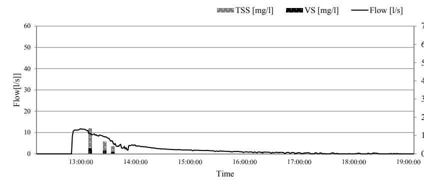


Cumulative pollution, TSS and VS

Inlet

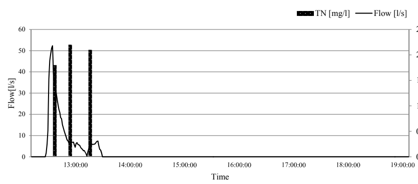


Outlet

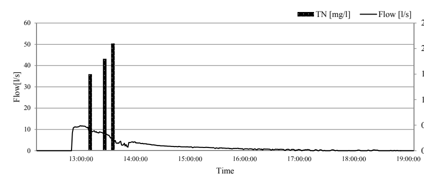


Cumulative pollution, TN

Inlet



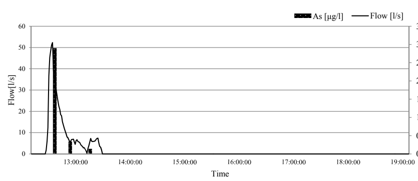
Outlet



Cumulative pollution, Metals

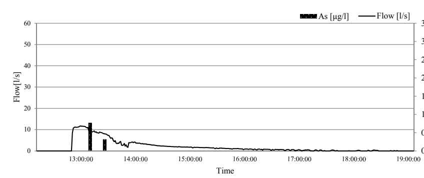
Inlet

As



Outlet

As



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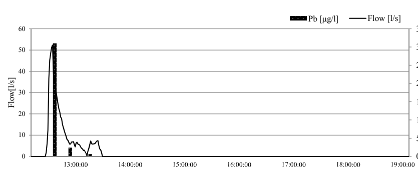

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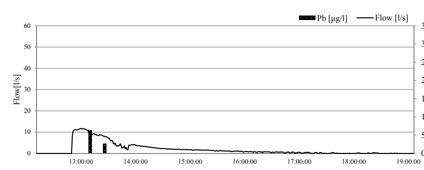
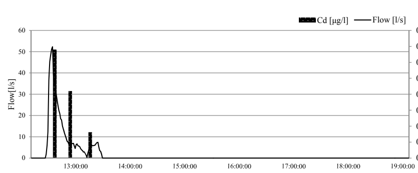


Cd



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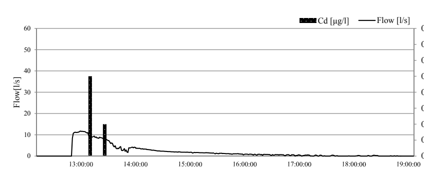
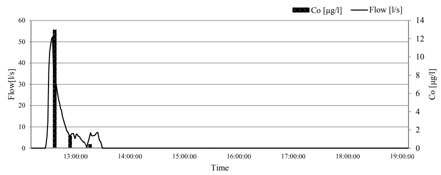


Appendix 7 – Cumulative Pollution Graphs

Co



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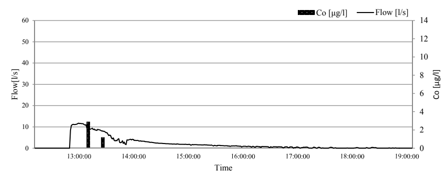

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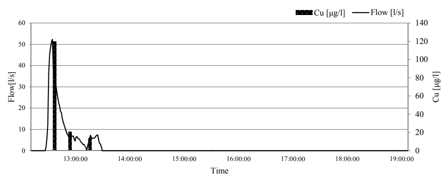

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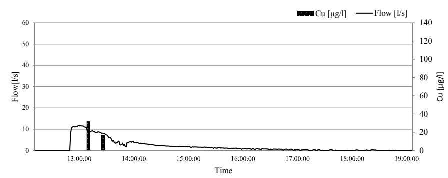

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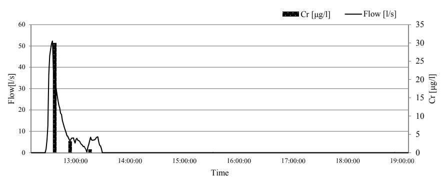

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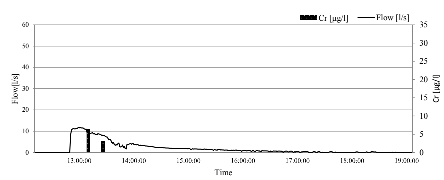
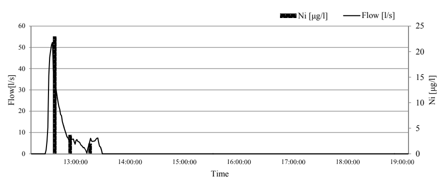


Ni



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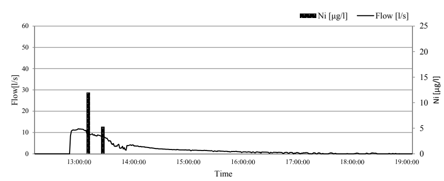

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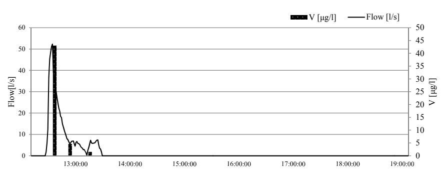

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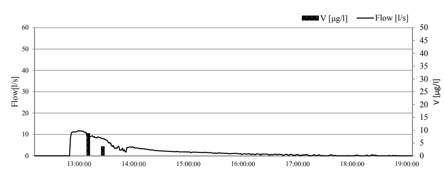

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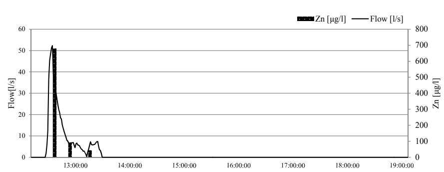

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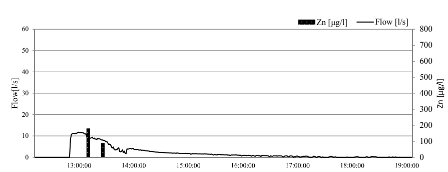
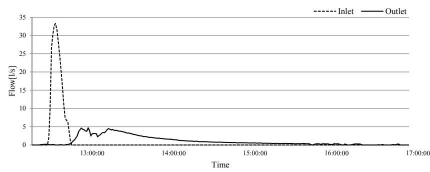


Appendix 7 – Cumulative Pollution Graphs

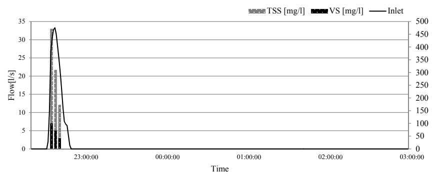
Rain Event 2

Hydrograph - inlet and outlet

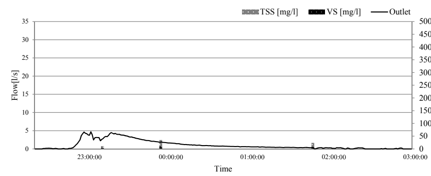


Cumulative pollution, TSS and VS

Inlet

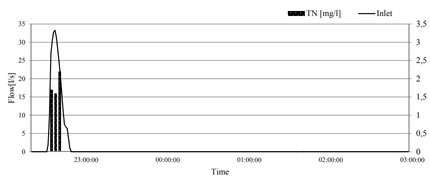


Outlet

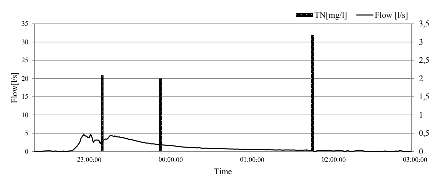


Cumulative pollution, TN

Inlet



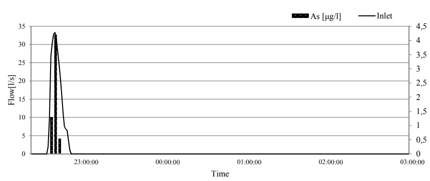
Outlet



Cumulative pollution, Metals

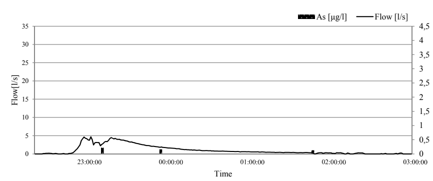
Inlet

As



Outlet

As



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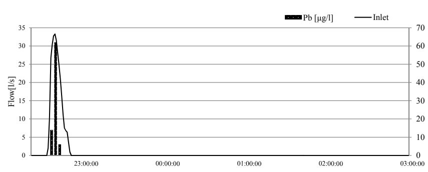

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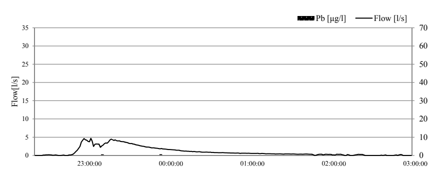

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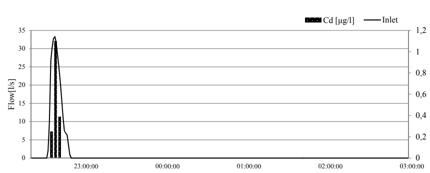

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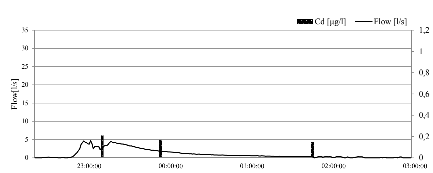
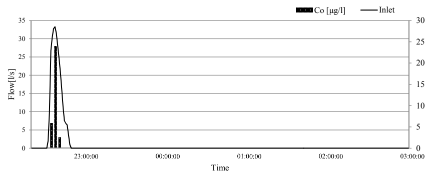


Appendix 7 – Cumulative Pollution Graphs

Co



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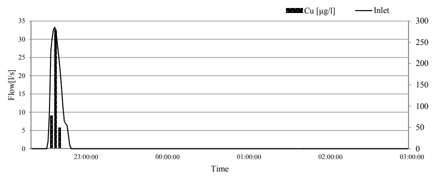
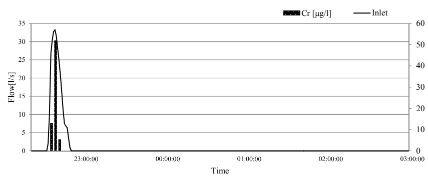


Cr



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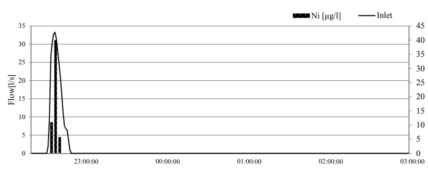

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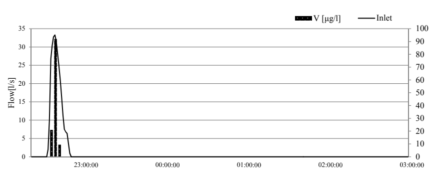

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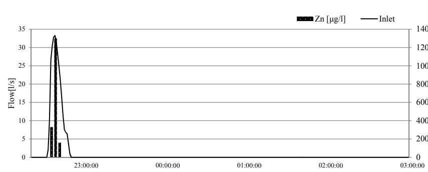

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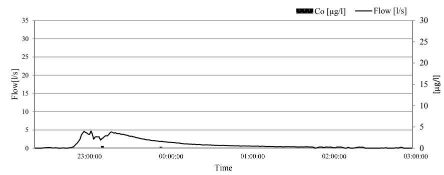

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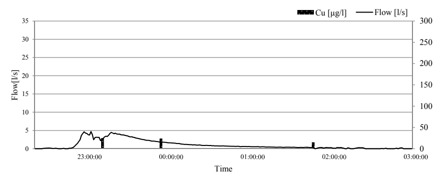

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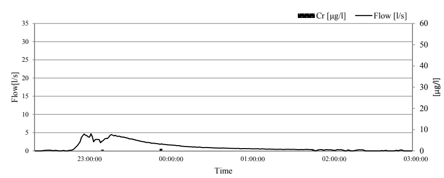

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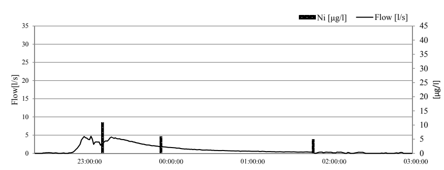

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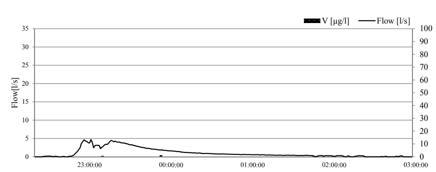

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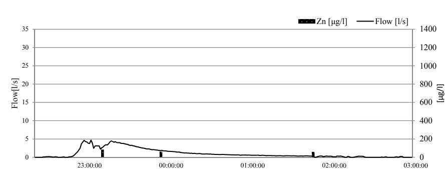
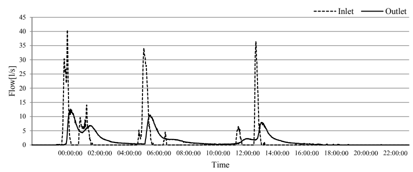


Appendix 7 – Cumulative Pollution Graphs

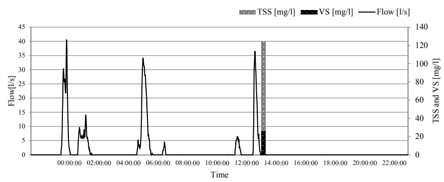
Rain Event 3

Hydrograph - inlet and outlet

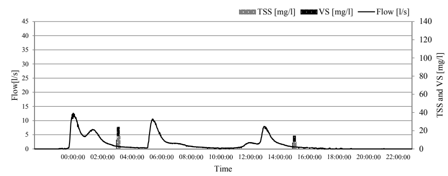


Cumulative pollution, TSS and VS

Inlet

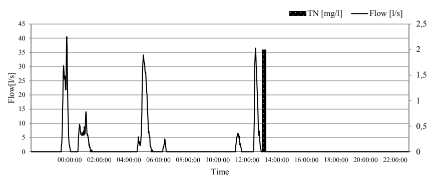


Outlet

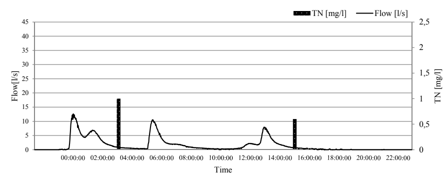


Cumulative pollution, TN

Inlet



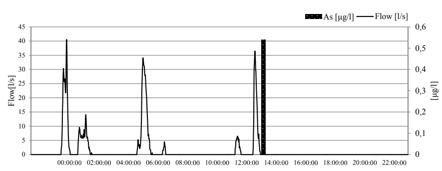
Outlet



Cumulative pollution, Metals

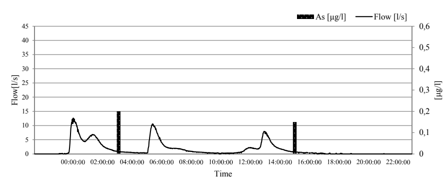
Inlet

As

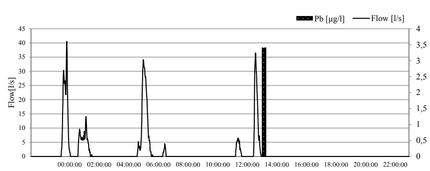


Outlet

As



Pb



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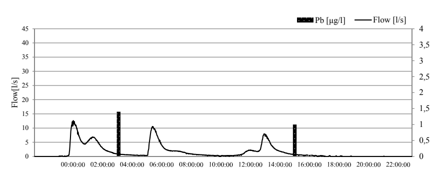

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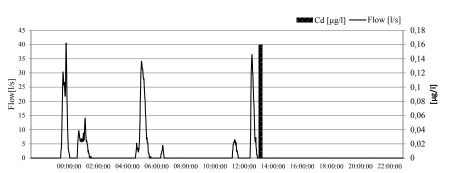

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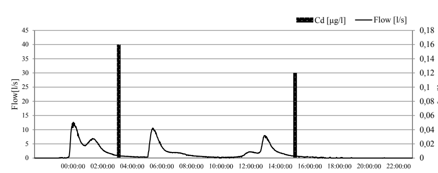
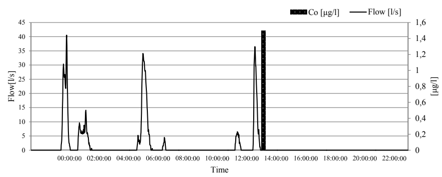


Appendix 7 – Cumulative Pollution Graphs

Co



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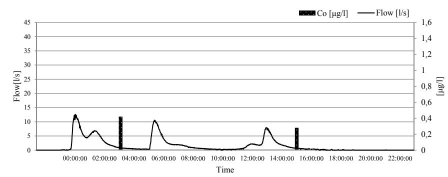

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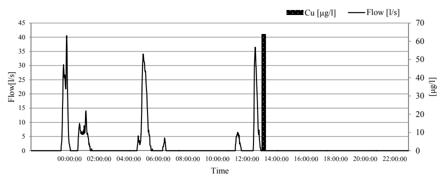

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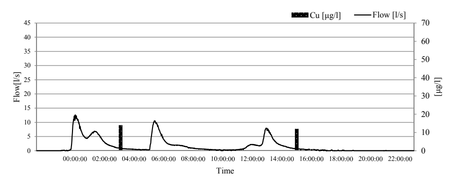

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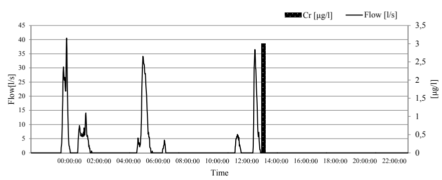

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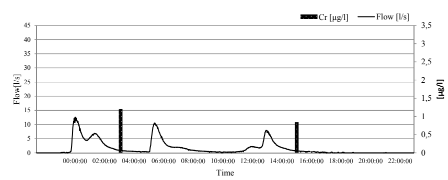
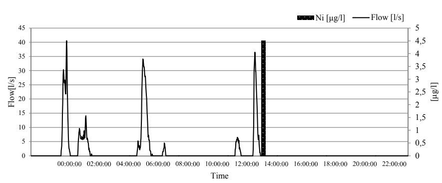
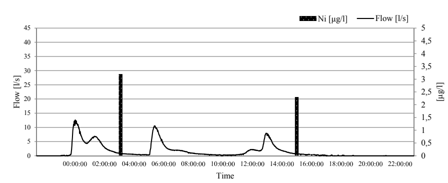


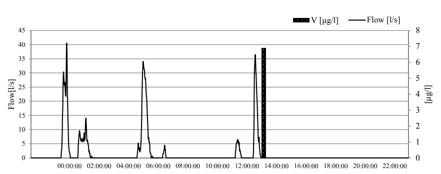
Ni



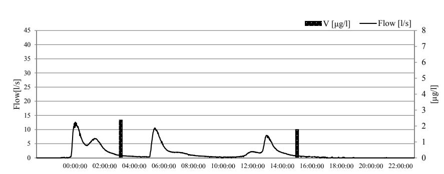
Ni



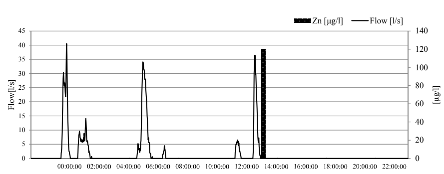
V



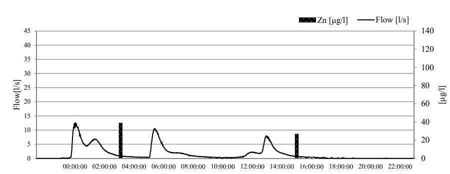
V



Zn



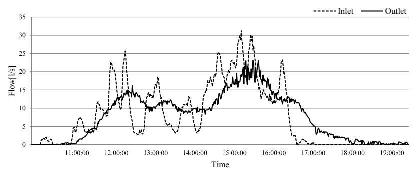
Zn



Appendix 7 – Cumulative Pollution Graphs

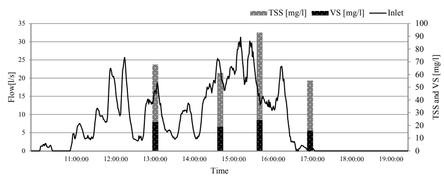
Rain Event 4

Hydrograph - inlet and outlet

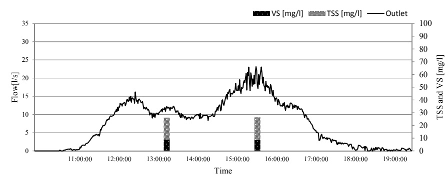


Cumulative pollution, TSS and VS

Inlet

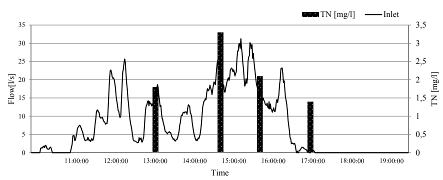


Outlet

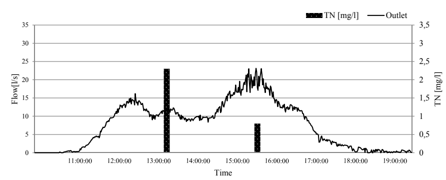


Cumulative pollution, TN

Inlet



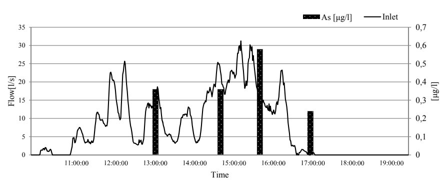
Outlet



Cumulative pollution, Metals

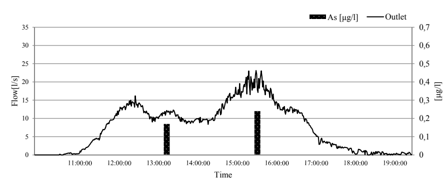
Inlet

As

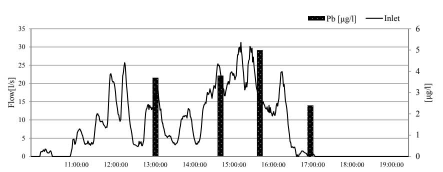


Outlet

As



Pb



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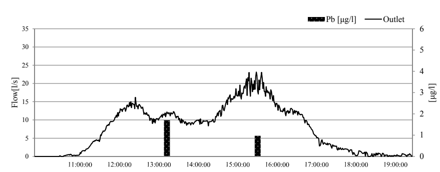
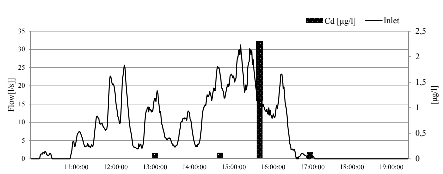
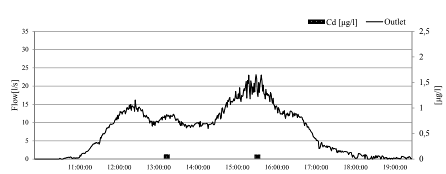


Cd

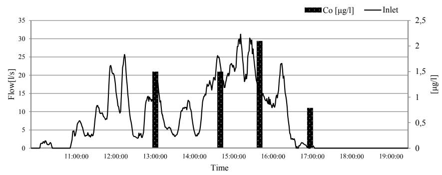


Cd

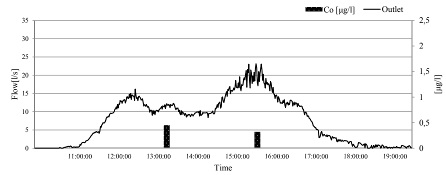


Appendix 7 – Cumulative Pollution Graphs

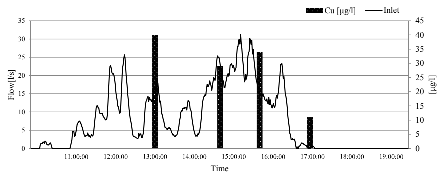
Co



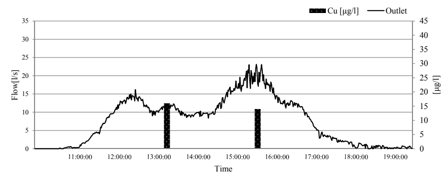
Co



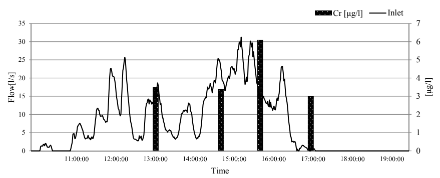
Cu



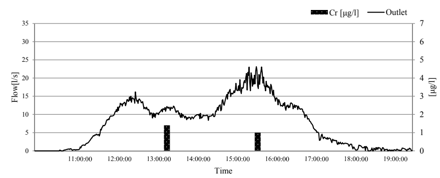
Cu



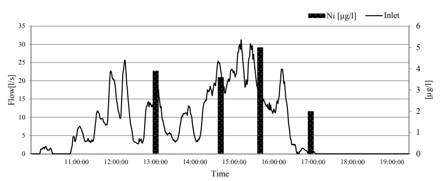
Cr



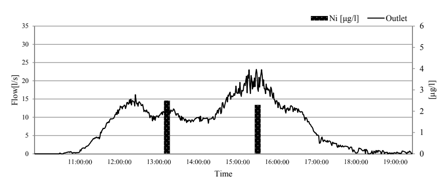
Cr



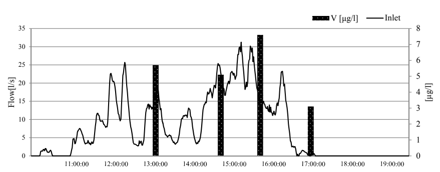
Ni



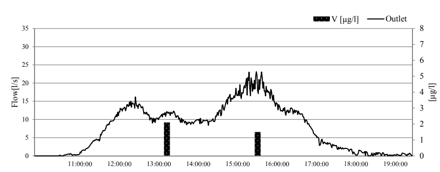
Ni



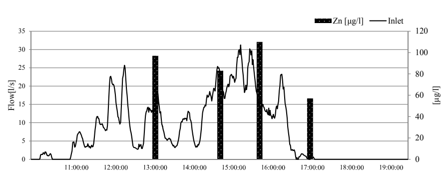
V



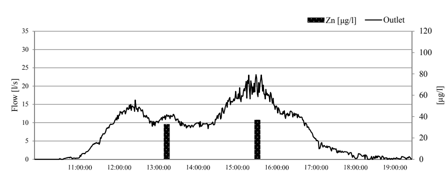
V



Zn



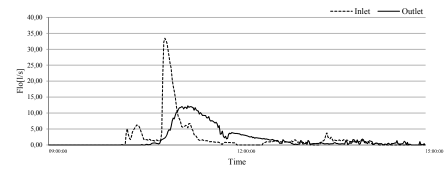
Zn



Appendix 7 – Cumulative Pollution Graphs

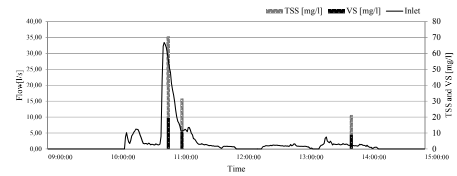
Rain Event 5

Hydrograph - inlet and outlet

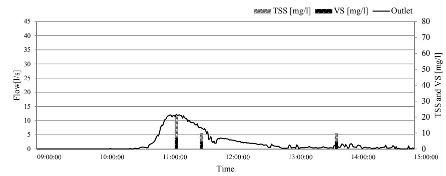


Cumulative pollution, TSS and VS

Inlet



Outlet



Cumulative pollution, TN

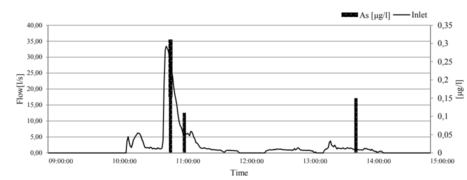
Inlet

Outlet

Cumulative pollution, Metals

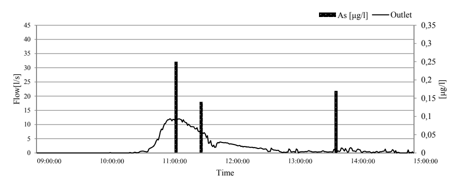
Inlet

As

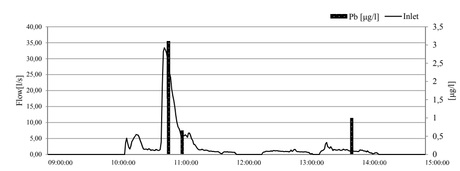


Outlet

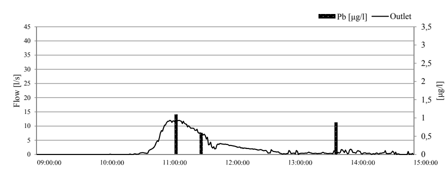
As



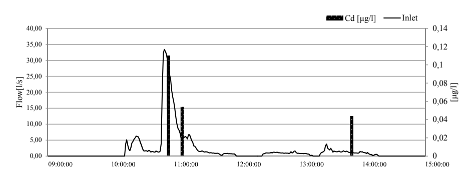
Pb



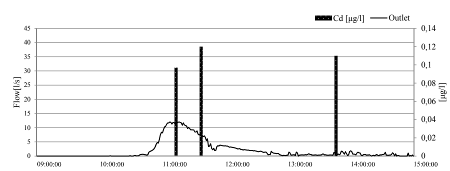
Pb



Cd

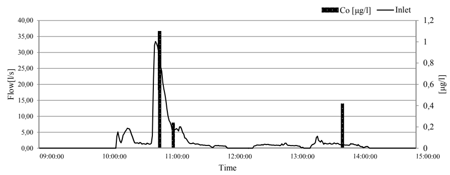


Cd

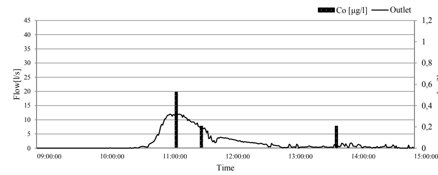


Appendix 7 – Cumulative Pollution Graphs

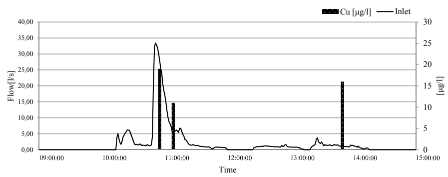
Co



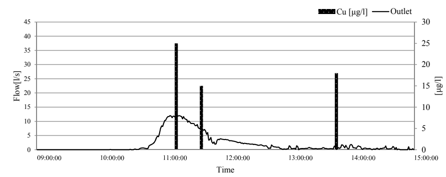
Co



Cu



Cu



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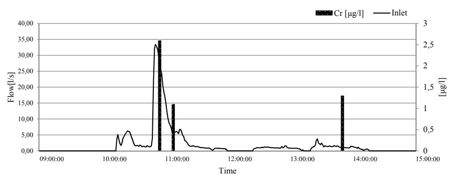

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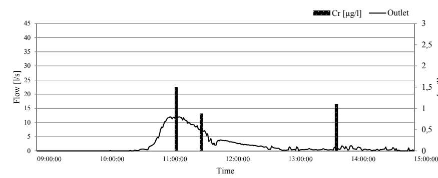
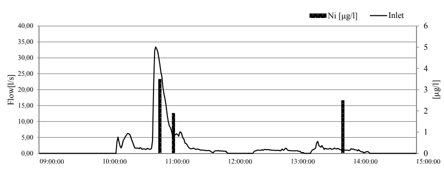
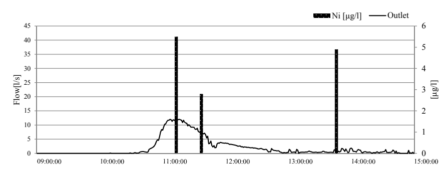


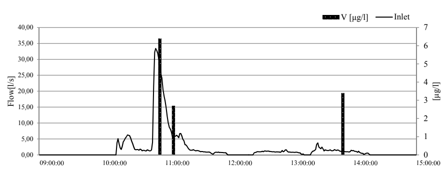
Ni



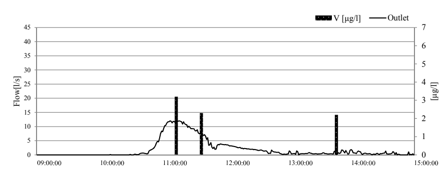
Ni



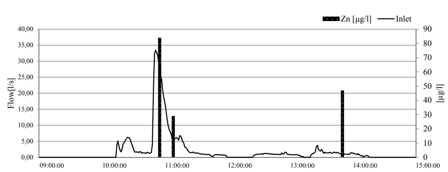
V



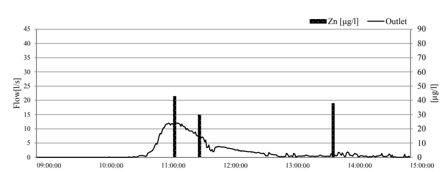
V



Zn

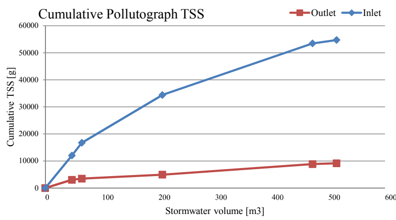


Zn

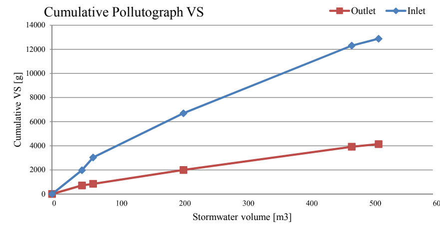


Appendix 8 – Accumulated Pollutant Graphs

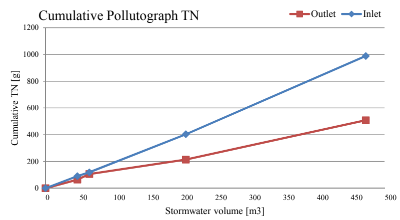
TSS



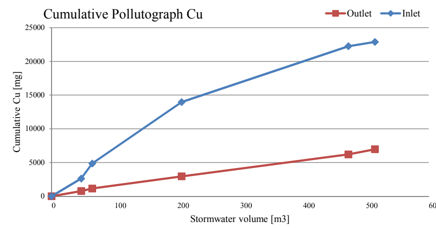
VS



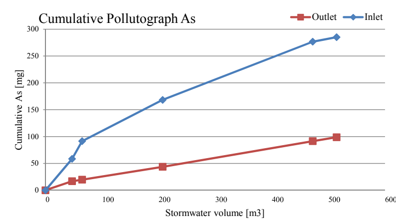
TN



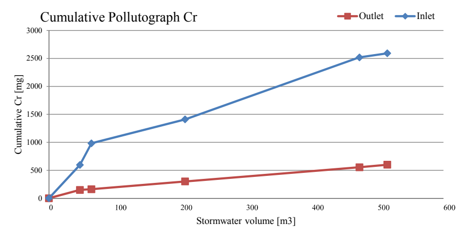
Cu



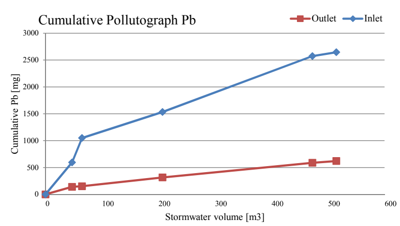
As



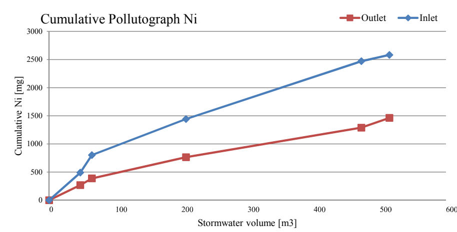
Cr



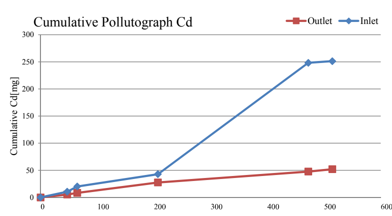
Pb



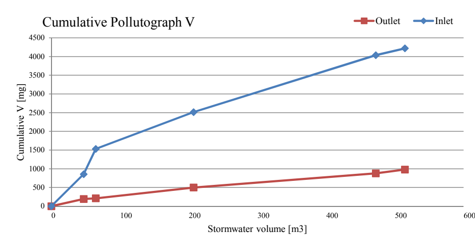
Ni



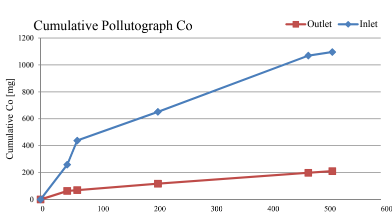
Cd



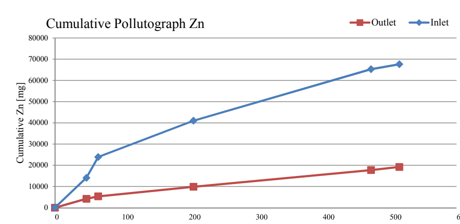
V



Co



Zn



Appendix 9: Results for EMC and Cumulative Pollutant Calculations

Storm 1

Parameter	EMC inlet [mg/l]	EMC outlet [mg/l]	M-Pollutant inlet [mg]	M-Pollutant outlet [mg]	Reduction [%]
TSS	255	45.9	12028694	3051213	75
VS	41.9	10.2	1973964	712049	64
TN	1.92	0.9	90590	64532	29
Zn (total)	298.99	68.2	14077005	4211557	70
Zn (dissolved)	58.61	33.3	2759473	2187330	21
As (total)	1.24	0.3	58571	16830	71
As (dissolved)	0.12	0.1	5453	3740	31
Pb (total)	12.65	2.3	595619	140669	77
Pb (dissolved)	0.16	0.1	7445	7089	5
Cd (total)	0.23	0.1	10612	5388	49
Cd (dissolved)	0.07	0.1	3516	4271	-22
Co (total)	5.50	1.1	258742	63283	76
Co (dissolved	0.58	0.3	27390	16332	40
Cu (total)	55.70	12.3	2622510	771736	71
Cu (dissolved)	10.29	3.7	484547	260929	46
Cr (total)	12.65	2.4	595449	148485	75
Cr (dissolved)	0.41	0.2	19153	13839	27
Ni (total)	10.43	4.4	490842	268395	45
Ni (dissolved)	2.07	3.1	97307	189635	-95
V (total)	18.17	3.2	855353	193175	77
V (dissolved)	0.77	0.2	36302	15677	57

Storm 2

Parameter	EMC inlet [mg/l]	EMC outlet [mg/l]	M-Pollutant inlet [mg]	M-Pollutant outlet [mg]	Reduction [%]
TSS	267	25.2	4699429	442710	91
VS	60	7.4	1060609	130029	88
TIN	2	2.4	28245	41431	-46.7
Zn (total)	560	65.0	9836035	1142558	88.4
Zn (dissolved)	50.67	63.4	890597	1114525	-25.1
As (total)	2	0.2	32871	2865	91.3
As (dissolved)	0.09	0.1	1557	2406	-54.6
Pb (total)	26	0.6	453664	10857	97.6
Pb (dissolved)	0.26	0.4	4535	6529	-44.0
Cd (total)	1	0.2	9572	3007	68.6
Cd (dissolved)	0.08	0.2	1437	3449	-139.9
Co (total)	10	0.4	178887	6496	96.4
Co (dissolved	0.35	0.3	6092	5499	9.7
Cu (total)	127	21.2	2230833	372543	83.3
Cu (dissolved)	14.18	19.6	249219	345086	-38.5
Cr (total)	22	0.7	387231	12945	96.7
Cr (dissolved)	0.28	0.5	4920	9254	-88.1
Ni (total)	18	6.8	310871	119540	61.5
Ni (dissolved)	2.05	6.9	36069	121332	-236.4
V (total)	38	1.0	675990	17677	88.4
V (dissolved)	0.98	0.6	17281	10642	38.4

Storm 3

Parameter	EMC inlet [mg/l]	EMC outlet [mg/l]	M-Pollutant inlet [mg]	M-Pollutant outlet [mg]	Reduction [%]
TSS	124	10.4	17669783	1458809	91.7
VS	25.7	8.11	3663016	1154645	68.5
TIN	2.0	0.76	284690	108033	62.1
Zn (total)	120.0	31.62	17081423	4501198	73.6
Zn (dissolved)	56.0	20.8	7971331	2960688	62.9
As (total)	0.54	0.17	76866	24006	68.8
As (dissolved)	0.27	0.08	38433	11203	70.9
Pb (total)	3.40	1.15	483974	164042	66.1
Pb (dissolved)	0.16	0.38	22775	53606	-135.4
Cd (total)	0.16	0.13	22775	19205	15.7
Cd (dissolved)	0.11	0.13	15658	18203	-16.3
Co (total)	1.50	0.33	213518	47613	77.7
Co (dissolved	0.35	0.11	49821	15764	68.4
Cu (total)	64.00	12.65	9110092	1800383	80.2
Cu (dissolved)	42.00	9.79	5978498	1394240	76.7
Cr (total)	3.00	0.98	427036	139237	67.4
Cr (dissolved)	0.47	0.46	66902	65213	2.5
Ni (total)	4.50	2.64	640553	376097	41.3
Ni (dissolved)	2.60	2.18	370098	310071	16.2
V (total)	6.90	2.02	982182	288071	70.7
V (dissolved)	2.50	1.01	355863	144035	59.5

Storm 4

Parameter	EMC inlet [mg/l]	EMC outlet [mg/l]	M-Pollutant inlet [mg]	M-Pollutant outlet [mg]	Reduction [%]
TSS	71.9	14.7	19062393	3899553	79.5
VS	21.2	7.26	5612437	1924265	65.7
TIN	2.20	1.11	584910	294358	49.7
Zn (total)	92	29.8	24280284	7892857	67.5
Zn (dissolved)	28.7	22.3	7616310	5926417	22.2
As (total)	0.41	0.2	108350	47762	55.9
As (dissolved)	0.1	0.1	17495	31606	-80.7
Pb (total)	3.9	1.0	1040973	272017	73.9
Pb (dissolved)	0.2	0.4	60456	116748	-93.1
Cd (total)	0.8	0.1	205279	20126	90.2
Cd (dissolved)	0.1	0.1	19817	20082	-1.3
Co (total)	1.6	0.3	418075	81096	80.6
Co (dissolved	0.2	0.1	45057	23535	47.8
Cu (total)	31	12.3	8276681	3260442	60.6
Cu (dissolved)	14.2	9.9	3774940	2617644	30.7
Cr (total)	4.2	1.0	1109363	252939	77.2
Cr (dissolved)	0.9	0.5	231522	135389	41.5
Ni (total)	3.9	2.0	1028368	525619	48.9
Ni (dissolved)	1.6	1.7	419836	450080	-7.2
V (total)	5.7	1.4	1522474	379408	75.1
V (dissolved)	0.8	0.6	224482	163072	27.4

Storm 5

Parameter	EMC inlet [mg/l]	EMC outlet [mg/l]	M-Pollutant inlet [mg]	M-Pollutant outlet [mg]	Reduction [%]
TSS	30	7.2	1264808	302986	76.0
VS	13	5.2	568961	218292	61.6
TIN					
Zn (total)	55.30	34.6	2343191	1464437	37.5
Zn (dissolved)	16.2	25.0	684802	1057496	-54.4
As (total)	0.20	0.2	8400	7321	12.8
As (dissolved)	0.08	0.1	3274	4577	-39.8
Pb (total)	1.71	0.8	72668	33636	53.7
Pb (dissolved)	0.18	0.2	7474	10099	-35.1
Cd (total)	0.07	0.1	3049	4393	-44.1
Cd (dissolved)	0.05	0.1	2056	3415	-66.1
Co (total)	0.63	0.3	26643	12213	54.2
Co (dissolved	0.16	0.1	6897	3622	47.5
Cu (total)	15.30	17.9	648232	760245	-17.3
Cu (dissolved)	9.57	14.3	405304	604472	-49.1
Cr (total)	1.72	1.1	73084	45598	37.6
Cr (dissolved)	0.74	0.5	31515	22514	28.6
Ni (total)	2.65	4.1	112485	172821	-53.6
Ni (dissolved)	1.93	3.6	81966	152051	-85.5
V (total)	4.30	2.4	182226	101400	44.4
V (dissolved)	2.31	1.6	97678	69055	29.3