Environmental assessment and sustainable stormwater planning with regard to climate change through multi-criteria analysis (MCA)

– Case study Guldheden

Master’s Thesis in the Master’s programme Industrial Ecology

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Department of Civil and Environmental Engineering
Division of GeoEngineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Chalmer reproservice
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SUMMARY

Stormwater connected to the combined drainage system in Gothenburg are today putting a lot unnecessary pressure on the WWTP (Ryaverket). The future urban expansion of the city and the effects of climate change are predicted to further increase this pressure through changed increased urban stormwater runoff that contains more pollutants than today. The city of Gothenburg has set up some goals with regard to sustainable wastewater management that involves disconnecting areas that uses the old combined drainage system and continuously work to improve the wastewater quality.

This master thesis study aims at contributing to the research done on sustainable stormwater solutions within urban areas (Gothenburg) through multi-criteria analysis (MCA). The purpose was to design a method that evaluates stormwater solutions with regard to environmental-, social- and economic criteria. Two different time scenarios were investigated: short time (<2020) and long time (<2100) in order to evaluate the present and future impact (i.e. with respect to climate change) with regard to both the local- and regional scale. The study area is located in Guldheden (Gothenburg). Two stormwater solutions (i.e. dry pond and macadam basin) was investigated and compared to the present urban drainage system (i.e. the combined system). Stakeholder interviews with experts from a variety of different fields were conducted as a part of the MCA (i.e. MCA2) and compared to the analyst own MCA (i.e. MCA1).

The result showed that the dry pond was the best choice (the final conclusion were the same for both MCA1 and MCA2). Although some variations did occur in the final weighted ranking for the other two options (when MCA1 was compared to MCA2) the macadam basin was ranked the second best choice and keeping the present system (i.e. the combined system) was the least preferred option.

This master thesis study was conducted at COWI AB in close collaboration with Gryaab AB and Kretslopp och Vatten in Gothenburg.

Keywords: multicriteria analysis (MCA), urban stormwater, dry pond, macadam basin, sustainable stormwater management, pollutant removal, combined urban drainage system, urban climate change.

Miljöutvärdering av hållbar dagvattenplanering med hänsyn till klimatförändringar genom multikriterieanalys (MKA)
- Fallstudie Guldheden
Examensarbete inom Industriell Ekologi
NATHALIE BERGQVIST
Institutionen för bygg- och miljöteknik
Avdelningen för geologi och geoteknik
Chalmers tekniska högskola

SAMMANFATTNING

Dagvatten och dränvatten som är påkopplat det kombinerade systemet orsakar idag onödig belastning på avloppsreningsverket (dvs. Ryaverket) i Göteborg. Den förväntade urbana expansionen av Göteborg stad i combination med de framtida effekterna av klimat förändringar förväntas att ytterligare öka belastningen genom ökad dag- och dränvatten avrinning som innehåller mer föroreningar än idag. Göteborg stad har tagit fram mål med hänsyn till hållbar avloppshantering som involverar att gradvis koppla bort områden som använder det kombinerade systemet och kontinuerligt jobba med att förbättra avloppsvattnets kvalité.

Det här mastersexamensarbetet har som mål att bidra till forskningen på hållbara dagvatten lösningar inom urban miljöer (dvs. Göteborg) genom multi-kriteria analys (MKA). Målet var att ta fram en metod som utvärderar dagvatten lösningar med hänsyn till miljö-, sociala och ekonomiska kriterier. Två olika tidscenarion undersöktes: kort tidsperspektiv (<2020) och lång tidperspektiv (<2100) med syftet att utvärdera den nuvarande och framtida (med hänsyn till klimat förändringar) påverkan med hänsyn till både lokal- och regional skala. Studieområdet ligger i Guldheden (Göteborg). Två dagvatten lösningar (dvs. torr damm och perkoloationsmagasin) undersöktes och jämfördes med det nuvarande avloppssystemet på plats (dvs. det kombinerade systemet). Interjuver med experter från en rad olika bakgrunder genomfördes som en del i MKA (dvs. MCA2) och jämfördes med analytikerns egen MKA (dvs. MCA1).

Resultatet visade att torr dammen var det bästa valet (den slutgiltiga bedömningen var densamma för både MCA1 och MCA2). Variationer i slutrankning förekom mellan de andra två alternativen (när resultatet från MCA1 jämfördes med MCA2) men det viktade slutresultatet visade att perkolationsmagasinet var det näst bästa alternativet och att behålla det nuvarande systemet (dvs. det kombinerade systemet) var det minst föredragna lösningen.

Det här mastersexamensarbetet genomfördes på COWI AB med nära samarbete med Gryaab AB och Kretslopp och Vatten i Göteborg.

Nyckelord: multi-kriteria analys (MKA), urban dagvatten hantering, hållbar vattenplanering, föroreningstransport, kombinerat avloppssystem, urbana klimatförändringar.

TABLE OF CONTENTS

PREFACE

This master thesis was initiated by COWI AB (Gothenburg) and carried out by Nathalie Bergqvist from January to August 2014 at the Department of Civil and Environmental Engineering, Division of Geoengineering at Chalmers University of Technology, Sweden.

First of all I would like to thank my supervisors, Yvonne Andersson-Sköld and Helena Frohm at COWI AB and Andreas Lindhe at Chalmers University of Technology for all your amazing support and feedback during this master thesis project. Your help has been indispensible for me.

Second, I would also like to thank the members of my stakeholder group; David I`Ons (Gryaab) and Helen Ander (Kretslopp och Vatten) for their input, feedback and assistance during this thesis project. I would also like to thank Fredrik Bähr (COWI AB) for his help with Bidcon.

Third, I would like to thank all the persons that agreed to sit down and do an interview with me as part of this thesis project: Anna-Karin Nilsson, Lena Blom, Annika Malm, Ingela Gustafsson, Niklas Blomkvist, Håkan Strander, Thomas Pettersson, Ann Mattsson, Jenny Lindh, Mikael Bengtsson, Stefan B Andersson, Ronnie Ljung and John Thulin.

Finally I would like to express my gratitude towards the co-workers at COWI AB (Gothenburg) for making me feel welcome and as a part of the team during my stay at the company.

Gothenburg, August 2014
Nathalie Bergqvist

ABBREVATIONS

BAU	Business as Usual
CSO	Combined Sewer Overflows

PART 1 – INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

Urban drainage systems are responsible for collecting and transporting storm- and wastewater away from city areas and are a vital part of urban infrastructure (Zhou, 2014). The development of urban areas has altered the natural water cycle by exploiting natural land and replacing it with artificial structures and impervious surfaces. This action has resulted in an increased urban surface water runoff (in relation to natural land infiltration) that the urban drainage system has to deal with (Butler and Davies, 2004). Urban areas generate waste and surface water that comes into contact with different urban surfaces, such as roads, rooftops and buildings will absorb and transport the contaminants downstream down into the urban drainage system. Stormwater is therefore closely connected to both environmental status and human health aspects in urban environments (Barbosa et al, 2012). In addition to this, urbanization is expected to put additional pressure on urban drainage systems in the nearby future (Zhou, 2014).

In the western part of Sweden, climate change is predicted to cause an impact on the urban environment through seasonal changes in water flow and precipitation (Länsstyrelsen Västra Götalands Län, 2011). Climate model simulations suggest a higher stormwater runoff flow as a direct result of the effects of global warming. The design and implementation of the current urban drainage system was based on climate- and population statistics that now are outdated and no longer can be used as a basis for decision-making (Mailhot *et al*, 2010). Climate change will result in more pressure being put on the urban drainage system and it is therefore very important that governmental institutions include the long-term effects of climate change into the urban waste- and stormwater management (Olsson *et al*, 2009). In Sweden, the combined urban drainage system have been identified as being extra vulnerable to the effects of climate change and more investigations are required in order to ensure its functionality in the future (Svenskt Vatten 2011, Stahre 2004). One way to do this is to focus on sustainable storm- and wastewater management.

Sustainable stormwater management has received a lot of attention in Sweden during the last 20 years. Within city planning, sustainable drainage systems (including local stormwater management, LOD) has developed from the old traditional way of just considering technical aspects to include a variety of aspects such as social, ecological and economic values (Stahre, 2004). The need for continuous adaption of the urban drainage system in order to avoid problems such as combined sewer overflows (i.e. CSOs) and flooding downstreams, are gaining more attention than ever before in society. Sustainable stormwater management has the potential to provide additional positive effects on water quality and re-creational values in urban areas (Zhou, 2014). However there are only a few studies at present that covers the evaluation of environmental and social impacts of sustainable drainage systems. The evaluation of stormwater management is a rather complex process that includes a variety of different aspects which tend to complicate studies since there are not many tools available for sustainability assessment that can handle this amount of input data (Ludiza e al, 2014). Additional investigations are therefore required.

One tool that is commonly used for sustainability assessment is multi-criteria analysis (MCA) where a range of different aspects can be taken into account in order to solve complex problems. MCA is often used as basis for governmental decision-making and is easily communicated to different stakeholder groups in society (DLGC, 2009). It is therefore a good tool to use when evaluating sustainable stormwater solutions for a specific site.

1.2 BACKGROUND

Combined urban drainage systems are a commonly used in Sweden today as a mean for collecting and transporting both storm- and wastewater in the same pipeline to the local WWTP (Svenskt Vatten, 2007). In Gothenburg the combined drainage system were favored up until the 1950s and are consequently present in the older parts of the city (Gryaab, 2013). However, despite its many limitations the combined system is still in operation today (due to economic considerations) even though it is responsible for adding a lot of unnecessary pressure on the WWTP (i.e. Ryaverket). The city estimated in 2010 that about 54% of all the wastewater transported to the WWTP (Ryaverket) originated from stormwater (including drain water) and pipe infiltration (Göteborg stad, 2010). This means that there is a lot of excessive water being transported to the WWTP (i.e. Ryaverket) in Gothenburg that, besides taking up governmental resources unnecessary, contributes to problems such as flooding and CSOs downstream (Stahre, 2004). One way to solve this problem is to apply stormwater solutions on site in order to delay (or re-direct) the stormwater locally in order to increase the capacity of the WWTP. When evaluating sustainable stormwater solutions, long term effect (such as climate change) are important to take into account.

This study focus on the urban area of Guldheden in Gothenburg city (Sweden) that today is dominated by the combined urban drainage system. The study site is the park area beside Sister Ainas Street, located approximately 2-3 km from the city center. See figure 1a below for the location of Gothenburg city in Sweden and figure 1b for the study site in Guldheden.

Figure 1a: Location of Gothenburg City within Sweden (Lantmäteriet, 2014).
Figure 2b: Park area beside Sister Ainas Street in Guldheden, photo taken by the author (Bergqvist, 2014).

1.3 AIM OF THE STUDY

This master thesis aims at contributing to the research done on sustainable stormwater solutions within Gothenburg through multi-criteria analysis (MCA). The purpose was to design a method based on MCA that could be applied for evaluation of stormwater solutions, with respect to different time scales. The focus was on identifying suitable stormwater solutions that were evaluated based on environmental, social and economic criteria (i.e. criteria for sustainable development) that could be implemented on the study area Guldheden within Gothenburg city. Two different stormwater options and were evaluated and compared to the current combined system (i.e. BAU scenario) with regard to two time scales: short term (<2020) and long term (<2100) with respect to climate change.

Interviews with different stakeholders were conducted in order to complement the results of the MCA done by the author. A sensitivity analysis was conducted in order to evaluate the results and to what extent different criteria influence the final outcome of the MCA.
This master thesis evaluates the impact on the WWTP in Gothenburg (i.e. Ryaverket) with respect to the chosen stormwater solutions. The goal is to evaluate how different solutions affect the WWTP and the local conditions on site from a sustainable perspective.

1.4 METHODOLOGY

This master thesis consists of a literature study and a multi-criteria analysis (MCA) that was performed by the author in combination with 13 stakeholder interviews conducted during May and June 2014. The literature study provided background knowledge of (for example) urban stormwater characteristics and treatment facilities, the wastewater drainage system in Gothenburg, climate change and the procedure of an MCA.

Background stormwater calculations with regard to the two stormwater solutions (i.e. dry pond and macadam basin) were performed at COWI AB with the assistance of Helena Frohm. Economic calculations of the two stormwater solutions were done through the software programme Bidcon with the assistance of Fredrik Bähr.

As part of this master thesis, regular meetings with stakeholders from Gryaab AB, Kretslopp & Vatten, COWI AB and Chalmers University of Technology (i.e. the stakeholder group GKCC) took place in order to identify suitable candidates for interviews as part of the MCA and to evaluate suitable criteria that highlighted the goal and objectives of the study.
The MCA calculations were done in Excel (2007) and the results were illustrated in graphs. Furthermore, a sensitivity analysis was performed in order to evaluate the results further.

1.4.1 Data collection

Data was collected through scientific articles and literature, books, governmental institution internet pages and through interviews with selected stakeholders in Gothenburg. Gryaab provided data with regard to Ryaverket and Kretslopp och Vatten provided data with regard to the combined system at the study site in Guldheden.

1.5 DELIMITATIONS

The results from this master thesis study is based on the knowledge and experience of the stakeholders that were interviewed and the scientific information collected by the author. Even though the stakeholder group GKCC did its best to identify suitable candidates (for interviews) from a variety of different fields (i.e. such as wastewater engineers, hydrologists, politicians, architects, consulting companies etc) there is no guarantee that all the important aspects with regard to stormwater solutions in Gothenburg were covered. The criteria used were identified by the stakeholder group GKCC but since it is impossible to include “all sustainable aspects” within the MCA – focus were given on the criteria that were assumed to cover the most important and influential aspects of this particular study. The rest of the criteria were excluded due to limitation of both time and resources.

PART 2 –HYDROLOGY AND STORMWATER

2.1 THE HYDROLOGICAL CYCLE AND URBAN STORMWATER

Today, the natural hydrological cycle (i.e. the description of the movement of water below, above and on the earth’s surface) (USGS, 2014) has to a large part been replaced by an artificial water system (i.e. urban drainage) within city areas. In nature, when precipitation falls upon the natural soil surface a large amount of the water is absorbed by the local vegetation. The majority of the water (that has not been absorbed by vegetational/plant roots) is either transported and discharged into downstream surface water recipients (such as rivers, streams and lakes) or becomes a part of the groundwater through continuous infiltration of the soil and bedrock. The amount of surface water runoff in a specific area will be influenced by the geological conditions on site (i.e. type of bedrock and soil layer that exist in the area and how fast the soil gets saturated) as well as climate conditions (i.e. intensity and duration of precipitation). Since precipitation varies over the year the flow rates will also vary with respect to seasons. Soil has some capacity to bind water but when saturated the runoff tends to increase rather rapidly, resulting in a higher and more intensive water flow (Butler and Davis, 2004).

Stormwater is the water runoff created by precipitation and snow melting events that comes into contact with different urban surfaces and materials without being absorbed by the natural ground (i.e. soil). Due to this stormwater is often contaminated by a broad range of different pollutants since the water moves through and absorbs substances from a variety of urban surfaces (i.e. parking lots, roads with heavy traffic and eroded urban surfaces such as rooftops) (EPA, 2014b). Furthermore, pollution originating from atmospheric deposition will also find its way into the stormwater runoff (Butler and Davies, 2004).

The following subchapters present a description of the urban stormwater runoff, ground characteristics and pollutant sources.

2.2. URBAN STORMWATER RUNOFF

In the following subchapters a description of urban stormwater runoff with regard to transport, ground characteristics, precipitation (including effective rainfall) and pollution will be described.

2.2.1 Stormwater runoff transport

The development of urban areas has had a significant impact on urban stormwater runoff and generation (Butler and Davis, 2004) due to the replacement of natural green infiltration surfaces (i.e. natural soil cover) with impervious surfaces (such as concrete roads, rooftops and buildings) within cities (EPA, 2009). Due to this, stormwater is transported downstream at a much faster rate (since water moves faster over hard surfaces in comparison to natural surfaces). The result will be that urban areas experience a faster moving runoff flow (with a higher peak flow) that will enter the urban drainage system at a faster rate. But the urban runoff flow will also die away much faster (compared to natural green areas) which will result in a higher peak flow (Butler and Davies, 2004). The figure 2 below illustrates the difference in runoff volume before urbanisation and after urbanisation has taken place.

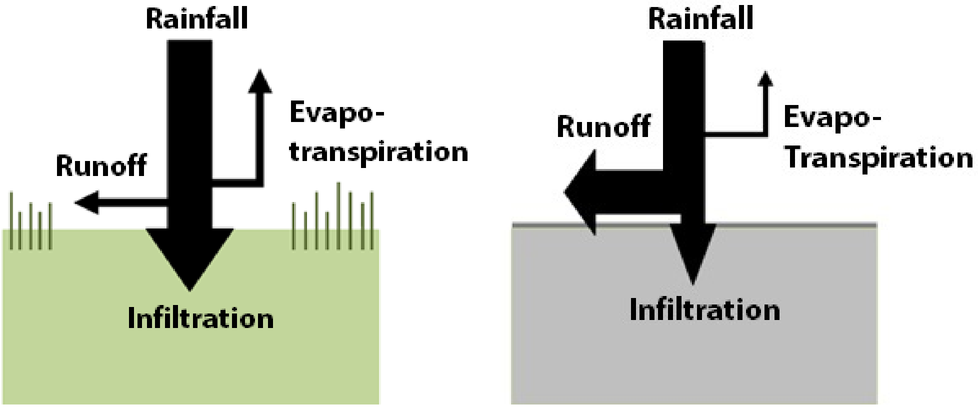

Figure 2: Demonstration of water transport as a result of precipitation before urbanisation (i.e. natural surfaces) and after urbanisation (i.e. urban areas) (based on Butler and Davies, 2004).

2.2.2 Precipitation characteristics and evaluation

As mentioned above in section 2.2.1, the peak flow will be higher in urban areas due the increased amount of impervious surfaces and general lack of natural surface areas. Most stormwater is the direct result of precipitation (but could also be influenced by snow melting events in cold regions) occurring in the area and the urban drainage system is required to deal with this kind of water. The urban effect on stormwater runoff peak flows (as compared with natural/rural surfaces) is illustrated below in figure 3.

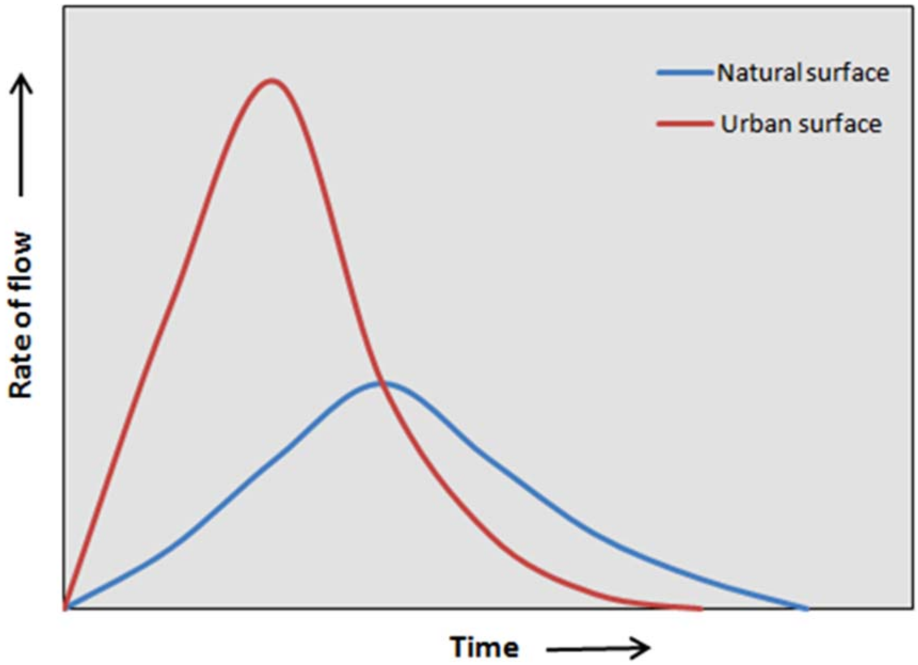

Figure 3: Effect of urbanisation volume and rates of surface water runoff (based on WAV, 2014).

Urban water management and planning are depending on rainfall measurement and statistics in order to evaluate the occurring precipitation trends and make adjustment for the future. Urban drainage water application may involve; design and planning-, analysis and operation- and evaluation of the sewer systems in operation today and CSO volumes and trends. Since urban drainage systems are required to handle both an increase in stormwater (due to climate change) and wastewater (due to an expected population increase) water planning is essential and depends on precipitation data (Butler and Davis, 2004).

Rainfall is normally measured as *intensity* (mm/hour) and is representative on a specific location and often recorded together with duration and frequency. Rainfall *duration* refers to the specific time period for which the rainfall lasts. Rainfall *frequency* is an expression of the return period of a similar rainfall event with the same magnitude rate and is normally expressed in years. As an example, if a specific rainfall occurs 25 times during a 100 year period then it has a return period of 4 years) (Butler and Davis, 2004).
During a rainfall event the intensity is typically the largest at the beginning (i.e. the first hour) and then diminishes with every hour after that (i.e. the intensity reduces with duration). This could be illustrated in an IDF graph (i.e. how rare or frequent a certain rainfall event is) (Butler and Davis, 2004).

2.2.3 Ground characteristics influencing urban runoff

During a rainfall event, much of the stormwater generated will be subjected to losses due to interception, wetting losses, evapotranspiration and infiltration. See table 1 for description for factors influencing runoff (Butler and Davis, 2004).

Table 1 - Factors influencing stormwater runoff (Butler and Davis, 2004).

Runoff losses	Factors influencing	Description
Initial	Interception and wetting losses	Rainfall is collected and detained by the urban vegetation cover or detained by the land area. This factor is rather small in urban areas and commonly neglected.
	Depressing storage	Water becomes initially contained in small catchment surfaces or small depressions during a short amount of time.
Continuing	Evapotranspiration	Water is evaporated from the vegetational cover or open water bodies. This factor is rather small in urban areas and commonly neglected during short rainfall events.
	Infiltration	The soils capacity to absorb water will depend on the geological conditions on site (i.e. soil type, surface cover and initial water content etc.) that will determine the infiltration rate.

Once the initial and continuing losses have been accounted for, the result will be the *effective rainfall* that is transported downstream that will produce the amount of stormwater runoff in that area creating *overland flow*, which is the surface water flow moving down towards the nearest entry point (i.e. the well connecting to the underground urban drainage system) or water surface body (such as a lake or river) (Butler and Davis, 2004).

The urban water runoff will depend upon (for example): the intensity and duration of the rainfall event, the angle of the streets, the layout and grouping of the infrastructure, land use and vegetational cover in the city (Butler and Davis, 2004).

2.2.4 Stormwater calculations

As described above, water movement and runoff time is important to consider when evaluating urban stormwater system and design. Stormwater facilities must be able to detain a certain amount of water in order to motivate the construction of the facility in a specific area. When conducting calculations of stormwater runoff (of a specific drainage area) in Sweden, national standards are provided by the Swedish Water & Wastewater Association (SWWA) in, for example in publication P90. These standards include factors such as: ground characteristics, size and shape of drainage area, rain intensity, type of development and slope. Runoff coefficients and runoff time coefficients are described below from P90 (Svenskt Vatten, 2004).

The Rational Method

The Rational Method is used to roughly calculate the design flow for a small drainage area in Sweden and can be used to estimate the requirements of a storage facility. The method is best suited for calculations of upstream storage facilities. Some requirements are needed in order to make sure that the outcome of the calculations is acceptable. First, the area used for the calculation should have a rectangular shape (or close to at least). Second, drainage coefficients of the same value should be equally distributed (i.e. represented) across the area and third, the runoff times within different parts of the drainage area most not vary too much from each other (Svenskt Vatten, 2004).

The design flow can be calculated with the rational method with the following equation 1.

$$q_{d\,dim} = A * \varphi * i(t_r) \qquad \text{(eq. 1)}$$

Where;
qdim =design flow [l/s]
A= drainage area [l/s]
φ = runoff coefficient [-]
$i(t_r)$ = design rain intensity [l/s*ha]

(t_r = rain duration – equal to the runoff time within the drainage area in the Rational Method)

The runoff coefficient φ is dimensionless and closely connected to the amount of different (often paved) surface areas and describes how much of the precipitation that will result in runoff. It is a measure on the total amount of the drainage area that contributes to the runoff volume and depends on the rain intensity, slope and on the amount of different surface areas (i.e. extent of urbanization) that the area is made up by (after initial losses) (Östlind, 2012). The runoff coefficient is always less than 1 (Svenskt Vatten, 2004).

Rain characteristics from a selected area or region could be derived from time-series of rainfall. The design rain intensity $i(t_r)$ is based on nationwide observations of daily precipitation rates that is provided by the SMHI in Sweden (including return periods). Often, the return periods will depend on the level of urbanization; high return periods up to 10 years (high level of urbanization), low return periods of about a year (low level of urbanization, example rural areas) depending on the stormwater conveyance. The return period is based on the chosen design that will depend upon the expected consequences associated with a certain area and the stormwater facility.

The rain duration t_r is assumed to be of equal to time of concentration t_c (i.e. equal to the time of entry and time of upstream flow in the designated area) when using the Rational Method. (Svenskt Vatten, 2004).

Stormwater storage

Stormwater storages are often designed as covered storages (such as pipeline storages, bedrock storages, macadam basins under parking lots etc) or open water storage (i.e. stormwater ponds etc). Most water storage facilities will be constructed so that natural fall (or an installed pump) will regulate the water levels in the storage. When pipelines are connected to the storage facility they must be adapted for the dimensioned flow coming from the local water drainage area. The water storages most also be adapted so that they can manage an overload of water, i.e. be designed with some sort of overflow mechanism (i.e. safety mechanism). This can be done, through example, a separate outlet point that directs the water downwards towards another stormwater pipeline, or towards a local recipient in the area (Svenskt Vatten, 2004).

In order to limit the outflow - the outlet point (i.e. outlet pipeline) can be constructed in a smaller dimension, thus allowing less water to pass through over time (as one example). If a larger flow regulation is required, a flow regulator can also be applied to the system. The total volume of water storage can be calculated through taking into account: the outgoing flow, the total concrete area connected, the maximum outflow from the facility and precipitation rates and its return periods for the local area (Svenskt Vatten, 2004).

Calculation of dimensioned flows with regard to water storage

Dimensioned flows can be reduced through the construction of stormwater storages that are connected prior to the urban drainage system. The technical design is very important in order to avoid problems (i.e. such as flooding) and a safety measure of some kind is highly recommended (i.e. that during intensive rainfalls transports the water out and away from the facility, for example through a separate pipeline that has its exit point in a local river etc), especially in areas were the facility does not rely on natural downfall (Svenskt Vatten, 2004).

The Rain Envelope Method (without considerations to runoff time)

When the stormwater is delayed in stormwater storage or an LOD facility it becomes unpractical to use the rational method to decide dimensioned flows downstream of the facility. Instead the Rain Envelope Method is used which provides a simplified calculation with the purpose to determine the dimensioned flow downstream of a (detaining/delaying) stormwater facility and the volume required of the stormwater storage. Some requirements are needed in order to make sure that the outcome of the calculations is acceptable. First, the method is best suited for water storage facilities with a slow drainage (i.e. 20-30 l/s*ha), were long-term precipitation will be dimensioned according to the size of the water storage facility. Second, the calculations are conducted in the cases were the water storage facility is entirely empty when the precipitation starts (Svenskt Vatten, 2004).

The volume of the water storage facility is calculated through equation 2.

$$M_{dim} = \max\,[V_{in}(t)-V_{out}(t)] \qquad \text{(eq. 2)}$$

The parameters V_{in} (t) and V_{out} (t) is calculated according to equation 3 and 4.

V_{in} (t) $=10*i_0*t^{0,28}$ (eq. 3)

V_{out} (t) = $86,4*q_{out}*t$ (eq. 4)

Where,
$V_{in}(t)$ = catchment envelope flow [m^3/ha]
V_{out} (t) = accumulated outflow [m^3/ha]
t = block rain intensity [day]
i_0 = rain intensity for t=1 and current return period [mm/day]
t_{dim} = dimensioned duration [day]
q_{out} = choked outflow from the facility [l/s*ha]
M_{dim} = volume of the water storage facility [m^3/ha]

2.3 STORMWATER QUALITY

Urban stormwater can be heavily contaminated by a range of different substances such as natural organic- and inorganic materials and man-made substances originating from a variety of sources such as industrial activities, infrastructure and transport. These substances are deposited into the stormwater from urban practices, urban materials and atmospheric sources (Butler and Davies, 2004). The highest concentration of pollutions is normally observed at the beginning of a storm water event (i.e. the initial runoff volume transports the majority of the pollutions) and decreases steadily afterwards (Barbosa et al, 2012). There are several factors influencing stormwater runoff quality, including: the weather (especially precipitation), the geographical location, urban infrastructure (i.e. buildings and roofing types) and traffic and road conditions on site (Butler and Davies, 2004).

The following sub-chapters describe these processes in more detail.

2.3.1 Factors influencing pollutant transport

As described briefly in section 2.2.1 and 2.2.2, stormwaters ability to transport pollutants will depend on a number of factors that influence runoff and peak flow, including weather conditions (such as the intensity, duration and frequency of precipitation), the geographical location and geophysical conditions on site (i.e. topography, the extent of the drainage area and available green park areas that allows for natural infiltration), land use changes (i.e. how much of the natural soil and vegetation cover that has been replaced by paved areas) (Barbosa et al, 2012), urban infrastructure (i.e. what kind of materials that erodes from buildings and roof tops) and traffic and road conditions (i.e. emissions from fuel, attrition from tire wears and roads etc) (Butler and Davies, 2004).

Furthermore, since stormwater comes into contact with different urban land use activities and atmospheric deposition (besides urban surfaces) (Marsalek et al, 2011) it is recognized as one of the main sources of heavy metals found in downstreams recipients, for example in the wastewater and/or in the receiving rivers and lakes (i.e. water bodies) downstream (Barbosa et al, 2012). The table 2 below illustrates different transport pathways for stormwater pollutants.

Table 2- Pollutant transport and origin in urban areas (Marsalek et al 2011, Butler and Davis 2004).

	Pollution transport	Description
Urban surface	Wind, precipitation and stormwater runoff	Infrastructural materials that is exposed to precipitation and/or stormwater runoff. Surface substances are released through erosion, attrition and corrosion.
Urban land use activities	Wind, infiltration and stormwater runoff.	Residential land uses, open parks, urban waste and traffic.
Atmospheric deposition	Wet fallout and Dry fallout	Industry, energy production, land use activities and vehicles.

Urban surfaces

Urban surfaces have a major impact on the stormwater quality through erosion, attrition and corrosion. *Sediment erosion* is often intensified through urban construction since the natural vegetation and topsoil cover is removed. This will enhance the erosion potential during a short time period, since soil particles will be more exposed to the influence of water (i.e. precipitation and snow melting etc) and enhance the transportation of other surface particles that the runoff comes into contact with. Sediment erosion is therefore often considered to be the major source of Total Suspended Solids (TSS) within urban areas. *Attrition* is the releasing of particles from pavements and roads within the urban area.

Corrosion from urban infrastructure (and catchments surfaces) is a major contributor to pollutants (i.e. heavy metals such as Zn, Cu and Pb) found in stormwater. It has been estimated that about one third of all the heavy metals that end up in urban stormwater is coming from corrosive surface buildings (Marsalek et al, 2011).

Urban land use activities

Common urban land use activities influencing stormwater quality includes for example; residential land uses (i.e. spills of garden chemicals and residential garbage), open parks (i.e. the use of pesticides and fertilisation, faces and urine from pets and animals) (Marsalek et al, 2011), traffic (i.e. vehicle emissions include PAHs and volatile solids, tier wears and vehicle corrosion releases heavy metals, oil spills etc) and urban debris (street debris, organic materials and litter). Paved surfaces will release various substances into the urban environment such as metals and fine sediments, tar, carbonates and bitumen and aromatic hydrocarbons when subjected to attrition (Butler and Davies, 2004).

Some of the pollutants will accumulate on the catchment surface over some time before precipitation makes it possible for the contaminants to be transported to downstream areas through stormwater runoff. The strength of a certain pollutant will depend on factors such as its biodegradability and mobility (i.e. transport capabilities) (Marsalek et al, 2011).

Atmospheric deposition

The amount of atmospheric deposition in an area will depend on many factors such as local and global weather patterns (i.e. wind circulation and precipitation intensity) and the sources of pollution may also be both local and global in its origin. Pollutants can be disposition through *wet fallout* (i.e. precipitation) or/and through *dry fallout* (i.e. wind). During wet fallout the pollutants are often transported directly into the urban drainage system (i.e. through runoff) and during dry fallout the pollutants will settle on the land surface (Marsalek et al, 2011). The amount of pollutants will originate mainly from anthropogenic activities such as; industry and waste incineration, traffic and energy production (Butler and Davies, 2004).

2.3.2 Common pollutants found in urban stormwater

The fate and concentration of contaminants that are introduced into the subsurface is based on the chemical, biochemical and physical interaction processes that occur between the contaminant and the environment. Some of the most important contaminants in stormwater are organic pollutants, suspended solids, heavy metals and nutrients (Lie and Lipták, 2000).

Organic pollutants

Stormwater contains a wide variety of organic pollutants such as pesticides and polycyclic aromatic hydrocarbons (PAH) (Lamprea and Ruban, 2008). There are many different kinds of classes of PAHs and most of them originate from atmospheric depositing (i.e. often as a result of combustion processes). PAHs are of special concern since they have low solubility and often attach themselves to suspended particles in stormwater. PAHs are an indication of the environmental status of surface waters (since it is known to be both toxic and carcinogenic) and high concentrations are often an indication of pollution nearby (WHO, 2003). Since stormwater is often the carrier of PAHs to receiving waters (i.e. resulting in an accumulation in both the sediment besides the water) and therefore stormwater is often subjected to evaluation (i.e. upstreams work to prevent pollution downstream) and sometimes treatment.

Organic compounds

Stormwater contains large amounts of organic matter that is easily oxidized (i.e. chemically or biologically) to stable compounds such as nitrate, carbon dioxide, sulphate and water. When organic matter is decomposed, dissolved oxygen (DO) is consumed by the microorganisms which results in oxygen depletion in the stormwater and/or wastewater systems. Thus DO is an indicator of the environmental status of a receiving waters (i.e. without oxygen no higher life can exist in aquatic environments). Therefore, when evaluating the amount of organic matter present in stormwater, organic compounds like biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are important parameters to consider when evaluating stormwater quality since these two test provides an indication towards the extent of the organic matter existing within the water (Butler and Davies, 2004).

Suspended solids

The suspended solids (SS) is the amount of (both organic and inorganic) suspended solid matter present in a water sample. Heavy metals are especially bound to smaller particles of SS (< 63µm) and can be transported a long distance with the stormwater runoff (Butler and Davies, 2004) and accumulates within the sewer system (Barbosa et al, 2012). SS is often used as an indication of stormwater quality and high concentrations may result in a variety of different effects on recipients (i.e. receiving waters) downstreams, such as (for example); reduce light penetration and affect fish and aquatic invertebrates by exposure to heavy metals runoff (Butler and Davies, 2004).

Heavy metals

Heavy metals (such as Cu, Zn, Cd, Ni, Cr and Pb) are found in a variety of urban sources such as; buildings, roof tops, industrial waste vehicles (parts and components such as fuel, oil and tires), vegetation (logs and leaves) and animals (fecal contribution and dead bodies). Heavy metals have a toxic effect on humans and the environment and stormwater runoff contains a very large amount of metals that are transported downstream into the wastewater system or to receiving waters (Barbosa et al, 2012).

Nutrients

Nutrients such as nitrogen (N) and phosphorous (P) are of major importance to the growth of vegetation (i.e. plants) and microorganisms. Nutrients are used to enhance fertility and are often applied artificially by society (i.e. through farmers and municipalities park/landscape divisions etc) or are the result of discarded waste that contains nutrients (Lie and Lipták, 2000). However, leaching of nutrients into stormwater affects the quality negatively through eutrophication (i.e. growth of algae and floating macrophytes) and cause eutrophic conditions in severe cases (Butler and Davies, 2004).

The table 3 below summarizes the different contaminates commonly found in stormwater that are mentioned previously in section 2.3.

Table 3 – Summary of common pollutants found in stormwater and their effect on the environmental and human health (Barbosa et al 2012, Lie and Lipták 2000, Butler and Davies 2004).

Pollutant group	**Measurement parameter**	**Known sources**	**Comments on effect**
Heavy metals	Cu, Zn, Cd, Ni, Cr and Pb	Industrial waste, vehicles (parts and components such as fuel, oil and tires), vegetation (logs and leaves) and animals (fecal contribution and dead bodies).	Heavy metals have a toxic effect on humans and the environment.
Nutrients	Nitrogen (N), phosphorous (P).	Fertilizers, organic waste, pesticides and atmospheric deposition.	Eutrophication problems (i.e. algae growth), water discoloration.
Solids	Suspended solids (SS)	Atmospheric deposition, constructions sites, anthropogenic waste, pavement wear.	Accumulates within the sewer system and heavy metals and PAHs are bound to smaller particles (< 63µm). High concentrations may affect recipients in a variety of ways, such as interfere with fish and aquatic invertebrates and reduced light penetration.
Organic pollutants	Numerous substances such as; PAHs	Atmospheric deposition through incomplete fossil fuel combustion (PAHs)	Is known to be both carcinogenic toxic to both humans and the environment.
Pathogenic micro-organisms	Total coliforms: Escherichia coli	Animals (for example: birds, dog and cats)	Lower concentration in stormwater than in wastewater.

2.4 URBAN STORMWATER TREATMENT FACILITIES

There are several technical solutions available for the management of stormwater in urban areas. The following section describes two of the most common solutions: dry pond (i.e. dry detention pond, extended detention basin, extended detention pond etc) and macadam basin (i.e. percolation basin).

2.4.1 Dry Pond

The main function of the dry pond is to delay stormwater runoff during an event of intensive (or of long duration) precipitation. The dry ponds function is to take pressure of the local urban drainage system (in order to and to avoid problems such as flooding) and to remove contaminants from the stormwater through filtration and absorption of plants and soil in the designated area (Svenskt Vatten, 2008). Dry detention ponds do not have a permanent pool of water, but are designed to detain stormwater runoff for some time during extreme weather events (EPA, 2014). The infiltration capacity of the pond will depend on the local geology (i.e. bedrock and soil layer) and the climate (i.e. seasonal change in temperature). For example, infiltration works better in soils that are dominated by sand than, for example by clay (SGI, 2011) and the temperature will influence the chemical, biological and physical processes in the pond and affect the uptake of contaminants and transport of water (i.e. water density and ice formation etc) (Svenskt Vatten, 2008). Plants are often used within this kind of facility in order to improve the water uptake and to prevent water logging on site. The area set aside for the dry pond is often designated a multifunctional area that can be used by the public (i.e. as a park area or soccer field etc) when the area is not flooded (SGI, 2011). This aspect together with the notion that applying a dry pond in an urban area means that green areas are preserved – makes dry ponds a good stormwater management choice in many urban areas.

Technical and social aspects

A dry pond will be constructed through artificially submerging the designated area into a catchment that will collect stormwater (when required). It is not unusual to use a dry pond in combination with other stormwater management techniques, such as wetlands. Special consideration needs to be taken into its design when a dry pond is applied in a residential area in order to avoid social problems (such as esthetical considerations and the occasional smell if maintenance is neglected) (Karlsson, 2009). A dry pond will be able to detain stormwater runoff from a couple of hours (Strander, 2014) up to 12-24 hours (depending on the design and local climate) on site. Dry detention ponds can be constructed in areas that are characterized by a slope (max 15^o) that has a relatively deep groundwater level (i.e. in order to avoid flooding). Design may vary from area to area but all dry ponds require regular maintenance to work at full capacity. Dry ponds have a positive effect on groundwater levels in an area (due to infiltration) and can provide channel protection (EPA, 2014). However there are certain social risks associated with open stormwater solutions (i.e. children playing near fast flowing waters or beside open water could be associated with an increased risk for drowning etc) (ICAT, 2012). See figure 4 for a schematic example.

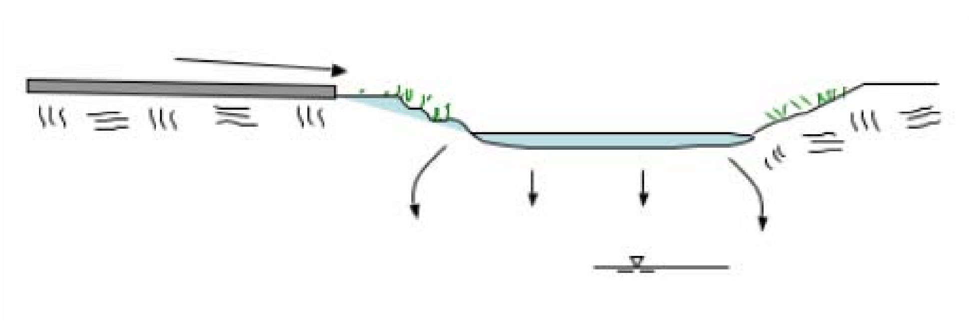

Figure 4: Schematic example of a dry detention pond (Westlin 2004).

Pollutant removal capacity

Dry detention ponds provide moderate pollutant removal (if the design, construction and maintenance has been done properly) and the effectiveness will therefore vary between different ponds (EPA, 2014). The following generalisation has been made through the use of StormTac (see appendix C for details) in table 4 below for a standard dry pond.

Table 4 – Calculated general reduction efficiency of a dry detention pond (StormTac, 2014b)

Facility	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	Oil	PAH	COD	BOD	E-coli
Removal (%)	20	25	80	30	45	80	45	60	10	55	75	60	30	30	85

Dry detention ponds normally have a high efficiency to remove pollutants (i.e. due to settling in the pond) but are often rather ineffective in removal soluble pollutants (i.e. due to the lack of a permanent water surface) (EPA, 2014).

A short summary of the dry pond is found below in table 5.

Table 5- Summary of dry pond (SGI 2011, Svenskt Vatten 2008, EPA 2014, StormTac 2014b)	
Positive aspects (+)	Negative aspects (-)
• Within urban areas (where space is limited) multifunctional areas are highly sought after since the area can be used for other purposes (for example a recreational green area) during most times of the year, when the area is not flooded. • Has potential to delay stormwater runoff (and take pressure of the local WWTP). • Provides moderate pollution removal on site, for example: - SS 55% - Fosfor (P)20% - Kväve (N) 25% - Heavy metals (Pb, Cd, Zn etc.) 10-60% • Plants and vegetation in cities are considered to be positive for people's well-being. • Has an impact on the local micro-climate (and has the ability to compensate for temperature variations on site). • Open stormwater solutions can be used for educational purposes by the local people (i.e. teaching them about stormwater management in urban areas etc). • Relatively cheap construction and maintenance costs.	• A dry pond will take up public green space when flooded and prevent ongoing activities on site. • If the stormwater is polluted (which is often the case in urban areas) then some of the pollutants will remain in the soil and plants (i.e. through uptake and absorption) which could mean a risk for the local population (i.e. children eating soil on site etc). • Regular maintenance and inspection will be required to guarantee full functionality. • The function of the dry pond will depend on site specific conditions (i.e. geology etc), technical design and climate. Dry ponds will *not* have full function (or no function at all in some regions in Sweden) during cold seasons (i.e. winter) due to lasting snow- and ice cover. • Dry ponds can sometimes cause a degradation of property values in an area. • There is a certain social risk associated with open stormwater solutions in urban areas (risk for children drowning etc).

2.4.2 Macadam Basin

The main objective of a macadam basin is to delay stormwater runoff. A macadam basin (i.e. percolation basin) is often used as an alternative when there are no available green surface areas to use for managing stormwater through natural infiltration. The catchment area for stormwater is often limited for this kind of construction. A Macadam basin is an artificial created infiltration bed (for example situated under a pavement area such as a parking lot) that collects stormwater through wells from the surface. The stormwater runoff is then transported down into the infiltration bed where the water is temporarily detained and allowed to infiltrate the natural soil layer. The water could also be transported out through a connected pipeline (i.e. outlet) that is part of the controlled drainage system (Stahre, 2004). Furthermore, macadam basins are capable of removing some pollutants from the urban stormwater (StormTac, 2014b).

Technical and social aspects

The infiltration bed is made out of artificially added coarse materials (i.e. macadam materials such as gravels and pebbles) that allows for infiltration down to the natural soil layer (Westlin 2004). In order for this construction to work, the groundwater levels most be situated well below the surface in order to avoid flooding (i.e. underneath the bottom the macadam basin). The infiltration capacity will depend on site specific conditions such as geology (i.e. better infiltration through sand than clay) and the local climate (i.e. temperature etc). The facility has one main disadvantage that is that suspended particles transported down from the surface may block the pore space in the coarse gravels and thus prevent stormwater from reaching the natural soil layer – a problem that could result in flooding. If that happens then the facility will no longer work according to its design and needs to be removed and/or re-constructed on site. Furthermore, wells are often blocked by leafs and other materials and therefore required regular maintenance. The estimated lifespan of this kind of facility is seldom more than a few decades (Stahre, 2004). It is highly recommended to use some sort of pre-treatment step of the stormwater in areas (such as parking lots) were contaminants such as oil may become a problem when transported down into the macadam basin. The figure 5 and 6 below illustrate some of the common designs of macadam basins used today (Westlin 2004).

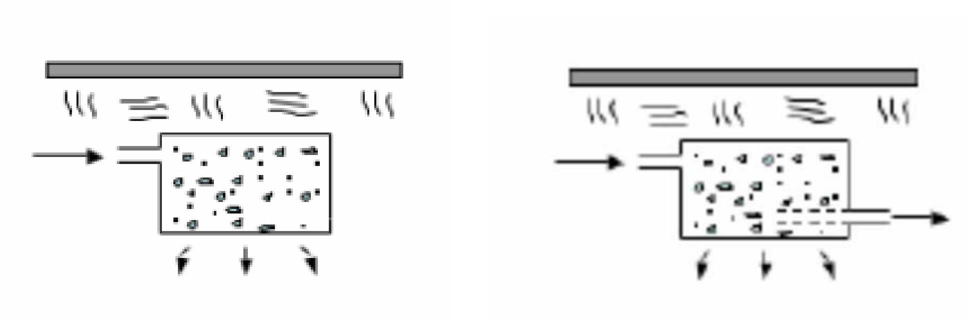

Figure 5 (to the left) illustrates a macadam basin that relies solemnly on natural infiltration. Figure 6 (to the right) illustrates a macadam basin that is equipped with a stormwater outlet drainage pipeline were excessive water is transported out (Westlin 2004).

Pollutant removal capacity

Macadam basins provide a moderate pollution removal (if the design, construction and maintenance has been done properly) on site. The following generalisation has been made through the use of StormTac (see appendix C for details) in table 6 below for a standard macadam basin.

Table 6 – Calculated general reduction efficiency of a macadam basin (StormTac, 2013b)

Facility	P	N	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	Oil	PAH	COD	BOD	E-coli
% Removal	50	40	70	35	40	65	50	80	35	75	80	70	-	-	-

A short summary of the macadam basin is found below in table 7.

Table 7- Summary of macadam basin (Westlin 2004, Stahre 2004, StormTac 2014b, Frohm 2014).

Positive aspects (+)	Negative aspects (-)
• Within urban areas (where space is limited) a macadam basin may provide a great opportunity to manage stormwater in areas that do not have many green areas for open stormwater solutions. • Has potential to delay stormwater runoff (and take pressure of the local WWTP). • Provides moderate pollution removal on site, for example: - SS 70% - Fosfor (P)50% - Kväve (N) 50% - Heavy metals (Pb, Cd, Zn etc.) 10-80% • The cost will depend on its construction design and maintenance.	• A macadam basin has an expected lifetime of a few decades at most (due to suspended particles that blocks the porous space between the gravels and prevents infiltration). • Regular maintenance (i.e. removal of leafs from wells etc) and inspection will be required to guarantee full functionality. • The function of the macadam basin will depend on site specific conditions (i.e. geology and soil layer etc), technical design and climate. • Provides no educational value for the main society (i.e. ”out of sight –out of mind”).

2.4.4 Economic Calculations

For the purpose of this study, simplified cost-calculations for the construction of a dry detention pond and macadam basin at Guldheden were performed at COWI AB through the software Bidcon (version 6) in June 2014 (for more details about the Bidcon programme see appendix E). The estimated size was based on the stormwater calculations (see appendix A for details) that were made for each solution.

The following sub-sections describe the assumptions made and the estimated costs for each stormwater solution.

Dry pond - estimation of costs

The cost for a dry detention pond will vary deepening on its design, construction material and site specific conditions (among several factors). The following assumptions were made regarding a dry pond using a total area of 500 m^3 (with storing capacity of 250 m^2) in order to calculate the approximately costs (see table 8 below).

Table 8 – Preliminary cost calculations for a dry pond (Bidcon 2014).

Type of Cost	Definition	Estimated price*
Net costs	+ Materials (stormwater well, flow regulator, additional soil and plant material etc)	179 600 SEK
	+ Machines, transport, shreds/containers etc.	119 500 SEK
	+ Salaries, staff management, expenditure template etc.	57 300 SEK
Other costs	+ Consumer goods	9000 SEK
	+ Waste management	7000 SEK
Raw sum for project (excluding taxes and without a 10% profit for the consulting company)		~372 400 SEK
Total Sum		510 200 SEK (~ 55 200 EURO)

**The price is a simplified estimation of cost for a typical dry pond facility. The prices have been rounded to provide an easy overview of the costs. Euro is based on the exchange rates in august 2014.*

Macadam basin – estimation of costs

The following assumptions were made regarding a macadam basin using a total area (i.e. parking lot) of 1300m^2 (i.e. whereof gravels 750 m^3) in order to calculate the approximately costs for a facility with a storing capacity of 250 m^2 (see table 9 below).

Table 9– Preliminary cost calculations for a Macadam basin (Bidcon 2014).

Type of Cost	Definition	Estimated price*
Net costs	+ Materials (gravels etc)	601 700 SEK
	+ Machines, transports, shreds/containers etc.	251 900 SEK
	+ Salaries, staff management, expenditure template etc.	199 000 SEK
Other costs	+ Consumer goods	30 100 SEK
	+ Waste management	7000 SEK
Raw sum for project (excluding taxes and without a 10% profit for the consulting company)		1089 700 SEK
Total Sum		1492 900 SEK (~161 600 EURO)

**The price is a simplified estimation of cost for a typical macadam basin facility. The prices have been rounded to provide an easy overview of the costs. Euro is based on the exchange rates in august 2014.*

The typical cost for this kind of facility will depend on its technical design, the number of wells connecting the pavement area (i.e. for example a parking lot) and how much material that is needed (sometimes if there are ongoing construction on site there will be much leftover materials such that gravels that could be re-used in this kind of facility). In this example the estimated cost were based on the assumption that the demolition and re-constructing of the parking lot was required and that the municipality had to buy all the raw materials (including gravel etc). However, in reality a macadam basin is often chosen since it is a rather practical and relatively economic way to use old materials (i.e. gravels etc) from ongoing construction on the site which would result in a much lower cost for materials (about 447 000 SEK/48 300 EURO would be saved in this case) (Frohm, 2014). In other words, if there are no costs for materials then the macadam basin would only be twice as expensive as the dry pond. In the estimated example above in table 9, the macadam basin is three times as expensive as the dry pond.

Furthermore, the demolition and re-constructing of a paved (asphalt) surface area is rather expensive (about 332 800 SEK/36 000 EURO in this case) which explains why this kind of facility is originally more costly than the dry detention pond (Bähr, 2014).

See Appendix E for cost estimation of both the dry pond and macadam basin.

2.5 CLIMATE CHANGE IN SWEDEN AND GOTHENBURG

The Swedish government ordered a special investigation into how climate change would impact Sweden that was completed in 2007 (i.e. SOU 2007:60). The conclusions showed (among many things) that Sweden should start adaptations with regard to climate change as soon as possible (i.e. the scientific scenarios that had been developed was considered robust enough to support this statement) to adapt to changed climate conditions that would occur in the future (SOU, 2007).

2.5.1 Effects of Climate Change in Västra Götaland and Gothenburg

An climate change investigation for the region of Västra Götaland (including Gothenburg) was conducted by the Swedish Metrological and Hydrological Institute (SMHI) in 2011 with regard to parameters such as; temperature, precipitation, vegetation season, water flows and snow. Three time scenarios were used; a reference period covering the years 1961-1990 and two future scenarios covering the years i) 2021-2050 and ii) 2069-2098.

From this investigation the following conclusions were made (Länsstyrelsen Västra Götalands Län, 2011):

Temperature

The annual temperature is expected to increase from 6.1 ^{o}C (1961-1990) until approximately 10 ^{o}C at the end of the century (with variations between 8-13 ^{o}C), where Gothenburg are predicted to receive the higher range of the predicted increase in temperature. Seasonal variations will increase to the end of the century with the largest increase taking place during the winter (i.e. higher temperatures resulting in shorter winter seasons).

Vegetation period

The vegetation period is the period when the daily temperature exceeds 5 ^{o}C under at least 4 days in a row. This period will increase to the end of the century to an average of 331 days (approx. 11 months) as compared with the reference period (1961-1990) of 206 days (approx.7 months).

Precipitation

Precipitation rates will change from an average 794 mm/year (1961-1990) up to a range between 824 mm/year – 914 mm/year (2021-2050) and 884 mm/year- 994 mm/year (1951-2098). The increase in precipitation is expected to be approximately between +10% up to +30% for the region at the end of the century. The coastal areas (including Gothenburg) are expected to get more rain than the inland areas (due to higher topography etc). The seasonal variation will continue with an increased precipitation during winter, spring and autumn. The summer will not be affected.

Heavy rainfall

Heavy rainfall (i.e. days with a precipitation above 10mm) is expected to increase to the end of the century (2021-2098) with the biggest increase taking place at the coastal areas (including Gothenburg).

Water flow

Water flow (i.e. the amount of water that flows through a stream) is expected to increase to the end of the century (2051-2098). The seasonal variation (for both the period 2021-2050 and 2051-2098) is the same all over the region with increased water flows at the beginning and end of the year (i.e. early spring and late autumn) and decreases during late spring and summer. The water flow rate increases steadily from 2021-2098. The changes are the result of an increased precipitation rate during winter (due to higher temperature) that causes less snow formation and higher water flows. The evaporation rate during spring and autumn will increase due to higher temperatures, extending the vegetation period for plants. This change will influence water flows, reducing the amounts of precipitation reaching the streams. At the end of the century (2051-2098) there will be an increase in total water flow up to +10% in large parts of the region.

Ground water availability

Increased precipitation and temperatures will affect the hydrological circle, causing changes in both groundwater and surface water. The ground water levels in the region are expected to increase with 5-10% (coarse grained soil) and about 0-5% (moraine) until the period 2051-2098 (in comparison with 1961-1990).

Snow

The amount of days with snow is expected to decrease to the end of the century from an average interval of 25-75 days (1961-1990), 5-35 days (2021-2050) and 0-15 days (2069-2098) at the catchment area Säveån (the river Göta älv – close to Gothenburg).

The table 10 below summarizes the impact of climate change in the region Västra Götaland (including Gothenburg) that is described above.

Table 10– Climate change impact on the region Västra Götaland (Länsstyrelsen Västra Götalands Län, 2011)

	Historical/Reference data set (1961-1990)	**The middle of the century (2021-2050)**	**The end of the century (2069-2098)**
Temperature	6 ^{o}C	-	10 ^{o}C (variation between 8-13 ^{o}C)
Vegetation period	206 days	-	331 days
Precipitation	794 mm/year	824-914 mm/year	884-994 mm/year
Heavy rain periods	-	Increasing	Increasing
Water flow	-	-	+ 10 % Seasonal variations: Autumn: Increase Winter: Increase Spring: Decrease Summer: Decrease
Ground water availability	-	-	0% to +10%
Snow period (GTB)	25-75 days	5-35 days	0-15 days

A study made by SMHI predicted that annual precipitation rate for 10-year day (i.e. 24 hours) precipitation would increase with an average of +5% to 2050 and + 20% to 2100. Predictions for short time (<1 hour) precipitation suggested an average increase of +10% to 2050 and +25% to 2100 (Olsson and Foster, 2013). The short time precipitation rates are important to consider in urban areas since it is (in most cases) the short time (intensive) precipitation that will create peak flows that cause problems for the local WWTP. Short time precipitation is used for stormwater calculations (see appendix A).

2.5.2 The impact of climate change on the urban drainage systems in Sweden

The municipality urban drainage system is expected to receive a higher amount of stormwater (due to expected increase of precipitation) with a different seasonal load (due to increased temperature that affect the urban water cycle, causing less snow formation and earlier melting). More extreme weather events are expected to happen in the future (i.e. higher frequency of intensive rainfalls) that will put more pressure on the urban drainage systems. The combined system has been identified as being more vulnerable in this regard. More flooding event are expected to take place as a result of increased precipitation and the economic cost to the society may be high (i.e. the flooding in Kalmar city caused by a heavy precipitation event in 2002 and 2003 cost the municipality about 7.4 million Euro). Also, the waste water treatment plants (WWTP) in Sweden are often situated on low-lying terrain (to improve natural inflow of waste water) and are therefore extra vulnerable for floodings (SOU, 2007).

It has been suggested that more focus should be directed towards improving local stormwater solutions in areas that use combined systems today through example open stormwater solutions in order to limit the stormwater runoff flow (that is predicted to increase in the future) being transported directly to the WWTP (SOU, 2007).

Generally the following conclusions regarding climate change can be made;

- The efforts taken today to decrease the stormwater flow and volume (transported to the WWTP) will also be required in future.
- Municipalities will have time to adapt and upgrade their drainage systems since the change in weather and seasonal patterns is expected to happen slowly.
- Areas that are today experiencing problems (i.e. overflows, flooding etc) will continue to be listed as “critical areas” in the future. Also it is very likely that new areas will be added to this list.
- Investigations should be conducted in areas that have been identified as being at risk so that measurements can be taken in order to avoid future problems (Svenskt Vatten, 2011b).

2.6 SUSTAINABLE DEVELOPMENT IN THE FIELD OF STORMWATER MANAGEMENT

Ever since the publication of the Brundtland Report in 1987, Rio-Earth summit in 1992 (and Agenda 21) sustainable development has gained more and more focus in all areas of society (Butler and Davies, 2004). Sustainable development (SD) is most commonly defined through the Brundtland Report as: “development that meets the needs of the present without compromising the ability for future generations to meet their own needs”. Sustainable development takes into account the environmental, social and economic impact that is associated with a certain action through evaluation (often based on criteria) (Visser, 2009). The concept of sustainable development comprises societal changes that are required for the long-term planning of society (i.e. globally, nationally and locally), and are especially important for urban drainage and stormwater management in Sweden (Törneke et al, 2008)

2.6.1 Sustainability within urban drainage systems

Sustainability has become an important aspect within urban drainage systems (including stormwater) since it provides tools for planning and evaluating the long-term effects. However, many different interpretations exist regarding how the concept of sustainability should be integrated into society. Butler and Davies (2004) suggested a list of what objectivities sustainable urban drainage should incorporate as:

+ Maintaining the public health barrier
+ Avoid local or regional pollution of the environment (i.e. soil, water, air)
+ Minimize the use of natural resources
+ Make sure planning and adaptation is done for the future
+ Apply cost-efficient (affordable) solutions
+ Be socially acceptable

Sustainable development has nothing to do with the technical design of stormwater facilities (i.e. for example, open stormwater solutions are not always the best sustainable choice at a designated site since there are many different criteria that most be evaluated in order to reach a good decision) (Stahre, 2004). Additional strategies such as avoiding mixing the stormwater runoff with the wastewater and/or to avoid the mixing of industrial wastewater with the domestic wastewater would be economically beneficial for the WWTP and society (Butler and Davies, 2004).

Sustainability in the field of stormwater management has resulted in management strategies that have received different names such as; Best Management Practices (BMP), Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Water Sensitivity Urban Design (WSUD) (Mambretti and Brebbia, 2012). Within Sweden, the term "Lokal fördröjning av dagvatten" (LOD) is the most common strategy used for stormwater management. LOD focus on different techniques to detain and delay the stormwater runoff on site (when possible) of locally before the water is transported into the urban drainage system. These techniques often use low-technology solutions and are often economically desirable (i.e. cost-efficient) for the municipality to use (Stahre, 2004).

2.6.2 Sustainable stormwater management in Sweden

During the last 20 years, the concept of sustainable development has meant a shift in focus within Swedish water management from the conventional thinking of *only capacity* towards a more sustainable way of thinking *capacity, water quality* and *urban environment* (Stahre, 2004). The old traditional way of "hiding stormwater" through underground pipeline systems has given way towards using a variety of open stormwater solutions (when the conditions are right for it– some solutions are not suitable for every situation) (Ljung 2014). An important aspect of this is the shift towards evaluating stormwater quality and its effect on downstream recipients. Stormwater is no longer thought of solemnly as a technical problem that the municipalities have to deal with, but as an opportunity to bring in water into urban areas and as a mean to educated people about stormwater management. However, successful stormwater integration into urban planning and management requires co-operation between different administrations within the municipality, including various stakeholders that may have an interest in the outcome – in order to guarantee successful results (Stahre, 2004). Long term planning (for a defined time period) is an essential part of sustainable water management and the municipalities play an essential role in guiding the development of urban areas and stormwater management (i.e. promoting stormwater solutions or not) (Lindström, 2012). As urban areas expand and condensates, the management and planning of stormwater become essential in order to avoid problems such as floodings and CSOs. By law, before any construction can begin on a site the stormwater management most have been decided upon.

The main strategy used nowadays within urban stormwater management is to try to delay the runoff flow (preferably on site) from entering the urban drainage system by natural techniques (when possible) (Svenskt Vatten 2011). There are 4 main categories of dealing with stormwater in Sweden and these are the following:

- Local disposal of stormwater (i.e. through green roofs, percolation, dams etc on private land).
- Delaying the stormwater near the source (i.e. through infiltration, ditches, wetlands etc on public land).
- Slow derivation of stormwater (i.e. through channels, ditches, streams etc on public land).
- Delaying stormwater through using special catchments (i.e. through dams, ponds, wetland areas on public land). (Svenskt Vatten 2011).

2.6.3 Stormwater values and social acceptance

Open stormwater solutions have been identified as having a positive effect on the urban environment and people's wellbeing (Stahre, 2004). The social acceptance of a certain stormwater solution will depend on many factors. It is a common knowledge that the more noticeable a solution is, the more peoples opinion regarding it will matter. In densely populated areas where people pass by every day the social acceptance will be more important than in less populated areas (for example in sub-urban areas). If a stormwater solution is esthetically beautiful it will score higher acceptance by the public (even though site specific conditions will determine what solution best fits a certain area). Natural green areas have a positive influence on the public (i.e. their wellbeing) and open stormwater solutions in combination to park areas improves both the biodiversity in the city and the air quality. However, economic considerations are essential for the municipality and economic values are important to consider when making a decision about stormwater management in a certain area (Ljung 2014, see appendix B).

The table 11 below illustrates some of the sustainable values that can be associated with open stormwater solutions.

Table 11 – Sustainable values of open stormwater solutions (Stahre 2004)

Values	Description
Social values	Stormwater has been identified as having: esthetic, re-creative and educational value (among many values). Open stormwater solutions are considered to be esthetic pleasing for the inhabitants (subjective value), supportive for the outdoor life (i.e. for example by adding walk- and bicycle routes beside water), and used to educate children, youth and the general public regarding stormwater management in urban areas
Environmental values	Stormwater has an ecological and biological value through increasing the biodiversity on site. Within urban areas that do not have much green areas (i.e. parks etc), open stormwater solutions may be adventitious.
Economic values	Open stormwater solutions are often economically desirable to apply in urban areas and could easily be integrated with the park- and street administration of a municipality.

The city of Gothenburg recognizes in their "green plan" for the city that easily accessible parks and green areas have many social and ecological values for the urban population (i.e. encourages recreational activities and contributing to peoples sense of belonging etc). Especially children and older people in the city highly values green areas and green paths alongside open water (i.e. channels, wetlands or open stormwater solutions) in the city (Göteborg stad, 2014). Green areas influence the local climate (i.e. temperature etc) and the urban biodiversity. Furthermore, open water of any kind makes the city more attractive and is an asset for the region. For example the most attractive sites for residential construction within the city is located beside (or in close proximity) to the water (Göteborg stad, 2014).

Green urban areas are therefore associated with high social-cultural-environmental values for the local population and are worth protecting both for the present- and for future generations (Thulin, 2014).

2.6.4 Sustainable water management goals and principles for Gothenburg

Gothenburg has included sustainable goals from a user- (i.e. social), environmental- and economic perspective in their wastewater action plan. The plan guides the city's future work (i.e. to the year 2030) and is a political document used for decision-making. A summary of some of the goals are described below in table 12.

Table 12: Summary of some of the main goals regarding sustainable water management for the city of Gothenburg to reach until 2030 (Göteborg stad, 2010).

User perspective	• Less than 40 floodings per year in buildings. • No stoppage in the critical part of the pipe network. • The quality of the bathing water in Gothenburg shall not be negative influenced by the waste water.
Environmental perspective	• The waste- and storm water should be deviated in such a way that it does not compromise the EU Water Framework Directive (regarding "good status" of surface water and ground water). • Storm water leakage into the wastewater treatment facility should be less than 50%. • Areas that are connected to the combined pipe network system should be diminished by approx. 15 ha/year. • The quality of the wastewater should be continuously improved.
Economic perspective	• Cost-efficient solutions should be applied.

2.6.5 The European Water Framework Directive in Sweden

The European Water Framework Directive (WFD) was legally put into force in 2000 (Directive 2000/60/EC) but became a part of Swedish law in 2004. The WFD was created in order to provide a more consistent legislation on water management within the EU (since many countries have different laws and regulations regarding water management). The focus is on protecting and improving the chemical and ecological status (i.e. water quality) of water in order to assure a sustainable urban water management for today's- and future generations (HaV, 2014). The goal is to reach a good water quality until the year 2015 (or the latest by 2027) (Vattenmyndigheterna, 2014). The WFD focus on all waters (i.e. both groundwater and surface waters such as: lakes, rivers, estuaries and coastal waters etc) (HaV, 2014).

PART 3 – THE STUDY AREA

3.1 URBAN WATER DRAINAGE SYSTEM AND PLANNING IN GOTHENBURG

In Gothenburg there are three major urban drainage systems in use: the combined system and the two separate systems (i.e. the duplicate and the separate system). These systems are described shortly below.

The Combined System

In the combined system, both wastewater and stormwater is collected and transported within the same urban drainage (pipeline) network to the WWTP (i.e. Ryaverket). As a result of this, combined systems are exposed to more pressure during intensive rainfalls (i.e. resulting in more CSOs in order to protect the downstream residential and industrial areas from flooding) (Svenskt Vatten, 2007). The combined system in Gothenburg was favored (with some exceptions) up until the 1950s since it was economically desirable to have one pipeline (instead of two) for the gathering and transporting of waste- and stormwater. Due to this, the combined system is found within the older (and often central) parts of the city (Gryaab, 2013).

The Separate systems

The separate system is divided into two main systems: the separate and the duplicate system. In the separate system wastewater and stormwater are collected and transported separate from each other within two different pipelines. The wastewater is transported directly to the WWTP (i.e. Ryaverket) while the stormwater is normally discharged (without further treatment) into receiving waters. The duplicate system is the same with the exception that the drain water is connected (additionally) to one of the two pipeline system (Svenskt Vatten, 2007). The separate systems in Gothenburg today were (mostly) built after the 1960s (Gryaab, 2013), were the duplicate system was favored (Gryaab, 2013b).

The table 13 below summarizes the urban drainage system and treatment used in Gothenburg today.

Table 13: Overview of the urban drainage system that is used in Gothenburg today (Svenskt Vatten 2004, Svenskt Vatten 2007, SOU 2007).

System type		**Description**	**Treatment**
Combined system (up to the 1950s)		Wastewater and stormwater are transported down into the same pipeline system and mixed.	The mixture of water is treated at the WWTP.
Separate system (after the 1960s)	**Separate**	Wastewater and stormwater is separated into (two) different pipeline systems.	Wastewater is treated at the WWTP. Stormwater is discharged into a dike or gutter.
	Duplicate	Wastewater and stormwater is separated into (two) different pipeline systems. Drain water (runoff from houses, buildings etc.) is connected to one of the pipelines.	Wastewater is treated at the WWTP. Stormwater is taken care of locally (i.e. LOD) or discharged into dikes or gutters. Drain water can be discharged into the one of the pipelines (stormwater normally).

3.1.1 Problems associated with urban drainage systems

Old urban drainage systems are often subjected to both infiltration- and exfiltration problems. For example, through pipe infiltration groundwater (together with additional excess stormwater that has drain through the top soil layers) enters the pipes through cracks and further dilutes the waste- or stormwater flow (putting extra pressure on the WWTP). But cracks in the pipelines may also be responsible for releasing untreated wastewater into the surrounding natural system through pipe exfiltration, resulting in an increased risk for the environment and human health. The combined system s more vulnerable during intensive precipitation (that results in high water flows) which often results in emergency discharge (CSOs) of untreated wastewater into the surrounding natural water bodies (Butler and Davies, 2000).

3.1.2 Dataset for stormwater flow in Gothenburg

Kretslopp och Vatten collected data with regard (among many things) to stormwater and drain water flow in 2005 for the city of Gothenburg. Table 14 below summarize the results (were unspecified systems are disregarded) (Gryaab, 2013b).

Table 14: Simplified summary of the extent of the urban drainage system in Gothenburg and stormwater and drain water flow in 2005 (Gryaab, 2013b)

Main Systems	**Stormwater and drain water is directed to**	**Area used in 2012**		**Storm water and drain water flow in 2005**		
		Ha	**% of total area**	**Mm^3 to recipient**	**Mm^3 to WWTP**	**Total sum (%) going to WWTP**
1. Combined	CP	3903	23	7.3	21.3	53
2. Separate	SR	2756	17	16.1	4.1	10
3. Duplicate	SWR	9986	60	58.4	14.7	37
Summary		16645 ha	100%	81.8 Mm^3	40.1 Mm^3	100%

CP= combined pipeline, SR = surface runoff, SWR= storm water runoff, WWTP= waste water treatment plant (Ryaverket).Published with approval from Kretslopp och Vatten (Ander, 2014).

From this dataset it can be concluded that about half (53%) of all the stormwater transported to the WWTP (i.e. Ryaverket) came from the combined system in Gothenburg 2005. The rest (47%) came from the two separate systems (i.e. separate and duplicate) systems. Furthermore, in 2012 the combined system covered an area of approximately 23% (in comparison to the two separate systems that covered about 77% of the total urban drainage area in Gothenburg) (Gryaab, 2013b).

3.1.3 Urban drainage system management within Gothenburg city

Within the municipality of Gothenburg, sustainable planning and management for the urban water system has been a key focus for many years. Long-term planning is required since the urban drainage pipeline system has an approximately lifetime of about 100 years.
However it has been recognized that since most of the urban drainage system are quite old, more effort may be required in order to maintain the high level of water quality in the city and the surrounding area. Within Gothenburg city there is an ongoing integration of waste

management with wastewater treatment in order to achieve long-term sustainability in the region. This is important since, for example, if an upstream factory is releasing a lot of contaminated waste- and stormwater into the urban drainage system (i.e. point source pollution) this will add additional pressure on the WWTP (i.e. Ryaverket) since industrial wastewater differs quite a lot from residential wastewater with regard to pollutant content (Ljung, 2014).

In Gothenburg city the goal is to work with upstream methods and try to de-connect highly contaminated areas (i.e. factories and dumps etc) from the urban wastewater system and instead require local treatment of waste water in order to improve the water quality downstreams. The ultimate goal for Gothenburg city is to be a closed-loped system; waste management must therefore be included in the planning process. Furthermore, the city is trying to preserve green areas in the city for the future (since they hold great potential for stormwater infiltration and open stormwater solutions among other social and biological values for the city) and new construction projects within the city should be directed (as much as possible) to old industrial areas (that are already consistent of pavement areas and buildings) instead of using untouched green areas (i.e. natural parks and forests etc). Furthermore, Gothenburg city is striving towards guiding the water management in the city with political decisions and funding for sustainable long-term project (Ljung 2014, see appendix B).

Within city planning (i.e. zoning) the city of Gothenburg normally appoint consultants (from different companies) to perform stormwater investigations on site. The consultants recommend suitable stormwater solutions that the city then considers (Nilsson, 2014).

3.1.4 Upgrading of the existing drainage system

In Sweden the mean value for upgrading of the existing urban drainage system was 0.4% per year for the wastewater system and 0.3% per year for the stormwater system between the years 2006-2008. The general conception is that the renewal and upgrading process of the national wastewater system should at least be 0.6 % per year during the coming 70-80 years (until about 2080s) with the understanding that the expansion of the existing urban drainage network continues as predicted (which will lower the upgrading of the existing drainage system) (Svenskt Vatten, 2011a)

Within Gothenburg city, old drainage pipelines underneath the city are normally not replaced until they are broken (and leaching) due to economic considerations. Politically, money has been put aside every year designated for the upgrading of the urban water system. For example in 2014 a sum of approximately 120 million SEK (i.e. approximately 13 million Euros*) were set aside for this task alone (Ljung 2014, see appendix B).

A study conducted in 2007 investigated what kind of urban drainage system that was the most sustainable in the long time period for the city of Gothenburg (with regards to the release of nutrients). The results concluded that the combined system should be kept with some improvement in certain areas (i.e. areas that is suffering from overflow problems etc) (Svenskt Vatten, 2011b). Today, the policy is to keep the old combined system due to economic considerations. However, Gothenburg city has recognizing that the combined system is not optimal (i.e. that the separate systems are much more desirable) and the city supports additional stormwater solutions when possible (Ljung 2014, see appendix B).

**based on the exchange rate in august 2014.*

3.1.5 Future problems for Ryaverket

Ryaverket has predicted that a new WWTP must be built in Gothenburg in the future in order to be able to handle the expected increase in wastewater volumes (i.e. resulting from the urban expansion of Gothenburg city and its surrounding areas) - if measures are not taken by the city to drastically decrease the stormwater inflow to Ryaverket. Already today, Ryaverket is under a lot of pressure with regard to managing the facility on the existing grounds in Gothenburg (even with the existing modern technology) (Gryaab, 2013). Many municipalities around Gothenburg are looking for approval to connect their own wastewater pipelines to Ryaverket. When Lerum (a small municipality located west of Gothenburg) was connected in 2012 this increased the pressure on Ryaverket with approximately + 3.5%. From an environmental perspective connecting surrounding WWTP to Ryaverket is a good idée (since many of these facilities are very old and do not provide very efficient treatment of wastewater), but from a technical point of view this will result in an increased pressure on the facility (Ljung 2014, see appendix B).

The expected increase in wastewater transported to Ryaverket in the near future will also result in a higher economic cost for the WWTP (i.e. through higher energy usage and more chemicals needed to treat the wastewater etc). Since stormwaters (in most cases) does not require the same treatment (i.e. chemical, physical and biological) as wastewater, Gryaab has recognised that applying more stormwater solutions (that delay or re-direct the runoff flow to Ryaverket) are highly desirable. Furthermore, the effects of climate change will put additional pressure on the facility, including larger quantities of stormwater runoff transported to the WWTP (that differ in both temporal and spatial variations) in the future. Gryaab has highlighted that any action or solution that would take the pressure of the facility would be greatly appreciated. To keep the urban drainage system in good condition (to prevent both pipe in- and exfiltration etc) is a good strategy, but limiting the amount of stormwater transported to Ryaverket through the pipeline network might be an even better strategy (Gryaab, 2013).

3.2 THE STUDY AREA – GULDHEDEN

Guldheden is situated approximately 2 - 3 km south of the main city area in Gothenburg and (Göteborg stad, 2012). Southern Guldheden has been recognized as an area that holds a high cultural-historical value for the city (Göteborg stad, 1999). Southern Guldheden is a green city area (i.e. many parks, bicycle paths and foot roads exist here including a lot of green areas around the residential areas). A lot of the original natural park areas have been protected (Göteborg stad, 2005) since the 1950s when residential construction began (Caldenby et al, 2006) and therefore holds an urban ecological value for Gothenburg city (Göteborg stad, 2009).

During the last years Guldheden has been recognized as an area with a high nightflow (i.e. the q/p value is 0.8) which motivates further investigations of the urban drainage system in the area and solutions that could decrease the wastewater flow and leakage (see Appendix L for description of night flow) (Svenskt Vatten, 2011b). Furthermore, Kretslopp och Vatten has identified Guldheden as an urban area that would benefit from additional stormwater solutions (Ander, 2014). The area is today dominated by the combined system (i.e. both stormwater and wastewater are collected and transported together to Ryaverket) and is situated relatively high (from a topographical point of view) from the neighboring areas and the city center (Göteborg stad, 2014).

The city of Gothenburg has plans to expand the area with about 200-300 new apartments the coming years (Göteborg stad, 2014b). Since the current governmental policy is to keep most of the old combined drainage systems in the city (Ander 2014, Ljung 2014) this will most likely result in the extension of the combined pipeline system in the area (i.e. more people connecting themselves to this system due to urban expansion etc) which will add more pressure to the WWTP (i.e. Ryaverket) if no further measure is taken. However, southern Guldheden has many green areas (Göteborg stad, 2014) that could be used for open stormwater solutions that have the potential to take pressure of the WWTP in Gothenburg.

Previous investigations that were done in connection to governmental zoning have shown that there is a strong resistance among the local population against new residential construction projects in the area (and/or any other project for that matter) that has the possibility to take away/limit or change the green public areas in Guldheden (Göteborg stad 2005, Göteborg stad 2009b).

The study site is located in southern Guldheden, in a small park (i.e. beside Sister Ainas street). See the figure 7 below for a simplified overview of the area.

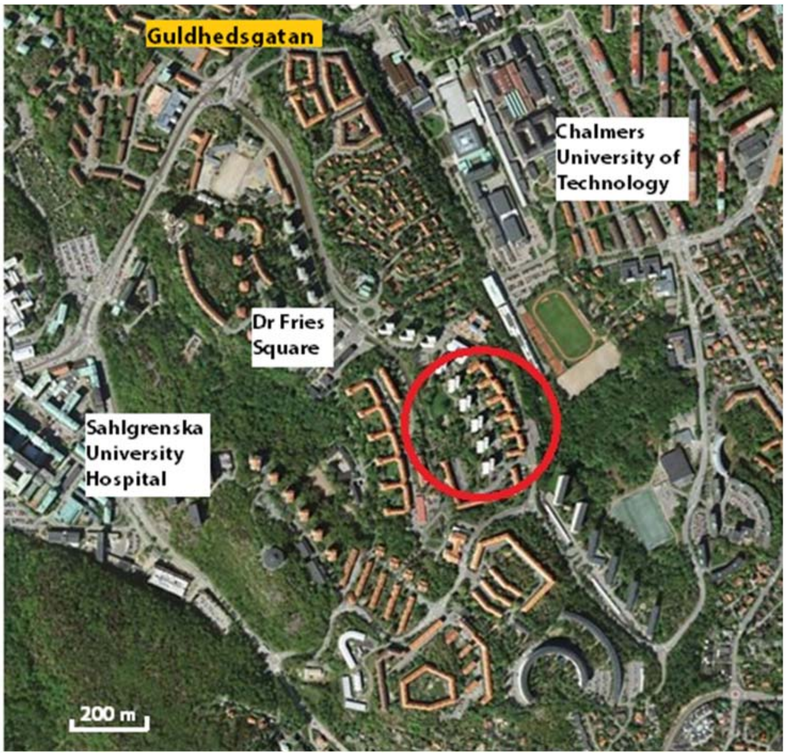

Figure 7: Illustration of Guldheden and its surroundings. The red circle indicates the study area. The white boxes show some important landmarks in the vicinity and the yellow box shows the biggest road in the vicinity (heavy traffic) (Eniro maps, 2014).

The following sub-chapter describes the study site in more detail.

3.2.1 The study site

The investigated urban park area is located beside Sister Ainas Street and covers an area of approximately 2.44 ha (see figure 8 below). Topographically the highest part is situated in the southern part that is dominated by a rocky hill (visible bedrock) and a grove of trees, while the lowest part is situated by the parking lot in the north.

Today the area is a construction site since the city of Gothenburg is constructing a new preschool at the site that is expected to be completed in March 2015. In connection to this project, the city has decided that the park should be upgraded with new plants, trees and wooden benches etc. Gothenburg city has stated that they strive to manage the stormwater and drain water locally on site (if possible) and/or creating green areas designated for infiltration of stormwater etc. The land is owned by Gothenburg city and the company Poseidon.

The area is a typical urban area, surrounded by concrete roads and high residential houses (i.e. apartments). A tram railway is located just outside the western parameter of the park. A social-ecological analysis that the Gothenburg city conducted in 2005 came to the conclusion that the park is to most part used only by the local residents (Göteborg stad, 2005b).

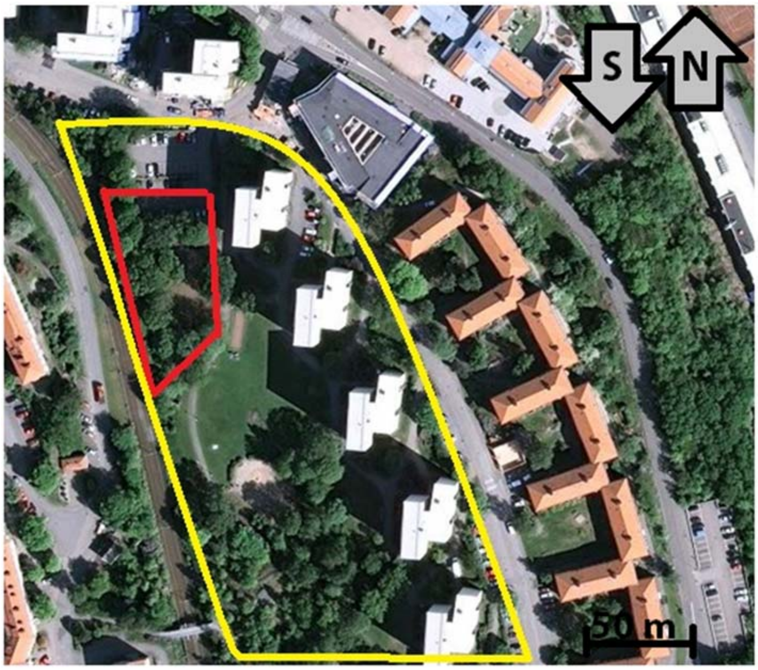

Figure 8: Satellite image showing the park area (see yellow area) and the ongoing construction site for the new preschool building (see red area) (Hitta map service, 2014).

Geological conditions

The area is dominated by post-glacial clay and sand overlaying the partly visible bedrock (see figure 9 and 10 below). Sandy till can also be found in some areas. The visible outcrops (i.e. rock) in the southern part is mainly granite, grandiorite and monzonit (i.e. sour intrusive bedrock) (SGU, 2009b) (see Appendix M for maps).

Figure 9 and 10 were taken by the author on the study site in May 2014 (Bergqvist, 2014).

PART 4 – DESCRIPTION OF MULTI CRITERIA ANALYSIS (MCA)

4.1 MULTICRITERA ANALYSIS

Multi-criteria analysis (MCA) or Multi-criteria decision analysis (MCDA) is a tool used to help decision-makers finding the best compromise (or solution) out of many alternative options to a complicated problem.

The benefits of MCA is that is takes into account many different perspectives (such as; economic, environmental, technical and social parameters etc) into the analysis. MCA is often used for complex situations and problems (when several options most be evaluated with respect to more than just one perspective) since it provides a structural and transparent way to evaluate and compare different options against each other (Linkov and Moberg 2012). MCA is a common tool for sustainability assessment that is often used as a scientific basis for communicating a solution to the public (or other stakeholder groups) and convincing them about its legitimacy (Achillas et al, 2013).

MCA is commonly used to identify the most preferred option (among a number of alternative options) but it can also be used to identify the most preferred options that will be subjected to further investigations - or just to distinguish the acceptable options from the unacceptable options. This is done through structured ranking based on a number of pre-selected criteria (DCLG, 2009). There are many ways to do this but one of the most common ways to do this is to use weighting, where the option that receives the overall highest weighted score will be the most preferred option followed by the second best option and so on (Steele et al, 2009). An MCA can be divided into two main stages – first, different policies and options are decided upon that will achieve the specific objectivities of the MCA. Second, weights and scores are attached to the objectivities (i.e. criteria) that allow comparison between the different suggested options and rank them in accordance to preferences. MCA is a tool that measures gain and losses for options within a certain project (Bhagtani, 2008).

MCA depends much upon the expertise and judgment of the decision-making group that puts the MCA together and decides upon what options to investigate for a certain problem and what criteria/objectivities, scores and weights to use in the analysis (Bhagtani, 2008). The preference matrix is an important aspect of the MCA where rows and columns are used to illustrate the performance of each option against the pre-selected criteria (DCLG, 2009).

The studied options are scored by assessing how well they perform with respect to each criterion and a pre-defined scale is used for this (e.g. 0-10 or -5 to +5). The option that will receive the highest score is the option that (in overall) is associated with the most positive grading (i.e. the most proffered among the selected options). Weights are assigned to each criteria in order to highlight their importance in the MCA (it is not necessary that all criteria are equally important in the decision-making process, for example the economic aspects might receive a higher weight than social aspects in some applications) (Bhagtani, 2008).

There are 8 steps in the MCA that will be described in the next section (DCLG, 2009). See figure 11 below.

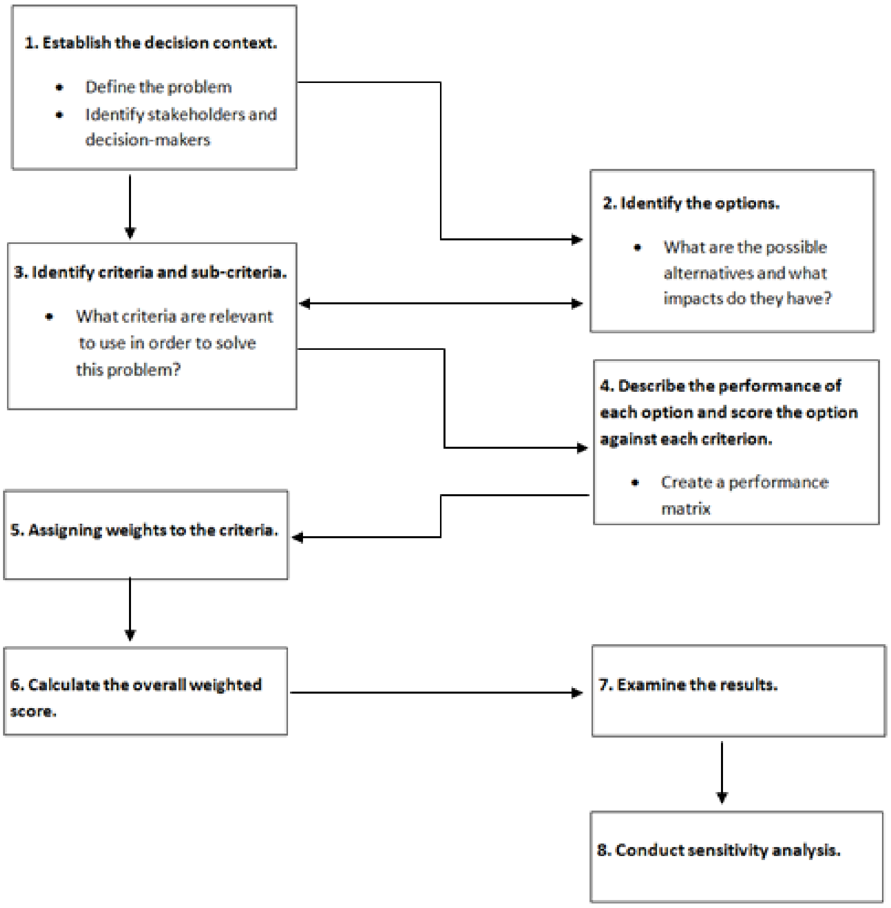

Figure 11: The 8 steps in the MCA. Figure is based and modified on information from DCLG 2009, Bhagtani 2008 and schematic model from Dooley *et al* 2005.

4.2 THE 8 STEPS IN MCA - STEP BY STEP

1. Establish the decision context.

The first step is to establish aims for the MCA and identify different stakeholders groups that is (or should be) involved in the analysis. It is sometimes recommended to make sure that the social-, political- and administrational structures surrounding the decision is established early in the process. Since MCA is based on the background and expertise of the people involved it is sometimes good to consider the objectives of the decision-making body. A MCA may also be influenced by the local administrative and historical context of the area and it is important to identify the different stakeholder groups that may be affected by the outcome (i.e. result).

In most cases, a single high level objective is identified at the beginning of a MCA that is later on broken down to several sub-objectives. The aim of the study most be clearly stated early in the process in order to avoid time consuming problems (such as gathering an excess of data and information for the wrong purposes) (DCLG, 2009).

The people responsible for the decision making should be identified at an early stage (i.e. such as scientists, public servants, private consultants and member of the urban population). A simple distinction can be made between different participants that contribute and participate to a MCA project; key players and stakeholders (see table 15 below for a summary). Key players are important since they hold knowledge and expertise regarding the subject of the analysis and no MCA can be conducted without this particular group (i.e. just involving stakeholders in the MCA is not acceptable). Stakeholders have an interest and/or investment in the outcome of the MCA (i.e. financially or socially) and it is important to make sure that their opinion is taken into account even though they may not be directly involved in the MCA (DCLG, 2009).

Table 15 – Recommended stakeholder groups to include in a MCA (DCLG, 2009).

People participating in a MCA project	Definition	Examples
Key players	Anyone that can make a useful contribution to the MCA.	Scientists, engineering consultants, public servants, citizens etc.
Stakeholders	Anyone who has an invested interest in the outcome of the MCA.	Governmental institutions, private companies, citizens etc.

It is important to discuss the socio-technical system aspect of the analysis. In what way (when and how) will the people participating in the MCA contribute to the analysis (i.e. social aspects) and what type of MCA would be best to use for this particular study and how should it be implemented? (i.e. technical aspects). For example, a MCA that is the foundation of an important decision-making process (such as finding the location of a new central station in an urban area) will have to incorporate a lot of different criteria and aspects from various stakeholders, key players and other interest groups. It is important to consider early in the process what kind of aspects that is important to incorporate in the analysis – and which that is not. One way to achieve this is to hold public and private meetings with a variety of different stakeholder- and interest groups (i.e. facilitated workshops) (DCLG, 2009).
A description of the current situation with clear goals of the study will make sure that the MCA stays “on the right track” towards reaching its objective.
There are many possible ways to structure a MCA in order to reach a common consensus and the result of this kind of analysis may also support decision-makers through providing (for example);

- Clarification about the differences between different options
- Provide a deeper understanding of the problem to the stakeholders
- Improve communication between isolated parts of society
- Sort out the acceptable options from the unacceptable ones

- Provide a basis for investigating alternative new options (if the ones included in the MCA do not meet the demand of the analysis). (DCLG, 2009).

2. Identify the options.

The second step is to consider what options that should be included and compared in the MCA. Often the decision making group has a lot of experience within their own fields (i.e. geology and hydrogeology, economy, environmental and technical analysis etc) and are able to provide a number of acceptable solutions that could fit the objective of the MCA. If however, none of these (often traditional and well established) solutions will work for a certain problem – then new fresh ideas are required. In order to accomplish this, the decision group may use brainstorming in order to creativity come up with a better alternative. The possibility of seeking additional input/ideas outside the groups owns members may also be required (DCLG, 2009).

There is no need to start gathering data before the options have been confirmed to be practical applicable in real life for the defined problem. Therefore a short list of viable options should be created before time-consuming data collection begins (Bhagtani, 2008).

3. Identify criteria and sub-criteria.

An MCA need to establish good criteria for the analysis since the criteria is the basis of comparison between different options. The criteria chosen need to be practical and operational – so that ranking can easily be done between the selected options. Examples of criteria could be; environmental impact, social aspects, technical performance etc.

The criteria is often chosen as a result of brainstorming with the selected group that participate in the MCA and thus normally reflects the values that this group associate with a good solution. But additional data may also be required and more information may be necessary in order to make a good decision regarding which criteria that should be kept for the study and which one to dismiss. The criteria should not be vague (or hard to interpretive) in order to make sure that the people scoring each option does not make mistakes (DCLG, 2009). The number of criteria chosen should not be too many (i.e. thus complicating the analysis more than necessary) or too small (i.e. thus simplifying the analysis to an unscientifically extent) (Bhagtani, 2008).

The criteria can also be grouped together into a series of sets (if they are distinguishable and separate components that relate to a head criterion). For example, the criteria “patient experience” can be divided into several sub criteria (i.e. sub sets) such as: i) time spent at the hospital, ii) speed of treatment, iii) degree of pain and iiii) discomfort etc.

Often grouping of criteria is portrayed as a “structured value tree” (thus illustrating the connection between objectives and criteria) in the MCA (DCLG, 2009).
When several criteria have been chosen for the MCA, an assessment should be done in order to assure that the criteria are representable with regard to the purpose of the MCA (see table 16 below).

Table 16 – Assessment of criteria for MCA (DCLG, 2009).	
Completeness	• Is all the criteria needed to make a good comparison between these options represented? • Is there any criteria missing? • Have all the key aspect of this MCA been represented?
Redundancy	• Are some of the criteria chosen for this analysis unnecessary?
Operationality	• Can each option be compared to each other and judged against the same criteria in a good representative way?
Mutual independence of preferences	• Can scores be assigned independently to each option for each category.
Double counting	• Make sure that the same impact is NOT portrayed in two (or more) criteria! (i.e. this is normally done by grouping and dividing the criteria into sub-criteria's in order to avoid double counting).
Size	• Too many criteria may complicate the MCA to an unnecessary degree and make communication of the results difficult. The number of criteria matters.
Impacts occurring over time	• Good decision-making should also focus on the long term effects of a decision and its future consequences.

4. Describe the performance of each option and score the option against each criteria

After grouping and dividing the criteria into different sub-criteria it is important to describe the consequences of each option investigated in the MCA. Often a simple qualitative description in a consequence table (i.e. a performance matrix) will suffice for this step - that has separate columns and rows for each criteria and option. For more complicated problems a separate consequence table can be constructed in order to evaluate each option separately from another (this often done for problems that use a value tree) (DCLG, 2009).

The list of suitable stakeholders chosen at the beginning of the MCA will then at this stage rate each option in relation to each criterion (i.e. scores will be added to the performance matrix). In MCA, scores represent preferences with regard to criteria and option. In other words, the performance of each option will be scored (i.e. through ranking) by the selected stakeholders based on their own background and knowledge. The scoring can be done in different ways, such as direct rating (DCLG, 2009).

Direct rating acknowledges the expertise and judgment of the people doing the rating. For example: a score set of -2,-1, 0, +1, +2 could be used in order to rate different options through selected criteria (see table 17 below). Another very common method is to use a score set between 0 to +100. The higher scores represent a better alternative (i.e. a more positive effect) than the lower scores (i.e. negative effect) (DCLG, 2009).

Table 17 – Rating (example)

Very positive effect	+2
Positive effect	+1
No effect (neutral option)	0
Negative effect	-1
Very negative effect	-2

Problems concerning the direct rating method could be associated with:
i) the number of different backgrounds of the experts doing the rating (i.e. the perception of what is a positive or negative effect may vary between different professionals) and
ii) the objectivity of the assessment (i.e. it is important to make sure that the experts doing the rating has no personal stake in the outcome of the MCA) (DCLG, 2009).

After this stage, consistency of the scores on each criterion is checked in order to ensure valid results. However, consistency checks may also take place during the process of assessing scores. The method chosen for this depends on which scaling set that has been used in the MCA. Some iterations may be required in order to assure that stakeholders understand and assign scoring points that relates to the “real world” (i.e. that their preference are made up by sufficient consistency) (DCLG, 2009).

5. Assigning weights to the criteria

After the performance matrix has been constructed and the scoring method decided, the selected group of experts (i.e. the decision-makers and MCA analyzer) normally sits down and scores each criterion in accordance to their own judgment and expertise. Some criteria may be considered to be more important than others. The rating will therefore reflect what criteria that are the most important ones (for making the overall decision) and which criteria that are less important to consider. This will enable comparison between the selected options in the MCA. In other words: “*the weight of each criterion reflects both the range of difference between the options and how much that difference matters*” (DCLG, 2009).

The method “swing weighting” is often used for this step and is (once again) based on preferences with regard to comparing differences between criteria. The scoring set are decided by the decision making group and could be, for example set to be 0 to +100 or just 0 to 1 (DCLG, 2009).

For example; if a score set of 0 to +100 is used – how much points will the four main criteria (environmental-, social-, technical- and economic aspects) receive? The weighting can be done as illustrated in table 18.

Table 18 – Example of weighting in MCA

Rank	Criteria	Group weight (i.e. points)	Simplified description of weight of each criteria in the MCA
1	Economic	40	Very important
2	Environmental	30	Rather important
3	Technical	20	Not very important
4	Social	10	Rather unimportant
	Sum:	100	

This means that for the decision-making group conducting the MCA, the most important criteria in their analysis is economic aspects (no 1) and the least important criteria is the social aspects (no 4) for the example illustrated in figure 18 above. The weighting is very subjective with regard to the people involved in the MCA (i.e. the decision making group) and will therefore vary from project to project.

6. Calculate the overall weighted score

When weights have been assigned to the criteria (and scoring has been done by the decision-making group´s participants) then it is time to calculate the overall weighted scores for each option in order to come to a final conclusion for the outcome of the MCA. This action can be done by a computer program or for simplified analysis – by a calculator (DCLG, 2009).

For the purpose of this study, the **linear additive method** (LAM) was used. The LAM is commonly used today due to the fact that models based on this method are known to provide decision-makers with transparent results on a variety of problems (DCLG, 2009). The linear model *combines* the value of each chosen option with the chosen criteria and puts it together into an overall score. Through multiplying the weight of each criterion with the value score for each criterion – the end score (i.e. result) is the sum of all the weighted scores combined for each option (DCLG, 2009). This is done in two steps:

First, every criterion, i (where i = 1, 2, 3… n) is assigned a certain score, R.
Second, every criterion is assigned a certain weight, W – which is weighted together with the score given for each criterion. The sum (i.e. end score) provides the weighted result for each option (Rosen et al, 2009).

$$\text{End score} = \sum_{i=1}^{N} \mathrm{W_i}\ \mathrm{R_i} \qquad \text{(Eq. 5)}$$

Before using the linear additive method (as a general rule) it is important to make sure that all of the criteria used for the MCA are *mutually preference independent* (i.e. the criteria must have been assessed thoroughly in order to assure that the scores assigned to each criteria are independent and does not influence the scoring between different options in the MCA) (DCLG, 2009).

7. Examine the results

The result of an MCA is given by the weighted average scores (calculated from the preference scores, i.e. the decision making group´s ratings). The result gives an indication about how "good" the best option is in relations to the other options that have been investigated.

For example, if option A, B and C scores -1, 0 and +2 respectively then option C is the best alternative (very positive effect – i.e. a good alternative) as compared to option B (neutral – i.e. no effect) and C (negative effect – i.e. a bad choice) (DCLG, 2009).

However it is important to evaluate the results thoroughly before taking any "real" decision. What the result is telling the reader is simply that "based on these few selected criteria that has been rating by this particular decision making group – this option is the most preferred one". An MCA can provide surprising results that may need to be discussed.

In order to communicate the results to a broad audience, graphs and plots are commonly used in order to show the main trade-offs between different options (DCLG, 2009).

8. Conduct sensitivity analysis

Sensitivity analysis is preformed, for example, to assess how much different criteria influence the final outcome of an MCA. It is a way to investigate how much the different criteria- and individual ranking affects the end result. Sensitivity analysis can also be performed in order to investigate how the interpretation matters due to vagueness regarding the selected options (DCLG, 2009).

The purpose of a sensitivity analysis can be expressed as to evaluate how "scientifically good" the analysis is. One way to perform the analysis is by changing the input variables (i.e. weighting and/or scoring of criteria) in order to evaluate which criterion/criteria that has the largest impact and influence on the final outcome of the MCA (DCLG, 2009).

Other aspects of uncertainty involved in MCA

Besides conducting a sensitivity analysis, it is also important to consult the selected decision making group (i.e. the experts responsible for weighting) about their opinions regarding the criteria used for the MCA and their own scoring. The final outcome of an MCA can often be surprising and if there exists disagreements within the decision-making group after the result has been presented – a thorough sensitivity analysis may help the group understand the circumstances better since its purpose is to elaborate on *why* a certain option was scored the highest. Sensitivity analysis can also help future investigations by highlighting some criteria that could be improved (or even cut off) from a similar MCA (DCLG, 2009) or if more information needs to be collected in order to ensure the validity of the results (Lindhe, 2014).

Risks assessment (including risk perception) will also vary between different groups of people and depend on much on their background and experience. For example, the public and the academic experts may *not* have the same idea about what a "risk" is (i.e. is risk a probability or just as an expression of uncertainty?) (DCLG, 2009).

4.3 BENEFITS AND DISADVANTAGES OF MCA

Even though MCA is a good scientific tool to use for complex problems there are some disadvantages that are associated with this kind of analysis. For a simplified summary of benefits and disadvantages of MCA - see table 19 below.

Table 19- Benefits and disadvantages of MCA (Achillas et al 2013, European Commission 2005, Bhagtani 2008, Resource Assessment Commission 1992, DCLG 2009).

Benefits	Disadvantages
• Are able to determine a specific solution to a complicated problem. • Incorporates many different parameters (i.e. social, economic, technical etc) into the decision making process. • Provides a transparent and structured scientific analysis. • Are able to use data that is both quantitative and qualitative. • Can incorporate different values and interests trough stakeholder interaction. • Excellent tool to use for stakeholder negotiations and debates. • Sensitivity analysis provides understanding to the outcome regarding what criteria that effected the results the most etc.	• Depends largely on the selection of criteria (i.e. if the criteria is inadequate for finding a good solution –the the result will be flawed). • Depends on the availability of data and the expertise and knowledge of the decision-making group that perform the ranking/scoring. • Can be very time-consuming (i.e. stakeholder debate regarding which criteria to use in the analysis etc). • Input into the model (i.e. weighting score for the criteria etc) is often based on the background and personal views of the expert group involved. • Problems could arise if the stakeholders involved have a personal interest in the outcome (i.e. risk for manipulation). • Different MCA methods may lead to different conclusions.

PART 5 – MULTICRITERIA ANALYSIS (MCA) OF GULDHEDEN

5.1 ASSUMPTIONS AND MOTIVATION

For the purpose of this study, a MCA that focused on sustainable development within the field of urban stormwater was constructed that evaluated two viable options for the study area (i.e. the dry pond and macadam basin) that was compared against the present system (i.e. the combined system/BAU alternative). The analysis focused on environmental, social and economic aspects of each alternative that were evaluated during two different time scales; short term (<2020) and long term (<2100). This resulted in six different scenarios that were evaluated in the MCA.

During the MCA the following simplified assumptions regarding local climate and urban expansion were made (see table 20 below).

Table 20 – Scenarios for Gothenburg used in the MCA with respect to the urban drainage system (Svenskt Vatten 2011, SGI 2011, SOU 2007, Länsstyrelsen Västra Götalands Län 2011)

Parameters	Short term (< 2020)	Long term (< 2100)
Local climate	No large difference from today.	Increase in annual precipitation, heavy rain periods and average temperature. Higher runoff flows during autumn and winter and less days with snow. Groundwater availability will increase.
Urban expansion and population	No large difference from today.	Expansion of urban drainage system will put extra pressure on Ryaverket and a new WWTP must be built.

Available data gathered during the literature review were used as a foundation for the motivation and ranking of the selected criteria. Based on stormwater calculations, schematics for suitable facilities on the study site were made which provided the basis for the estimated economic cost for the i) dry pond and ii) macadam basin, that were used for the economic analysis and grading.

5.2 THE ANALYTICAL PROCEDURE

The following sub-chapters describe the preformed MCA, step by step.

5.2.1. Establish the decision context.

The aim of the MCA was to find and evaluate suitable sustainable stormwater solutions that could be used at the study area in Guldheden (Gothenburg) that could be recommended to the city of Gothenburg. The time available for the MCA were decided to be approximately 20 weeks (fulltime).

Keyholders and stakeholders were identified through brainstorming with the stakeholder group GKCC and a list of suitable candidates was drawn up. The goal was to contact these individuals and ask them if they could submit themselves to an interview that would be complementary part of the MCA (see table 21).

Table 21 – Identification of stakeholder groups involved in the MCA

People participating in the project	Role in the MCA	People involved
Key players	Contacted for interviews and grading (i.e. scoring) of selected options with regard to criteria and time period.	Scientists and industrial researches (Chalmers University of Technology), engineering consultants (COWI AB), public servants from the city of Gothenburg (Kretslopp & Vatten, Gryaab AB and Office of public management) and local politicians.
Stakeholders	People who was identified as having an invested interest in the outcome (i.e. the result) of the MCA.	Governmental institutions (the city of Gothenburg – Gryaab AB, Kretslopp & Vatten), the citizens of Gothenburg.

The effect on the WWTP in Gothenburg was considered important and therefore highlighted in the criteria together with local conditions regarding the economic, social and environmental aspects in Gothenburg area and on the study site.

5.2.2 Identify the options.

It was decided that the study should focus only on a few stormwater options/solutions for the study area in order to ensure a more efficient and detailed investigation. The options were decided after initial discussion and brainstorming with a stormwater consultant at COWI AB (Frohm, 2014). It was further discussed on one of the initial stakeholder group meetings that the study should focus on two different time perspectives (for each option); *short time period* (>2020) and *long time period* (>2100). The short time perspective was thought to contain the time period during construction and a few years afterwards (for example if construction of a stormwater facility on site started in 2015 on site this option would evaluate the impacts up until 2020, approximately 5 years). The long time period (<2100) was chosen to incorporate the additional effects that climate change would have on the stormwater facility on site.

The following two options were decided for the study:

- Dry pond with vegetation
- Macadam basin

The "zero alternative" for these two options was chosen to incorporate the effects that the study area would have if they continued to connect their stormwater to the combined system – as they are doing today (i.e. Business As Usual, BAU).

The result was three different options to be closer investigated in the MCA with respect to two different time periods (see table 22 below for a summary). This provided the MCA with six different scenarios that were evaluated through stakeholder rating (i.e. scoring) in combination with a more detailed investigation of the available options by the MCA analyst.

Table 22 – Summary of options investigated in the MCA

Options considered	Location of facility	Time period
1. BAU (i.e. zero alternative)	Existing underground drainage pipeline system (i.e. no impact on the park)	a) Short time period (<2020) b) Long time period (<2100)
2. Dry Pond with vegetation	Middle of the park area	a) Short time period (<2020) b) Long time period (<2100)
3. Macadam basin	Underneath the existing parking lot (i.e. located at the rim of the park)	a) Short time period (<2020) b) Long time period (<2100)

5.2.3 Identification of criteria and sub-criteria.

Through brainstorming sessions with participants from the stakeholder group it was decided that environmental, social and economic aspects were the three main criteria that would best reflect the important aspects that was required in order to achieve the goal and objectives of the study -since the focus of the MCA evaluates the sustainability aspect of stormwater solutions, these three aspects were considered very relevant for the study.

These three main criteria were first broken down into *sets of criteria* that were considered relevant for the site. These criteria were then further re-shaped into *sub-criteria* (i.e. more specific criteria).

The table 23 below illustrates the criteria used for this study.

Table 23 – Summary of criteria used for the MCA

Main criteria	Sets of criteria	Sub-criteria
Environment	Pollutant load to the environment	• Environmental impact on recipients downstreams
	Pollutant load to the WWTP	• Environmental effect on sewage sludge at the WWTP
	Flow regulation to the environment	• Impact on local ground- and surface water cycle
	Flow regulation to the WWTP	• Potential to delay stormwater on site
	Biophysical environment on site	• Soil quality and soil erosion • Ecological diversity potential
Social	Cultural and social aspects	• Community acceptance • Risks for local community
	Educational and scientific aspects	• Opportunities for informal and formal education
Economic	Typical investment costs	• Land costs • Adaptation cost to existing urban drainage systems *(if required)* • Cost of installation of water facility on site
	Operation and maintenance (O&M)	• System reliability • Operation and maintenance costs
	Economic impact on WWTP	• Revenues relating to sewage sludge for the WWTP • Cost-saving potential for the WWTP due to decreased wastewater flow and volume

A more detailed description of what factors to include in the evaluation of each sub-criterion is found in below in table 24 (Environmental), table 25 (Social) and table 26 (Economic).

Environmental sub-criteria

The environmental sub-criteria are rated through how much effect the selected option/-s will have on the environment. In other words: “how much will this option influence the environment- both on the study site and downstreams the WWTP in the near future (<2020) or in the long time perspective (<2100)?”

Table 24 – Description of ENVIRONMENTAL parameters for selected environmental sub-criteria.

Sub-criteria	Parameters analyzed	Description
Environmental impact on recipients downstreams	• Drinking water quality and water status	Estimation of pollution concentration present in stormwater on site (after transport through stormwater facility), influencing drinking water quality for humans and water quality for recipients downstream of site.
	• Regulation of pollution transport downstreams	Estimation of stormwater solutions capacity to reduce and/or detain pollutions in combination with vegetation on site (i.e. some stormwater solutions in combination with vegetation may help contain some pollutants through; dilution, filtration and sequestration on site and lower the pollution load transported downstreams to recipients).
	• Impact on European Water Framework Directive	Potential to affect the chemical and ecological status in downstream recipients.
Environmental effect on sewage sludge at the WWTP	• Regulation of pollution transport downstreams (combined drainage system).	Potential to influence the WWTP sewage sludge quality if the stormwater is connected to the combined system.
Impact on local ground- and surface water cycle	• Impact on local water cycle	Potential impact on ground- and stormwater flows in the area (i.e. change in groundwater levels, increased runoff to local rivers).
Potential to delay stormwater on site	• Impact on stormwater flow.	Potential for decreasing the volume of wastewater transported to the WWTP.
	• Impact on flooding events.	Potential of decreased water flow through stormwater solution, resulting in fewer flooding intervals.
Soil quality and erosion potential	• Impact on urban soil quality and erosion potential.	Estimation of effect on soil quality on site, sediment retention and erosion potential.
Ecological diversity potential	• Impact on the ecological habitat.	Potential for change in biological diversity at site.

Social sub-criteria

The social sub-criteria are rated through how much effect the selected option/-s will have on the local population living at the site or in close proximity to the park (i.e. the study area). In other words: “how much will this specific solution impact the local people in the near future (<2020) and in the long time perspective (<2100)?”

Table 25 – Description of SOCIAL parameters for selected social sub-criteria.

Sub-criteria	**Parameters analyzed**	**Description**
Community acceptance	• Outdoor recreational activities	Impact on local people’s motivation for outdoor recreational activities in the vicinity (and inside) the park.
	• Beauty and aesthetic values of stormwater solution	Probability that people will find and aesthetic values in stormwater solutions added to the park.
	• Size of land required	Loss of public land for each solution.
Risks for local community	• Risk acceptance by the local community	Will the local community perceive any risks associated with this kind of solution? (i.e. open stormwater system could pose a risk for small children, through drowning etc.).
Opportunities for informal and formal education	• Education potential as a direct result of stormwater solution	Potential for site to have more educational opportunities after solution is applied (i.e. beautiful stormwater solutions may attract outsiders to area and provide learning opportunities for children etc.). Potential for increased tourism to area.

Economic sub-criteria

The economic sub-criteria are rated through how much effect the selected option/-s will cost the municipality of Gothenburg. In other words: "how much money will this particular solution cost society in the near future (<2020) and in the long time perspective (<2100)? ".

Table 26 – Description of ECONOMIC parameters for selected economic sub-criteria.

Sub-criteria	Parameters analyzed	Description
Land costs	- Land costs	Different solutions may require different amount of land area for construction – estimation of the land costs.
Adaptation cost to existing urban drainage systems	- Extension of urban drainage pipeline network (if required).	Estimation of costs relating to connecting the stormwater system to the stormwater drainage pipeline (if required).
Cost of installation of water facility on site	- Material and construction costs	Estimation of construction- and material cost for building the stormwater solution on site.
System reliability	- Lifespan and reliability of technology	Estimation of lifespan of technology and cost relating to system failure.
Operation and maintenance costs	- Operation- and maintenance costs of the facility for the municipality	Estimation of maintenance and operation costs for each solution.
Revenues relating to sewage sludge for the WWTP	- Quality of sewage sludge and revenues for the WWTP	Estimation of revenues related to sewage sludge quality for the WWTP (if stormwater system is still connected to the WWTP).
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	- Potential for saving treatment costs of wastewater at the WWTP	Estimation of possibility to cut cost (i.e. energy and chemicals etc.) through the treatment process at the WWTP as a direct result of a lower inflow to the system.

5.2.4. Describe the performance of each option and score the option against each criterion

Each of the 3 stormwater options were described in a consequence matrix with regard to i) main criteria (see table 27 below) and ii) with regard to a more detailed evaluation with regard to sub-criteria (see Appendix F). Consequences were identified in accordance to the two different time sets, i.e. short term (<2020) and long term (<2100).

See table 27 for a simplified summary of identified consequences and performances for the BAU, dry pond and macadam basin with regard to costs, environmental impact and social attribute.

Table 27 – Identifying consequences and performances (with and without measures)

Measure	**Identification of Impacts**	**Rough estimation of costs (short term <2020)**	**Rough estimation of costs (long term < 2100)**	**Rough estimation of environmental impact and social attributes (short term <2020)**	**Rough estimation of environmental impact and social attributes (long term < 2100)**
1. BAU	If no measure is taken to minimize the waste- and stormwater flow transported to Ryaverket then the only option is to build a new WWTP in Gothenburg that can handle the future increase in wastewater flow as a direct result of a growth in urban population in combination with climate change.	There will be a small to moderate increase in cost for Ryaverket (i.e. for energy and chemicals used for treatment of wastewater and for the extension of the existing urban drainage network yearly as the population increases etc). **→ Less expensive**	A new WWTP must be built in order to make sure that the environmental status of the treated wastewater is acceptable to the Swedish environmental guidelines (a most likely scenario today). This will add high costs for example, constructing a new connecting drainage network, the installation costs for the new facility, land costs etc. **→ Very expensive**	No significant change with regard to environmental concerns (i.e. pollutant load in stormwater going to Ryaverket). Socially there will be the same technical system in place and attitudes will most likely not change. **→ No change**	A new WWTP has the potential of improving the environmental status of the wastewater (due to more efficient technology). However climate change will put more pressure on the facility (i.e. more intensive rainfalls etc). Socially there will be the same technical system in place and attitudes will most likely not change. **→ Moderate improvement**
2. Dry pond with vegetation	A new stormwater solution at Guldheden will help decrease the waterflow to the WWTP and take some of the pressure Ryaverket. This action (on a larger scale) would improve the water treatment capacity of Ryaverket and help reduce problems during extreme weather events (during intensive rainfall or snow melting) such as CSOs and local flooding.	There will be a small cost for building and installing the stormwater facility on site (i.e. construction costs etc). **→ Less expensive**	There will be a small cost for maintenance work (i.e. removal of plants and new soil layer etc) on a yearly basis. An upgrading of the facility may be required. **→ Less expensive**	Small environmental improvement due to the detaining and natural filtration and binding of contaminated stormwater on site – reducing the water flow transported to Ryaverket. Social acceptance is very likely due to the esthetic values that the new plants will bring to the park etc. However, a small risk for society may exist for open stormwater solutions (i.e. small children playing by the water). **→ Small improvement**	Small environmental improvement due to the detaining and natural filtration and binding of contaminated stormwater on site (if the facility is maintained properly). Climate change will cause more frequent stormwater runoff volumes – increasing the pressure on the facility. Social acceptance is very likely to remain the same. **→ Small improvement**
3. Macadam basin		There will be a moderate cost for building and installing the stormwater facility on site (i.e. construction costs etc). **→ Moderately expensive**	There will be a moderate cost for re-building the facility on site (it won't last 80 yrs). Annual maintenance is also required (i.e. the removal of leafs from the wells etc). **→ Moderately expensive**	Small environmental improvement due to detaining and natural filtration of contaminated stormwater underground - reducing the water flow transported to Ryaverket. Social acceptance is very likely since no park area is used for the construction of this facility. **→ Small improvement**	Small environmental improvement due to detaining and natural filtration of contaminated stormwater underground (if the facility is maintained properly). Climate change will cause more frequent stormwater runoff volumes – increasing the pressure on the facility. Social acceptance is very likely to remain the same. **→ Small improvement**

5.2.4. Score the options based on the criteria

Direct rating was chosen as the most suitable ranking method. A scoring set of 5 options (i.e. -2,-1, 0, +1, +2) was used in order to rate the different options with respect to environmental, social and economic criteria in accordance to performance and impact (see table 28 below).

Table 28 – Rating	
Very positive effect	+2
Positive effect	+1
No effect (neutral option)	0
Negative effect	-1
Very negative effect	-2

As a general (simplified) guideline for rating with respect to the three main criterions, the descriptions below were used.

Environmental rating

The rating for environmental criteria will be solely taking into account the effect on the environment. The rating will be expressed as the following (as a general guideline): **very positive effect** (i.e. potential to largely improve the environmental status) will be rated (+2), **positive effect** on the environment (i.e. potential to improve the environmental status) will be rated (+1), **no change** in the environmental status due to this particular solution (0), **negative effect** (i.e. more contamination potential and due to this specific solution) will be rated (-1) and **very negative effect** (i.e. a large increase in contamination potential) will be rated (-2).

Social rating

The rating for social criteria will take the local people’s feelings and opinions into account. The rating can be expressed as the following (as a general guideline): The people will experience a **very positive effect** of the solution (i.e. people will *strongly approve* to the solution) will be rated (+2) or just a **positive effect** (i.e. people will approve of the solution) will be rated (+1), **no effect** on people’s motivation to live close by or to do recreational activities in the park will be rated (0), **negative effect** associated with the solution (i.e. people will object to the solution) will be rated (-1) and a **very negative effect** (i.e. people will *strongly object* to the solution) will be rated (-2).

Economic rating

The rating for the economic sub-criteria will be after this particular model, costs are expressed as negative values: **very expensive** (-2) and **expensive** (-1). No change in cost (i.e. **no effect**) will be scored as zero (0) and cost-saving potential will be expressed as the following: **cost saving potential** (+1) and **very good cost saving potential** (+2).

5.2.5 The stakeholder interviews

Interviews were conducted during the early summer in Gothenburg (May and June in 2014) - were stakeholders were asked to score each solution based on the selected criteria in accordance to the two time periods. A total of 13 interviews were conducted with professionals from a variety of academic backgrounds (politicians, engineering consultants within waste- and stormwater, architects, scientists, public servants and managers within hydrology, water and park management in Gothenburg city etc). From these interviews, nine were chosen to become a part of the MCA. A short description of these stakeholders is shown in table 29 below. The other four was added as complementary input into the analysis. The reason these stakeholders were not included were based on the fact that that they did not score all the options (i.e. they skipped some criteria that they felt unsure of) and so their scores became inconclusive.

Table 29 - Stakeholder description

Stakeholder	Background and experience
A	PhD. Adjunct professor at Chalmers University of Technology. Manager for Development, Quality and Environment at Gryaab AB in Gothenburg. Has 26 years of experience within the field.
B	Head of Division of Strategic Planning at *Kretslopp och Vatten* (Gothenburg city). She has 15 years of experience within the water sector.
C	Specialist hydraulic calculations (hydrological modeling) at *Kretslopp och Vatten* (Gothenburg city). He has 35 years of experience within the water sector.
D	Project manager within the water and soil area at the office of public management in Gothenburg city (i.e. stadskontoret). He has 15 years of experience within the water sector.
E	Investigator within water and urban drainage area at COWI AB in Gothenburg. He has 12 years of experience within the water sector.
F	PhD. Adjunct professor at Chalmers University of Technology. Works at the division of strategic planning at *Kretslopp och Vatten* in Gothenburg. She has 20 years of experience in the water sector.
G	Branch head of Parks and Landscape management within the municipality of Gothenburg city. She has 30 years of experience in the sector.
H	Scientist within water, environment and technology at Chalmers University of Technology. He has 20 years of experience in the water sector.
I	Head of civil engineering technology at COWI AB. He has 30 years of experience in the sector.

Prior to each interview the stakeholders received a short background documentation regarding the study area (Guldheden) and the stormwater solutions they were asked to evaluate based on their own working- and academic experience (see appendix G for the documentation). At the interviews, the stakeholders received the consequence table (see appendix H) and were asked to rate each option in accordance to the selected rating scale.

Each interview took about 30 min to 90 min depending on the stakeholders had any questions or additional opinions to add to the investigation.

Objectivity of the stakeholder interviews and ranking

It was the judgment of the analyst and stakeholder group GKCC that the stakeholders involved in the interviews would not have a personal interest in the outcome of the MCA (since this analysis is based on a theoretical case-study with no real "buyer") and therefore their objectivity (i.e. indifference about the outcome) could be assured. Furthermore, the stakeholder's different academic backgrounds and working experience was chosen on the basis of performing a MCA based on three different angles – assuring that the outcome were the reflection of several different viewpoints and opinions from different academic fields.

This broad selection of stakeholders further ensured that the outcome of the MCA would be impartial (i.e. not just reflect the values and opinions of one academic field, such as engineering – but of many others as well).

In order to make sure that the stakeholders understood the criterions properly the MCA analyst stayed in the same room during the entire interview and rating process (except in one case where the stakeholder told the analyst that he had no questions whatsoever) in order to make sure that the ranking was done in accordance to the defined parameters (i.e. so that no misunderstandings about a sub-criteria literature meaning would make result in a mistake – such as inaccurate rating by the stakeholder).

See Appendix J for the initial scoring tables (based on the interviews).

5.2.6. Assigning weights to the criteria

Brainstorming was used in order to set appropriate weights to each criterion (i.e. environmental, social and economic) in order to highlight its importance to the decision. The main-criterion was given a certain weight that was divided between its sub-criteria (equally). Since different main-criteria had different numbers of sub-criteria (i.e. they were not evenly distributed) this aspect was important in order to assure that each criterion was given the right weight.

First, an initial hierarchy of 1 to 3 was used as basis for the initial weighting (were 1 was the most important criterion and 3 the last important one for the MCA). Economic aspects were rated as nr 1 followed by environmental aspects (rated nr 2). Social aspects were rated as the least important criterion and were therefore given the rank of 3. Second, the group weights were in accordance to this also distributed differently to the sub-criteria of each of the three main criterions. A total score of 1.0 was used that were divided in accordance to rank into the following: Economic sub-criteria were given a group weight score of **0.45**, environmental sub-criteria were given a group weight of **0.35** and social sub-criteria were given a group weight of **0.20** of the total sum.

The motivation for this weighting was that society (in most cases) values economic criteria the highest when it comes to making a decision about applying a specific solution. Economics have a large influence on most of the global major decision-making processes and therefore it was decided that the rank nr 1 should be given to Economic criterion. Environmental concerns are very important aspect of the decision-making process and were therefore given the rank nr 2. The reason social criterion scored the lowest (nr 3) is based on the fact that governmental institutions (that possesses scientific knowledge and expertise) cannot rely on the local people to see the full scale of applying a certain solution.

The term “not in my backyard” (i.e. NIMBY) summarizes the conflicting attitudes and opinions of the public when considered a solution – meaning that even if a solution or strategy might be great, they do not want it in their backyard (i.e. they are not prepared to make changes to their own local environment to accommodate the “greater good” for society) (Vittes *et al* 1993, Baptista *et al* 2007).

See table 30 below for a summary.

Table 30 – Summary of weighted scores given to each criteria		
Main criteria	Rank	Weighted group score (sub-criteria)
Economic	1	0.45
Environmental	2	0.35
Social	3	0.20
	Sum:	1.00

Final remarks of the MCA process

The final results of both MCA (i.e. based on both the ranking and weighed scores) will therefore vary between the highest- and lowest scores that is possible for this analysis (i.e. be within the range of: +2 to -2). The three alternatives (BAU, dry pond and macadam basin) was compared and scored separately from each other. The dry pond and macadam basin was scored in comparison to the present (today's) situation.

5.3. THE RESULTS

The result were divided into two part; MCA1 (the authors own analysis, J) and MCA2 (based on the stakeholders analysis, A-I). The weighted value from MCA1 and the mean weighted value from MCA2 are shown below in section 5.3.2.

Part 1 describes the (raw) scoring results from MCA1 and Part 2 the weighted results from MCA1 and MCA2.

5.3.1 Description and motivation of the scoring results from MCA1

5.3.1.1 The BAU scenario

Within the environmental criteria the dry pond scored in the interval between (0) to (-2). For pollution load to the environment (i.e. *environmental impact in downstreams recipients*) the score were (-1) in the short time scenario (due to the possibility of wastewater leaching from the old pipelines) and (-2) in the long time scenario (due to increased urban pressure on the WWTP in combination to climate change and the possibility of still ongoing leaching). For pollution load to the WWTP (i.e. *environmental effect on the sewage sludge at the WWTP*) the scores were (0) in the short time perspective (due to the assumption that the study area is not heavily polluted today and no major changes are expected to occur in the near future that could change this) and (-1) in the long time perspective (due to the assumption of increased urbanization and traffic in the area together with climate change effects and an increased rate of atmospheric deposition). The flow regulation to the environment (i.e. *impact on the local ground- and surface water cycle* were scored (0) in the short time perspective (no change) and (-1) in the long time perspective (since climate change will add more stormwater to the urban system that will not be allowed to infiltrate the ground but instead being transported through the combined system to the WWTP). The flow regulation to the environment (i.e. *potential to delay stormwater on site*) was scored (0) in the short time perspective (no change) and (-1) in the long time scenario (climate change will add more stormwater to the area that will be transported to the WWTP, thus resulting in a negative trend). Within biophysical environment on site both the criteria (i.e. *soil quality and erosion*, *ecological diversity potential*) scored (0) for the short- and long time perspective since the urban drainage system will not have an effect on these aspects (i.e. the combined system its located underground).

Within the social criteria the BAU scored in the interval between (0) to (0).
For the social criteria cultural and social aspects (i.e. *community acceptance* and *risks for local community*) and educational and scientific aspects (i.e. *opportunities for informal and formal education*) the scoring were (0) in both the short- and long time perspective. This was based on the assumption that the local community will continue to approve and accept the combined system on site (as they always have) and that there will be no increase in the communities risk perception (regarding the urban drainage system), the social attitudes will stay the same for both time scenarios. The educational value of the current system is assumed to remain the same in the long time scenario as toady (i.e. no change).

Within the economic criterions the BAU scored in the interval between (0) and (-2). Typical investments costs were scored the following for both time scenarios: *land costs* (0), *adapting costs* (0) and *costs of installation of water facility on site* (0). Land costs were assumed to be low since a major part of the land area belongs to the city of Gothenburg. Adaptation costs were assumed to be zero since the combined system is already in place and fully operational within the area. The cost of installation on site is zero (since the system already exists on site). Within operation and maintenance (i.e. *system reliability* and *operation and maintenance costs*) the scores were (-1) for the short time perspective and (-2) in the long time perspective for both sub-criteria. The reason for this scoring is the expected cost for upgrading the urban drainage system in Gothenburg (the cost is expected to be higher in the future) and the increased pressure that climate change and the growth in urban population will have on the site (i.e. increased stormwater runoff volumes transported to the WWTP will cost more due to higher wastewater treatment costs etc). The economic impact on the WWTP were scored the following; *revenues relating to sewage sludge* was expected to remain the same during the short time perspective (scored 0) and increase slightly in the long time perspective (+1) due to a expected higher wastewater treatment technology used in the new WWTP and the continued disconnecting of upstreams point sources of pollution in Gothenburg. The *operation and maintenance cost* were scored (-1) in the short time perspective and (-2) in the long time perspective due to the expected increase in cost for upgrading and maintaining the urban drainage system (i.e. the combined system) on site. This cost is expected to increase in the future since the pipelines are getting much older (and the current money set aside every year for upgrading the urban drainage system today and for the short term scenario may not be enough but most likely increase in the future). *The economic impact on the WWTP* were scored the following; revenues relating to sewage sludge was scored (0) for the short time perspective and (+1) for the long time perspective (due to improved wastewater treatment technology). *The cost-saving potential for the WWTP with regard to decreased wastewater flow and volume* were scored (0) for both time perspectives since all the stormwater is transported to the WWTP for both scenarios.

5.3.1.2 The Dry Pond

Within the environmental criteria the dry pond scored in the interval between (+1) to (-1). For pollution load to the environment (i.e. *environmental impact on recipients downstreams*) the scores were (+1) in both time perspectives (due to its ability to remove pollutants from the stormwater). The pollutant load to the environment (i.e. *environmental effect on the sewage sludge at the WWTP*) was scored (+1) in both time perspectives since the facility will continue to absorb and detain pollutants on site and therefore improve the environmental quality of the sewage sludge. For flow regulation to the environment (i.e. *impact on local ground- and surface water cycle*) the scores were (+1) in the short time perspective (due to infiltration on site) and (+2) in the long time perspective (due to increased runoff flows due to climate change that will allow more water to infiltrate the ground as a consequence of more frequent rainfall events). For flow regulation to the WWTP (i.e. *potential to delay stormwater on site*) the score were (+1) for the both time perspectives since the facility will be able to detain some water on site through infiltration and absorption. This effect is assumed to be the same in the long time perspective. Within biophysical environment on site (i.e. *soil quality and soil erosion*) the scores were (0) in the short term perspective (due to the assumption that the erosion potential is very small and that the soil quality will not be that much affected during a few years) and (-1) in the long term perspective (due to the accumulation of pollutants in the sediments and plants on site and the possibility of some soil erosion). For the *ecological diversity potential* the scores were (+1) for both time perspectives (due to the extra plants/vegetation that will be added on site that will have a positive impact on the local biodiversity, which will remain even in long time scenario).

Within the social criteria the dry pond scored in the interval between (+2) to (-1).
For the criteria *community acceptance* the scores were (+1) for the short time perspective (due to the esthetical and ecological value that the facility will bring to the park) and (+2) for the long time perspective (the social acceptance is assumed to increase with time). Within *risks for local community* the scoring were both (-1) for both time scenarios (due to some risk associated with open water solutions such as small children drowning). Within the criteria educational and scientific aspects (i.e. *opportunities for informal and formal education*) the scoring were (+2) for both time perspectives (since the facility will present an opportunity to educate the local people about stormwater management in urban areas –both today and in the future).

Within the economic criterions the dry pond scored in the interval between (+1) and (-1).
For typical investment costs (i.e. *land costs*) the scoring was (0) for both time perspectives (the municipality owns most of the land so the assumption is that there will not be any additional costs). For *adapting costs to existing urban drainage system* the scoring were (-1) in the short time perspective (since a small cost is expected to connect the facility to the urban drainage system on site) and (0) in the long time perspective (i.e. the facility is already connected). For cost of installation of water facility on site the scores were (-1) in the short time perspective (since it will be a cost to build the facility on site) and (0) in the long time perspective (i.e. the facility is already built - no costs if maintenance is done accordingly). Within the criteria operation and maintenance the *system reliability* scored (0) in the short time perspective (a newly installed dry pond will be assumed to work well) and (-1) in the long time perspective (the facility's reliability will most likely decline with time even with maintenance) while *operation and maintenance costs* scored (-1) for both time perspectives (there will always be a small cost associated with operation and maintenance).

Within the criteria economic impact on the WWTP the *revenues relating to sewage sludge for the WWTP* scored (+1) for both time perspectives since the facility has the potential to detain and absorb contaminants on site which will result in an small improvement of stormwater quality at the WWTP (which is expected to continue in the future as well). The *cost-saving potential for the WWTP due to decreased wastewater flow and volume* scored (+1) for both time perspectives since the facility will detain and delay stormwater on site which will decrease the wastewater flow and volume going to the WWTP (which is expected to continue in the future as well).

5.3.1.3 The Macadam Basin

Within the environmental criteria the macadam basin scored between (+1) and (-2).
For the criteria pollutant load to the environment (i.e. *environmental impact on recipients downstream*) the macadam basin scored (+1) in the short time perspective (due to the soils capacity to absorb and bind contaminants on site which lowers the pollutant transport downstream) and (0) in the long time perspective (the facility's ability to improve the environmental status downstream will decline over time since the macadam basin will not last 80years). For pollution load to the WWTP (i.e. *environmental effect on sewage sludge at the WWTP*) the scores were set to be (+1) for the short time scenario (the macadam basin will have a moderate impact on the environmental status of the sewage sludge at the WWTP due to the soils capacity to bind and absorb contaminants) on site and (0) for the long time scenario (the facility's ability to improve the environmental status downstream will decline over time since the macadam basin will not last 80years). For flow regulation to the environment (i.e. *impact on local ground- and surface water cycle*) the scores were (+1) for both time perspectives since the macadam basin will have a small impact on the ground- and surface water cycle due to infiltration on site. For flow regulation to the WWTP (i.e. *potential to delay stormwater on site*) the scores were (+1) in the short time perspective (due to its possibility to delay and decrease the stormwater on site through underground infiltration on site) and (0) in the long time perspective (the facility's ability to delay stormwater on site will decline over time since the macadam basin will not last 80years). For the biophysical environment on site (i.e. *the soil quality and soil erosion*) the scoring was (0) in the short time perspective (i.e. it is assumed that the soil quality will not change much over a few years and the possibility for soil erosion is very small) and (-2) in the long time perspective (due to accumulation of pollutants in the soil layer, soil erosion is still assumed to be very small). For the ecological diversity potential the scores were (0) for both time perspective (the facility is located underground and have no impact on the local biodiversity).

Within the social criteria the macadam basin scored (0) on both cultural and social aspects (i.e. *community acceptance* and *risks for local community*) and educational and scientific aspects (i.e. *opportunities for informal and formal education*). The motivation for this was that since the facility is located underground (under the parking lot) and does not take up any of the park area that exist today, then there will most likely not be any change in the local peoples risk perception and community acceptance on site. Furthermore, since the facility is underground it will not provide the same opportunity (as the dry pond) for education (i.e. no change).

Within the economic criterions the macadam basin scored between (+1) and (-2).
For typical investment costs (i.e. *land costs*) the scoring was (0) for both time perspectives (the municipality owns most of the land so the assumption is that there will not be any additional costs). For *adapting costs to existing urban drainage system* the scoring were (-1) in the short time perspective (since a small cost is expected to connect the facility to the urban drainage system on site) and (0) in the long time perspective (i.e. the facility is already connected). For *costs of installing the water facility on site* the scores were (-2) in both time perspectives (the facility is about three times as expensive as the dry pond to install on site and it won't last 80 years so under the assumption that it will be reconstructed at the site, the cost will be the same in the future scenario). Within operation and maintenance (i.e. *system reliability*) the scores were (0) in the short time perspective (since newly installed macadam basin is assumed to work well) and (-2) in the long time perspective (since the facility will not last over time its reliability will be low). For *operation and maintenance cost* the scoring were (-1) for both time perspectives (since there will always be a small cost associated with

operation and maintenance). Within the criteria economic impact on the WWTP the *revenues relating to sewage sludge for the WWTP* scored (+1) in the short time perspective (since the facility has the potential to detain and absorb contaminants on site which will result in better sewage quality at the WWTP) and (-1) in the long time perspective (0) (the facility will not function at the same capacity during its lifetime due to saturation in the soil layer and therefore its ability to bind contaminants will decrease over time). For *cost-saving potential for the WWTP due to decreased wastewater flow and volume* the macadam basin scored (+1) in the short time perspective (the facility will detain and delay the stormwater on site which will decrease the wastewater flow and volume going to the WWTP) and (0) in the long term perspective (the facility will not function at the same capacity during its lifetime and the ability to reduce the stormwater flow transported to the WWTP will decrease over time).

5.3.2 The weighted values from MCA1

MCA1 was based on the MCA analyst own analysis. The initial scores were weighted according to the given group weight (see section 5.2.6) and the results are shown in figure 12.

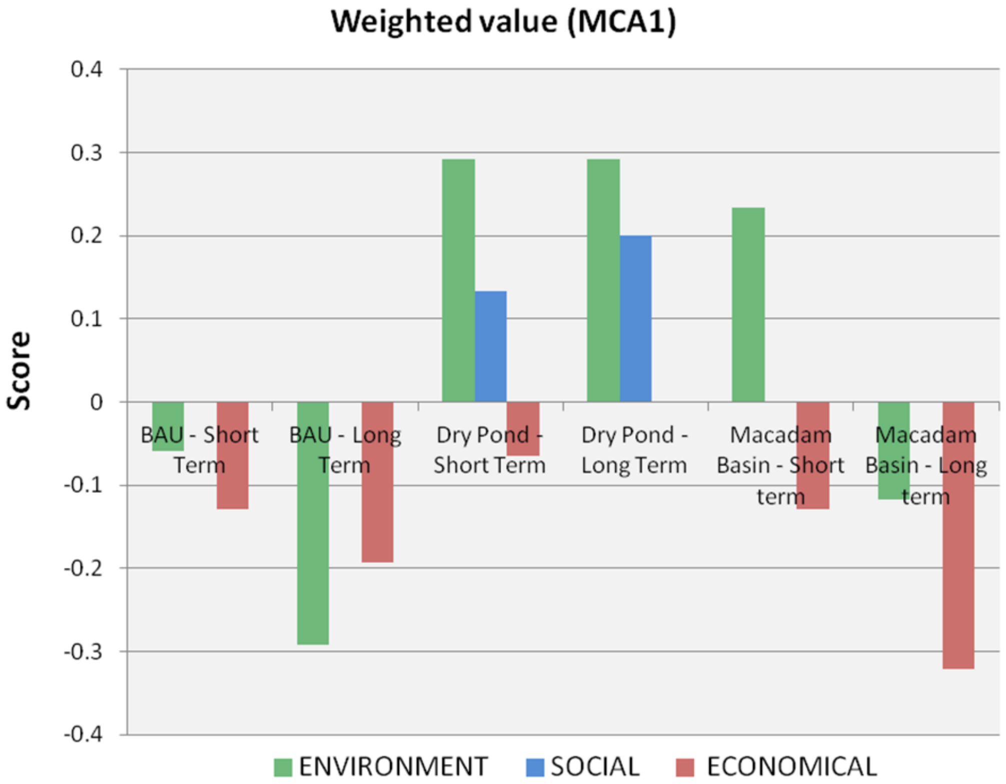

Figure 12: Final results from MCA1 (i.e. the initial scoring multiplied with the group weight) shown through environmental, social and economic criteria for each option. The data set is shown below in table 31.

Based on the weighted results from MCA1 the dry pond scored the highest in all three criteria (i.e. environmental, social and economic). For the short time scenario (< 2020) the weighted values were the following: +0.29 (environmental), +0.13 (social) and -0.06 (economic). For the long time scenario (<2100) the weighted values were: +0.29 (environmental), +0.20 (social) and 0.00 (economic).

The macadam basin scored worse on all three criteria (in comparison to the dry pond). For the short time scenario (<2020) the weighted values were the following: +0.23 (environment), 0.00 (social) and -0.13 (economic). In the long time scenario (<2100) the weighted values were: -0.12 (environmental), 0.00 (social) and -0.32 (economic).

The BAU scored worse than the dry pond but better than the macadam basin with regard to environmental criteria (short time perspective) and economic criteria (long time perspective). The weighted values were in the short time perspective (<2020) the following: -0.05 (environmental), 0.00 (social) and -0.13 (economic). In the long time perspective the weighted values were: -0.29 (environmental), 0.00 (social) and -0.19 (economic).

A data comparison is shown in table 31 below. ST stands for short time scenario (<2020) and LT stands for long time scenario (<2100).

Table 31– Weighted values from MCA1

Rank	Option	Environmental criteria	Social criteria	Economic criteria	Sum
1.	Dry pond (LT)	0.29	0.20	0.00	0.49
2.	Dry pond (ST)	0.29	0.13	-0.06	0.36
3.	Macadam basin (ST)	0.23	0.00	-0.13	0.10
4.	BAU (ST)	0.05	0.00	-0.13	-0.08
5.	Macadam basin (LT)	-0.12	0.00	-0.32	-0.44
6.	BAU (LT)	-0.29	0.00	-0.19	-0.48

As mentioned before, the dry pond scored the highest in MCA1. The highest scores came from the environmental criteria that where it scored +1 and above in all categories except in soil quality and erosion potential (0/-1). Within the social criteria the dry pond scored above +1 in all categories except for in “risks for local community” (-1/-1). Since the dry pond is associated with some costs it scored the lowest in the economic criteria but since the construction cost were cheaper than the macadam basin and its positive economic impact on the WWTP the final weighted score were still (0) in the long term perspective and only -0.06 in the short term perspective (many more associated costs in the construction phase).

The macadam basin (ST) had the same weighted score as the BAU (ST) on the social and economic criteria but with the exception on environmental criteria (where the macadam basin scored higher: 0.23 as compared to BAU: 0.05). The fact that the economic criteria scored the same for BAU (ST) and macadam basin (ST) is associated with the fact that the macadam basin do not have the same expected functionality over time as the dry pond and the urban drainage system and therefore this solution is associated with a higher costs (since it must be re-built after a few decades) and thus adds less economic benefits to the WWTP in the long time scenario. The cost associated with BAU (ST) is mostly associated with the assumption that in the long time perspective there will be higher operation and maintenance costs (i.e. more pressure on the system than today due to both urban expansion and climate change).

The macadam basin (LT) and BAU (LT) both had the same weighted score with regard for social criteria. However both the environmental and economic cost was higher for the BAU (LT) than the macadam basin (LT). This is again associated with the assumption of higher negative impact over time (the long time scenario) due to more urban pollutants in the stormwater, leakage of pipelines and climate change (i.e. more runoff water transported to the WWTP etc). The Macadam basin (LT) had the lowest weighted score in the economic criteria, mostly due to the assumption that the facility will not last over time and will have more costs (i.e. lower reliability and higher construction costs than the dry pond). The low environmental weighted scores is associated with its diminished function over time that results in less ability to delay stormwater on site and increased accumulation of pollutants in the underground soil layer.

This ranking in MCA1 (table 31 above) can be compared to MCA2.

5.3.3 The weighted values from MCA2

In MCA2 the initial scoring was the result of nine stakeholder (i.e. experts) interviews. Based on their scores an average value (i.e. mean value) was derived that was multiplied with the group weights (see section 5.2.6) and the results are shown in figure 13.

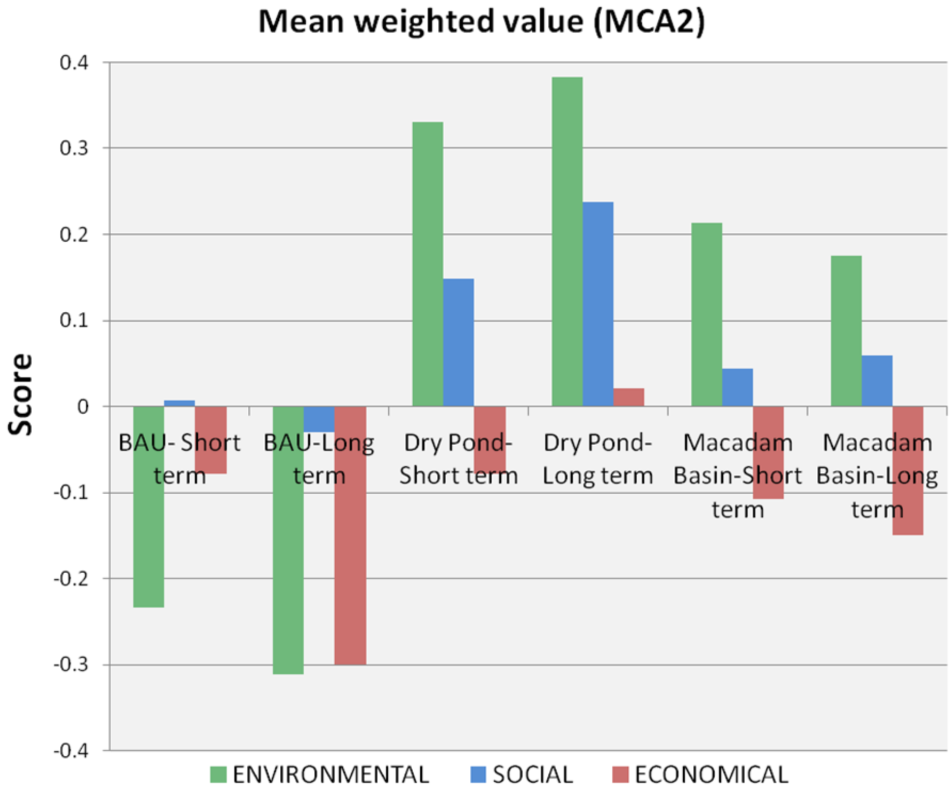

Figure 13: Final results from MCA2 (i.e. the mean value of scoring multiplied with the group weight) based on the ranking of experts, shown through environmental, social and economic criteria for each option. The dataset is shown below in table 32.

Based on the weighted results from MCA2 the dry pond scored the highest in all three criteria (i.e. environmental, social and economic). For the shirt time scenario (<2100) the weighted values were: +0.38 (environmental), +0.24 (social) and 0.02 (economic). For the long time scenario (< 2020) the weighted values were the following: 0.33 (environmental), +0.15 (social) and -0.08 (economic).

The macadam basin scored worse on all three criteria (in comparison to the dry pond) but better than the BAU. For the short time scenario (<2020) the weighted values were the following: +0.21 (environment), 0.04 (social) and -0.12 (economic). In the long time scenario (<2100) the weighted values were: 0.17 (environmental), 0.06 (social) and -0.15 (economic).

The BAU scored worse than the dry pond but better than the macadam basin with regard to environmental criteria, social criteria and economic criteria (long time scenario only). The weighted values were in the short time perspective (<2020) the following: -0.23 (environmental), 0.01 (social) and -0.08 (economic). In the long time perspective the weighted values were: -0.31 (environmental), -0.03 (social) and -0.30 (economic).

A data comparison for MCA2 is shown in table 32 below.

Table 32 – Weighted mean values from MCA2

Rank	Option	Environmental criteria	Social criteria	Economic criteria	Sum
1.	Dry pond (ST)	0.38	0.24	0.02	0.64
2.	Dry pond (LT)	0.33	0.15	-0.08	0.40
3.	Macadam basin (ST)	0.21	0.04	-0.12	0.15
4.	Macadam basin (LT)	0.17	0.06	-0.15	0.08
5.	BAU (ST)	-0.23	0.01	-0.08	-0.30
6.	BAU (LT)	-0.31	-0.03	-0.30	-0.64

It is difficult to describe any trends from the stakeholder scoring in MCA2 (since it is based on 9 different scorings with people from a variety of backgrounds) but in overall the BAU was associated with a negative scoring both in the short- and long time perspective (ST+LT) with regard to environmental criteria. The environmental criteria BAU (ST + LT) were both scored between +2 and -2, Dry Pond (ST + LT) were also scored between +2 and -2, Macadam basin (ST+LT) were scored between +2 and -1.

The social criteria were scored the highest for the dry pond (ST+LT) in the interval +2 to -1. The Macadam basin (ST/LT) was scored between +2 and -2 and the BAU (ST+LT) were scored between 0 and -2.

The economic criteria were scored the highest for the dry pond (ST+LT) in the interval +2 to -2. The Macadam basin (ST+LT) scored in the interval between +2 to -2 and the BAU (ST+LT) scored in the interval between 0 and -2.

The following section makes a comparison of MCA1 and MCA2.

5.3.4 Comparison between MCA1 and MCA2

As illustrated above in table 32, the dry pond (ST + LT) scored the highest in the MCA2 (as it did in MCA1) followed by the macadam basin and last – the BAU. The difference (as compared to MCA1) is that the macadam basin (LT) was ranked nr 4 (instead of 5 in MCA1) and BAU (ST) was ranked 5 (instead of 4 in MCA1).

The weighted ranking from MCA2 differs in some respect from MCA1. No criteria in MCA2 were scored 0 (i.e. no change) as in MCA1 (where all the social criteria for macadam basin ST+LT and BAU ST+LT were scored zero).

Environmental criteria
In MCA2 the weighted scoring for the environmental criteria was higher for the dry pond in both time perspectives (ST: 0.38 instead of 0.29 and LT: 0.33 instead of 0.29). In the environmental criteria (ST) the macadam basin scored higher in MCA1 (0.23) as compared to MCA2 (0.21). However, in the environmental criteria (LT) the macadam basin scored higher in MCA2 (0.17) than in MCA1 (-0.12). The BAU (ST) scored higher in MCA1 (0.05) than in MCA2 (-0.23). But MCA1 also scored higher in BAU (LT) (-0.29) as compared to MCA2 (-0.31).

Social criteria
All social criteria scored higher in MCA2 than in MCA1 except for BAU (LT) that in MCA1 were scored 0.00 as compared to MCA2 (-0.03).

Economic criteria
Most of the economic criteria scored higher in MCA2 than in MCA1. Except for the dry pond (ST) that were scored (0.0) in MCA1 and (0.02) in MCA2 and BAU (LT) that were scored (-0.19) in MCA1 and (-0.30) in MCA2.
The dry pond (LT) was in MCA2 scored (0.00) as compared to MCA1 (0.02), Macadam basin (ST) that in MCA1 was scored (-0.13) as compared to MCA2 (-0.12), Macadam basin (LT) that in MCA1 was scored (-0.32) as compared to MCA2 (-0.15) and BAU (ST) that in MCA1 was scored (-0.13) as compared to MCA2 (-0.08).

The difference between the weighted scoring in MCA1 and MCA2 is summarized in table 33 below.

Table 33 – Comparison* of weighted mean values from MCA1/MCA2

Rank	Option	Environmental criteria	Social criteria	Economic criteria	Sum
2/ 1	Dry pond (ST)	0.29/ 0.38	0.13/ 0.24	-0.06/ 0.02	0.49/ 0.64
1/ 2	Dry pond (LT)	0.29/ 0.33	0.20/ 0.15	0.00/ -0.08	0.36/ 0.40
3/3	Macadam basin (ST)	0.23/ 0.21	0.00/ 0.04	-0.13/ -0.12	0.10/ 0.15
5/4	Macadam basin (LT)	-0.12/ 0.17	0.00/ 0.06	-0.32/ -0.15	-0.44/ 0.08
4/5	BAU (ST)	0.05/ -0.23	0.00/ 0.01	-0.13/ -0.08	-0.08/ -0.30
6/6	BAU (LT)	-0.29/ -0.31	0.00/ -0.03	-0.19/ -0.30	-0.48/ -0.64

**gray color illustrate that the scoring was higher in MCA1 and the purple color illustrate were the scoring were lower in MCA1 (as compared to MCA2).*

As shown in the table 33 above, almost every criterion was scored higher in MCA2 (purple color) than in MCA1 (gray color). This indicates that the MCA2 stakeholder group in overall had a more positive image of the effects associated with the selected environmental, social and economic criteria with regard to the dry pond and macadam basin than MCA1. However, the MCA2 stakeholder group had in overall a more negative impression of the BAU than the MCA1.

It is important to point out that the results from MCA1 was based on only one persons rating (i.e. the MCA analyst) and the results from MCA2 was based on the average (i.e. mean) value of 9 experts.

5.3.4 Dry Pond - maximum, minimum and mean value

This section looks more closely at the variations in the weighted scores for the dry pond (since the results show that this is the most preferred option). The maximum, minimum and mean value were calculated for the MCA2 and compared with the (only one) point value from MCA1 with regard to both ST and LT. The results are shown in figure 14-15.

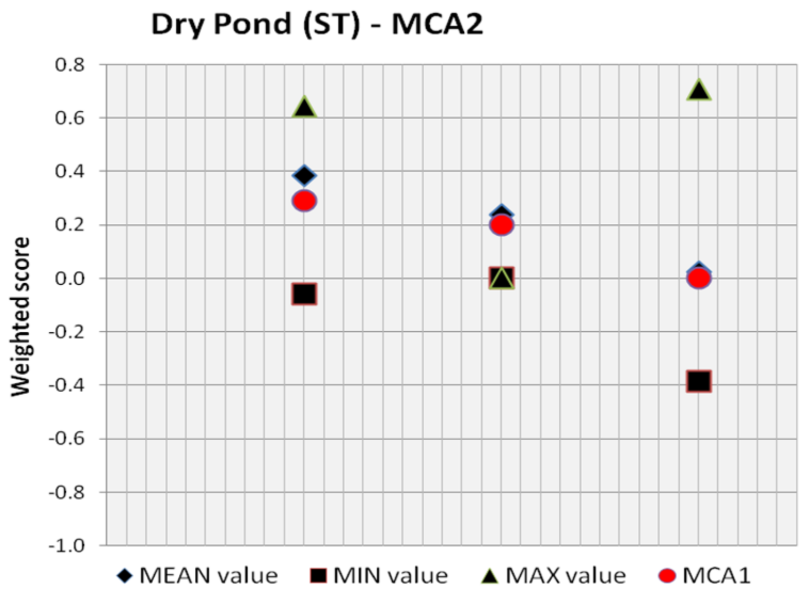

Figure 14: Dry pond comparison between the short term (ST) scenario of the weighted scores between for MCA1 (point value) and MCA2 (max-, min- and mean value). Data set is shown in table 34.

Table 34 - Comparison of Dry Pond (ST)

Parameters	Environment		Social		Economic	
	MCA1	MCA2	MCA1	MCA2	MCA1	MCA2
Point value	0.29	-	0.13	-	-0.06	-
Mean value	-	0.33	-	0.15	-	-0.08
Min value	-	0.06	-	-0.13	-	-0.51
Max value	-	0.58	-	0.40	-	0.77

The results from table 34 show that the difference in variation is larger in the MCA2 than in MCA1. The point value (MCA1) is relatively close to the mean value (MCA2) in all three criteria.

It is important to note that variations in MCA2 will be larger than MCA1 (since MCA2 is based on the scoring by 9 experts and MCA1 is only based on one persons scoring).

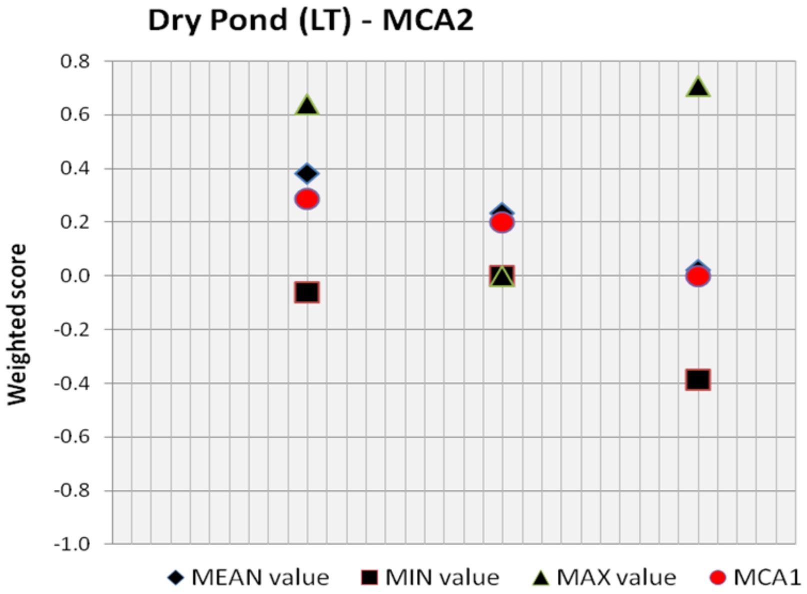

Figure 15: Dry pond comparison for the long term (LT) scenario of the weighted scores between MCA1 (point value) and MCA2 (max-, min- and mean value). Dataset is shown in table 35.

Table 35 - Comparison of Dry Pond (LT)						
Parameters	Environment		Social		Economic	
	MCA1	MCA2	MCA1	MCA2	MCA1	MCA2
Point value	0.29	-	0.20	-	0	-
Mean value	-	0.38	-	0.24	-	0.02
Min value	-	-0.06	-	0	-	-0.39
Max value	-	0.64	-	0	-	0.71

The results from table 41 show that (once again) the variations are larger in the MCA2 than in MCA1. The point value (MCA1) is relatively close to the mean value (MCA2) with the biggest difference in the environmental criteria (0.29 for MCA1 as compared to 0.38 for MCA2).

Additional graphs for the macadam basin and BAU (combined system) is found in Appendix K.

5.4 SENSITIVITY ANALYSIS

A sensitivity analysis was performed for MCA1 to further evaluate the results and see how much the result (i.e. weighted scores) are affected if the group weights given to each of the three categories (i.e. environmental, social and economic) are changed. An analysis where these parameters were changed was preformed and three examples are shown in figure 16-18 below. The three different scenarios are summarized in table 36.

Table 36 – description of three scenarios that were tested for MCA1

Nr.	Criteria			Description
	Environment	Social	Economic	
1.	0.333	0.333	0.333	All criteria are of equal importance (i.e. the perfect world scenario).
2.	0.45	0.1	0.45	Environmental- and economic criteria is of the same importance (i.e. a company that wants to focus on green PR).
3.	0.50	0.3	0.2	The Environment is the most important criteria followed by social and economic aspects (i.e. NGOs such as Greenpeace)

Scenario 1 – All criteria is of equal importance

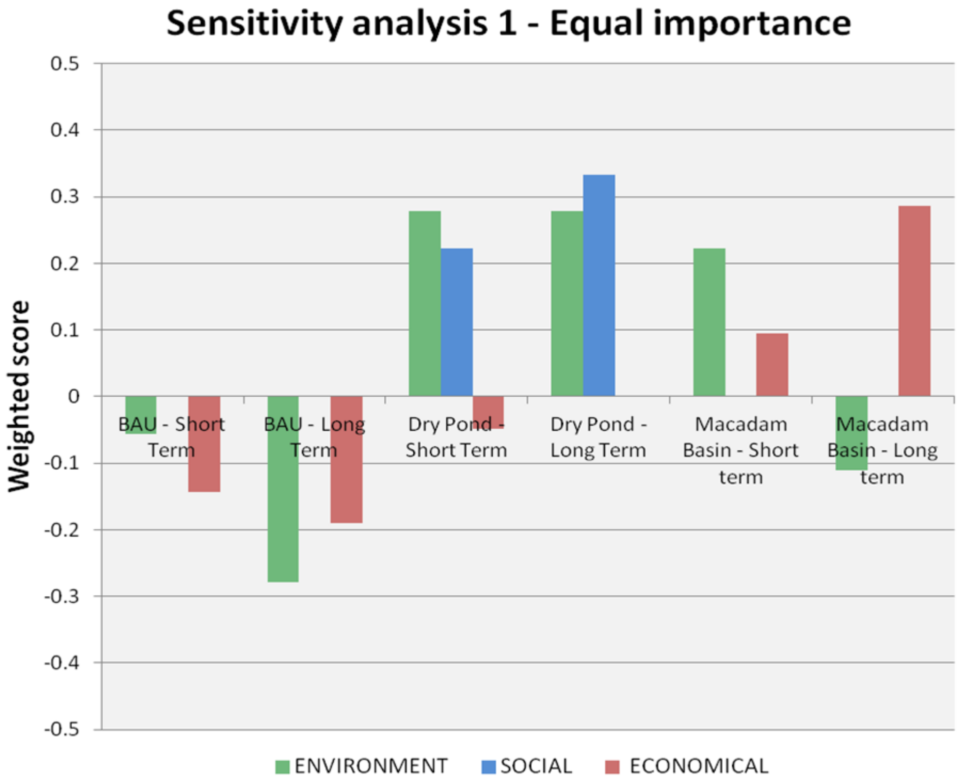

Figure 16: Sensitivity analysis (scenario nr 1). For comparison see figure 12 for MCA1.

When the scenario (nr 1) is compared to the MCA1 the ranking differs to some degree. The final ranking based on the weighted scores is shown below in table 37.

Table 37 – Comparison of MCA1 and scenario 1 based on final ranking

Rank	BAU (ST)	BAU (LT)	Dry pond (ST)	Dry pond (LT)	Macadam basin (ST)	Macadam basin (LT)
MCA1	4	6	2	1	3	5
Scenario 1	5	6	2	1	3	4

The conclusion is that changing the original weighted group scores (from originally economic: 0.45, environmental 0.35 and social 0.20) to 0.333 for all criteria did not change the main result (i.e. the dry pond is still the best solution) but it switched the ranking of BAU (ST) from originally rank 4 to rank 5 and Macadam basin (LT) from originally rank 5 to rank 4.

In other words, by making the environmental aspects less important and the social more important there were some minor changes in the original rank numbers from MCA1.

Scenario 2 - Same importance of environmental- and economic criteria

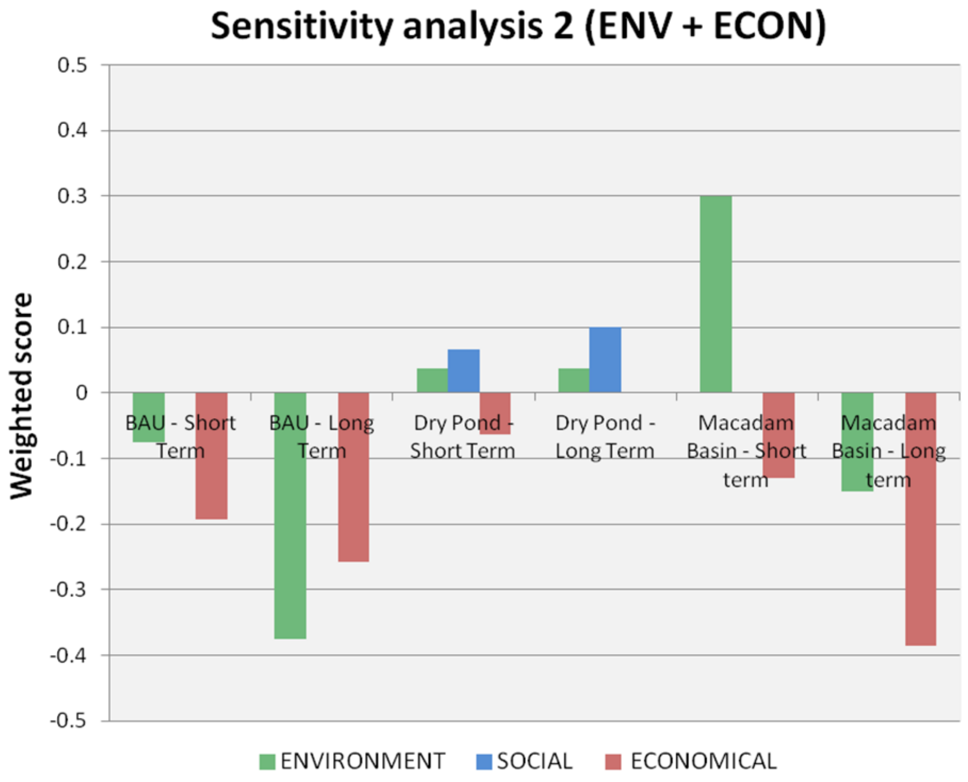

Figure 17: Sensitivity analysis (nr 2). For comparison see figure 12 for MCA1.

When the scenario (nr 2) is compared to the MCA1 the ranking differs to some degree. The final ranking based on the weighted scores is shown below in table 38.

Table 38 – Comparison of MCA1 and scenario 1 based on final ranking

Rank	BAU (ST)	BAU (LT)	Dry pond (ST)	Dry pond (LT)	Macadam basin (ST)	Macadam basin (LT)
MCA1	4	6	2	1	3	5
Scenario 2	4	6	3	2	1	5

The conclusion is that changing the original weighted group scores (from originally economic: 0.45, environmental 0.35 and social 0.20) to 0.45 for both environmental- and economic criteria changes the main results (i.e. the macadam basin ST is now the best solution). This change switched the top ranking of MCA1 were the dry pond (LT) is now ranked nr 2 (instead of 1) and the dry pond (ST) is now ranked 3 (instead of 2).
In other words, by making the environmental aspects as important as the economic, there were some changes in the original rank numbers from MCA1. Although in both the ST+ LT scenario the dry pond is still the best choice.

Scenario 3 – the environment is the most important criteria

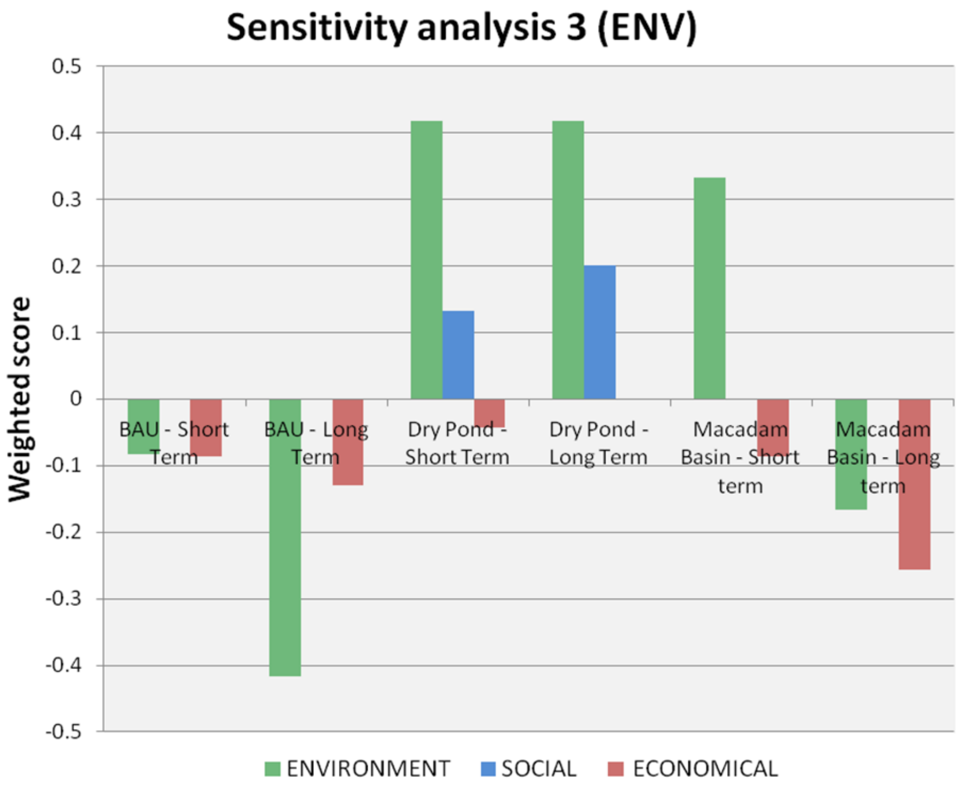

Figure 18: Sensitivity analysis (nr 3). For comparison see figure 12 for MCA1.

When the scenario (nr 3) is compared to the MCA1 the ranking is the same. The final ranking based on the weighted scores is shown below in table 39.

Table 39– Comparison of MCA1 and scenario 1 based on final ranking

Rank	BAU (ST)	BAU (LT)	Dry pond (ST)	Dry pond (LT)	Macadam basin (ST)	Macadam basin (LT)
MCA1	4	6	2	1	3	5
Scenario 3	4	6	2	1	3	5

The conclusion is that changing the original weighted group scores (from originally economic: 0.45, environmental 0.35 and social 0.20) to 0.50 for environmental criteria, 0.30 for social and 0.20 for economic criteria – the ranking stays the same (i.e. the dry pond is the best solution).

In other words, by making the environmental aspects as important as social and economic criteria together – the ranking stays the same.

Besides the overall three scenarios a variety of sensitivity analysis were conducted (that are not shown here) that showed that even if there are some small changes in ranking, when trying to find the best ST+LT alternative the dry pond scores the highest in most scenarios. These results indicate (together with the three scenarios) that the original result from MCA1 can be considered as relatively solid (when analyzed with the chosen criteria for environmental, social and economic that were selected on the basis of this particular study).

PART 6 – DISCUSSION, CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

6.1 DISCUSSION

The following sections contain a discussion regarding stormwater solutions, municipality work, the MCA, stormwater calculations and uncertainties.

6.1.1 Stormwater solutions and municipality work

Within Sweden and the rest of the developed world today there is a growing trend towards using sustainability practices. This investigation of sustainable stormwater solutions for the park area surrounding *Sister Ainas Street* (Guldheden) has provided an overview of suitable solutions that can be applied on the study site and be considered for the rest of the area. Two solutions (i.e. dry pond and macadam basin) were chosen to be investigated further based on initial discussion and suggestion from COWI since they were thought to provide the investigation with two rather different stormwater solutions (from a technical point of view) that was easily distinguishable and known by most professionals (i.e. easy to score). The two stormwater solutions investigated here has been studied as two separate systems (i.e. not connecting to each other) but in real life a combination of different stormwater solutions may be a better solution for certain areas. Sometimes it can even be easier for the municipality to apply one stormwater solution for a large area than many small ones (due to time limitation regarding operation and maintenance).

The planning and implementation of stormwater solutions falls upon the municipality. However, since there is often a lack of water related data at the beginning of a construction project there is often a gap regarding the recommendations of stormwater management for a certain area. Entrepreneurs that have been hired for the job of evaluating stormwater solutions may not always take the time to evaluate the situation on a larger scale but stick to their own traditional solutions that they recommended to the municipality (i.e. office of public management). This will in some cases result in a problem, especially if the entrepreneurs are not updated on the latest stormwater research (i.e. regarding the reliability of stormwater facilities etc) or have a good understanding about the surrounding area (i.e. knows the local stormwater system) and were the outflow is transported. For example if contaminated stormwater is being transported and released close to a Natura2000 area this would become a problem. It was suggested to the author by one of the experts (participating in the interviews) that the lack of demands regarding stormwater management within city planning (i.e. zoning) of Gothenburg was a problem.

Another problem associated with stormwater planning that was highlighted by one of the experts (participating in the interviews) was the division of work load (regarding stormwater facilities) between different administrations in Gothenburg city. Within Gothenburg city the two administrations involved in this is the park- and landscape administration (i.e. Park- och Naturförvaltningen) and Kretslopp och Vatten. At present there is an ongoing discussion regarding the workload (i.e. which administration that should be responsible for what) that is based on economic considerations. For stormwater solutions to work at peak efficiency it is crucial that the workload is decided upon before any new implementation of stormwater facilities take place in the city. Communication between administrations is vital in order to assure success and reach long-term goals regarding urban drainage and stormwater facilities.

6.1.2 Multicriteria analysis and stormwater calculations

The results from the MCA1 (i.e. the authors own investigation) and MCA2 (i.e. based on the 9 experts) differed slightly with regard to ranking but the main result (i.e. top ranking) was the same for both MCA. The MCA2 was conducted parallel to MCA1. The idea was that professionals associated to the stormwater and wastewater sector in Gothenburg city would provide their professional opinion and ranking (i.e. MCA2) that would be used for comparison with the authors own MCA1. The results showed that the professionals in overall had a higher opinion regarding the effectiveness and positive impact of the dry pond and macadam basin on site (than the author). However the BAU alternative was scored much lower (i.e. considered to have a much more negative impact) than the authors own evaluation.

Due to the time limitations, many criteria were excluded from the MCA (i.e. technical aspects etc) and many of the original criteria were thought to be to detailed to be used and scored by the expert group that were interviewed (since their background differed a lot) and were therefore re-written into more general criteria.

The MCA1 was to the most part based on the literature review and data gathering conducted at the beginning of this thesis study. However, assumptions were made with regard to both time perspectives but especially for the long time scenario regarding, for example, the future impact of climate change in the area and the influence of atmospheric deposition. Evaluation of future scenarios is often associated with many uncertainties. For example, how do you evaluate and predict a future society? Especially in the aspect of: social values, political rule and technology development. Many assumptions most be made, even though they are based on current trends. For example, how do you predict what people will feel about a certain stormwater facility/solution 80 years from now? Future predictions and scenarios will always include many assumptions (i.e. uncertainties) that must be taken into account when the final evaluation of a investigation is made.

In MCA2 interviews with experts were conducted. After the interviews had taken place, the participants were asked a few questions regarding how they perceived the scoring and the alternatives. Many of the experts found that the long time perspective (<2100) was more complicated to grade (than the short time perspective) since predicting the future is always difficult (i.e. many uncertainties). In theory the ideal future scenario in 2100 would mean that technology has advanced to the point were no more pollutants are being released.

Some of the experts through that the scoring scale could have benefited from using a larger number of scores (i.e. in this case a 5 number scale was used: +2, +1, 0,-1, -2). Some criteria were thought more difficult to grade since they suited, for example stormwater solutions better (than the urban drainage system, BAU alternative) and some experts wanted more alternatives to score (in order to get a better overview) since they thought only two solutions were not enough to evaluate what kind of solutions that best fitted the study area. One expert thought that the system limitations were a bit unclear (due to the usage of both a local/Guldheden and a regional scale/the WWTP) when scoring the different alternatives.

However, most of the experts thought that it was a good idea to include sustainability aspects into the evaluation of the urban drainage system and stormwater solutions and that the developed criteria (i.e. environmental, social and economic) were good and suited the purpose of the study.

The results of MCA1 and MCA2 are based on subjective ratings (i.e. the opinions of people) and should not be considered as a final conclusion regarding which stormwater facility that should be implemented on site – but as a first review of suitable stormwater solutions for the site. Since this MCA focused only on environmental, social and economic criteria (and not on technical aspects etc) the results should be used as a guideline regarding which solution that should be subjected to further investigation (and which to exclude) that is based on both the opinions of experts (MCA2) and that of the author (MCA1). MCA has many benefits such as transparency and is a good tool to use for governmental decision-making (i.e. easy to understand the process and the results) but should be accompanied with other investigations since the focus of the MCA might exclude many vital aspects that are (also) needed when making a decision. Since MCA also depends on the group weight given to each main criterion, the results will vary to some degree if the weight is changed (as the sensitivity analysis for MCA1 showed). Therefore it is important to note that different MCA on the same subject (i.e. with similar goals) might differ from each other and not come to the same conclusion.

The sensitivity analysis that was conducted provided some insights into how much the weighted group scoring was affecting the final result in MCA1. The group scores were changed a number of times, and despite some small variations in the final ranking - the combined scores of dry pond (ST+LT) scored the highest in the big majority of tests. This strongly suggests that the results provided by MCA1 can be considered as robust and valid for the purpose of this particular analysis.

For the purpose of this MCA simplified schematics were drawn up regarding the technical layout of the dry pond and macadam basin at the study site that were used in order to make an economic estimation (used as a basis for the evaluation and scoring of the economic criteria). However, these schematics could be a source of error since they were rather simplified (i.e. general in nature) due to time restrictions. Within the stormwater calculations, a value of $250m^3$ was used as the final stormwater storage volume required for a stormwater facility on site (which was a value between the statistical value and the predicted climate change scenario for 2100). This value was based on the scientific view regarding the future effect of climate change in Gothenburg/Sweden which differs quite a lot from the present demand from Gothenburg city (i.e. 73 m^3). This difference in stormwater storage volume could indicate that the city´s requirements are outdated and may need to be re-evaluated.

6.1.3 Uncertainties

Uncertainties in MCA1 can be associated with the data collection, storm water calculations and the economic estimation of the three different stormwater solutions. Since this MCA covered a very broad range of subjects that were taken into account in the evaluation (i.e. scoring and ranking), the data collection was dependent upon available data sources that the author could find during the limited time reserved for this thesis study. In some cases the ranking were based on only one or two data sources (which could provide a problem since it is better to validate data through many other data sources of the same subject). Another uncertainty can be associated with the interviews conducted for MCA2 in May and June 2014. Even though the author in (almost) every case stayed in the same room in order to be able to answer the participant's questions, there is still the possibility that some categories were misinterpreted by the participants and scored wrongly (i.e. due to the wrong interpretation of a criteria). Furthermore, at the interviews a short description of each criterion was provided to the participants that illustrated the author's definition of each criterion. These descriptions were in some cases not read thoroughly by the participants (i.e. due to the fact that the participant in question told the author that they already understood the meaning). This could be an uncertainty since there is no way to actually check afterwards if they really understood what the criterion stood for and thus scored "correctly".

Conclusively, the uncertainties in this MCA is not considered to be more apparent than in any other MCA investigation that covers the same subject and has the same (or similar) goals. Human error is always a possibility when conducting an investigation that depends on people's perception, background (i.e. knowledge) and values. It is a well known fact that peoples risk perception determines how they compare and rank different alternatives against each other. As mentioned before, the results of an MCA will depend the selected people that are doing the scoring and the analyst - and should therefore be considered as a guideline as to what alternatives/solutions to focus future (i.e. more technical) investigations on.

6.2 CONCLUSION

This master thesis has complemented the research done on sustainable stormwater solutions within Gothenburg city through multi-criteria analysis. A MCA method based on sustainable criteria (i.e. environmental, social and economic) was developed specifically for stormwater applications that were implemented on the selected study area in Guldheden. Two different time scale were investigated (<2020 and <2100) that provided different results on the three selected options (i.e. dry pond, macadam basin and the combined urban drainage system) with regard to climate change. Two MCAs were performed parallel to each other: MCA1 (the authors own analysis) and MCA2 (based on the scoring of 9 experts) that were compared against each other in order to provide consensus.

Based on the chosen criteria for this particular study, the MCA1 results showed that the dry pond (ST+LT) was the best choice for the study area. The macadam basin (ST+LT) scored the third and fifth place, thus making it the second best choice. The BAU (ST+ LT) scored the fourth and sixth place, therefore making it the worst option to apply in the study area (out of the three that were investigated). The sensitivity analysis of MCA1 showed that the results can be considered as relatively robust.

The results from the MCA2 showed almost the same thing. The dry pond (ST+LT) was scored the first and second place, the Macadam basin (ST+LT) scored the third and fourth place and the BAU (ST and LT) scored the fifth and sixth place, thereby making it the worst option to apply in the study area (out of the three that were investigated).

The conclusion from this study is that the dry pond is the best choice for the study area (both with regard to local impact on the study site and with regard to the WWTP/Ryaverket in Gothenburg) when compared to the selected alternatives (i.e. macadam basin and keeping the combined system/BAU). However, if the choice were to only choose between the last two options then the macadam basin would still be a better choice than just keeping the combined system on site.

6.3 SUGGESTIONS FOR FURTHER RESEARCH

Based on the reasoning of the discussion further studies (that may incorporate a larger number of stormwater solutions) would be recommended before any decision is made. A MCA that evaluated 5-6 stormwater solutions based on only one time perspective (maybe <2050) would be interesting and complement the results obtained from this master thesis analysis. Also, since the group weighting in MCA1 and MCA2 was based on (solemnly) the authors own perception, and the ranking was conducted through pre-selected criteria (that were thought to reflect the values and opinions of the stakeholder group GKCC) another MCA covering the same subject (with similar goals) would be interesting in order to compare with the results from this study.

Furthermore, many aspects (such as technical) were not included in this study that still is very relevant to consider when making a decision (i.e. in order to confirm that the dry pond is the best solution for the site) and more investigations of this kind is encouraged in order to complement the results of this master thesis analysis.

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APPENDIX A – STORMWATER CALCULATIONS

Stormwater calculations were based on national standards provided by the Swedish Water & Wastewater Association (SWWA) in publication P90. The stormwater calculations were done in order to estimate the appropriate water storage volume that facilities (i.e. dry pond and macadam basin) most have on site (i.e. the study area). The following sub-chapter describes the dataset used and the calculation process.

A1. Background data sets

When calculating the runoff volumes a return period of 10 years were used for rain.

A.1.1 Rain intensiveness

Rain intensiveness was calculated using table A1 below that illustrates the duration (min) and return period (years) provided by P104 (Svenskt Vatten, 2011c).

Table A1: Dahlström dataset for rain intensiveness (Svenskt Vatten, 2011c).

	Duration, min												
Return periods, years	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**90**	**120**	**360.0**	**720**	**1440**
0.5	116.8	85.2	67.8	56.9	43.9	36.3	31.2	27.6	20.9	17.2	8.4	5.6	4.0
1	146.6	106.9	84.9	71.2	54.8	45.2	38.8	34.2	25.8	21.1	10.0	6.5	4.5
2	184.2	134.1	106.5	89.2	68.5	56.4	48.4	42.6	32.0	26.1	12.1	7.7	5.2
5	249.3	181.3	143.8	120.3	92.3	75.8	64.9	57.1	42.7	34.7	15.7	9.8	6.3
10	313.5	228.0	180.6	151.0	115.7	95.0	81.3	71.4	53.3	43.1	19.2	11.8	7.5
20	394.5	286.7	227.0	189.8	145.3	119.2	101.9	89.4	66.6	53.8	23.7	14.3	8.9
50	534.7	388.4	307.4	256.9	196.5	161.1	137.6	120.7	89.7	72.4	31.5	18.7	11.4
100	673.2	488.8	386.8	323.1	247.0	202.5	172.8	151.5	112.5	90.6	39.1	23.0	13.8

A. 1.2 Runoff speed based on different transport pathways

It is important to consider runoff speed when making estimations of water transport in a certain area. The runoff time through different transport media is illustrated in the table A2 below. From the table A2 it can be concluded that water transport in pipeline systems obtain the highest velocity as compared to natural land.

Table A2: Runoff speed for common transport pathways (Svenskt Vatten, 2004).

Transport pathway	**Runoff speed (m/s)**
Pipeline	1.5
Tunnel or large pipeline	1.0
Ditch and gutter	0.5
Land	0.1

A2. Calculations of water flow and water storage

An urban drainage map covering the pipeline network system at the study area was provided by Kretslopp och Vatten in February 2014. The software programme AutoCAD (Civil 3D, 2011) was then used to calculate the different surface area types and distances for the study area (i.e. the area in close approximation to the park). From this map the surface runoff distance was estimated to be 300 meters (from the highest point in section 2 to the lowest point in section 19). See the figure A1 below for an illustration of the study area and the different surface types.

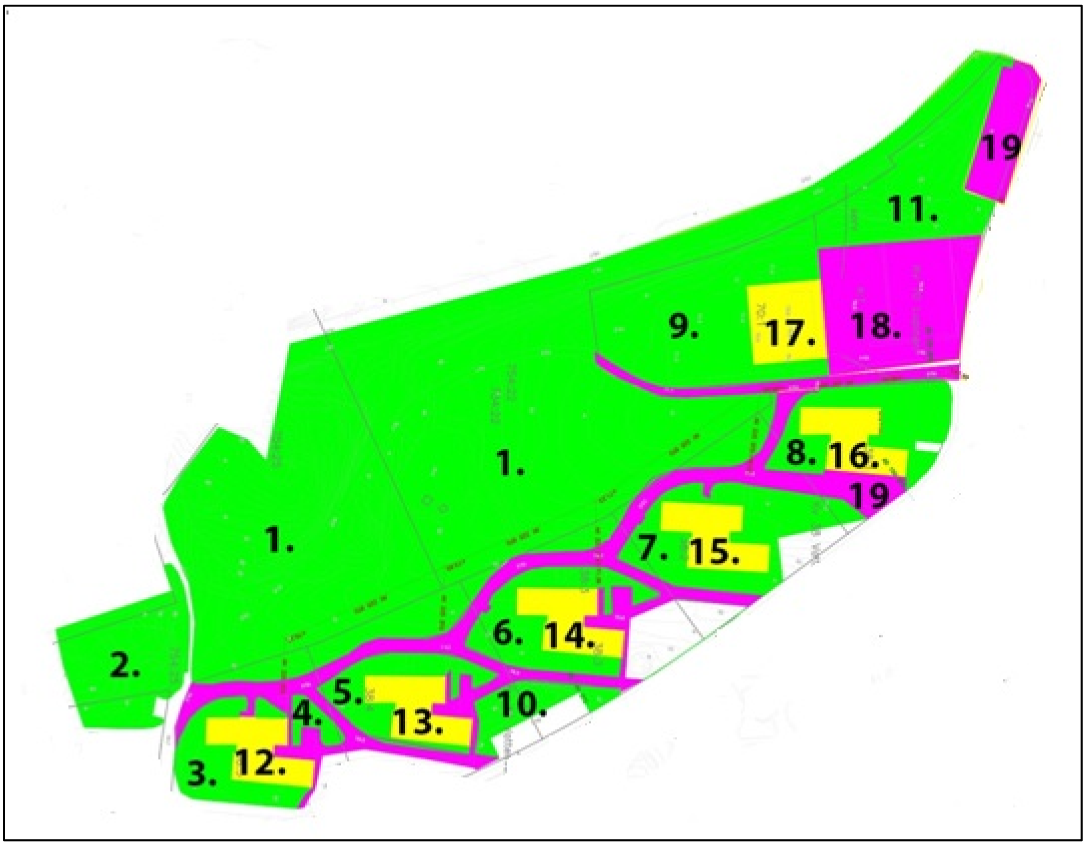


Figure A1: Map provided and approved for publication by Kretslopp och Vatten. Modified after color in order to illustrate different surface types: green= natural land/park, yellow= roof tops and pink = concrete roads and paved areas (i.e. section 18 is the parking lot) in AutoCAD.

Based on the map above, three types of surface areas where identified and used for calculations of the study area (see table A3 below for a summary). Runoff coefficients were taken from the publication P90 (Svenskt Vatten 2004) and modified according to COWI´s own standard for stormwater calculations.

Table A3: Surface types, total area and relevant runoff coefficients used (AutoCAD 2011, Svenskt Vatten 2004 and Frohm 2014).

Surface type	**Total area (ha)**	**Runoff coefficient *before* exploitation**	**Runoff coefficient *after* exploitation**
Green areas	1.8	0.05	0.1
Roof tops	0.22	0.05	0.9
Concrete roads	0.41	0.05	0.8
Total sum	2.44 ha		

The data used for calculations were:

- Runoff coefficients for common surface types (see table A3) from P90
- Runoff speed for common transport pathways (see table A2) from P90
- Rain intensiveness (see table A.1) from P104
- Area (ha) and surface area types (see table A3 and figure A1 above)

Equations that were used for calculations:

- The Rational Method for stormwater storage requirements (see section 2.2.4.1)
- The Rain Envelope Method for stormwater volume requirements (see section 2.2.4.2)

PART 1 – CALCULATE SURFACE WATER RUNOFF TIME

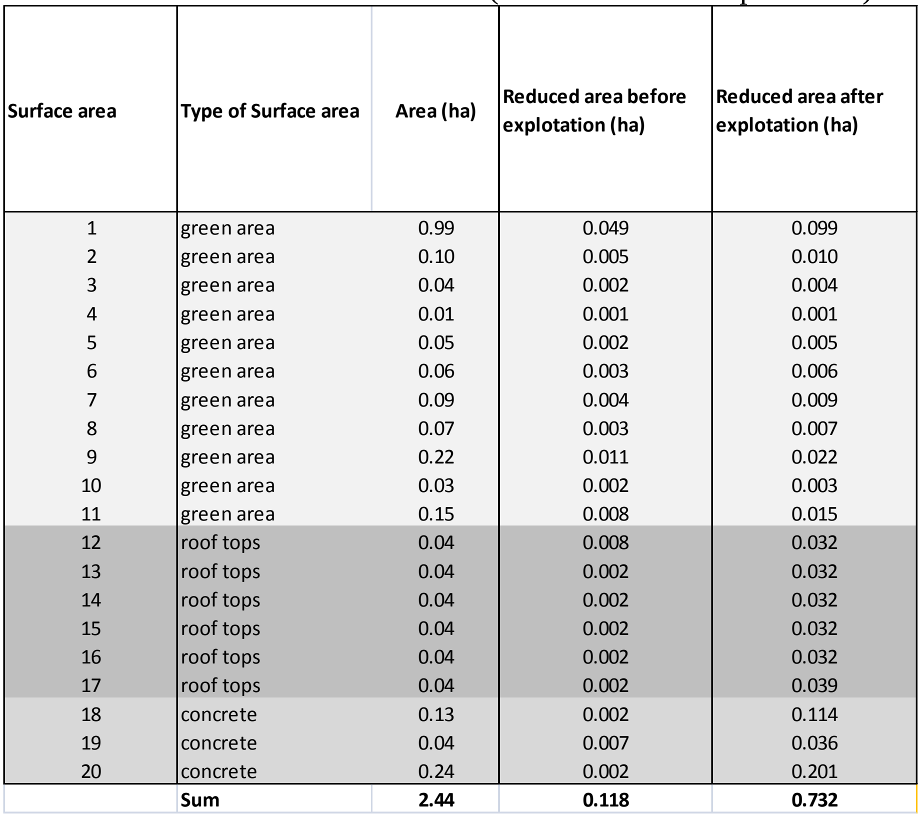
After an estimation of surface areas had been concluded, the first step was to calculate the surface water runoff time for the area for these two scenarios:

1) Before exploitation began (i.e. natural land).
2) After that exploitation had been completed (i.e. with different surface areas).

The surface water runoff time for the area was calculated to be **50 min** (before construction begins) and **10 min** (after construction was completed) using table A3 for the area.

Each surface area was first (1) multiplied with the appropriate runoff coefficient (i.e. unexploited green area) in order to get the "*reduced area before exploitation*" and second (2) multiplied with the appropriate runoff coefficient (i.e. green area, roof tops, concrete roads etc) in order to get the "*reduced area after exploitation*" in ha.
The results from this step were that the reduced area *before* exploitation (1) was **0.118 ha** and *after* exploitation (2) were **0.732 ha.** The results are illustrated in table A4 below.

Table A4: Estimation of reduced area (before and after exploitation).



Surface area	Type of Surface area	Area (ha)	Reduced area before explotation (ha)	Reduced area after explotation (ha)
1	green area	0.99	0.049	0.099
2	green area	0.10	0.005	0.010
3	green area	0.04	0.002	0.004
4	green area	0.01	0.001	0.001
5	green area	0.05	0.002	0.005
6	green area	0.06	0.003	0.006
7	green area	0.09	0.004	0.009
8	green area	0.07	0.003	0.007
9	green area	0.22	0.011	0.022
10	green area	0.03	0.002	0.003
11	green area	0.15	0.008	0.015
12	roof tops	0.04	0.008	0.032
13	roof tops	0.04	0.002	0.032
14	roof tops	0.04	0.002	0.032
15	roof tops	0.04	0.002	0.032
16	roof tops	0.04	0.002	0.032
17	roof tops	0.04	0.002	0.039
18	concrete	0.13	0.002	0.114
19	concrete	0.04	0.007	0.036
20	concrete	0.24	0.002	0.201
	Sum	**2.44**	**0.118**	**0.732**

PART 2 – INVESTIGATE CLIMATE SCENARIOS

The second step was to investigate different climate scenarios for three alternatives (i.e. statistical rain as a zero alternative, dry pond and magazine basin).

The following three scenarios were used for the study area (short-intensive rain <1 hour);

1) Statistical rain (no climate factor added) – used as reference value.
2) Climate change factor 1.20 was added according to P104 (standard for Gothenburg).
3) New Climate factor 1.25 added in accordance to new research based on IPCC climate models for the year 2100.

The reason a short-intensive rain scenario was used (<1 hour) is because this is the scenario that that is associated with the most problems for stormwater facilities (and WWTPs). In short, it is these kind of rainfalls are responsible for producing a large volume of runoff that will put large pressure on the WWTPs (especially from areas still connected to the combined system), resulting in emergency release of wastewater (i.e. CSOs) in the area.
The statistical rain in scenario 1 is used as a reference to scenarios 2+3 and does not incorporate any additional input regarding future changes in precipitation (i.e. it is a measure of today’s situation). The climate factor that was added for the calculating of water flow in scenario 2 is 20% (this value is standard to use for calculations within the region of Västra Götaland and is used by COWI AB and the consulting industry in Sweden) (Frohm, 2014). For scenario 3 a new scientific study from SMHI was used (Olsson and Foster, 2013) that illustrated that the expected future increase in precipitation will (most likely) be +25% to the year 2100.

A summary of the three scenarios is shown in table A5 below.

Table A5– Summary of the different climate factors used for different climate scenarios.

Scenario	Climate factor added (% in increased precipitation)	Timeframe
1) Statistical rain	0%	Present time (statistical)
2) Climate factor added for the region of Västra Götaland in accordance to P104.	+ 20%	Future (not related to any specific year)
3) New scenario based on new scientific research in Sweden (SMHI, 2013).	+25%	2100

In order to find the area that were dimensioned (SWE: dimensionerande) for the area the following calculations were done.

Scenario 1 - The Statistical Rain
The flow was calculated using precipitation data (Svenskt Vatten, 2011c) for: 50 min for all the reduced areas (before exploitation) and 10 min for reduced paved areas (after exploitation). This step is repeated for all three scenarios.
The result of this was:

1) the outflow after 10 years rain (l/s) without climate factor – for just concrete areas = **126 l/s**
2) the outflow after 10 years rain (l/s) without climate factor – for all areas = **59 l/s.**

Scenario 2 – Climate change factor (1.2) is added according to P104
Since the standard climate factor for Västra Götaland is +20% the calculations were done in the same way as for scenario one above: 50 min for all the reduced areas (before exploitation) and 10 min for reduced paved areas (after exploitation).
The result of this was:

3) the outflow after 10 years rain (l/s) without climate factor – for just concrete areas = **151 l/s**
4) the outflow after 10 years rain (l/s) without climate factor – for all areas = **71 l/s.**

Scenario 3 – New Climate factor added (1.25) in accordance to new research and IPCC models for the year 2100.
New research from SMHI (Olsson and Foster, 2013) specifically designed to Sweden has come to the conclusion that the future (2050-2100) change in precipitation rates will be expected to be approximately +25% (10 year return period, 1 hour duration) for Sweden. In order to illustrate this, the following calculations were done for two scenario (the same as scenario 1 and 2); 50 min for all the reduced areas (before exploitation) and 10 min for reduced paved areas (after exploitation).
The result of this was:

5) the outflow after 10 years rain (l/s) without climate factor – for just concrete areas = **157 l/s**
6) the outflow after 10 years rain (l/s) without climate factor – for all areas = **74 l/s.**

The result for all three scenarios is summarized below in table A6:

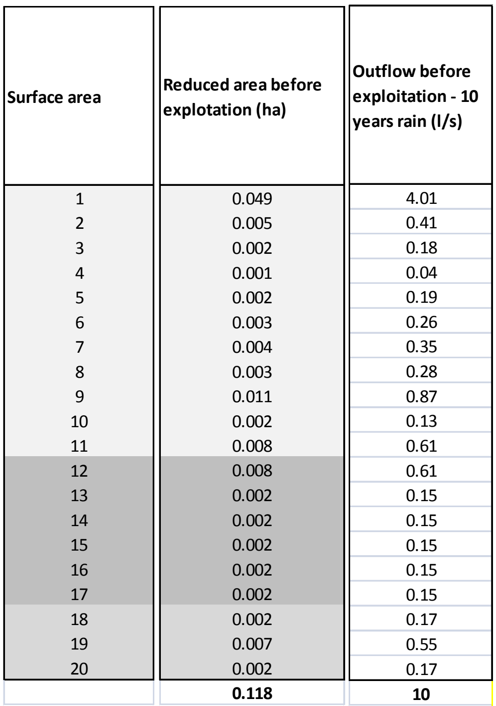
Table A6: Results regarding Scenario 1 (Statistical rain), Scenario 2 (Gothenburg future) and Scenario 3 (Sweden in the year 2100).

Statistical Rain	**Statistical Rain**	**Climate factor added (1.2) according to P104**	**Climate factor added (1.2) according to P104**	**Climate factor (1.25) according to new research and IPCC models**	**Climate factor (1.25) according to new research and IPCC models**
Scenario 1	Scenario 1	Scenario 2	Scenario 2	Scenario 4	Scenario 4
Outflow after 10 years rain (l/s) without climate factor. Only concrete area.	**Outflow after 10 year rain (l/s) without climate factor. All areas**	**Outflow after 10 year rain (l/s) with climate factor 1,2. Only concrete area. Future scenario.**	**Outflow after 10 year rain (l/s) with climate factor 1,2. All areas. Future scenario.**	**Outflow after 10 year rain (l/s) with climate factor 1.25. All only concrete areas. Future scenario (2100)**	**Outflow after 10 year rain (l/s) with climate factor 1.25. All areas. Future scenario (2100)**
	8.0		9.6		10.0
	0.8		1.0		1.0
	0.4		0.4		0.4
	0.1		0.1		0.1
	0.4		0.4		0.5
	0.5		0.6		0.6
	0.7		0.8		0.9
	0.6		0.7		0.7
	1.7		2.1		2.2
	0.3		0.3		0.3
	1.2		1.5		1.5
7.3	2.6	8.8	3.1	9.2	3.3
7.3	2.6	8.8	3.1	9.2	3.3
7.3	2.6	8.8	3.1	9.2	3.3
7.3	2.6	8.8	3.1	9.2	3.3
7.3	2.6	8.8	3.1	9.2	3.3
8.8	3.1	10.6	3.8	11.0	3.9
26.0	9.3	31.2	11.1	32.5	11.6
8.2	2.9	9.9	3.5	10.3	3.7
45.9	16.4	55.1	19.7	57.4	20.5
126	**59**	**151**	**71**	**157**	**74**

PART 3 – CALCULATIONS OF STORMWATER STORAGE DIMENSIONING

First, the prior stormwater outflow was calculated during a 10 year rain period (l/s) through multiplying available rain intensity datasets (Svenskt Vatten, 2011c) with before exploitation (calculated in part 1). The result for the entire land area (including all surface types) was 10 l/s (see table A7below).

Table A7: Calculation of outflow before exploitation.



Surface area	Reduced area before explotation (ha)	Outflow before exploitation - 10 years rain (l/s)
1	0.049	4.01
2	0.005	0.41
3	0.002	0.18
4	0.001	0.04
5	0.002	0.19
6	0.003	0.26
7	0.004	0.35
8	0.003	0.28
9	0.011	0.87
10	0.002	0.13
11	0.008	0.61
12	0.008	0.61
13	0.002	0.15
14	0.002	0.15
15	0.002	0.15
16	0.002	0.15
17	0.002	0.15
18	0.002	0.17
19	0.007	0.55
20	0.002	0.17
	0.118	**10**

This was calculated as a basis for the stormwater storage dimensioning calculations.

Second, in order to make an evaluation we need to know the top volume of the water storage for each scenario. Different duration periods are used (i.e. 10-, 20-, 30-, 40-, 50-, 60-, 90-, 120- and 360 min) and calculated for a return period of 10 yrs in order to get the “final” maximum stormwater storage volume.

Calculations were done through the **Rain Envelope Method** (see section 2.2.4.4 and equation 2). The calculations are done for an arbitrary surface in order to evaluate the maximum volume. Based on this fact, the dimensioned rain could be estimated. The results showed that the **120min** dimensioned rain received the highest storage volume (see table A8 below).

Therefore the 120min dimensioned rain was used for calculating water storage.

Table A8: Stormwater storage dimensioning

Stormwater storage-dimensioning	Scenario 1		Scenario 2		Scenario 4	
Possible dimensioned rain	**10 years, no climate factor**	**Stormwater storage volume**	**10 years, climate factor 1,2**	**Stormwater storage volume**	**10 years, climate factor 1,25**	**Stormwater storage volume**
min	l/s*ha	m3	l/s*ha	m3	l/s*ha	m3
10	228	131	274	158	285	165
20	151	170	181	206	189	215
30	116	191	139	233	145	243
40	95	205	114	251	119	262
50	81	215	98	264	102	276
60	71	223	86	274	89	287
90	53	236	64	294	67	308
120	43	241	52	303	54	319
360	19	208	23	291	24	312
	Max	**241**	**Max**	**303**	**Max**	**319**

PART 4- WATER STORAGE CALCULATIONS

Stormwater storage requirement was calculated through using the Rational Method (see section 2.2.4.1 and equation 1). First, the reduced area (after exploitation) was multiplied with the 10mm/concrete area demand from Gothenburg city (in order to found out the minimum requirement for Gothenburg). This demand is adopted from the publication P105 (Svenskt Vatten, 2011) and is the minimum requirement for rain with a return period of 2 years.

Second, the three scenarios were calculated. The results are shown below (and table A9 below).

0. The water storage demand from Gothenburg city: **73 m^3**
1. Statistical rain = **219 m^3**
2. Climate change factor (1.2) is added according to P104: **264 m^3**
3. New Climate factor added (1.25) in accordance to new research and IPCC models for the year 2100: **276 m^3**

Table A9: Stormwater storage requirement outlet (as unexploited 120min rain)

Stormwater storage demand from the city of Gothenborg	**Statistical Rain**	**Climate factor added (1.2) according to P104**	**Climate factor (1.25) according to new research and IPCC models**
Krav från Göteborgs stad i planprogrammet	Scenario 1	Scenario 2	Scenario 4
Required stormwater storage (m3) as required with 10mm/concrete area	**Stormwater storage requirement outlet as unexploited, 120-min rain (m3)**	**Stormwater storage requirement outlet as unexploited, 120-min rain (m3)**	**Stormwater storage requirement outlet as unexploited, 120-min rain (m3)**
10	27	33	35
1	3	3	4
0	1	1	2
0	0	0	0
0	1	2	2
1	2	2	2
1	2	3	3
1	2	2	2
2	6	7	8
0	1	1	1
2	4	5	5
3	9	11	12
3	10	12	12
3	10	12	12
3	10	12	12
3	10	12	12
4	12	14	15
11	35	42	44
4	11	13	14
20	62	75	78
73	**219**	**264**	**276**

The results shown that there are a great difference between Gothenburg cities demand on required stormwater storage today (i.e. minimum 73m^3) as compared to the statistical scenario 1 (i.e. zero alternative, 219m^3), scenario 2 (i.e. minimum 264 m^3) and scenario 3 (minimum 276m^3) on the study site.

Based on the results in table A9 above, an average water storage volume of 250m^3 was used as a basis to draw up schematics for a simplified stormwater solution on site (i.e. calculate the size required etc) for the dry pond and macadam basin. These schematics were then used to calculate the economic cost for each facility on site that could be used as basis for the MCA (i.e. economic criteria). Economic calculations were done in with the program Bidcon.

APPENDIX B – INTERVIEW WITH A POLITICIAN

The following text is a summary from an interview conducted the 5th May 2014 with the politician Ronnie Ljung in Gothenburg. He is a chairman of the organisation Kretslopp och Vatten (Gothenburg city) and has worked as a full time politician (the green party) since 2003 in Gothenburg city. Before that he worked many years as a teacher within natural science.

1. Why are sustainable urban drainage system and planning important for GTB?
Since the urban drainage pipeline system has an approximately lifetime of about 100 years, sustainability needs to be integrated into the long-term water management and planning within Gothenburg city. When making decisions in this area it is important to consider all the available facts before taking a decision, if something goes wrong then the city just have to learn to live with it (i.e. if you choose one kind of solution that after a while did not live up to the city's original expectations), maybe for a long time afterwards.

2. Do you think that the urban drainage system management is sustainable today in GTB?
The city of Gothenburg is working continuously with sustainable development in all sections, including urban drainage. Waste- and wastewater management should be integrated in the process in order to achieve long term sustainability since they influence each other. For example, if an upstream factory is releasing a lot of contaminated waste- and stormwater into the urban drainage network then the pressure on Ryaverket (the WWTP) in Gothenburg will be greater with regard to treatment processes.

Gothenburg city is slowly replacing old storm- and wastewater systems. At present, approximately 120 million SEK (*about 12.6 million euro*) per year is set aside to improve and upgrade the existing urban drainage pipeline network in the city. However, a lot of work is required beyond this measure since the existing drainage system is very old (some pipelines still in use today are over a hundred years old).

3. What approaches do you think is best when it comes to meeting the future demand on safe and environmental friendly waste water treatment for the city?
There are probably not just one approach that will solve all problems but we need to use a variety of methods in order to get the results that we want, such as: education, information campaigns to all sectors of society, promote innovation, using economic means to promote a certain development and of course laws (i.e. ABVA – the Swedish law regarding public water- and wastewater management and other environmental laws) etc.

The city of Gothenburg is striving to become a "closed-looped" system. In order to achieve this it is important to include waste management, wastewater treatment and environmental aspects in the planning process. A lot more needs to be done but we are on the right track.

4. What environmental aspects are important to consider for Gothenburg (i.e. environmental criteria aspects)?
One of the things the city is working on is de-connecting large areas where stormwater is connected to the combined system. There are many large green areas in Gothenburg today that originally was planned to be sites for residential construction of houses and apartments in the 1940s and therefore was connected to the combined system (i.e. the area of Slätta Damm etc). The stormwater in many of these areas are still transported to Ryaverket, causing an increased (and unnecessary) wastewater pressure on the WWTP. However water planning is

essential for this since you can't just re-direct a lot of stormwater into a local stream without first evaluate the environmental impacts on the site.
In the earlier days of wastewater planning, the law made it impossible to charge people for water management and treatment without a pipe network system that connected the houses to the WWTP. The solution to this was to expand the pipeline network underground, resulting in today's system. Today this law is outdated and there is currently a new stormwater tax planned for Gothenburg city that will help improve the stormwater management work (i.e. a surface based taxation of water).

Today the city is promoting open stormwater solutions when possible since it has been proven that people find esthetic beauty in this kind of facility. It also makes the public aware about the city´s stormwater management work. The application of natural systems that apply biological treatment of chemicals and metals through plants and soil is important to use whenever possible (i.e. open stormwater solutions and dry ponds etc). Furthermore, these system are also often more easy to maintain long-term.

On a larger scale it is important to preserve green areas (i.e. forests, parks etc) in order to maintain and improve the stormwater infiltration capacity in the city. New construction should (if possible) first be directed to older industrial areas in the city (that has already been exploited) rather than using "unspoiled" green areas. Most of these industrial areas are located close to water and is today rather attractive land for construction. However, since this kind of land often require the construction company to pay an extra cost for decontamination of the area they often prefer to build on natural "unspoiled green areas" instead.

Moreover, it is important to keep on working with problem areas located "upstream" of Gothenburg and try de-connecting contaminated areas (i.e. such as industrial areas and dumps) from the urban drainage system and instead apply local wastewater treatment on site. These areas are often large point-sources of heavy contamination. Gothenburg city is right now in the process of locating and de-connecting these kinds of areas (i.e. Brudaremossen in 2017 etc) and in doing so the sewage sludge quality will greatly improve once these areas are gone.

Theoretically, it should only be wastewater from common households that should be treated by Ryaverket (WWTP). But even this kind of wastewater is today contaminated with chemicals originated from clothes/textiles, foods and medicines that will have a negative impact on the wastewater. Regulation of chemical by laws is important in order to improve the wastewater quality.

5. What social aspects are important to consider for Gothenburg (i.e. social criteria aspects)?
From a social perspective, the more noticeable a solution is – the more people's opinions regarding it will matter. In areas where a lot of people move through every day, the social acceptance of a solution becomes more important. It is important to give people the opportunity to get involved and to have an opinion regarding changes in their environment in order to promote acceptance.

Beautiful esthetics solutions are to be preferred, but often the decision maker most also be practical. Some solutions cannot be applied to every area due to site-specific conditions. It is important to use a variety of solutions, and not just one typical solution for the entire city.

However, the idea that the city has to use “out-of-sight” underground pipeline network system for stormwater drainage management is outdated. Investigations have shown that people enjoy and feel aesthetic beauty in open stormwater solutions. So trying to keep as much of the “natural stormwater solutions” as possible is very important along with making sure that the biological diversity of the city is not compromised. Politically, it would have been better if the city had some sort of tool to measure the economic value of green areas in relation to the public´s opinion and wellbeing. Natural green areas have a positive influence on the public’s wellbeing but also on the soil-, water- and air quality in the city. Therefore it is important to maintain and protect green city areas. Gothenburg is also working towards minimizing the number of concrete roads in the city.

6. What economic aspects are important to consider for Gothenburg (i.e. economic criteria aspects)?

Normally old pipes are not replaced until they are broken, and it will take a long time to upgrade and replace the existing drainage network in the city (due to high costs). The availability for the public will also be affected when pipelines are changed due to construction work on site. The most cost-beneficial application is to focus on the combined system and upgrade this part of the city (i.e. into a separate system) over time.

Today, many municipalities around Gothenburg are looking for approval from the city to connect their wastewater pipeline to Ryaverket (the WWTP). Lerum (a small municipality located west of Gothenburg) was connected in 2012 which increased the pressure on Ryaverket with approximately + 3.5%. From an environmental perspective this action was good since Lerum´s own WWTP was old and did not provide efficient wastewater treatment (thus this action reduced the local contamination load going to nearby recipients outside Lerum). But from an economic perspective this action resulted in an increased wastewater load going to Ryaverket, which resulted in higher treatment costs and the possibility of a future increase in the number of CSOs in the region (during intensive rainfalls etc.).

Economically it is important to guide the water management in the city with political decisions and funding for projects that will promote a sustainable future. Communication between different sectors is also required in order to get everyone to work towards the same goal regarding water management. Politically, analysis that compare the cost-benefits of different actions and technological solutions for the city improves decision making and are highly valued by the city of Gothenburg´s politicians.

APPENDIX C – STORMTAC

StormTac is a software modeling tool used for planning and dimensioning stormwater flow. StormTac takes into consideration the entire exchange with the watershed system including pollution transport, impacts in receiving recipients (i.e. water impacts), the design of the transport, flow detention facilities and pollutant treatment. StormTac does calculations with regard to both water quantity and water quality with regard to different kind of systems. For example, StormTac quantity calculations include the following aspects (StormTac 2014a):

- Quantification of average yearly water flows (i.e. runoff volumes, base flow and groundwater) and runoff during average rain events.
- Design of stormwater transport systems (i.e. channels, sewers and ditches).
- Estimation of flow capacity for new- or existing transport systems.
- Design of stormwater detention facilities (i.e. such as dry/wet ponds and detention basins).
- Estimates different return times for different designed flows with regard to climate factors etc.

For example, StormTac quality calculations include the following aspects (StormTac 2014a):

- Estimates the average pollutant load and concentration (per year) in selected discharge points with respect to different land uses.
- Compare measured concentration data to calculated values.
- Identifies the largest pollutant sources and discharge locations to a recipient (illustrating contaminant loads associated with different land uses and materials like copper etc).

C1. Free StormTac dataset for average pollutant reduction efficiency

StormTac also provides a free excel dataset (that can be downloaded from their homepage) that provides the average pollutant reduction efficiency of different stormwater treatment facilities that can be used for average estimations and calculations for the stormwater industry. This dataset was used for estimation of pollutant reduction efficiency (%) for the dry pond and macadam basin.

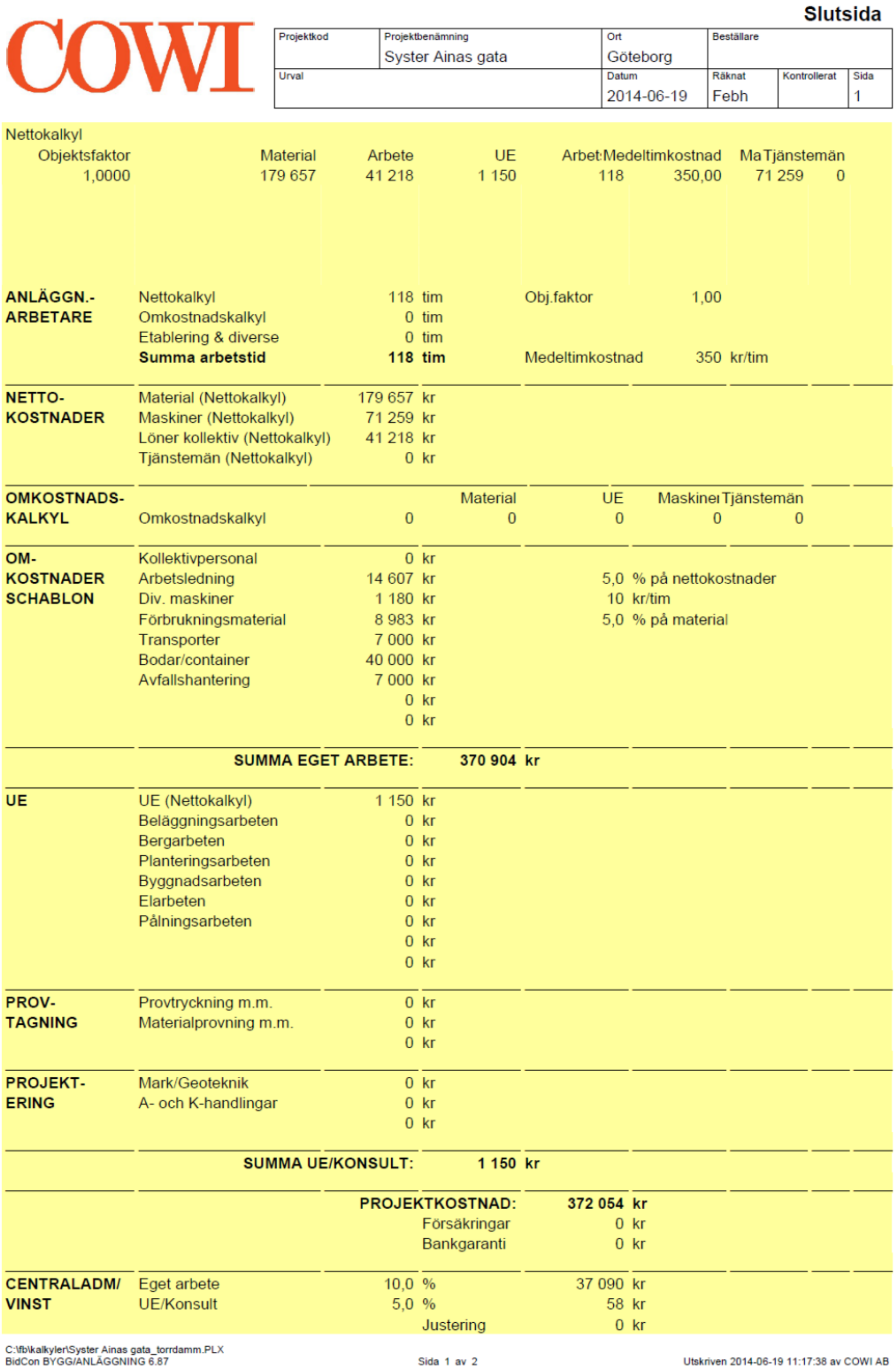
The Excel dataset can be downloaded from here 2014-06-25: http://www.stormtac.com/Downloads.php ("Updated data base for standard concentrations for stormwater, base flow and facility reduction efficiencies", 2014-01-22). The dataset is regularly updated based on ongoing research (StormTac 2014b).

APPENDIX D – BIDCON

Bidcon is a software programme developed for the purpose of calculating construction costs for entrepreneurs. It is based on materials- and personal costs and is widely used in Sweden. Bidcon (version 6) was used in order to make a simple calculation of the cost associated with building i) a dry detention pond and ii) a macadam basin at Guldheden (Consultec, 2014). The results (in Swedish SEK) are illustrated below in section E1 and E2.

APPENDIX E – ECONOMIC ESTIMATIONS OF STORMWATER

E1. Calculation of average costs associated with a dry detention pond (in Swedish)



COWI

Slutsida

Projektkod	Projektbenämning	Ort	Beställare		
	Syster Ainas gata	Göteborg			
Urval		Datum	Räknat	Kontrollerat	Sida
		2014-06-19	Febh		1

Nettokalkyl

Objektsfaktor	Material	Arbete	UE	Arbet	Medeltimkostnad	Ma	Tjänstemän
1,0000	179 657	41 218	1 150	118	350,00	71 259	0

ANLÄGGN.-ARBETARE	Nettokalkyl	118	tim	Obj.faktor	1,00	
	Omkostnadskalkyl	0	tim			
	Etablering & diverse	0	tim			
	Summa arbetstid	**118**	**tim**	Medeltimkostnad	350	kr/tim
NETTO-KOSTNADER	Material (Nettokalkyl)	179 657	kr			
	Maskiner (Nettokalkyl)	71 259	kr			
	Löner kollektiv (Nettokalkyl)	41 218	kr			
	Tjänstemän (Nettokalkyl)	0	kr			

			Material	UE	Maskiner	Tjänstemän
OMKOSTNADS-KALKYL	Omkostnadskalkyl	0	0	0	0	0

OM-KOSTNADER SCHABLON	Kollektivpersonal	0	kr			
	Arbetsledning	14 607	kr	5,0	% på nettokostnader	
	Div. maskiner	1 180	kr	10	kr/tim	
	Förbrukningsmaterial	8 983	kr	5,0	% på material	
	Transporter	7 000	kr			
	Bodar/container	40 000	kr			
	Avfallshantering	7 000	kr			
		0	kr			
		0	kr			
	SUMMA EGET ARBETE:	**370 904**	**kr**			
UE	UE (Nettokalkyl)	1 150	kr			
	Beläggningsarbeten	0	kr			
	Bergarbeten	0	kr			
	Planteringsarbeten	0	kr			
	Byggnadsarbeten	0	kr			
	Elarbeten	0	kr			
	Pålningsarbeten	0	kr			
		0	kr			
		0	kr			
PROV-TAGNING	Provtryckning m.m.	0	kr			
	Materialprovning m.m.	0	kr			
		0	kr			
PROJEKT-ERING	Mark/Geoteknik	0	kr			
	A- och K-handlingar	0	kr			
		0	kr			
	SUMMA UE/KONSULT:	**1 150**	**kr**			
			PROJEKTKOSTNAD:	**372 054**	**kr**	
			Försäkringar	0	kr	
			Bankgaranti	0	kr	
CENTRALADM/ VINST	Eget arbete	10,0	%	37 090	kr	
	UE/Konsult	5,0	%	58	kr	
			Justering	0	kr	

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BidCon BYGG/ANLÄGGNING 6.87

Sida 1 av 2

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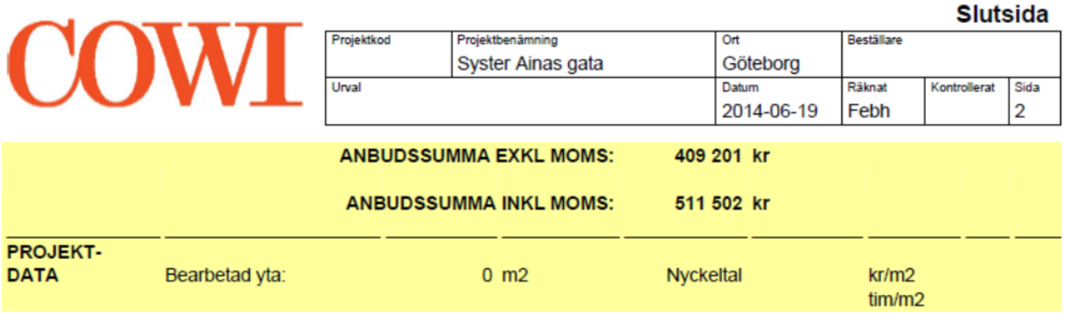

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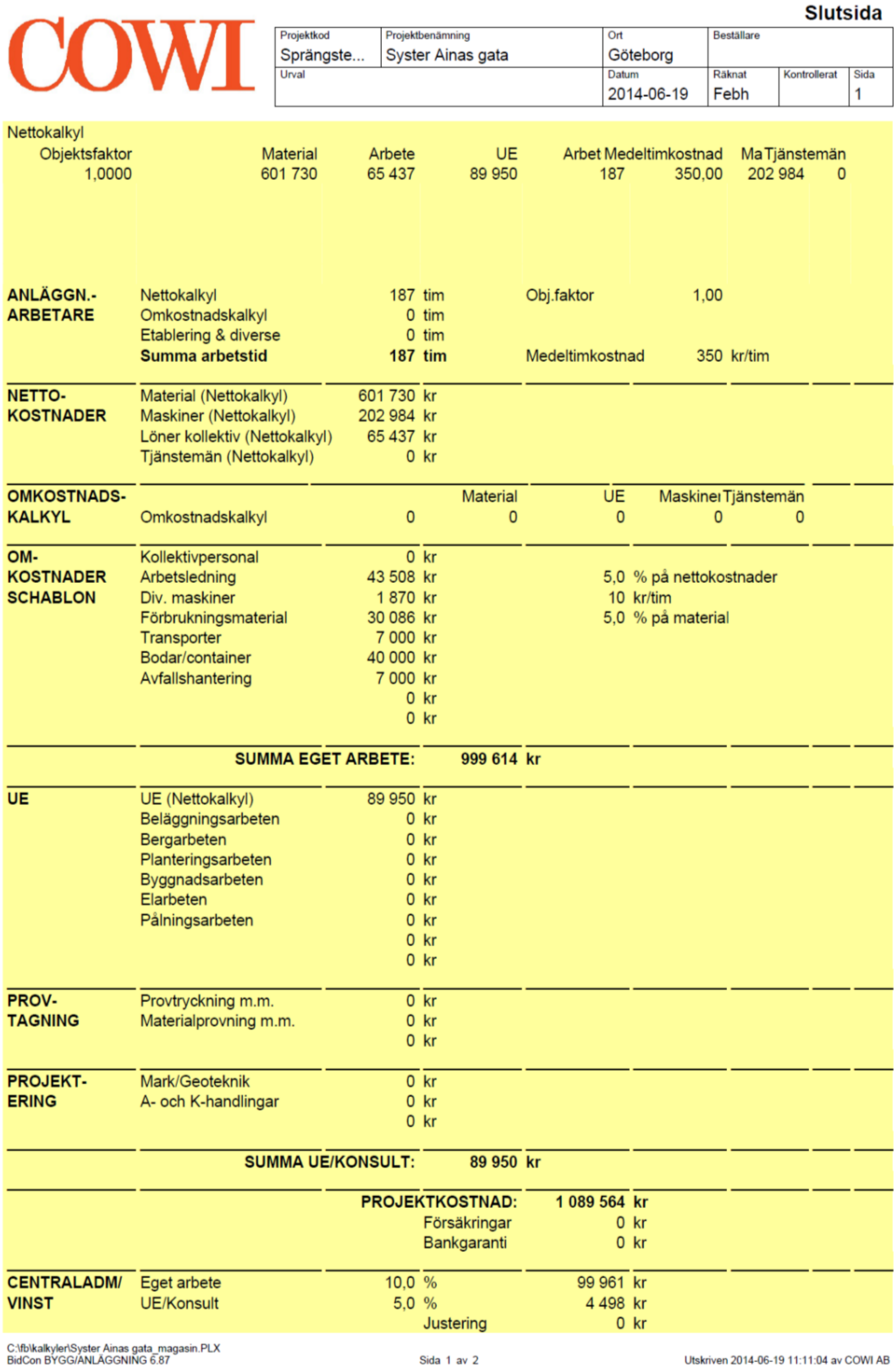
Projektkod	Projektbenämning	Ort	Beställare		
	Syster Ainas gata	Göteborg			
Urval		Datum	Räknat	Kontrollerat	Sida
		2014-06-19	Febh		2

ANBUDSSUMMA EXKL MOMS: **409 201 kr**

ANBUDSSUMMA INKL MOMS: **511 502 kr**

PROJEKT-DATA	Bearbetad yta:	0 m2	Nyckeltal	kr/m2 tim/m2

E2. Calculation of average cost associated with a Macadam Basin (in Swedish)



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Projektkod	Projektbenämning	Ort	Beställare		
Sprängste...	Syster Ainas gata	Göteborg			
Urval		Datum	Räknat	Kontrollerat	Sida
		2014-06-19	Febh		1

Nettokalkyl

Objektsfaktor	Material	Arbete	UE	Arbet	Medeltimkostnad	Ma	Tjänstemän
1,0000	601 730	65 437	89 950	187	350,00	202 984	0

ANLÄGGN.-	Nettokalkyl	187	tim	Obj.faktor	1,00	
ARBETARE	Omkostnadskalkyl	0	tim			
	Etablering & diverse	0	tim			
	Summa arbetstid	**187**	**tim**	Medeltimkostnad	350	kr/tim

NETTO-	Material (Nettokalkyl)	601 730	kr
KOSTNADER	Maskiner (Nettokalkyl)	202 984	kr
	Löner kollektiv (Nettokalkyl)	65 437	kr
	Tjänstemän (Nettokalkyl)	0	kr

			Material	UE	Maskiner	Tjänstemän
OMKOSTNADS-						
KALKYL	Omkostnadskalkyl	0	0	0	0	0

OM-	Kollektivpersonal	0	kr		
KOSTNADER	Arbetsledning	43 508	kr	5,0	% på nettokostnader
SCHABLON	Div. maskiner	1 870	kr	10	kr/tim
	Förbrukningsmaterial	30 086	kr	5,0	% på material
	Transporter	7 000	kr		
	Bodar/container	40 000	kr		
	Avfallshantering	7 000	kr		
		0	kr		
		0	kr		

SUMMA EGET ARBETE: 999 614 kr

UE	UE (Nettokalkyl)	89 950	kr
	Beläggningsarbeten	0	kr
	Bergarbeten	0	kr
	Planteringsarbeten	0	kr
	Byggnadsarbeten	0	kr
	Elarbeten	0	kr
	Pålningsarbeten	0	kr
		0	kr
		0	kr

PROV-	Provtryckning m.m.	0	kr
TAGNING	Materialprovning m.m.	0	kr
		0	kr

PROJEKT-	Mark/Geoteknik	0	kr
ERING	A- och K-handlingar	0	kr
		0	kr

SUMMA UE/KONSULT: 89 950 kr

PROJEKTKOSTNAD: 1 089 564 kr

Försäkringar	0	kr
Bankgaranti	0	kr

CENTRALADM/	Eget arbete	10,0	%	99 961	kr
VINST	UE/Konsult	5,0	%	4 498	kr
			Justering	0	kr

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Sida 1 av 2

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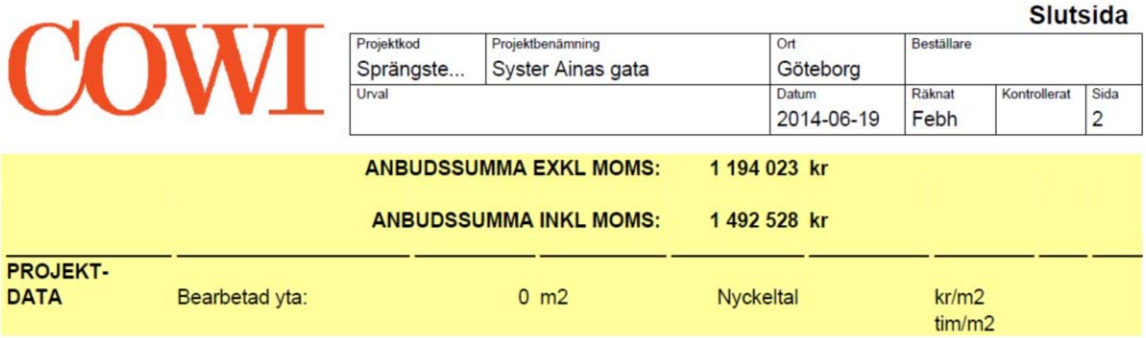


Slutsida

COWI

Projektkod Sprängste...	Projektbenämning Syster Ainas gata	Ort Göteborg	Beställare	
Urval		Datum 2014-06-19	Räknat Febh	Kontrollerat	Sida 2

ANBUDSSUMMA EXKL MOMS: **1 194 023 kr**

ANBUDSSUMMA INKL MOMS: **1 492 528 kr**

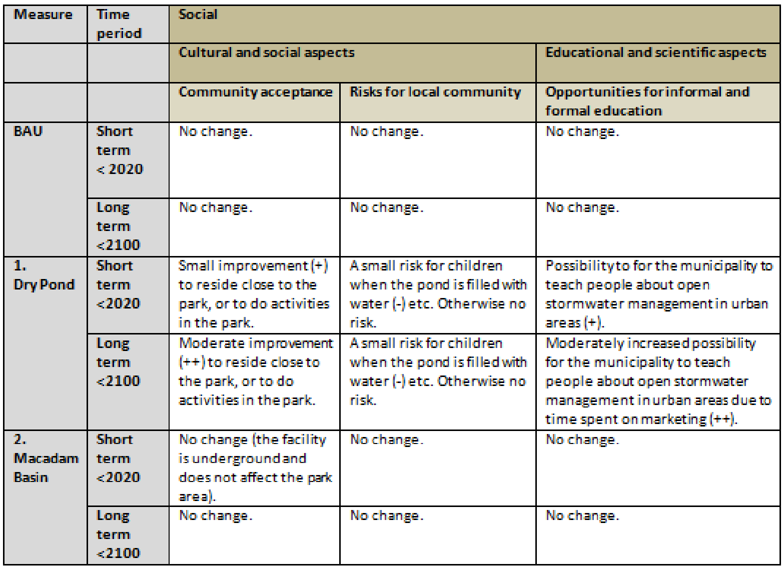
PROJEKT-DATA	Bearbetad yta:	0 m2	Nyckeltal	kr/m2 tim/m2

APPENDIX F – DETAILED PREFORMANCE MATRIX

1. Environmental

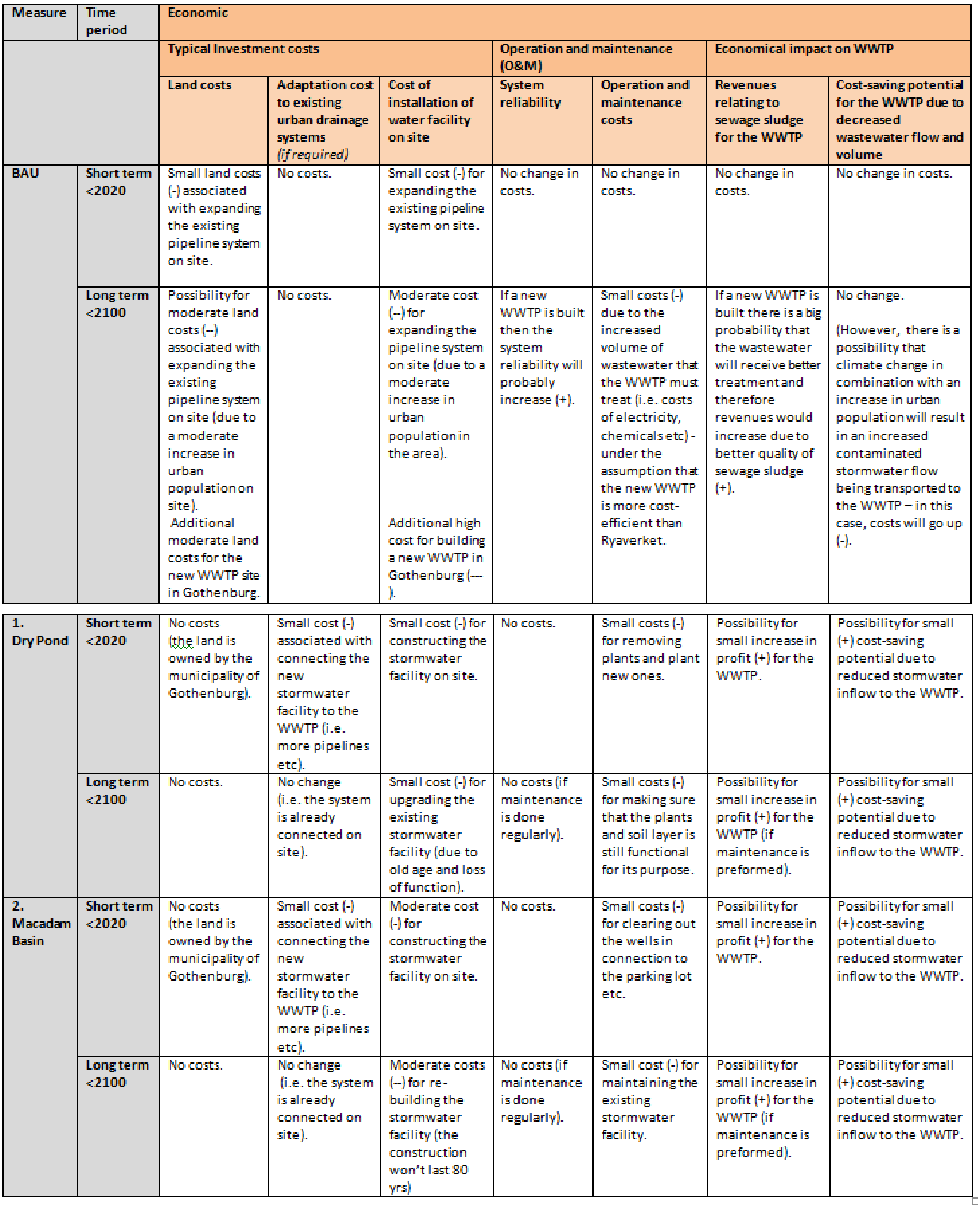
Measure	Time period	Environmental					
		Pollution load to the Environment	Pollution load to the WWTP	Flow Regulation to the Environment	Flow regulation to the WWTP	Biophysical environment on site	
		Environmental impact on recipients downstreams	Environmental effect on sewage sludge at the WWTP	Impact on local ground- and surface water cycle	Potential to delay stormwater on site	Soil quality and soil erosion	Ecological diversity potential
BAU	Short term <2020	No change.	No change.	No change.	No change.	No change.	No change.
	Long term <2100	New WWTP has the potential of moderately improving the environmental status downstreams (++). However, climate change impact in combination with an increase in urbanization will result in a higher load of contaminants transported downstream (-).	New WWTP has the potential of moderately improving the environmental status of sewage sludge (++). However, climate change will result in a larger volume of more heavily contaminated urban stormwater being transported to the WWTP.	No change or possible a small improvement (+) due to higher runoff volumes in the study area due to climate change (increased precipitation and changed seasonal weather climate patterns).	No change.	No change.	No change.
1. Dry Pond	Short term <2020	Small improvement (+) of environmental status downstreams of the study area.	Small improvement (+). Potential for improved local stormwater quality (transported to the WWTP).	Small improvement (+) due to filtration from the stormwater facility.	Small improvement (+) due to the detaining and filtration of stormwater on site.	No change or a potential small degradation (-) in soil quality due to absorption of contaminants. Possibility of small increased erosion potential (-) on site.	Small improvement (+) due to increase in biodiversity at the site.
	Long term <2100	Small improvement (+) of environmental status downstream of the study area.	Small improvement (+). Potential for improved local stormwater quality (transported to the WWTP).	Small improvement (+) due to filtration from the stormwater facility.	Small improvement (+) due to the detaining and filtration of stormwater on site.	No change if the facility is receiving maintenance and soil layer is replaced. Otherwise a moderate to large soil degradation on site (--) due to the decreased ability of the soil to bind contaminants. Possibility for increased erosion potential (-).	Small improvement (+) of biodiversity o site (if maintenance is done properly).
2. Macadam Basin	Short term <2020	No change of environmental status downstream due to lack of absorption from plants. Potential for a small improvement (+) due to soil absorption and binding.	Small improvement (+). Potential for improved local stormwater quality (transported to the WWTP).	No change (if the bottom of the facility is made of concrete). Otherwise a small improvement (+).	Small improvement (+).	No change or possible a potential small to moderate degradation (-) in soil quality due to saturation (the soil cannot absorb any more contaminants). Small possibility for increased erosion potential (-) on site.	No change.
	Long term < 2100	Small improvement (+) due to soil absorption and binding (if the facility is properly managed and updated).	Small improvement (+). Potential for improved local stormwater quality (transported to the WWTP).	No change (if the bottom of the facility is made of concrete). Otherwise a small improvement (+).	Small improvement (+).	No change if the facility is taken care of and soil layer is replaced. Otherwise a moderate to large soil quality degradation (-) due decreased ability of the soil to bind contaminants (i.e. due to saturation).	No change.

2. Social



Measure	Time period	Social		
		Cultural and social aspects		Educational and scientific aspects
		Community acceptance	Risks for local community	Opportunities for informal and formal education
BAU	Short term < 2020	No change.	No change.	No change.
	Long term <2100	No change.	No change.	No change.
1. Dry Pond	Short term <2020	Small improvement (+) to reside close to the park, or to do activities in the park.	A small risk for children when the pond is filled with water (-) etc. Otherwise no risk.	Possibility to for the municipality to teach people about open stormwater management in urban areas (+).
	Long term <2100	Moderate improvement (++) to reside close to the park, or to do activities in the park.	A small risk for children when the pond is filled with water (-) etc. Otherwise no risk.	Moderately increased possibility for the municipality to teach people about open stormwater management in urban areas due to time spent on marketing (++).
2. Macadam Basin	Short term <2020	No change (the facility is underground and does not affect the park area).	No change.	No change.
	Long term <2100	No change.	No change.	No change.

3. Economic



Measure	Time period	Economic						
		Typical Investment costs			Operation and maintenance (O&M)		Economical impact on WWTP	
		Land costs	Adaptation cost to existing urban drainage systems *(if required)*	Cost of installation of water facility on site	System reliability	Operation and maintenance costs	Revenues relating to sewage sludge for the WWTP	Cost-saving potential for the WWTP due to decreased wastewater flow and volume
BAU	**Short term <2020**	Small land costs (-) associated with expanding the existing pipeline system on site.	No costs.	Small cost (-) for expanding the existing pipeline system on site.	No change in costs.	No change in costs.	No change in costs.	No change in costs.
	Long term <2100	Possibility for moderate land costs (--) associated with expanding the existing pipeline system on site (due to a moderate increase in urban population on site). Additional moderate land costs for the new WWTP site in Gothenburg.	No costs.	Moderate cost (--) for expanding the pipeline system on site (due to a moderate increase in urban population in the area). Additional high cost for building a new WWTP in Gothenburg (---).	If a new WWTP is built then the system reliability will probably increase (+).	Small costs (-) due to the increased volume of wastewater that the WWTP must treat (i.e. costs of electricity, chemicals etc) - under the assumption that the new WWTP is more cost-efficient than Ryaverket.	If a new WWTP is built there is a big probability that the wastewater will receive better treatment and therefore revenues would increase due to better quality of sewage sludge (+).	No change. (However, there is a possibility that climate change in combination with an increase in urban population will result in an increased contaminated stormwater flow being transported to the WWTP – in this case, costs will go up (-).
1. Dry Pond	**Short term <2020**	No costs (the land is owned by the municipality of Gothenburg).	Small cost (-) associated with connecting the new stormwater facility to the WWTP (i.e. more pipelines etc).	Small cost (-) for constructing the stormwater facility on site.	No costs.	Small costs (-) for removing plants and plant new ones.	Possibility for small increase in profit (+) for the WWTP.	Possibility for small (+) cost-saving potential due to reduced stormwater inflow to the WWTP.
	Long term <2100	No costs.	No change (i.e. the system is already connected on site).	Small cost (-) for upgrading the existing stormwater facility (due to old age and loss of function).	No costs (if maintenance is done regularly).	Small costs (-) for making sure that the plants and soil layer is still functional for its purpose.	Possibility for small increase in profit (+) for the WWTP (if maintenance is preformed).	Possibility for small (+) cost-saving potential due to reduced stormwater inflow to the WWTP.
2. Macadam Basin	**Short term <2020**	No costs (the land is owned by the municipality of Gothenburg).	Small cost (-) associated with connecting the new stormwater facility to the WWTP (i.e. more pipelines etc).	Moderate cost (-) for constructing the stormwater facility on site.	No costs.	Small costs (-) for clearing out the wells in connection to the parking lot etc.	Possibility for small increase in profit (+) for the WWTP.	Possibility for small (+) cost-saving potential due to reduced stormwater inflow to the WWTP.
	Long term <2100	No costs.	No change (i.e. the system is already connected on site).	Moderate costs (--) for re-building the stormwater facility (the construction won't last 80 yrs)	No costs (if maintenance is done regularly).	Small cost (-) for maintaining the existing stormwater facility.	Possibility for small increase in profit (+) for the WWTP (if maintenance is preformed).	Possibility for small (+) cost-saving potential due to reduced stormwater inflow to the WWTP.

APPENDIX G – BACKGROUND INFORMATION GIVEN TO THE STAKEHOLDERS (BEFORE INTERVIEWS WAS CONDUCTED)

NOTE: Some of the references in this text have been removed before publication since they are not used in this thesis report.

Bakgrunds material till MCA analysen av dagvatten lösningar på Guldheden (GTB)

1. Backgrund till studien

Jag som gör den här studien heter Nathalie Bergqvist och läser just nu mitt sista år på mastersprogrammet ”Industriell Ekologi” på Chalmers Tekniska Högskola. Mitt arbete utgår ifrån att försöka hitta lämpliga dagvatten lösningar i stadsmiljöer som gör att man kan minska belastningen (dvs. vattenflödet) av dagvatten + tillskottsvatten som transporteras via kombinerat system till reningsverket i Göteborg (Ryaverket) som idag är hårt belastat.

I den här studien har jag (tillsammans med mina handledare på COWI) tagit fram några vanliga dagvatten lösningar som används av branschen i Sverige idag. Studien kommer att genomföras genom att först göra en litteratur studie inom området och sedan utvärdera de olika dagvattenlösningarna genom en multikriterieanalys (MKA).

I arbetet för att ta fram lämpliga hållbara bedömningskriterier (dvs. ekonomiska-, sociala- och miljö kriterier) har dessutom flera yrkesverksamma tjänstemän och konsulter i Göteborg kontaktas och deras åsikter och synpunkter har integrerats i bedömningskriterierna.

MKA bygger på att man utvärderar alternativ baserat på kriterier som betygsätts/rangordnats efter deltagarnas omdöme/erfarenhet. I detta fall genomförs intervjuer med yrkesverksamma inom Göteborg stad och konsultbyråer – detta resultat kommer att sedan slås ihop tillsammans med min egen analys för att få en sammanvägd slutsats som kommer att utgöra studiens resultat.

1.1 Södra Guldheden (Göteborg)

Guldheden ligger ca 2.5 km söder om Göteborg centrum. Södra Guldheden byggdes under 1950 talet och är ett område som idag är karaktäriserat av sina många gröna områden (parker, vandringsleder, skog). Befolkningen var 2005 uppskattad till 6200 personer och den största delen av marken ägs av Göteborg stad. Södra Guldheden har ett mindre torg med en matbutik, bibliotek och flera andra små butiker (Göteborg stad, 2005). Södra guldheden har blivit erkänt som ett område av ”kulturhistorisk värdefull bebyggelse”.

Undersökningar som gjorts i samband av upprättande av detaljplaner för området har visat att det finns ett starkt motstånd hos de boende i området mot nybyggen och andra projekt som riskerat att förändra/skära ned på grönområden och allmänna ytor i området (Göteborg stad, 2005).

Området har kombinerat system (d.v.s. påkoppling av både dagvatten/dränvatten och spillvatten) och ligger förhållandevis högt (topografiskt sett) i jämförelse med övriga närområden och Göteborg centrum. Göteborg stad har planer på expandera området med över 300 bostäder de närmsta åren och detta innebär att det kommer att bli en ökad belastning på ledningsnätverket samtidigt som Guldheden har många grönområden där man kan tillämpa olika dagvattenlösningar som potentiellt skulle kunna avlasta ledningsnätverket (Göteborg stad, 2014).

1.2 Studieområdet – parken vid *Syster Ainas Gata (södra Guldheden).*

Parken vid Syster Ainas gata är idag (maj 2014) en byggarbetsplats – Lokalförvaltningen i Göteborg Stad håller på att bygga en ny förskola på platsen som beräknas stå färdig i mars 2015. I samband med detta ska parken rustas upp.

I genomförandebeskrivningen av detaljplanen för förskolan framgår att Göteborg Stad strävar efter att i området (om möjligt) i första hand ta hand om dag- och dränvatten lokalt, och att skapa grönytor för infiltration/översilning av dagvattnet. Marken ägs av Göteborg stad och Poseidon.

1.2.1 Geotekniska förhållanden

Parken kommer efter förskolan att utgöra en area på ca 10 000m^2. Terrängen är kuperad och den topografiska höjdpunkten ligger i parkens södra del (som utgörs av en träddunge med berg i dagen som består av gnejsig grandiorit). Parkens lägsta punkt ligger i norr (dvs. parkeringen). Det översta jordlagret i parken (ca1.0-1.3 meter ned i jordlagret) består av; grus, sand, silt och mulljord.

1.2.3 Bilder och Översiktskarta över parken

Bild G1 (till vänster) illustrerar satellit bild över studieområdet vid Syster Ainas Gata (gult område markerar området som tillhör/angränsar till parken och det röda området utgör byggnadsplatsen för förskolan idag) (Hitta karttjänst, 2014).

Bild G2 (till vänster) visar parken ifrån östläge (entré till parken - bakom parkeringen). Bild G3 (till höger) visar parken ifrån västläge (topografisk höjdpunkt i parken). Bilder tagna av författaren (Bergqvist, 2014).

Bild G4 (till vänster) visar byggnadsplatsen och parkeringen i öst. Bild 6 (till höger) visar terrängen/layouten i parkens mitt (sett från väst). Bilder tagna av författaren (Bergqvist, 2014).

Bild G6 (till höger) och Bild G7 (till vänster) visar nuvarande parkeringsplatsen i anslutningen till syster Ainas Gata och ingången till parken (lägsta topografiska punkten i parken). Bilder tagna av författaren (Bergqvist, 2014).

1.2 Dagvattenlösningar

För området så har följande dagvattenlösningar valts ut som lämpliga för studien;
0) Nollalternativet– inga lokala dagvattenlösningar tillämpas (allt vatten transporteras till Ryaverket)*

1) Torr dam med vegetation/växter (mitt i parken)
2) Sprängstensmagasin (under parkeringsplatsen).

*Nollalternativet (”BAU – *business as usual*”) är att man inte anlägger/tillämpar några mer dagvatten lösningar och istället bygger ett nytt avloppsreningsverk i Göteborg (då Ryaverket redan idag är under hög belastning är detta ett alternativ man överväger). I och med att staden expanderar årligen och att miljökvalitetskraven ökar på avloppsvatten så ligger det i Göteborg stads intresse att se över dagvattenhanteringen (Gryaab har uppskattat att om hela avloppssystemet i Göteborg blev omgjort till kombinerat system idag så skulle inflödet av dag- och spill vatten till Ryaverket mer än öka dubbelt upp).

1.2.2. Funktion och fakta (kort)

En torr dam betyder att man anlägger en sänka (med eller utan extra vegetation) som under intensiva regnperioder är tänkt att kvarhålla och fördröja regnvattnet på plats (och hindra att vattnet transporteras direkt till det kombinerade systemet och Ryaverket). Normallt brukar en sådan här anläggning kunna fördröja regnvattnet upp till 48 tim (beroende på utformning och lokala förutsättningar på plats mm). Området som utnyttjas för denna anläggning kan under större delen av året utnyttjas av de boende (torrdam med enbart gräs) eller tillföra estetisk värde till parken (torrdam med extra vegetation) då många människor uppskattar vackra dagvatten lösningar.

Denna typ av anläggning är relativt billig i jämförelse med andra dagvatten anläggningar, men kan innebära en ökad arbetsinsats i form av parkskötsel av växterna och underhåll av anläggningen av Göteborg stad. En torr dam har en medelbra reningseffekt av dagvattnet.

1.2.3 Sammanfattning (kort)

Generellt Positivt	Generellt Negativt
• Grönt område i parken som kan tillföra estiskt värde och som kan användas av invånarna större delen av säsongen. • Relativt billig i anläggningskostnad och drift (beroende på utformning och plats). • Tillhandahåller medelbra rening av föroreningar i dagvattnet genom avsättning, uppskattningsvis: - SS 55% - Fosfor (P)20% - Kväve (N) 25% - Tungmetaller (Pb, Cd, Zn, Hg etc.) 10-60% • Har potential att minska översvämningsrisken nedströms och fördröja vattenflödet till Ryaverket vid kraftiga regn; - vattenupptag av växter och avdunstning efter regn minskar flödet . • Synliggör dagvatten hanteringen i samhället – informativt.	• Anläggningen kan ta upp plats (damm med extra vegetation) som annars skulle kunna ha användas av de boende i området. • Kan kräva extra skötsel av Göteborg stad. • Reningsfunktionen beror på hur anläggningen är utformad och hur stor den är. – Anläggningen är dock sämre på att avlägsna mindre partiklar som inte sedimenteras lika lätt. • Viss samhällsrisk med öppna vattenspeglar för barn mm.

1.3.1 Sprängstensmagasin (parkeringsplats)

1.3.2 Funktion och fakta (kort)

Sprängstensmagasin innebär att man anlägger en genomsläppligt magasin (ofta bestående av sprängsten) under en asfalterad yta (i detta fall utgörs detta av parkeringsplatsen vid ingången till parken). Vattnet leds ned via rännstensbrunn till ledning under mark (sprängstensmagasin) och transporteras sedan vidare till Ryaverket eller infiltrerar direkt på plats.
Bättre reningsförmåga av vattnet på plats. Transporteras vattnet till Ryaverket så renas det dock ytterligare. Kräver en del underhåll (rengöring av rännstensbrunnar ifrån löv, sediment etc.) för att garantera funktionen.
Kostnad beror på utformning, antal rännstensbrunnar och hur mycket material som man har att tillgå från början (t.ex. om man måste köpa och transportera in extra sprängsten mm).

1.3.3 Sammanfattning (kort)

Generellt Positivt	Generellt Negativt
• Tar inte upp någon andel av parken, osynliggörs genom att den ligger under parkeringsplatsen. • Enkel lösning, sprängsten och material är lätt att tillgå. • Tillhandahåller relativt bra rening av föroreningar i dagvattnet genom avsättning, uppskattningsvis: - SS 75% - Fosfor (P)50% - Kväve (N) 50% - Tungmetaller (Pb, Cd, Zn, Hg etc.) 10-80% • Har potential att minska översvämningsrisken nedströms och fördröja vattenflödet till Ryaverket vid kraftiga regn. • Kostnad varierar med anläggningens utformning och platsspecifika förhållanden.	• Hel anläggningen sätts igen med finsediment över tid – vilket innebär att hela anläggningen då måste bytas ut. Utöver detta så krävs det kontinuerligt underhåll av rännstensbrunnarna för att behålla en så hög funktion som möjligt. • Ej platseffektivt – en äldre lösning som kräver ganska mycket grävarbete. • Synliggör *inte* dagvatten hanteringen i samhället.

1.4. Förväntade klimatförändringar i Västra Götaland och Göteborg (GTB)

Nederbörden förväntas öka med ca +11% till +25% fram till år 2100 (jämfört med referens perioden 1961-1990). Vattenavrinningen förväntas minska under vår och sommar (pga ökad medeltemperatur och högre avdunstning) och öka under vinter och höst (mer regn och mindre snö/is bildning). Vegetationsperioden blir förlängd med +125 dagar till år 2100 (mer växter som binder vatten). Snöperioden förväntas gå ned till 0-15 dagar till år 2100 för regionen. ¨

	Historisk/Referens data (1961-1990)	**Slutet på århundradet (2069-2098)**
Temperatur	6 ^{o}C	10 ^{o}C (medelvärde: variation mellan 8-13 ^{o}C för regionen)
Vegetation period	206 dagar	331 dagar
Nederbörd	794 mm/år	884-994 mm/år
Intensive regn perioder	-	Ökar
Vattenflödet	-	+ 10 % Säsongs variationer: Höst: ökning Vinter: ökning Vår: minsking Sommar: minsking
Grundvatten tillgänglighet	-	0% till +10%
Snöperiod (GTB)	25-75 dagar	0-15 dagar
Havsnivå ökning (GTB)	4 cm (2010)	74 cm

Källa; (Länsstyrelsen Västra Götalands Län, 2011).

2. MCA analysen

Multikriterieanalys (MKA) är ett strukturerat sätt att beskriva hur olika lösningar uppfyller vissa utvalda kriterier som passar ett givet scenario. Lämpliga kriterier väljs ut som bedöms (dvs poängsätts) och sedan vägs allt ihop till ett slutgiltigt resultat .MKA används ofta för komplicerade scenarion där många olika aspekter måste vägas samman.

Denna studie fokuserar på *hållbar utveckling* och kriterierna är uppdelade enligt: Ekonomiska-, Miljö- och Samhälls-/brukar aspekter. Varje kategori har tilldelats ett antal kriterier som ska bedömas.

Även framtida klimatpåverkan på dagvattenlösningarna har inkluderats i studien. Totalt görs bedömningen enligt två tidsscenarior: **Kort tid** (under konstruktion av anläggningen och några år därefter) och **Lång tid** (fram till år <2100).

2.1 Rangordning

Rangordningen görs efter att personen ifråga får betygsätta hur pass bra varje kriteria är för varje dagvatten lösning samt noll alternativet (BAU) utifrån sin egen kunskap och yrkesbakgrund.

Detta görs på följande sätt;

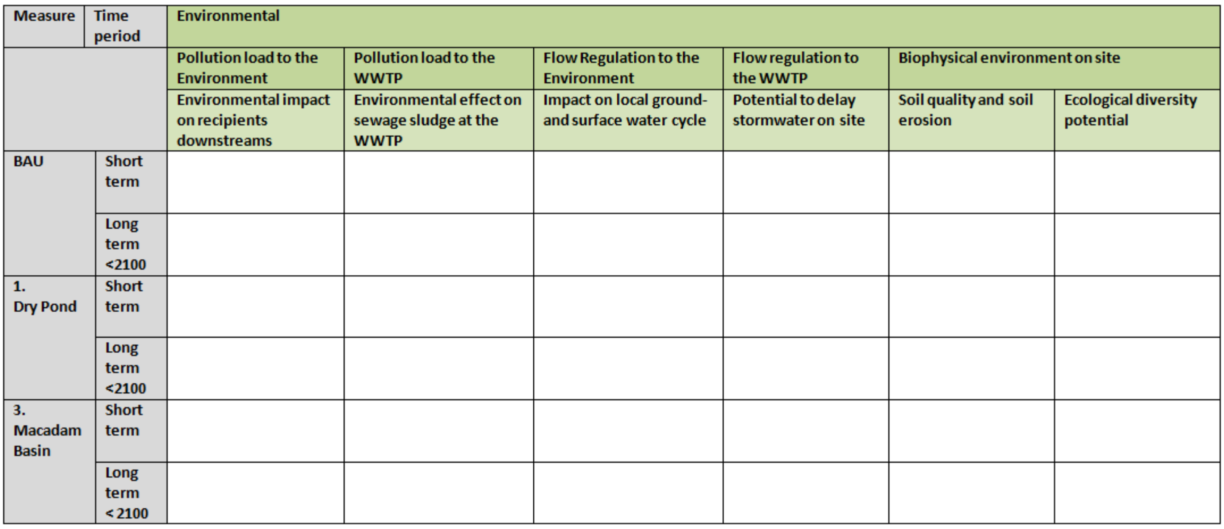
Stor positiv påverkan	+2
Positiv påverkan	+1
Ingen påverkan (neutralt)	0
Negativ påverkan	-1
Stor negativ påverkan	-2

Självklart kan man välja att vara anonym! Då detta projekt utgör en del i det internationella EMOVE projektet som COWI AB är inblandad i kommer detta resultat (förutom examensarbetet) att utgöra underlags material i denna studie också. Alla deltagare kommer automatiskt att bli anonyma i EMOVE studien.

APPENDIX H – CONSEQUENSE TABLES (MCA)

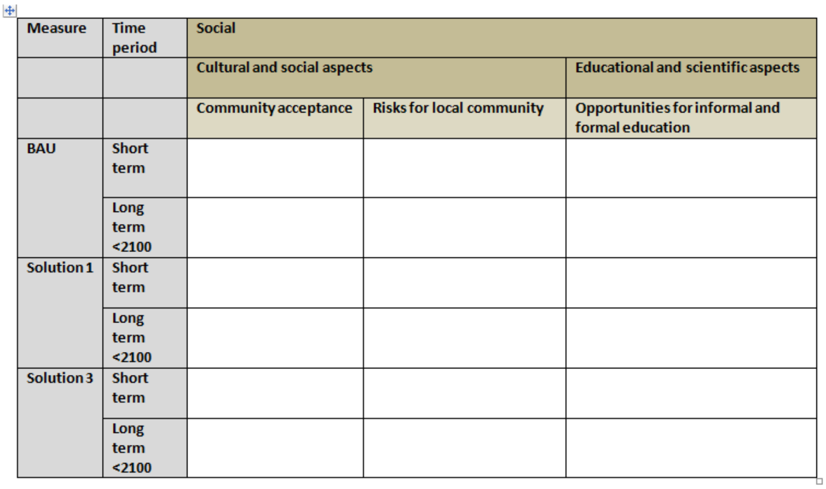
The following consequence tables were used at the interviews (i.e. so the stakeholders wrote their rankings directly on them).

1. Environmental criteria



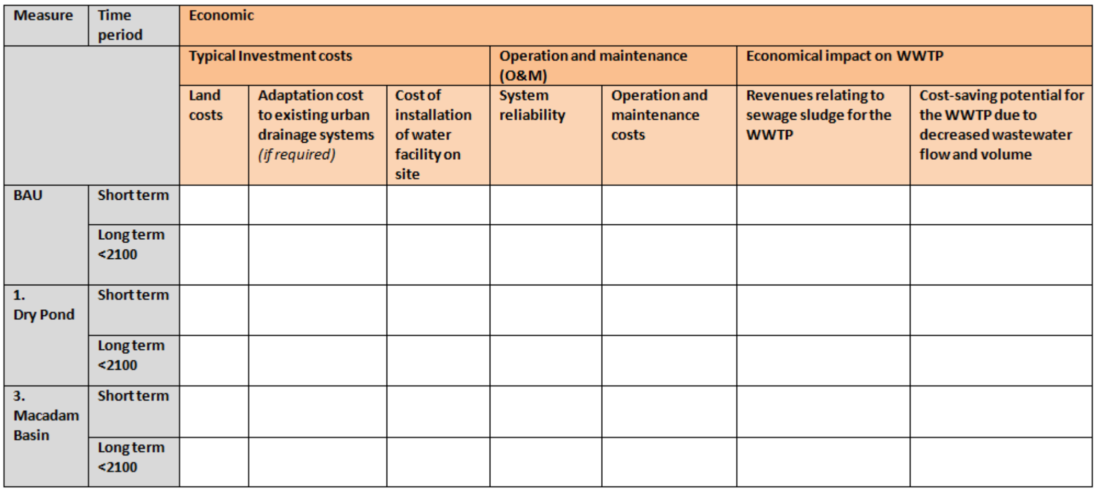
Measure	Time period	Environmental					
		Pollution load to the Environment	Pollution load to the WWTP	Flow Regulation to the Environment	Flow regulation to the WWTP	Biophysical environment on site	
		Environmental impact on recipients downstreams	Environmental effect on sewage sludge at the WWTP	Impact on local ground- and surface water cycle	Potential to delay stormwater on site	Soil quality and soil erosion	Ecological diversity potential
BAU	Short term						
	Long term <2100						
1. Dry Pond	Short term						
	Long term <2100						
3. Macadam Basin	Short term						
	Long term < 2100						

2. Social criteria



Measure	Time period	Social		
		Cultural and social aspects		Educational and scientific aspects
		Community acceptance	Risks for local community	Opportunities for informal and formal education
BAU	Short term			
	Long term <2100			
Solution 1	Short term			
	Long term <2100			
Solution 3	Short term			
	Long term <2100			

3. Economic criterion



Measure	Time period	Economic						
		Typical Investment costs			Operation and maintenance (O&M)		Economical impact on WWTP	
		Land costs	Adaptation cost to existing urban drainage systems *(if required)*	Cost of installation of water facility on site	System reliability	Operation and maintenance costs	Revenues relating to sewage sludge for the WWTP	Cost-saving potential for the WWTP due to decreased wastewater flow and volume
BAU	Short term							
	Long term <2100							
1. Dry Pond	Short term							
	Long term <2100							
3. Macadam Basin	Short term							
	Long term <2100							

APPENDIX I – RANKING OF MCA1

The following section describes the motivation for each individual ranking of MCA1. Each solution is described with regard to the two different time scenarios.

A. ENVIRONMENTAL CRITERIA

1) Pollution load to the Environment → Environmental impact on recipient's downstreams

BAU

Table I1 – Environmental impact on recipients downstream (Svenskt Vatten 2011, Gryaab 2013 and Svenskt Vatten 2011b, SOU 2007).

Short term (<2020)	Long term (<2100)
The WWTP has a small impact on the environmental status downstream (i.e. water quality and pollution transport) since the wastewater is transported through a relatively closed underground drainage system. If leaching from the pipelines is taken into account (some of the pipelines in Gothenburg is over 100 yrs old) then this will have some influence on the local environment and the study area (i.e. leaching is a problem today 2014). The impact on the European Water Framework Directive (WFD) regarding ecological and chemical status will most likely not change much for downstream recipients during the short term scenario (a few years).	If a new WWTP is in operation in Gothenburg during the long term scenario, then it will (most likely) result in an improvement in environmental status (i.e. better water treatment technology etc) including water quality and pollutant transport. Under the assumption that the urban drainage system in Gothenburg will continue to receive an annual upgrade, then it can be assumed that the oldest pipelines (i.e. that are today 2014 leaching) will have been replaced. But this action alone is no guarantee that leaching has stopped completely (i.e. newer pipelines of different materials than the old ones have so far in 2014 not been underground long enough to allow a thorough evaluation of their effectiveness and technical stability for the long term scenario). The impact on the WFD on downstream recipients (regarding ecological and chemical status) will most likely be improved. Also, the future expansion of the city most also be taken into account (that could result in an extended population connected to the old combined system) together with the effect of climate change (i.e. more intensive short period rainfalls patterns etc). This will put additional pressure on the WWTP (especially under the assumption that no extra stormwater solutions are applied).
Therefore the score given will be: -1	**Therefore the score given will be: -2**

DRY POND

Table I2 – Environmental impact on recipients downstreams (StormTac 2014, Svenskt Vatten 2008, SGI 2011, Länsstyrelsen i Västra Götalands Län 2011).	
Short term (<2020)	Long term (<2100)
The Dry Pond has a moderate impact on the environmental status downstream during rainfalls since the plants will help detain contaminants through uptake from the soil and water (i.e. limiting pollutant transport downstreams). In the short time scenario a small improvement of water quality can be expected and consequently on the chemical and ecological status downstream. **Therefore the score given will be: +1**	The Dry Pond will continue to have a moderate impact on the environmental status downstream if maintenance is done properly (i.e. removal and disposal of old of plants, re-placing the old soil with new ones etc) since the plants and the soils capacity to bind contaminants are not unlimited on site. There will most likely be a moderate effect on the water quality and consequently on the chemical and ecological status downstream. Climate change will result in higher runoff flows that is likely to be more contaminated (i.e. more intensive traffic in the area are to be expected since the area will most likely incorporate more residential areas in the future, since it is a very attractive area for residential construction). This will put additional pressure on the facility on site. However if maintenance is done accordingly then the assumption would be that the facility will continue to function properly and reducing the environmental impact on recipients downstreams from the site. **Therefore the score given will be: +1**

MACADAM BASIN

Table I3 – Environmental impact on recipients downstream (StormTac 2014, Länsstyrelsen i Västra Götalands Län 2011, Stahre 2004)	
Short term (<2020)	Long term (<2100)
The Macadam Basin has a moderate impact on the environmental status downstream due to the soils capacity to absorb and bind contaminants from stormwater (i.e. limiting pollutant transport). There will likely be a small improvement in water quality downstreams (including the chemical and ecological status). **Therefore the score given will be: +1**	The facilities ability to improve the environmental status downstream will decline over time (i.e. since the macadam basin will not last 80yers) even if maintenance is done accordingly. Climate change may result in higher runoff flows that is more contaminated (i.e. more intensive traffic in the area are to be expected since the area will most likely incorporate more residential areas in the future, since it is a very attractive area for residential construction). This will put additional pressure on the facility on site during its expected lifetime. **Therefore the score given will be: 0**

2. Pollution load to the WWTP → Environmental effect on sewage sludge at the WWTP

BAU

Table I4 – Environmental effect on the sewage sludge (Länsstyrelsen i Västra Götalands Län 2011, SOU 2007, Ljung 2014, Butler and Davies 2004)	
Short term (<2020)	Long term (<2100)
Since the area surrounding the study area (i.e. park) is mostly made up by residential areas with concrete roads that do not have much traffic today, it can be assumed that the stormwater is not that heavily contaminated from the start (i.e. leaching cupper from roofs etc). Therefore, if the study area continues to connect stormwater to the wastewater drainage network the effect on the sewage sludge (at Ryaverket) will most likely continue to be the same during the short time period. **Therefore the score given will be: 0**	The new WWTP in Gothenburg is expected to increase the efficiency of wastewater treatment (i.e. more efficient technology) and therefore an expected environmental improvement of sewage sludge could be expected. If Gothenburg city will continue to disconnect point sources upstream of the WWTP then this will also automatically improve the quality of the sewage sludge (i.e. less pollutants from the start in the wastewater). However, it can be assumed that more and more municipalities around Gothenburg want to connect themselves to the WWTP (since their own WWTP may not be adequate to meet the higher environmental standards that are expected in the future without considerable investments). This will further increase the pressure on Gothenburg's WWTP. Climate change is expected to increase the stormwater flow (especially from areas still connected to the combined systems) to the new WWTP. Especially if no further stormwater solutions are applied in Gothenburg. Urban expansion together with an increased airborne pollution (i.e. through atmospheric deposition) will further influence the local stormwater quality and put additional pressure on the WWTP. **Therefore, the score given will be: -1**

DRY POND

Table I5 – Environmental effect on the sewage sludge (StormTac 2014, Svenskt Vatten 2008, Länsstyrelsen i Västra Götalands Län 2011, Butler and Davies 2004).

Short term (<2020)	Long term (<2100)
The Dry Pond will have a moderate environmental impact on the sewage sludge at the WWTP due to its capacity to bind stormwater contaminants (i.e. through plant- and soil absorption) on site. **Therefore, the score given will be: +1**	The facility will continue to have a moderate environmental effect on the sewage sludge at the WWTP (based on the assumption that maintenance is done accordingly during its lifetime) in the long time scenario. Climate change (i.e. more intensive rainfalls and higher peak flows etc) in combination will urban expansion and atmospheric deposition (i.e. higher concentration of pollutants) will add extra pressure on the facility. However, under the assumption that maintenance is done accordingly there should still be an overall positive effect on the WWTP. **Therefore, the score given will be: +1**

MACADAM BASIN

Table I6 – Environmental effect on the sewage sludge (Stahre 2004, StormTac 2014, Länsstyrelsen i Västra Götalands Län 2011)

Short term (<2020)	Long term (<2100)
The macadam basin will have a moderate impact on the environmental status of the sewage sludge at the WWTP (due to the soils capacity to bind and absorb contaminants) on site. **Therefore, the score given will be: +1**	The facilities ability to have an environmental affect on the sewage sludge at the WWTP will decline over time (i.e. since the macadam basin will not last 80yers) even if maintenance is done accordingly. Climate change may result in higher runoff flows that are more contaminated (i.e. more intensive car traffic in the area and at the parking lot). This will put additional pressure on the facility on site during its expected lifetime. **Therefore, the score given will be: 0**

3. Flow Regulation to the Environment→ Impact on local ground- and surface water cycle

BAU

Table I7 – Impact on local ground- and surface water cycle (Länsstyrelsen i Västra Götalands Län 2011)

Short term (<2020)	Long term (<2100)
No change since all of the stormwater is connected through the combined system and transported to Ryaverket in the short time scenario. **Therefore the score given will be: 0**	The area will still be connected to the combined system and therefore (as in the short term scenario) most of the stormwater in the area will be transported to the new WWTP. Climate change will increase the weather patterns in the region (with an expected increase in precipitation and waterflow) that instead of infiltrating the ground on site will be transported to the WWTP instead. This will result in a negative impact on the local ground- and surface water cycle in the area. **Therefore the score given will be: -1**

DRY POND

Table I8 – Impact on local ground- and surface water cycle (EPA 2014, Länsstyrelsen i Västra Götalands Län 2011).

Short term (<2020)	Long term (<2100)
The dry pond will have a small impact on the ground- and surface water cycle (due to infiltration) on the site. **Therefore the score given will be: +1**	In the long time scenario, the facility is assumed to have a increased impact on the local ground- and surface water cycle as a direct result of climate change (with an expected increase in precipitation and waterflow) that will result in more frequent intensive weather event that will allow the open water mirror to be in operation (more intensive infiltration) on site. **Therefore the score given will be: +2.**

MACADAM BASIN

Table I9 – Impact on local ground- and surface water cycle (Stahre 2004, Länsstyrelsen i Västra Götalands Län 2011)	
Short term (<2020)	Long term (<2100)
The Macadam basin will have a small impact on the ground- and surface water cycle (due to infiltration) during rainfall events at the site. **Therefore the score given will be: +1**	The facility is assumed (while in operation) to have an impact on the local ground- and surface water cycle. Climate change (with an expected increase in precipitation and waterflow) will provide more intensive weather patterns that will allow for more underground infiltration on site. However, since the facility won't last 80years its influence will diminish. **Therefore the score given will be: +1**

4. Flow regulation to the WWTP →Potential to delay stormwater on site

BAU

Table I10 – Potential to delay stormwater on site (Länsstyrelsen i Västra Götalands Län 2011)	
Short term (<2020)	Long term (<2100)
No change. Most stormwater will be transported to Ryaverket through the combined system (i.e. no change in the potential to delay and/or decrease stormwater on site). The impact on flooding and CSOs is assumed to stay the same. **Therefore the score given will be: 0**	Still no change. Most of the stormwater will be transported to the new WWTP (i.e. no change in the potential to delay and/or decrease stormwater on site). Climate change will result in higher runoff flows transported to the new WWTP, adding more pressure to the WWTP. This could influence the possibility for problems such as flooding and CSOs. **Therefore the score given will be: -1**

DRY POND

Table I11 – Potential to delay stormwater on site (Svenskt Vatten 2008, EPA 2014, Länsstyrelsen i Västra Götalands Län 2011).

Short term (<2020)	Long term (<2100)
The dry pond will have some possibility in delaying and decreasing stormwater volumes on site (due to both detention and infiltration). This is likely to improve the odds for in less floodings and CSOs in the area. **Therefore the score given will be: +1**	The facility is assumed to continue to have some effect in delaying and decreasing stormwater volumes on site (of maintenance is done accordingly during its lifetime). Climate change will result in higher runoff flows, putting extra pressure on the facility. But the assumption will remain that the facility still has potential in delaying stormwater on site and improve the odds for less floodings and CSOs in the area. **Therefore the score given will be: +1**

MACADAM BASIN

Table I12 – Potential to delay stormwater on site (Stahre 2004, Länsstyrelsen i Västra Götaland s Län 2011)

Short term (<2020)	Long term (<2100)
The macadam basin will have some possibility in delaying and decreasing stormwater on site (due to both detention and underground infiltration). This is likely to improve the odds for in less floodings and CSOs in the area. **Therefore the score given will be: +1**	The facilities ability to delay and detain stormwater on site will decline over time (i.e. since the macadam basin will not last 80yers) even if maintenance is done accordingly. Climate change will put more pressure on the facility, resulting in higher waterflow bringing down more sediments/suspended particles that may block the pore space in the coarse gravels and thus prevent stormwater from reaching the natural soil layer and infiltrate the ground. In this respect, it could be assumed that the expected lifespan of the facility will shorten further due to climate change (i.e. less and less impact on floodings and CSOs in the area). **Therefore the score given will be: -1**

5. Biophysical environment on site→ Soil quality and soil erosion

BAU

Table I13 – Soil quality and soil erosion (Ljung 2014, Svenskt Vatten 2011b).	
Short term (<2020)	Long term (<2100)
No change. The impact on soil quality and soil erosion on the site is assumed to be non-existing (even if leaching of underground pipelines may have an impact on soil quality may continue). **Therefore the score given will be: 0**	Still no effect on soil quality and soil erosion on site. Leaching of wastewater may still continue underground but to what extent will depend on the political will in the city (i.e. the budget for renewal and upgrading of the urban drainage system). But under the assumption that the upgrading rate will not be less than in the short term period, the effects of leaching will stay the same. **Therefore the score given will be: 0**

DRY POND

Table I14 – Soil quality and soil erosion (SGI 2011, StormTac 2014b, SWAC 2011)	
Short term (<2020)	Long term (<2100)
The dry pond will most likely not cause any major changes on site in soil quality (even if the stormwater contains some pollutants) over a time period of a few years. Some soil erosion on site is a possibility for stormwater ponds in general, but erosion caused by a dry pond (that is covered with grass and vegetation) is rather small. **Therefore the score given will be: 0**	The facility is assumed to have an increased impact on the soil quality on site (due to accumulation of pollutants from stormwater in soil and plants on site) in the long term perspective even if maintenance is done accordingly (i.e. through the removal of plants and the top soil layer) that will decrease the build-up of pollutants in the sediments on site. Some soil erosion on site is a possibility (due to more intensive and frequent stormwater runoff that will impact the infiltration bed) even though it may be hard to predict to exact what extent. **Therefore the score given will be: -1**

MACADAM BASIN

Table I15 – Soil quality and soil erosion (StormTac 2014b)	
Short term (<2020)	Long term (<2100)
The macadam basin will most likely not cause any major changes on site in soil quality (even if the stormwater contains some pollutants) over a few years. Since the facility is located underground the possibility for erosion is assumed to be very small (or non-existent). **Therefore the score given will be: 0**	The facility is assumed have a larger impact on the underground soil quality on site (due to accumulation of pollutants from stormwater in soil layer) and the concentration will continue to increase until the day when the facility is declared non-operational. Since the facility is located underground the possibility for erosion continues to be very small (or non-existent). **Therefore the score given will be: -2**

6. Biophysical environment on site→ Ecological diversity potential

BAU

Table I16 – Ecological diversity potential	
Short term (<2020)	Long term (<2100)
No effect on the ecological diversity potential in the study area. **Therefore the score given will be: 0**	No effect on the ecological diversity potential in the study area. **Therefore the score given will be: 0**

DRY POND

Table I17 – Ecological diversity potential (SGI 2011, Länsstyrelsen i Västra Götaland s Län 2011)	
Short term (<2020)	Long term (<2100)
The dry pond is assumed to have a positive impact on the ecological diversity on site (i.e. new plants added to the park etc). **Therefore the score given will be: +1**	The dry pond will continue to have a positive impact on the ecological diversity on site. Climate change (i.e. increased temperature etc) may influence (i.e. improve) the conditions for vegetation on site. **Therefore the score given will be: +1**

MACADAM BASIN

Table I18 – Ecological diversity potential	
Short term (<2020)	Long term (<2100)
No effect on the ecological diversity potential in the study area (the facility is located underground). **Therefore the score given will be: 0**	No effect on the ecological diversity potential in the study area (the facility is located underground). **Therefore the score given will be: 0**

B. SOCIAL CRITERIA

1. Cultural and social aspects – Community acceptance

BAU

Table I19 – Community acceptance (Göteborg stad, 2005)	
Short term (<2020)	Long term (<2100)
No change. **Therefore the score given will be: 0**	No change. **Therefore the score given will be: 0**

DRY POND

Table I20 – Community acceptance (Göteborg stad 2005, Stahre 2004)	
Short term (<2020)	Long term (<2100)
The dry pond will add ecological and esthetic value to the park that probably will outweigh the loss of available park land. **Therefore the score given will be: +1**	The dry pond will probably have grown in public acceptance when it has been in operation for a while and the local people have gotten the chance to see its value for their park. *Note: a beautiful park in proximity to residential areas may increase the residential prices in the neighborhood.* **Therefore the score given will be: +2**

MACADAM BASIN

Table I21 – Community acceptance (Göteborg stad 2005)	
Short term (<2020)	Long term (<2100)
The macadam basin will be located underground; therefore it is assumed that no change in community acceptance will occur (i.e. out of sight, out of mind). **Therefore the score given will be: 0**	The macadam basin will still be located underground; therefore it is assumed that no change in community acceptance will occur in the long time scenario either. **Therefore the score given will be: 0**

2. Cultural and social aspects – Risks for local community

BAU

Table I22 – Risks for local community	
Short term (<2020)	Long term (<2100)
No change in risk precipitation (same system as the area has always used and is accustomed to use). **Therefore the score given will be: 0**	No change regarding risk precipitation is expected in the future. **Therefore the score given will be: 0**

DRY POND

Table I23 – Risks for local community (Länsstyrelsen i Västra Götalands Län 2011)	
Short term (<2020)	Long term (<2100)
There might be a small risk associated with open water solutions (i.e. an increased risk for children drowning) for the local community. **Therefore the score given will be: -1**	There will continue to be a small risk associated with open water solutions (i.e. an increased risk for children drowning), especially when climate change will result in higher runoff flows. However, the risk is still estimated to be rather small for the local community. **Therefore the score given will be: -1**

MACADAM BASIN

Table I24 – Risks for local community	
Short term (<2020)	Long term (<2100)
No social risk for the local people is associated with the macadam basin (since it is well concealed underground). **Therefore the score given will be: 0**	No social risk for the local people is associated with the macadam basin (since it is still well concealed underground). *NOTE: If the facility is not maintained then there will be an increased risk for flooding in the area.* **Therefore the score given will be: 0**

3. Educational and scientific aspects – Opportunities for informal and formal education

BAU

Table I25 – Opportunities for informal and formal education	
Short term (<2020)	Long term (<2100)
No change. **Therefore the score given will be: 0**	No change. **Therefore the score given will be: 0**

DRY POND

Table I26 – Opportunities for informal and formal education (Moore and Hunt, 2012)	
Short term (<2020)	Long term (<2100)
The dry pond will present an opportunity to educate the local people about stormwater management in urban areas (especially children since there is a preschool being built on the site today). **Therefore the score given will be: +2**	The dry pond will continue to present an opportunity to educate the local people about stormwater management in urban areas. Also, a beautiful dry pond may attract visitors from other areas. **Therefore the score given will be: +2**

MACADAM BASIN

Table I27 – Opportunities for informal and formal education	
Short term (<2020)	Long term (<2100)
No change since the facility is located underground and does not provide the same opportunity (as the dry pond) for education. **Therefore the score given will be: 0**	No change (still) since the facility is located underground and does not provide the same opportunity (as the dry pond) for education. **Therefore the score given will be: 0**

C. ECONOMIC CRITERIA

1. Land costs

BAU

Table I28 – Land costs (Göteborg stad, 2005).	
Short term (<2020)	Long term (<2100)
No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). **Therefore the score given will be: 0**	The same assumption. No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). **Therefore the score given will be: 0**

DRY POND

Table I29 – Land costs (Göteborg stad, 2005).	
Short term (<2020)	Long term (<2100)
No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). * **Therefore the score given will be: 0**	The same. No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). * **Therefore the score given will be: 0**

**NOTE: The dry pond will require a bigger surface land area (m^2) than the macadam basin.*

MACADAM BASIN

Table I30 – Land costs (Göteborg stad, 2005).	
Short term (<2020)	Long term (<2100)
No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). **Therefore the score given will be: 0**	The same. No change in cost (the municipality owns most of the land at the study site therefore the assumption is that there will be no additional costs). **Therefore the score given will be: 0**

2. Adaptation costs to existing urban drainage systems

BAU

Table I31 – Extension of urban drainage pipeline network (if required)	
Short term (<2020)	Long term (<2100)
No change (i.e. the combined system already exist on site) and no further adaption costs are required. **Therefore the score given will be: 0**	No change (i.e. the combined system already exist on site) and no further adaption cost are required **Therefore the score given will be: 0**

DRY POND

Table I32 – Extension of urban drainage pipeline network (if required)	
Short term (<2020)	Long term (<2100)
There will (most likely) be a very small cost associated with the extension of the drainage pipeline to the new facility. **Therefore the score given will be: -1**	When the facility has been built on site there are no additional costs for urban drainage pipelines. **Therefore the score given will be: 0**

MACADAM BASIN

Table I33 – Extension of urban drainage pipeline network (if required)	
Short term (<2020)	Long term (<2100)
There will (most likely) be a very small cost associated with the extension of the drainage pipeline to the new facility. **Therefore the score given will be: -1**	When the facility has been built on site there are no additional costs for urban drainage pipelines. **Therefore the score given will be: 0**

3. Cost of installing the water facility on site

BAU

Table I34 – Material and construction costs

Short term (<2020)	Long term (<2100)
No additional cost (the combined system already exists on site). **Therefore the score given will be: 0**	No additional cost (the combined system already exists on site and will most likely not be re-constructed/rebuilt in the future either since it is a rather poor urban drainage solution in comparison to the separate systems) under the assumption that the political point of view does not change from today's. *NOTE: But the new WWTP in Gothenburg will cost a lot to build (-2).* **Therefore the score given will be: 0 / -2**

DRY POND

Table I35 – Material and construction costs (Bidcon 2014).

Short term (<2020)	Long term (<2100)
There will be a cost for constructing the facility on site. **Therefore the score given will be: -1**	Under the assumption that maintenance is done accordingly, there should be no additional cost for construction a new dry pond at the site. However, after some time the soil layer will have to be removed (due to accumulation of pollutants) and replaced it with new soil. This will however depend upon many factors such as total stormwater pollution load in the area (but since there are no streets with heavy traffic in the near vicinity around the park/study site – the assumption is that there will not be much pollution accumulating in the sediment) and therefore this cost will be negligible. **Therefore the score given will be: 0**

MACADAM BASIN

Table I36 – Material and construction costs (Bidcon 2014, Stahre 2004).

Short term (<2020)	Long term (<2100)
The cost for construction a macadam basin is about twice as much as that for a dry pond. **Therefore the score given will be: -2**	The facility will not last more than a few decades and must therefore be rebuilt on site. **Therefore the score given will be: -2**

4. System reliability

BAU

Table I37 – Lifespan and reliability of technology

Short term (<2020)	Long term (<2100)
Urban drainage pipeline systems are not unlikely to have a lifetime of about 100 years. However, upgrading the system will be required after some time, and the pipelines in the area are old. Therefore cost for this is assumed. **Therefore the score given will be: -1**	The combined system needs to be upgraded during the long term scenario, which is assumed to be costly. As the city expands, the urban drainage system must be maintained, updated and replaced (i.e. new pipelines etc). *NOTE: The cost will depend upon how much money that has been regularly invested into upgrading the urban drainage system over this time period (i.e. political will).* **Therefore the score given will be: -2**

DRY POND

Table I38 – Lifespan and reliability of technology (EPA, 2014)

Short term (<2020)	Long term (<2100)
A newly installed dry pond will be assumed to work well (under the conditions that the construction was done properly at a site that has favorable geological conditions for infiltration). It will therefore not be any additional costs. **Therefore the score given will be: 0**	The dry ponds lifespan will depend on site specific conditions and maintenance (among other factors) and is hard to predict. But the facility’s reliability will most likely decline with time. Therefore there will be an additional cost. **Therefore the score given will be: -1**

MACADAM BASIN

Table I39 – Lifespan and reliability of technology (Stahre, 2004).

Short term (<2020)	Long term (<2100)
A newly installed macadam basin will be assumed to work well (under the conditions that the construction was done properly at a site that has favorable geological conditions for infiltration). It will therefore not be any additional costs. **Therefore the score given will be: 0**	Since the facility will not last over time its reliability will be low in the long time perspective. **Therefore the score given will be: -2**

5. Operation and maintenance cost

BAU

Table I40 – Operation and maintenance cost for the facility for the municipality (Ljung 2014, Svenskt Vatten 2011a)

Short term (<2020)	Long term (<2100)
There will be a cost to maintain the urban drainage systems functionality (i.e. combined system on site). The city of Gothenburg has a special budget set aside for operation and maintenance of the urban drainage system in Gothenburg. **Therefore the score given will be: -1**	There will most likely be an increased cost in the future for operation and maintenance of the urban drainage systems since investigations done for Swedish municipalities conclude that the upgrading has been to slow previously. Therefore the cost will be assumed to be higher in the long term scenario. Also an increase in population will also put extra pressure on the urban drainage system (including the combined system). **Therefore the score given will be: -2**

DRY POND

Table I41 – Operation and maintenance cost for the facility for the municipality (EPA 2014, SWAC 2011).

Short term (<2020)	Long term (<2100)
There will be a small cost associated with operation and maintenance (i.e. removal of old plants, cutting of grass etc) on site. **Therefore the score given will be: -1**	There will continue to be a small cost associated with operation and maintenance (i.e. removal of old plants, cutting of grass etc) on site. **Therefore the score given will be: -1**

MACADAM BASIN

Table I42 – Operation and maintenance cost for the facility for the municipality (Stahre 2004).

Short term (<2020)	Long term (<2100)
There will be a small cost associated with operation and maintenance (i.e. removal of old leafs and sediments from the wells etc) on site. **Therefore the score given will be: -1**	There will continue to be a small cost associated with operation and maintenance (i.e. removal of old leafs and sediments from the wells etc) on site. **Therefore the score given will be: -1**

6. Revenues relating to the sewage sludge for the WWTP

BAU

Table I43 – Quality of sewage sludge and revenues for the WWTP (Ljung 2014)

Short term (<2020)	Long term (<2100)
No change is predicted in the near future (i.e. the same urban drainage system and pollutant sources). Therefore no change in revenues for the WWTP. **Therefore the score given will be: 0**	During the condition that a new WWTP is built that provides a better wastewater treatment (thus increasing the quality of the sewage sludge) and point sources upstream is disconnected (i.e. less pollution going to the WWTP) then there is a possibility that this will increase the quality and increase revenues for the WWTP. **Therefore the score given will be: +1**

DRY POND

Table I44 – Quality of sewage sludge and revenues for the WWTP (StormTac 2014, EPA 2014, Svenskt Vatten 2008)

Short term (<2020)	Long term (<2100)
The dry pond has potential to detain and absorb contaminants on site which will result in an improvement of stormwater quality on site. This will result in an improved water quality going to Ryaverket and therefore improved sewage sludge. Therefore it will mean increased revenues. **Therefore the score given will be: +1**	If the dry pond is maintained properly then it will most likely continue to detain and absorb contaminants on site, which will result in improved stormwater quality on site. This will result in an improved water quality going to the new WWTP and therefore improved sewage sludge. Therefore it will mean increased revenues. **Therefore the score given will be: +1**

MACADAM BASIN

Table I45 – Quality of sewage sludge and revenues for the WWTP (Westlin 2004)

Short term (<2020)	Long term (<2100)
The macadam basin has potential to detain and absorb contaminants which will result in an improvement of stormwater quality on site. This will result in an improved water quality going to Ryaverket and therefore improved sewage sludge. Therefore it will mean increased revenues. **Therefore the score given will be: +1**	The facility will not function at the same capacity during its lifetime (slowly deterioration functionality and pollutant absorption) due to saturation in the soil layer. Its effect on sewage sludge quality will be less and less until the facility stops to function. Therefore the revenues will most likely go down to the same levels that existed before the facility was built on site. **Therefore the score given will be: 0**

7. Cost-saving potential for the WWTP due to decreased wastewater flow and volume

BAU

Table I46 – Potential to save treatment costs for wastewater at the WWTP	
Short term (<2020)	Long term (<2100)
No change (the same urban drainage system in operation). **Therefore the score given will be: 0**	A new WWTP can be assumed to be more effective (and therefore save money in the form of chemicals and energy usage). But the population is expected to increase, putting extra pressure on the WWTP. Therefore the assumption will be that (even though using a more efficient wastewater treatment process) the change in treatment cost will be 0 (due to increased pressure). **Therefore the score given will be: 0**

DRY POND

Table I47 – Potential to save treatment costs for wastewater at the WWTP (Svenskt Vatten 2008)	
Short term (<2020)	Long term (<2100)
The dry pond will detain and delay the stormwater on site. Part of the stormwater will be infiltrated naturally on site, therefore decreasing the water flow going to Ryaverket. This will save money for treatment costs (less water, less cost). **Therefore the score given will be: +1**	The dry pond (if maintenance is done accordingly) will continue to function properly and decreasing the water flow going to Ryaverket. It is assumed that this will continue to save money for treatment costs for the new WWTP. **Therefore the score given will be: +1**

MACADAM BASIN

Table I48 – Potential to save treatment costs for wastewater at the WWTP (Stahre, 2004)	
Short term (<2020)	Long term (<2100)
The macadam basin will detain and delay the stormwater underground. Part of the stormwater will be infiltrated naturally on site, therefore decreasing the water flow going to Ryaverket. This will save money for treatment costs (less water, less cost). **Therefore the score given will be: +1**	The facility will not function at the same capacity during its lifetime due to saturation. Its potential to decrease the waterflow going to Ryaverket will be less and less until the facility stops working. Therefore the potential to save money for treatment cost will not exist. **Therefore the score given will be: 0**

APPENDIX J – INITIAL SCORING TABLES

The initial scoring of the 6 different scenarios are shown in table J1-J6 below and are based on the stakeholder (i.e. experts) interviews (A-I) and the authors own analysis (J). The motivation for the authors scoring is found in Appendix I.

Table J1: BAU scores (short term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	-2	0	-1	-1	-1	-1	-2	0	0	-1
Environmental effect on sewage sludge at the WWTP	-1	0	-2	-1	-1	-1	-2	0	0	0
Impact on local groundwater and surfacewater cycle	-2	-2	0	-1	-1	-1	-2	0	0	0
Potential to delay stormwater on site	-2	-2	0	-2	-1	-2	-1	0	0	0
Soil quality and soil erosion	0	0	0	2	0	0	0	0	0	0
Ecological diversity potential	0	-1	0	0	0	0	-2	0	0	0
Community acceptance	0	2	0	0	0	0	0	0	0	0
Risks for local community	0	2	-1	0	0	0	0	0	0	0
Opportunities for informal and formal education	0	0	0	0	0	0	-2	0	0	0
Land costs	0	0	0	0	0	0	0	0	0	0
Adaption cost to existing urban drainage system (if required)	-1	0	0	0	0	0	0	0	0	-1
Cost of installation of water facility on site	0	0	0	-1	0	0	0	0	0	0
System reability	-1	0	0	0	0	0	0	0	0	-1
Operation and maintenance costs	-1	0	-1	0	0	0	0	0	0	-1
Revenues relating to sewage sludge for the WWTP	0	0	-2	0	0	0	-1	0	0	0
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	0	0	-2	0	-1	0	0	0	0	0

Table J2: BAU scores (long term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	-1	2	-1	-2	-1	-2	-2	0	-2	-2
Environmental effect on sewage sludge at the WWTP	-1	2	-2	-2	-1	-2	-2	-1	-2	-1
Impact on local groundwater and surfacewater cycle	-2	-2	0	-2	-1	-2	-2	0	-2	-1
Potential to delay stormwater on site	-2	-2	0	-2	-1	-2	-1	0	-2	-1
Soil quality and soil erosion	0	0	0	2	0	-1	0	0	0	0
Ecological diversity potential	0	-1	0	0	0	-1	-2	0	0	0
Community acceptance	0	2	0	0	0	0	-1	0	-2	0
Risks for local community	0	2	-1	0	0	0	0	0	-2	0
Opportunities for informal and formal education	0	-1	0	0	0	-1	-2	0	0	0
Land costs	-2	0	0	0	0	0	0	0	0	0
Adaption cost to existing urban drainage system (if required)	-1	0	0	0	0	0	0	0	0	-1
Cost of installation of water facility on site	0	0	0	-2	0	0	-1	0	0	0
System reability	-1	0	0	-1	0	-2	-2	-1	-2	-2
Operation and maintenance costs	-1	0	-1	-1	0	-2	-2	0	-1	-2
Revenues relating to sewage sludge for the WWTP	0	0	-2	-1	0	0	-2	-1	-2	1
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	-2	0	-2	0	-1	-2	-2	0	-2	0

Table J3: Dry pond scores (short term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	2	1	2	1	0	1	1	-1	1	1
Environmental effect on sewage sludge at the WWTP	1	1	2	1	0	1	1	1	1	1
Impact on local groundwater and surfacewater cycle	2	2	1	1	1	1	2	1	1	1
Potential to delay stormwater on site	2	2	2	2	2	1	1	1	1	1
Soil quality and soil erosion	0	0	-1	-1	-1	0	0	-1	0	0
Ecological diversity potential	1	2	1	2	1	1	2	1	1	1
Community acceptance	1	2	1	2	0	-1	1	2	1	1
Risks for local community	-1	2	1	-1	-1	-1	-1	0	-2	-1
Opportunities for informal and formal education	2	2	2	2	1	1	2	2	1	2
Land costs	0	-1	-2	2	-1	-2	0	-2	-1	0
Adaption cost to existing urban drainage system (if required)	-1	-2	-1	0	-2	-1	2	-1	-1	-1
Cost of installation of water facility on site	-1	-1	-1	2	-1	-2	-1	-1	-1	-1
System reability	-1	0	2	2	1	-1	-1	0	0	0
Operation and maintenance costs	-1	-1	0	-1	0	-1	-1	0	-1	-1
Revenues relating to sewage sludge for the WWTP	0	0	2	0	0	1	0	1	1	1
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	0	1	2	1	1	1	1	1	1	1

Table J4: Dry pond scores (long term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	1	2	2	1	0	2	2	-2	1	1
Environmental effect on sewage sludge at the WWTP	1	2	2	1	0	2	2	1	1	1
Impact on local groundwater and surfacewater cycle	2	2	1	1	1	2	2	2	1	2
Potential to delay stormwater on site	2	2	2	1	2	2	1	1	1	1
Soil quality and soil erosion	-1	0	1	-2	-1	1	0	-2	0	-1
Ecological diversity potential	2	2	1	2	1	2	2	1	1	1
Community acceptance	2	2	2	2	1	1	2	2	1	2
Risks for local community	0	2	1	-1	-1	0	2	0	-2	-1
Opportunities for informal and formal education	1	2	2	2	1	2	2	2	2	2
Land costs	0	-1	-2	2	0	0	0	-2	-1	0
Adaption cost to existing urban drainage system (if required)	-1	0	-1	0	-1	0	2	0	0	0
Cost of installation of water facility on site	-1	-1	-1	2	-1	-1	2	-1	-1	0
System reability	-1	-1	1	1	1	-1	1	-1	-1	-1
Operation and maintenance costs	-1	-1	-1	-2	-1	-1	0	-1	-1	-1
Revenues relating to sewage sludge for the WWTP	1	0	2	0	0	2	0	1	1	1
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	2	2	2	1	1	2	1	1	2	1

Table J5: Macadam basin scores (short term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	2	1	2	1	0	1	1	-1	1	1
Environmental effect on sewage sludge at the WWTP	1	1	2	2	0	1	1	1	1	1
Impact on local groundwater and surfacewater cycle	0	2	1	2	1	1	0	1	-1	1
Potential to delay stormwater on site	2	2	2	0	2	1	1	1	1	1
Soil quality and soil erosion	0	0	0	-1	-1	0	0	0	-1	0
Ecological diversity potential	0	-1	0	1	0	0	-1	0	0	0
Community acceptance	0	2	1	0	0	0	0	0	0	0
Risks for local community	0	2	1	0	0	0	1	0	0	0
Opportunities for informal and formal education	0	0	0	0	0	1	-2	0	0	0
Land costs	0	0	-1	0	-1	-1	0	-1	-2	0
Adaption cost to existing urban drainage system (if required)	-1	-2	-1	0	-2	-1	-1	-1	-1	-1
Cost of installation of water facility on site	-2	-1	-1	-1	-1	-1	-1	-1	-2	-2
System reability	-1	0	1	-1	1	-1	1	0	-1	0
Operation and maintenance costs	-1	0	-1	0	1	-1	0	0	-1	-1
Revenues relating to sewage sludge for the WWTP	0	0	2	1	0	1	0	1	1	1
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	0	1	2	2	1	1	1	1	1	1

Table J6: Macadam basin scores (long term perspective).

	A	B	C	D	E	F	G	H	I	J
Environmental impact on downstream recipients	1	2	0	1	0	1	1	-2	1	0
Environmental effect on sewage sludge at the WWTP	1	2	0	2	0	1	1	1	1	0
Impact on local groundwater and surfacewater cycle	0	2	1	1	1	1	0	2	-1	1
Potential to delay stormwater on site	2	2	1	0	2	1	1	1	1	-1
Soil quality and soil erosion	0	0	0	-1	-1	0	0	0	-1	-2
Ecological diversity potential	0	-1	0	1	0	-1	-1	0	0	0
Community acceptance	0	2	1	0	0	0	0	0	2	0
Risks for local community	0	2	1	0	0	0	1	0	0	0
Opportunities for informal and formal education	0	0	0	0	0	1	-2	0	0	0
Land costs	0	0	-1	0	0	0	0	-1	-2	0
Adaption cost to existing urban drainage system (if required)	-1	0	-1	0	-1	0	1	0	-1	0
Cost of installation of water facility on site	-2	-1	-1	-1	-1	0	-1	-1	-2	-2
System reability	-1	-2	0	-2	-1	-1	-1	-1	-2	-2
Operation and maintenance costs	-1	-2	-2	-1	-1	-1	-1	-1	-2	-1
Revenues relating to sewage sludge for the WWTP	1	0	1	1	0	1	0	1	1	-1
Cost-saving potential for the WWTP due to decreased wastewater flow and volume	2	2	1	1	1	2	1	1	2	0

APPENDIX K – MEAN, MAXIMUM and MINIMUM VALUE

The difference between MCA1 and MCA2 is showed below in figure K1-K4. Since the result of MCA1 is only based on one person (the analyst) and MCA2 is based on 9 experts, there tend to be more variations in the MCA2 (when compared to MCA1). In other words, MCA1 is a (single) point value used for comparison between the mean-, max- and minimum values derived from MCA2.

Scenario 1 - Business as usual

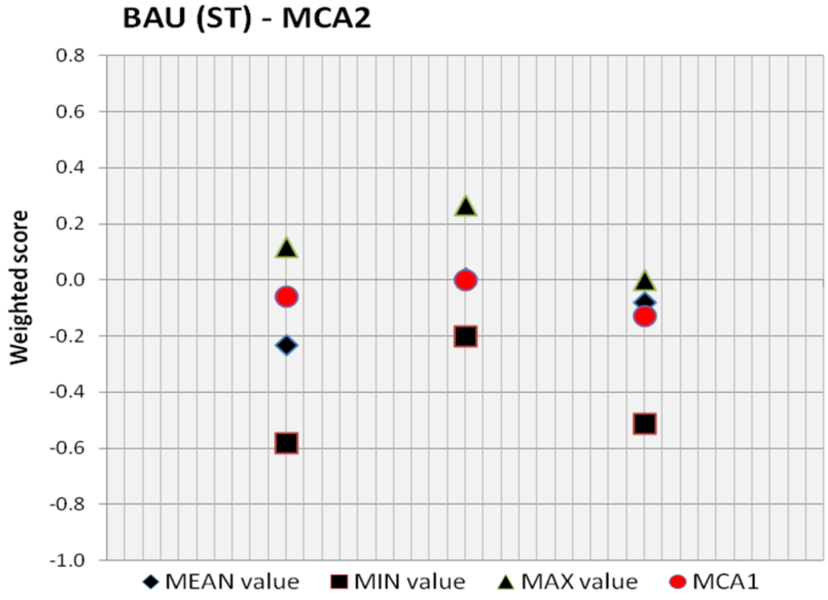


Figure K1: Comparison between BAU (i.e. the combined system/zero alternative) during the short term (ST) scenario for MCA1 (point value) and MCA2 (max-, min- and mean value).

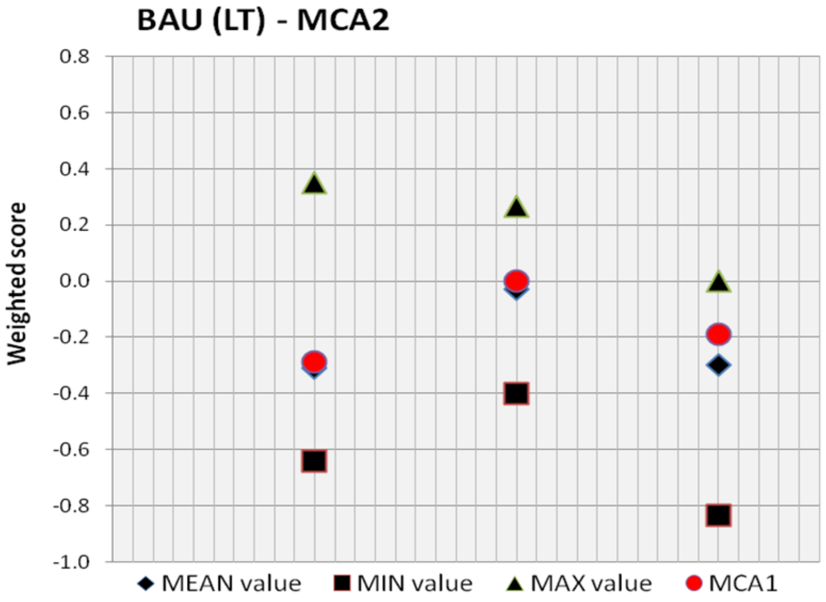


Figure K2: Comparison between BAU (i.e. the combined system/zero alternative) during the long term (LT) scenario for MCA1 (point value) and MCA2 (max-, min- and mean value).

Scenario 3 – Macadam Basin

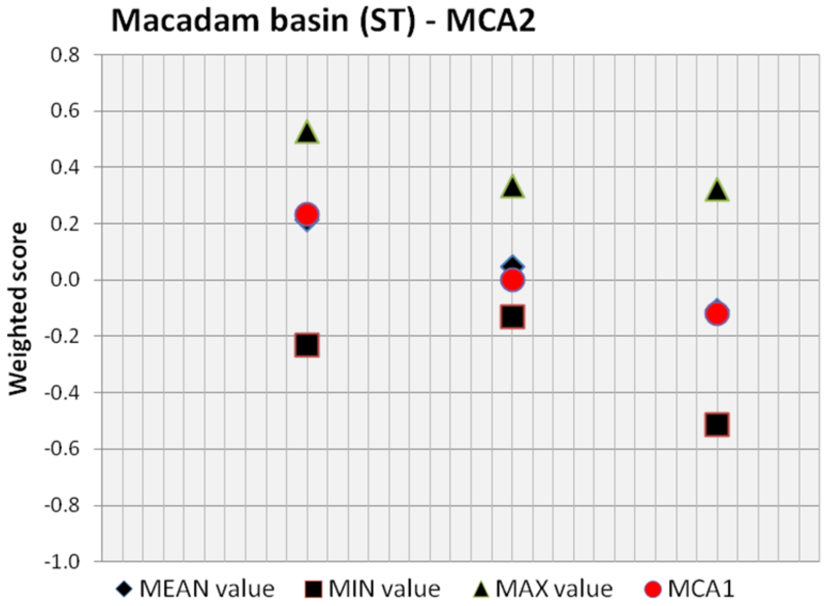


Figure K3: Macadam basin comparison for the short term (ST) scenario for MCA1 (point value) and MCA2 (max-, min- and mean value).

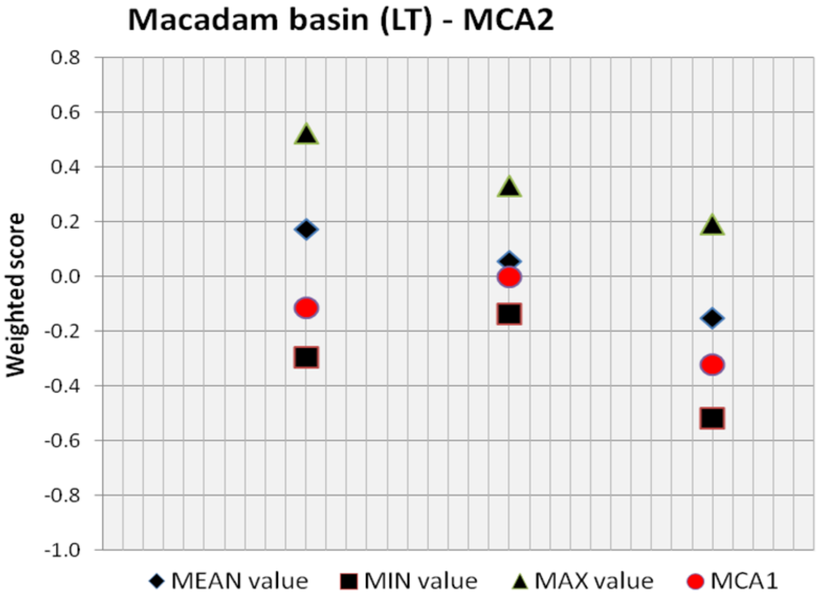


Figure K4: Macadam basin comparison for the long term (LT) scenario for MCA1 (point value) and MCA2 (max-, min- and mean value).

APPENDIX L – NIGHTFLOW

The night flow per person (expressed as q/p) indicates how large the urban drainage water leakage is in an area which is based on measurements taken of the nightly usage of water (data is normally collected in the morning between 2.00 – 4.00 AM).

Depending on the quota (q/p) the measurement gives an indication about when it becomes relevant to look closely at the leakage in an area.

As a general rule; leakage should be investigated more closely if the quota (q/p value) is:

>0.5 in older residential houses or close to the city center
>0.4 in newer residential areas or smaller family houses
>0.3 in small communities outside the city (sub-urban areas)
>0 in industrial areas (i.e. if no industrial activity is happening during the night then all outflow will be considered as leakage) (Svenskt Vatten, 2011).

(NOTE: Guldheden has a quota of 0.8 and is situated close to the city center)

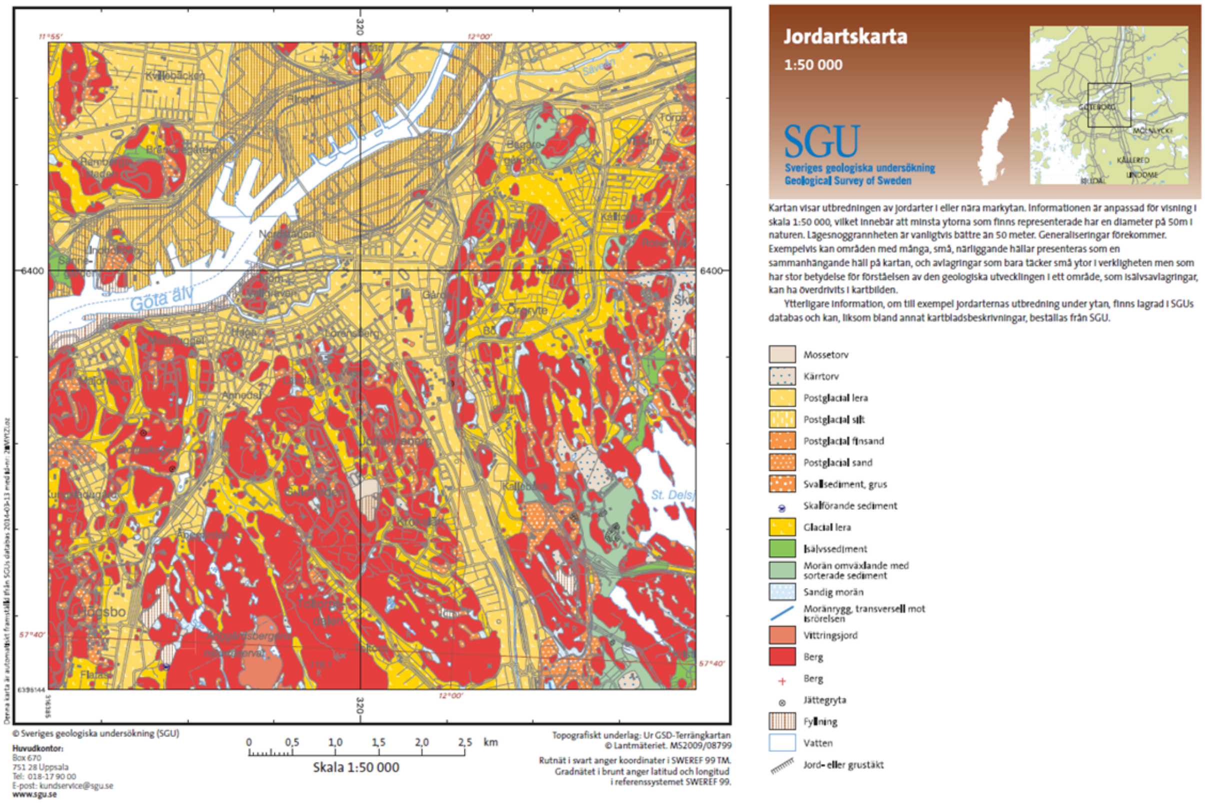
Where,

q= liter/min
p = person

APPENDIX M – MAPS FROM SGU

The following maps were downloaded from SGU´s homepage.

M1. Soil Map



Kartan visar utbredningen av jordarter i eller nära markytan. Informationen är anpassad för visning i skala 1:50 000, vilket innebär att minsta ytorna som finns representerade har en diameter på 50m i naturen. Lägesnoggrannheten är vanligtvis bättre än 50 meter. Generaliseringar förekommer. Exempelvis kan områden med många, små, närliggande hällar presenteras som en sammanhängande häll på kartan, och avlagringar som bara täcker små ytor i verkligheten men som har stor betydelse för förståelsen av den geologiska utvecklingen i ett område, som isälvsavlagringar, kan ha överdrivits i kartbilden.

Ytterligare information, om till exempel jordarternas utbredning under ytan, finns lagrad i SGUs databas och kan, liksom bland annat kartbladsbeskrivningar, beställas från SGU.

Denna karta är automatiskt framställd från SGUs databas 2014-03-13

© Sveriges geologiska undersökning (SGU)

Huvudkontor:
Box 670
751 28 Uppsala
Tel: 018-17 90 00
E-post: kundservice@sgu.se
www.sgu.se

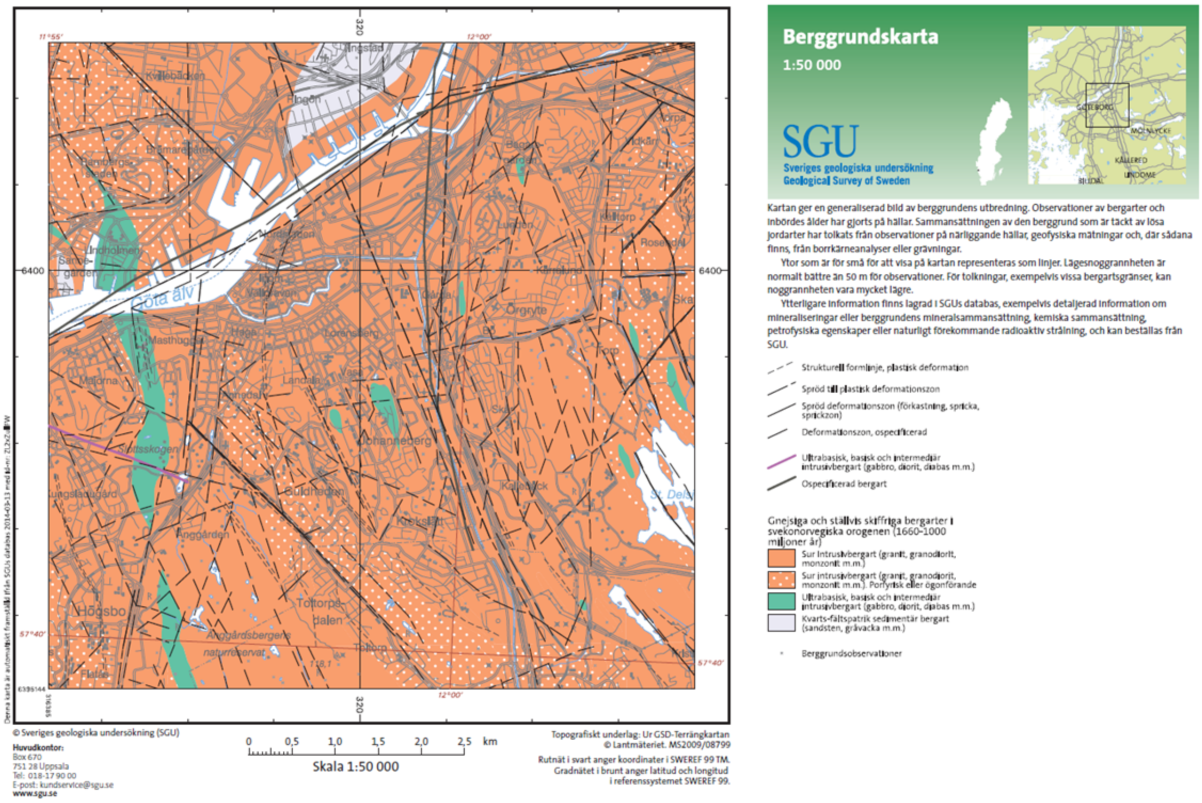
Topografiskt underlag: Ur GSD-Terrängkartan
© Lantmäteriet. MS2009/08799

Rutnät i svart anger koordinater i SWEREF 99 TM.
Gradnätet i brunt anger latitud och longitud
i referenssystemet SWEREF 99.

Figure M1: Top soil map of the central parts of Gothenburg (including Guldheden) (SGU, 2009a).

Description of soil map; the area of Guldheden is consistent with post-glacial clay (yellow), post-glacial sand (orange), visible bedrock (red) and some sandy till (light blue).

M2. Bedrock Map



Kartan ger en generaliserad bild av berggrundens utbredning. Observationer av bergarter och inbördes ålder har gjorts på hällar. Sammansättningen av den berggrund som är täckt av lösa jordarter har tolkats från observationer på närliggande hällar, geofysiska mätningar och, där sådana finns, från borrkärneanalyser eller grävningar.

Ytor som är för små för att visa på kartan representeras som linjer. Lägesnoggrannheten är normalt bättre än 50 m för observationer. För tolkningar, exempelvis vissa bergartsgränser, kan noggrannheten vara mycket lägre.

Ytterligare information finns lagrad i SGUs databas, exempelvis detaljerad information om mineraliseringar eller berggrundens mineralsammansättning, kemiska sammansättning, petrofysiska egenskaper eller naturligt förekommande radioaktiv strålning, och kan beställas från SGU.

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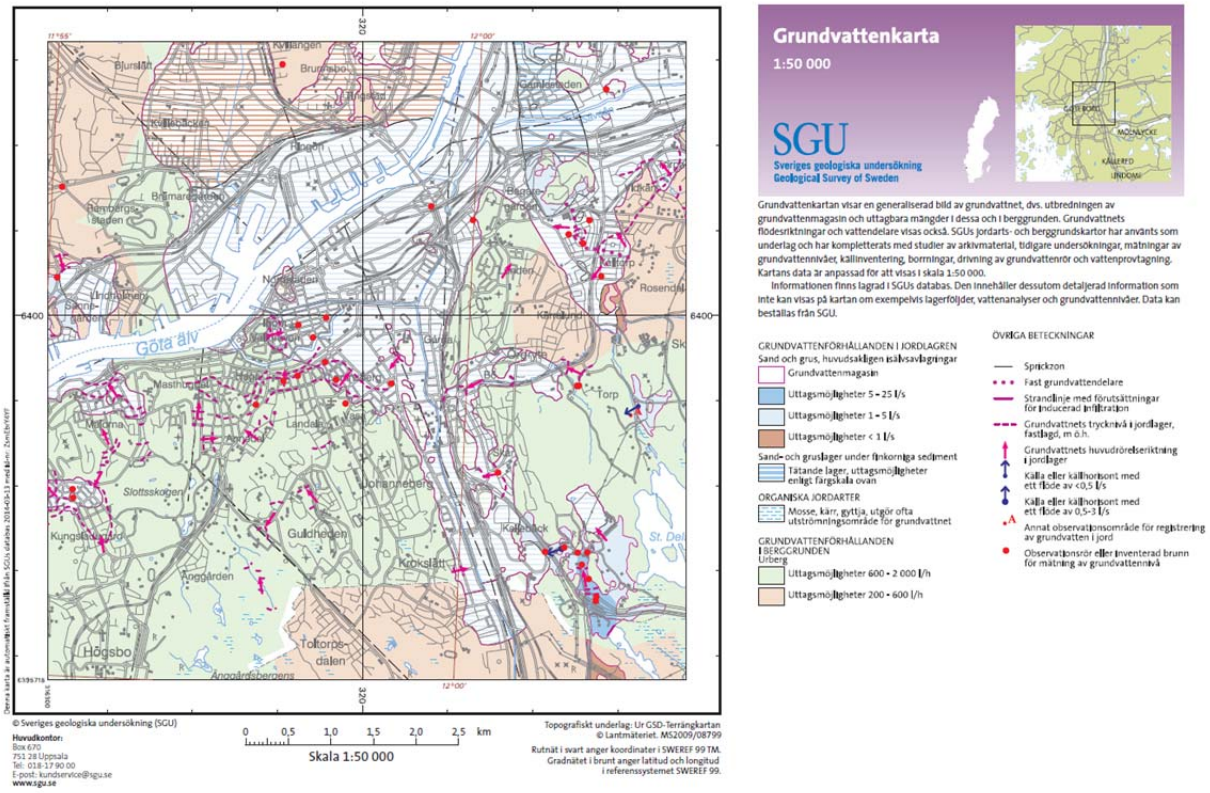
Figure M2: Bedrock map of the central part of Gothenburg (including Guldheden) (SGU, 2009b).

Description of bedrock map; the area of Guldheden consist of mostly granite, grandiorite and monzonit (i.e. sour intrusive bedrock). At Guldheden there is a plastic deformation illustrated as several doted lines (i.e. areas that are too small to be visible on the map is illustrated as lines).

M3. Groundwater Map



Grundvattenkartan visar en generaliserad bild av grundvattnet, dvs. utbredningen av grundvattenmagasin och uttagbara mängder i dessa och i berggrunden. Grundvattnets flödesriktningar och vattendelare visas också. SGUs jordarts- och berggrundskartor har använts som underlag och har kompletterats med studier av arkivmaterial, tidigare undersökningar, mätningar av grundvattennivåer, källinventering, borrningar, drivning av grundvattenrör och vattenprovtagning. Kartans data är anpassad för att visas i skala 1:50 000.

Informationen finns lagrad i SGUs databas. Den innehåller dessutom detaljerad information som inte kan visas på kartan om exempelvis lagerföljder, vattenanalyser och grundvattennivåer. Data kan beställas från SGU.

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Gradnätet i brunt anger latitud och longitud
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Figure M3: Ground water map covering the central part of Gothenburg (including Guldheden) (SGU, 2009c)

Description of groundwater map; the area of Guldheden is made up by extraction possibilities up to 600-2000 liters/hour from the bedrock (green colored area). The ground water at Guldheden is mainly being transported first -towards the northwest, and then going towards the southwest (see red arrows). This map represents an overview of the ground water movement on site.