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Cost-benefit analysis for sustainable stormwater management

- A case study for Masthuggskajen, Gothenburg

Petter Berglund

Abstract

Cost-benefit analysis for sustainable stormwater management - A case study for Masthuggskajen, Gothenburg

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Densification and intensified precipitation patterns due to climate change, has increased the need for sustainable stormwater management. Sustainable stormwater management can be implemented as blue-green infrastructure (BGI), which integrates green features for natural infiltration and detention such as green roofs and rain gardens. Through the use of BGI, added values can be provided as ecosystem services. Authorities and organizations in Sweden imply the need for valuation of ecosystem services for future integration in decision-making. This thesis include monetary estimations of ecosystem services within the use of a cost-benefit analysis (CBA), for two alternatives of stormwater management in Masthuggskajen, Gothenburg. The applied valuation methods are methods commonly used in economic analysis. The ecosystem services identified and monetarily estimated as benefits within this project were flood protection, water treatment, air quality regulation, noise regulation and added recreational value. The result of the CBA indicated that the most profitable alternative was considered to be the implementation of BGI rather than underground solutions.

The ecosystem services contributing the most to the result was added recreational value, noise regulation and flood protection. A sensitivity analysis was concluded by altering the value of costs and benefits. Further analysis of the uncertainty in monetary estimates is of importance in order to integrate ecosystem services in decision-making.

The difficulty in covering the full extent of benefits generated by BGI indicates the need of complementary tools in decision-making. However, this study highlights the importance of inclusion of ecosystem services in decision-making.

Keywords
stormwater management; blue-green infrastructure (BGI); monetary valuation; ecosystem services; cost-benefit analysis (CBA)

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Referat

Kostnads- nyttoanalys vid införande av hållbar dagvattenrening - en fallstudie för Masthuggskajen, Göteborg

Petter Berglund

En ökad urbanisering och förtätning av städer i Sverige har ökat andelen hårdgjorda ytor i urbana miljöer. Tillsammans med förändrade nerderbördsmönster har behovet av en mer hållbar dagvattenhantering ökat. Hållbar dagvattenhantering kan implementeras genom blå-grön infrastruktur (BGI), som integrerar gröna ytor för naturlig infiltration och fördröjning, såsom gröna tak och växtbäddar. Genom implementering av BGI kan ytterligare värden skapas genom ekosystemtjänster. Myndigheter och organisationer i Sverige uttrycker behovet av att synliggöra värdet av ekosystemtjänster för framtida beslutsfattning. Denna uppsats inkluderar monetär värdering av ekosystemtjänster inom en kostnads-nyttoanalys (KNA) av två alternativ för dagvattenhantering inom området Masthuggskajen i Göteborg. Ekosystemtjänsterna som inom projektet identifierats och monetärt värderats är nyttor från översvämningsskydd, vattenrening, luftreglering, bullerreglering samt ökade rekreativa värden. Resultatet av den utförda KNA visade att det mest lönsamma alternativet för dagvattenhantering var implementering av BGI framför konventionella lösningar under mark.

De ekosystemtjänster som bidrog mest till resultatet var ökade rekreativa värden, bullerreglering samt översvämningsskydd. En känslighetsanalys utfördes genom att alternera värdet av kostnader och nyttor. En utvidgad analys av osäkerheten i de monetära värderingarna är av vikt för framtida integrering av ekosystemtjänster inom beslutsfattning.

Svårigheten i att monetärt värdera alla ekosystemtjänster indikerar behovet av kompletterande verktyg som beslutsunderlag. Med denna studie åskådliggörs dock värdet av ekosystemtjänster genererade från hållbar dagvattenhantering och vikten av dessa inom framtida stadsplanering.

Nyckelord
dagvattenhantering; blå-grön infrastruktur; monetär värdering; ekosystemtjänster; kostnads-nyttoanalys (KNA)

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Preface

This project was conducted as a 30 credits master thesis within the Master Programme of Environmental and Water Engineering at Uppsala University. The project was performed in company with Ramboll Sweden where Mikaela Rudling has been supervising. Sofia Eckersten, previously at Ramboll, now PhD at Kungliga Tekniska Högskolan (KTH) has also been supervising. Subject reviewer has been Roger Herbert, Associate Professor at the Department of Earth Science at Uppsala University.

First of all I would like to thank Sofia Anderzon as my companion during our thorough examination of stormwater management and ecosystem services. Our shared aim in assessing the value of ecosystem services and collaboration with Ramboll resulted in a background partly written together. Section 2.1, 2.1.1, 2.1.2 and 2.2 was written together with Sofia, where she was the main author for the sections:

- Green roofs
- Trees
- Rain gardens
- Ecosystem services

Furthermore, the encouragement, support and assistance from Mikaela and Sofia throughout this project have been invaluable. I would also like to thank Ingrid Boklund-Nilsén and colleagues at Ramboll Uppsala.

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Populärvetenskaplig sammanfattning

En ökad urbanisering och förtätning av städer i Sverige har ökat andelen hårdgjorda ytor i urbana miljöer. En ökad befolkningstillväxt gör att trenderna kring ökad exploatering av naturliga miljöer förväntas att fortsätta. Den ökande mänskliga påverkan på våra miljöer uttrycker sig även via de klimatförändringar som går att utläsa. Redan idag kan vi se trender kring hur antalet extrema väderhändelser och naturkatastrofer ökar i världen. Flera stora städer såsom New York och Köpenhamn har utrett vilka konsekvenser och skador extrema regnoväder kan orsaka inom den urbana miljön. För att tackla dessa problem ställs höga krav på att klimatanpassa städer och hitta nya lösningar för att skapa en mer hållbar utveckling. Inflytesrika organisationer såsom FN har definerat mål kring hur en övergripande hållbar utveckling kan nås och vilka åtgärder som krävs.

En viktig aspekt gällande en hållbar urban planering utgår från ståndpunkten av att stora nederbördsmängder inte skall orsaka översvämningar i städer. Det regnvatten som inte infiltreras ned i marken defiernas som dagvatten. Traditionellt så har dagvatten avletts under jord till ett ledningssystem med övrigt vatten, för att sedan transporteras vidare ut i nedströms recipient. Den ökade andelen hårdgjorda ytor har gett upphov till större volymer dagvatten att hantera vilket under extrema väderförhållanden kan leda till urbana översvämningar. För att hantera dessa problem har nya lösningar tagits fram som handlar om att återinföra gröna miljöer för att möjliggöra en naturlig infiltration och rening av dagvatten. Dessa lösningar kan definieras inom begreppet blå-grön infrastruktur (BGI). Exempel på några sådana lösnigar är till exempel införandet av svackbeklädda diken, gröna tak och dagvattendammar som simulerar det naturliga vattenflödet. Målet med införandet av BGI är utöver den tekniska funktionen i och med hanteringen av dagvatten, att skapa mervärden i urbana miljöer. Dessa mervärden kan defineras som ekosystemtjänster och är vitala i produktionen av många av människans naturliga miljöer. Ekosystemtjänster kan delas upp i olika grupper, där ett exempel på en försörjande ekosystemtjänst är växternas fotosyntes som möjliggör mänskligt liv på planeten Jorden.

För att främja en hållbar utveckling så har den Svenska regeringen i uppgift att synliggöra värdet av ekosystemtjänster. Bidraget från olika ekosystemtjänster kan värderas utifrån olika värdegrunder. Historiskt har ekosystemtjänster värderats kvalitativt där dess påverkan har belysts genom deras funktion. Sedan tidigt 2000-tal har röster höjts kring värdet av vidare ekonomiska värderingar för att försöka synliggöra värdet. Målet med denna studie var att monetärt värdera ekosytemtjänster genererade av BGI och inkludera detta som ett underlag vid beslutsfattning.

I denna rapport har en kostnads- nyttoanalys (KNA) utförts utifrån att jämföra två olika dagvattenlösningar, ett med BGI samt ett förslag implementerat under jord, för ett nytt planerat område i Göteborg, Masthuggskajen. En KNA utgår från att beräkna alla kostnader och nyttor i monetära termer över livstiden på investeringen. Analysen utgår från pengars minskade värde över tid vilket betyder att de kostnader och nyttor som genereras i framtiden nuvärdesberäknas med hjälp av en diskonteringsränta. Kostnader beräknades i detta fall som de kapital och underhållskostnader som uppstår vid investeringar i BGI. Nyttor beräknades som det monetära värdet av ekosystemtjänster. De ekosystemtjänster som identiferades inom ramen för implementeringen av BGI i detta projekt var översvämningsskydd, vattenrening, kontroll av luftkvalité, bullerreglering samt ökade rekreativa värden.

Resultatet av den utförda KNA visade att investeringen av BGI var ekonomiskt lönsam över den angivna tidsperioden av 100 år. Samma beräkning utförd för det konventionella lösnignsförslaget med dagvattenhantering under mark visade sig inte ekonomiskt lönsamt under samma tidsperiod. En känslighetsanalys utfördes genom att alternera de använda kostnaderna och nyttorna. De ekosystemtjänster som visade sig ha störst påverkan på resultatet var det ökade rekreationsvärdet, bullerreglering samt översvämningsskydd. Ytterligare studier kring värdering av urbana ekosystemtjänster skulle öka förståelsen för vikten av värdering av ekosystemtjänster.

Studien visar att det är möjligt att integrera monetär värdering i en KNA, men belyser vikten av vidare studier i hur ekosystemtjänster påverkar den mänskliga omgivningen och hur dessa skall värderas.

Contents

1 INTRODUCTION

Today, over half of the world's population lives in cities (UNFPA, 2016). The densification contributes to great challenges when it comes to creating sustainable living environments. The United Nations (UN) have acknowledged 17 goals in relation to a sustainable development which include measures to introduce smarter, more liveable cities through mitigation measures against climate change (UN, 2015). The urban environment contributes to multiple environmental issues as traffic, construction and altering of land-use release pollutants in air, soil and water (Naturvårdsverket, 2015). Higher concentrations of impervious areas within an urban context have shifted the hydrological cycle leading to less infiltration and transpiration while greater volumes of stormwater turns into runoff (Svenskt vatten, 2016). As the issue of intensified precipitation patterns has emerged in certain areas, e.g. Sweden, sustainable solutions regarding management of stormwater are of great importance.

Diversion and detention of stormwater have traditionally been through an underground sewage pipe network. National incentives of sustainably densify metropolitan areas have called upon new guidelines in the management of stormwater. Major cities in Sweden have adopted guidelines to invoke local treatment and detention of stormwater (Göteborg Stad, 2017; Stockholm Stad, 2017). Blue-green infrastructure (BGI) aims to make use of natural elements to detain and treat stormwater locally. BGI is implemented as a way of simulating the natural flow of water by using green space in urban areas to reduce water speeds and utilize water for biodiversity. Through green roofs, rain gardens and stormwater dams, stormwater management can be integrated within the urban environment, contributing not only to stormwater management but providing natural values (c/o City, 2014). Natural values can be represented by ecosystem services, which are defined as services benefiting the human existence provided by nature. The Swedish government has established goals regarding a sustainable living environment and one important measure is to visualize ecosystem services (SOU, 2013:68). Through the implementation of BGI, it is therefore of importance to identify the ecosystem services that can be provided within an urban context.

Valuing ecosystem services is a way of illustrating and create an understanding of human dependence of the surrounding ecosystems by defining the values connected to the services that they provide (Naturvårdsverket, 2015b). Monetary valuation of ecosystem services has been controversial through the difficulty to cover the full extent of the benefits ecosystems provide in monetary terms. This has caused a lack in integration within policy and decision-making. By monetary estimating ecosystem services, the aim is to imply the importance of the production of ecosystem services for sustainable development and to policy makers when planning the future (Bateman et al., 2010; TEEB, 2010, de

Groot et al., 2012; Naturvårdsverket, 2015). Expressing the provision of ecosystem services in monetary terms could act as a more communicative tool within decision-making, enabling more long-term sustainable decision-making (Bateman et al., 2010; Groot et al., 2012; TEEB, 2010). BGI is often associated by increased costs compared to the use of conventional sewage network. In order to assess the accumulated economic value by various investment options can the use of a cost-benefit analysis (CBA) be used. The use of a cost-benefit analysis could highlight the benefits drawn by ecosystem services and increase the use of more long-term sustainable urban planning. An important measure in order to mitigate future impacts of climate change.

1.1 AIM AND PURPOSE

The aim of this thesis is to develop a methodology for conducting a cost-benefit analysis for sustainable stormwater management, where two alternatives for stormwater management are compared. Within the cost-benefit analysis lays importance in defining the benefits provided from the implementation of blue-green infrastructure as ecosystem services.

Three research questions create a focus for the study:

- which ecosystem services can be derived from blue-green infrastructure?
- identify and apply monetary values to these services, where relevant monetary estimates are available
- within the case study, is it favorable to implement blue-green infrastructure rather than conventional solutions?

1.2 DEMARCATIONS

To fulfill the purpose of this thesis, following demarcations was considered.

- There are a wide range of solutions regarding sustainable stormwater management. The ones described within the scope of this thesis are the ones most commonly implemented in an urban context in Sweden.
- Ecosystem services are defined through an urban perspective and based on a site visit and available documentation.
- The extent of different stormwater solutions within the case area was estimated based on available documentation for the proposed area Masthuggskajen and with guidance of experts at Ramboll.

- In this thesis, ecosystem services are assumed to be fully functioning by the end of the implementation period. Thereafter costs and benefits are assumed to be converted on an annual basis though they might vary over time.
- The ecosystem services and benefits provided have been assumed to only affect people living within the residential area.

1.3 REPORT STRUCTURE

The background will present the foundation for stormwater management and discuss various measures of implementation in urban environments. It will further explain the relationship between the generation of ecosystem services and different features of BGI. Ecosystems provide services and assessment of those can be determined through various forms of valuation. An overview of generic monetary valuation methods is presented in the background.

The section cost-benefit analysis will discuss the reasoning behind the method and present the integral steps for conduction of economic analysis. A cost-benefit analysis is to be conducted as a case study for implementation of stormwater management in Masthuggskajen, Gothenburg. In the section Case Study, both of the methods for valuation of costs and benefits, along by the results are presented.

Following the results, a discussion is held concerning the assumptions involved in valuation and the contribution of this study to research.

2 BACKGROUND

In this section, the background of this thesis is presented. This section presents the main incentives for stormwater management, implementation of different solutions and additional values which can be provided as ecosystem services.

2.1 STORMWATER MANAGEMENT

The main method for stormwater drainage has traditionally been to construct storm sewers in which stormwater can be directed to adjacent recipients. Growing urban areas have caused an increase in impervious surfaces (Stahre, 2006). The increase in impervious areas has shifted the hydrological cycle in urban areas to increase the runoff and decrease the evapotranspiration and soil infiltration (Svenskt Vatten, 2016). Changing precipitation patterns due to climate change with more intense rainfall sessions are to be expected, contributing to an increase of urban stormwater. Existing sewer system will be more prone to overload and urban flooding will likely increase (Stahre, 2006). Swedish insurance companies have recorded a steady increase in flood damages for residential properties the past decades (Grahn & Nyberg, 2017). The urban environment also contains many pollutants which, can be collected and transported during intense rainfalls, worsening water quality in recipients. Main sources for pollutants in stormwater are traffic and areas in the process of a change in land-use and construction (Naturvårdsverket, 2017).

2.1.1 Regulatory standards and guidelines for stormwater in Sweden

The foundation regarding administration of water within Sweden and the EU is the Water Framework Directive (2000/60/EG), which was accepted in 2000 by the EU. The aim was to ensure the protection of water as a natural resource, decrease pollutant loads and contribute to lessen the effects of extreme weather events (2000/60/EG). The framework for water administration served the purpose of unifying countries within the EU by establishing the same goals regarding water quality, but allowing own measures of action to be taken in reaching those (Naturvårdsverket, 2005). Through the implementation of the Water Directive into Swedish law in 2004, environmental quality standards for water were introduced. The quality standards serves as measures in achieving the status of a "good water quality" for a specific water body (Naturvårdsverket, 2005).

There are no current national guidelines concerning the release of polluted stormwater. Initiatives in regulating the release of pollutants to downstream recipients have however been taken by the cities of Stockholm and Gothenburg (Göteborgs stad, 2017; Andersson et al., 2016). The City of Gothenburg in accordance with the environmental administration of Gothenburg has directed a guide for local treatment of stormwater. The kind of treatment is dependent on the pollutant load of the site, which indirectly takes land-use into consideration, and the ecological status of the downstream recipient (Göteborgs Stad, 2017). The aim with the guide is to enable and withstand treatment where treatment is needed to better allocate resources.

2.1.2 Sustainable stormwater management

Blue-green infrastructure (BGI) is a way to sustainably and locally treat stormwater and attenuate flow peaks. BGI is in literature denoted by many different names; Sustainable urban Drainage Systems (SuDS), nature-based solutions (NBS) and Low Impact Developments (LID) are all considering the implementation of sustainable stormwater management. BGI is implemented as a way of simulating the natural flow of water by using blue and green space in urban areas to seize water and thus regulating water flow which can be seen in figure 1. The aim for BGI is to generate additional environmental and social values, leading to a more sustainable future (Svenskt vatten, 2016).

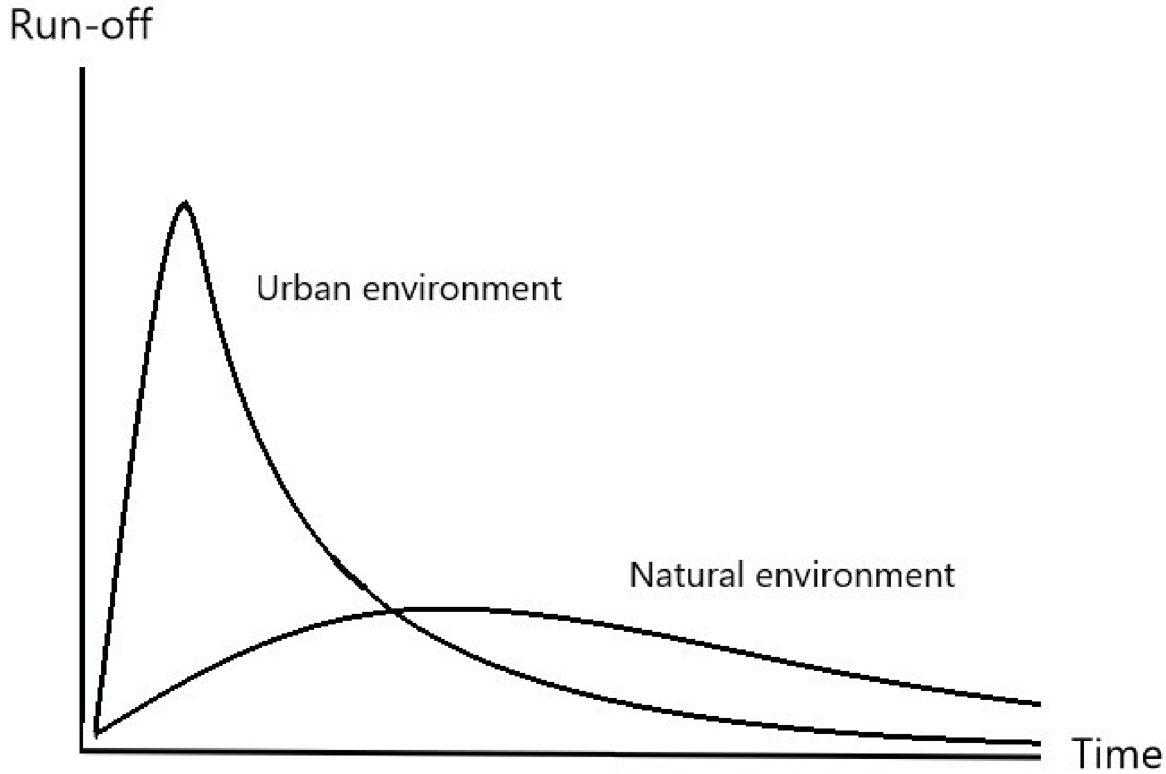

Figure 1: Simulation of flow regulation by implementation of BGI as a mean of regulating runoff.

Depending on the extent of pollution and its characteristics, various infrastructural solutions are better adjusted for treatment. Local issues concerning either inadequate water quality or an area prone to flood is regulating the type of treatment needed (Blecken, 2016).

The project primarily focuses on urban blue-green infrastructure on district level. Below follows a selection of the BGI features selected for the aim of this thesis: Green roofs, trees, rain gardens, swales, detention basin, detention ponds and attenuation storage tanks.

Green roofs

Green roofs are vegetation systems placed on roofs. Green roofs are used for retaining and reducing flow rates of stormwater, and do not necessarily intend to treat the water, as the precipitation that is collected on the roof is not considered very contaminated. They consist of multiple layers: outermost, there is a vegetation layer, anchored to an inner soil layer, then a drainage layer and at the bottom a sealing layer, preventing the roof to get damaged by the water. The vegetation and soil layer can retain precipitation, while the drainage layer can either store or drain out excessive water (Blecken, 2016). Vegetation can be in need of irrigation when precipitation is not sufficient. Maintenance, like controlling downpipes and gutters, is recommended to be carried out at least twice a year (Blecken, 2016).

As for stormwater management, green roofs can reduce runoff by 25-75 % (Alfredo et al., 2010), and with about 50 % over a year. To maximize the effect, it is important that the slope of the roof is not too steep (Stahre, 2006). The reduced runoff is a result of a delay in initial runoff, reduced amount of total runoff and slower runoff over a longer period of time (Blecken, 2016). If precipitation is intense and the system gets saturated with water, the effect of the system decreases greatly (Stahre, 2006). However, it is still argued that even with a saturated system, flow peaks of runoff water would be delayed which reduces the risk of flooding the stormwater drainage system (Blecken, 2016).

Trees

Planting trees along roads as a complement to a conventional underground pipe system yields both detention and treatment of stormwater. For the tree to be able to thrive in urban environments, and to avoid risk of damaging the pipes, careful city planning is needed. Trees surrounded by hard surfaces need soil with special qualities to be able to grow. Structural soils are used for this purpose and are a mix of macadam, which can hold up the hard surfaces, and soil that fills the pores in between the macadam. The soil can hold nutrients and humidity and give the room plants need for its roots to grow. About $\frac{2}{3}$ are macadam and $\frac{1}{3}$ soil (Svenskt Vatten, 2011). For good conditions, there also needs to be some kind of drainage to supply the tree with a sufficient amount of water, and drainage underneath for excess water. Trees can hold water either in the canopy or in the roots after the water infiltrates the soil (Svenskt Vatten, 2011).

Rain gardens

The shaping of rain gardens is flexible, and can therefore be implemented in varying environments, like parking lots or city centers. Rain gardens are often dimensioned to be able to treat rainfalls with 0.5-2 year recurrence. More intense rainfalls will overflow to the conventional pipeline system. When water percolates through the filter, the filter adsorbs, mechanically traps and biologically treats the water. In the top layer, a biofilm usually forms that treats the water biologically. The vegetation plays a central role and serves many purposes, like maintaining the infiltration capacity, enabling microbial water treatment processes and offer esthetical values. Prioritizing the aesthetics of a rain garden, that may need an addition of nutrients to the soil, can on the other hand be on the expense of water quality (Blecken, 2016). Rain gardens can reduce total concentrations of metals and total suspended solids (TSS) by 80-90 % (Blecken, 2016). A large fraction of particulate metals, that is metals attached to particles, and TSS is separated through mechanical filtering (Hatt, Fletcher & Deletic, 2008). The extent of separation of dissolved metals depends on the interaction between the specific metal and filter, but is executed through adsorption, surface deposition and fixation to clay minerals (Alloway, 1995). Conditions like extent of rainy/dry periods, temperatures, concentration of the contaminants, type of filter and plants affects the water treatment of dissolved metals in rain gardens. Rain gardens are still considered to generally have more potential to treat water of dissolved metals than other stormwater facilities like ponds. It is of greater importance to treat dissolved rather than particulate metals, as dissolved metals are bioavailable (Blecken, 2016).

Swales

A swale is designed as a vegetated trench without permanent water surface. Swales are among the most common facilities within BGI and are useful for the collection and drainage of stormwater. Swales are mostly used in vicinity to roads and streets where an important design criterion is submerged edges in the connection between road and swale. This prevents road inundation due to damming (Blecken, 2016).

The purpose of implementing swales is to regulate high water flows. It is important in the process of implementation to allow infiltration and thus avoiding longer periods of stationary water. Swales alone do not in general serve as sufficient treatment to reach a good water quality. Sedimentation can act as a process for treatment before reaching finer filtering systems for enhanced treatment. This process improves the efficiency for further treatment downstream (Svenskt Vatten, 2016).

If designing swales with an underlying macadam structure, a better infiltration capacity can be achieved. Vegetated swales give further resistance and regulate flow; it also contributes to enhanced treatment due to increased retention time (VINNOVA, 2014). To further enhance removal and treatment of nutrients, special consideration could be adopted regarding the type of vegetation implemented; generally plants are more efficient than grass (Svenskt Vatten, 2016; Winston et al., 2012).

Detention basins

Detention basins are designated surfaces with the ability to store and attenuate water. They can be vegetated and thus allow treatment of polluted stormwater (CIRIA, 2015) and erosion prevention. Since detention basins do not need to carry water continuously, the green surface can be used for other purposes, such as recreational activities. In order to effectively be using the area, the basin should be connected to a drainage system, quickly draining and enabling the use of the green area (Svenskt Vatten, 2011).

Detention basins mainly provide treatment by removing sediment and coarse particles. Enhanced treatment and water quality can be achieved by extended detention time for intense rain events. Through interception in soil, nutrients, heavy metals, toxic waste and oxygen-demanding materials can be reduced within vegetated detention basins (CIRIA, 2015).

Detention ponds

Detention ponds are implemented in order to detain and treat large volumes of stormwater as an "end-of-the-pipe" solution. Stormwater throughout the catchment is being drained in ponds where a substantial residence time enables various treatment processes. Detention ponds have been widely used globally in the past and are in Sweden among the most used treatment methods of stormwater (Svenskt Vatten, 2016).

Detention ponds are efficient when it comes to separation of suspended solids and metals. The process of treatment in ponds is based on sedimentation of suspended solids. Coarse sediment is deposited close to the inlet due to gravitational forces whereas finer sediment is transported further down the pond. Finer sediments hold a higher concentration of metals, leading to more deposition of metals downstream within the dam. This is important when taking account to the percentage of suspended material being released from the dam, which usually contains greater percentage of more fine sediment and hence proportionally more metals. Nutrients as nitrogen that are not bound to particles do not separate in the same extent as particulate nutrients, like phosphorus, that is generally bound particularly. The degree of separation varies heavily depending on local circumstances implicating the importance of planning and design (Svenskt Vatten, 2016).

Attenuation storage tanks

In areas where there is a limited amount of open space, as is often the case in highly urbanized areas, underground storage spaces could be constructed. The aim is to temporarily store water underground to decrease the risk of inundation. Tanks can be connected to green spaces with an infiltration capacity draining to the underground storage space. An alternative approach for designing temporary storage systems is to oversize pipes within the stormwater drainage system and thus enables storage for water during intense rainfall (CIRIA, 2015). Underground storage can also consider geocellular storage systems which, are implemented as a compact measure of detaining and storing large volumes of stormwater.

In order to limit the need for maintenance and improve the performance of attenuation, pre-treatment should be considered in order to limit the risk for sediment accumulation (CIRIA, 2015).

Filters

During site conditions when the space is limited, a measure for treatment of stormwater is through filters in connection to wells. There is a wide range of available filter materials with varying treatment capacity. However, limited amount of studies regarding the removal efficiency makes it difficult to conclude any general degree of purification (Blecken, 2016).

In order to limit saturation of filter material and sediment accumulation, regular maintenance is recommended. The high amount of maintenance does not make it feasible for implementation for large areas. It could rather be seen as a good measure for treatment of point sources (Blecken, 2016).

2.1.3 Capital and operational costs of stormwater solutions

BGI

The incentive for implementation of BGI is the provision of natural values as ecosystem services in urban environments. The maintenance of BGI is focused largely around the maintenance of vegetation and accumulation of sediment loads. Maintenance of BGI is of importance not only for the actual technical functioning of infiltration but also for the appearance in order to retain recreational values. Approximate capital and operational costs for different measures of BGI are represented in table 1

Table 1: Investment and operating costs for various open stormwater facilities (Andersson & Åkerman, 2016; GBG Stad, 2015; Magnussen et al., 2015; Klimatanpassningsportalen, 2017; Falk, 2016).

Facility	Investment cost (SEK)	Operating cost (per year)
Green roofs	400-900/m^2	2-10 SEK/m^2
Rain gardens	1000-4000/m^2	12-35 SEK/m^2
Detention basin	200-2100/m^2	6-20 SEK/m^2
Trees	15000-120000/tree	450 SEK/tree

Underground stormwater management

The incentives for underground detention and treatment are the generally lowered cost and need for maintenance and the limited amount of space needed in urban environments. Replacement of filters in wells and flushing of sediment loads in storage systems can conclude maintenance of underground stormwater management.
Approximate capital and operational costs for different measures of underground stormwater management can be seen in table 2.

Table 2: Investment and operating costs for various underground stormwater facilities (Magnussen et al., 2015; Eneroth, 2017; Göteborgs Stad, 2016).

Facility	Investment cost (SEK)	Operation cost (SEK/year)
Geocellular storage systems	4000-6000/m^3	50-85/m^3
Oversize plastic pipes	4000-4500/m^3	50-85/m^3
Filter	6000/filter	350/filter

2.2 ECOSYSTEM SERVICES

By implementing BGI in urban environments, additional values than regulation and treatment of water can be generated. Trees and vegetation have for example the ability to regulate the amount of air pollutants and create recreational values in urban areas. These values are denoted as ecosystem services.

Ecosystem services are defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily, 1997). Ecosystem services are therefore an anthropocentric term, where the basis of the development of the concept comes from making the benefits that humans can gain from ecosystems visible (Naturvårdsverket, 2012). Ecosystem services produce ecosystem goods, such as food, fuels and fiber, support functions necessary for life, such as cleaning and renewal, and they confer many intangible cultural services like recreation (Daily, 1997). The expression ecosystem service is rather new, even though the knowledge of man's dependence to nature is probably ancient. In the middle of the 20th century, natural capital was introduced in academia, and a few decades later, the expression environmental service was coined. Ecosystem services got more known outside of the academic community in early 21st century, through the UN initiative Millennium Ecosystem Assessment (MA) (Naturvårdsverket, 2012). The MA was intended to assess the ecosystem's contribution to human well-being, as well as consequences of ecosystem changes for human well-being and what action that would be needed to conserve and to be able to sustainably use these systems (MA, 2005).

There are now three international systems for classification of ecosystem services, where the MA is one of them. The other two are The Economics of Ecosystems and Biodiversity (TEEB) and Common International Classification of Ecosystem Services (CICES). These three vary in the sense that they have different perspectives and purposes. However, they are still developing, so which system that will become the standard of ecosystem services valuation is still to be determined (Naturvårdsverket, 2012).

Ecosystem services are divided into four categories based on what type of service they provide. These are provisioning, regulating, cultural and supporting ecosystem services. Definition of and examples to the different categories of ecosystem services are presented in table 3.

Table 3: Categorization of ecosystem services (MA, 2005; TEEB, 2010).

Category	Definition	Examples of ecossytem services
Provisioning services	Physical services like material and energy outputs	Food Fresh water Raw materials
Regulating services	Services provided when ecosystems act as regulators to necessary processes	Flood protection Water treatment Regulation of climate Air quality regulation Noise regulation Erosion prevention
Cultural services	All the intangible services that ecosystems provide humans with	Recreation Education Social relations
Supporting services	Provides all other ecosystem services with the neccesary conditions for their operation	Biodiversity Photosynthesis Soil formation

For identification of ecosystem services, Naturvårdsverket have completed a guide with useful measures and strategies where the first step is to conclude a gross list of services possibly generated (Naturvårdsverket, 2015b). A compiled list of ecosystem services can be viewed in table 24 in Appendix. Naturvårdsverket propose the use of prior determinations of ecosystem services within the area and currently available information as a foundation for the identification of ecosystem services. This could comprise site investigations and natural values assessments (Naturvårdsverket, 2015b). The proposed methodology will be conducted for identification of present ecosystem services within Masthuggskajen, Gothenburg.

2.3 MONETARY EVALUATION OF ECOSYSTEM SERVICES

An ecosystem service covers the direct and indirect effects to human well being from an ecosystem (SOU 2013:68; TEEB, 2010). Ecosystem services can be valued in various manners. Fundamentally, valuation of ecosystem services can be defined from three different standpoints, ecological, socio-cultural and economic (MA, 2003). The basis of ecological value lies upon the state of the ecosystem, described by particular characteristics whereas the effects it gives to people related to culture and community describe the valuation of socio-cultural values. However, economic value is often captured in monetary terms and has been difficult to estimate for ecosystem services due to nature not being put to a market price (de Groot et al., 2010).

The modern foundation of monetary valuation of ecosystem services lies within "The Economics of Ecosystems and Biodiversity" (TEEB). An initiative was taken by the former G8 countries to investigate the protective measures been taken in regard of biodiversity in relation to the benefits provided by ecosystems.

Due to the fact that nature or ecosystem services have not been put a price tag on, biodiversity and ecosystem services have been considered externalities and considered as free 'goods' (de Groot, 2012; TEEB in Policy, 2011, TEEB Synthesis, 2010). The purpose of estimating ecosystem services in monetary terms is to imply the importance of production of ecosystem services for policy makers planning the future. The wide range of decision-making tools imply that monetary evaluation of ecosystem services could be considered as an alternative, complementing other instruments used today (de Groot, 2012). The amount that people are willing to pay for a particular service is highly dependent on the basic socio-economic condition it relies on. Reasoning concerning this could be dependent on human preferences, institutions, culture and economic welfare at the time (TEEB, 2010).

2.3.1 Current state of valuation

There is a range of databases that have compiled information regarding valuation studies of ecosystem services. The EU are funding an ongoing project, NATURVATION, which address the focus of monetary valuation of ecosystem services in relation to implementation of nature-based solutions or BGI. They have collected and reviewed previous valuation studies to make estimations of the impact of urban ecosystem services, acting as foundation in future decision-making (NATURVATION, 2017).

On a national level in Sweden, the Swedish Board of Agriculture has compiled generally applicable values to be used in economic analysis within environmental decision-making. (Söderqvist & Wallström, 2017). They constitute of a range of monetary valuations in academia and national agencies to be effectively used in Sweden. The database was introduced in 2017 and is to be updated continually to ensure its consistency (Naturvårdsverket, 2017b). Generally applicable values should be implemented rather than using single valuation metrics from previous studies.

2.4 MONETARY VALUATION METHODS

The scope for valuation of ecosystem services and environmental impacts has increased rapidly the last decades (TEEB, 2010). An increased focus on the importance of urban ecosystem services has widened the use of different valuation methods with the scope of covering the full extent of ecosystem services. The type of valuation method implemented is highly dependent on the availability of dependable data for the site-specific conditions.

In this section, a range of monetary valuation methods are presented for possible integration in a cost-benefit analysis. There are so-called can be drawn between tradable and non-tradable assets. The provision of certain goods from ecosystems is represented in an economical market and is thus tradable. Services can thereby be monetarily estimated based on the present market prices (Naturvårdsverket, 2012). However, regulating services such as the ability for vegetation to take up nutrients for enhanced water quality are not marketed and thus in need for an alternate valuation approach. When it comes to estimation of non-tradable assets, a wide range of valuation methods can be applied. In this section below, several valuation methods are described.

Replacement cost
Non-tradable ecosystem services can be valued by indirect market prices. The idea of replacement cost is based on the amount it would cost to replace a service the ecosystem provide by an artificial procedure. The ecosystem of interest produces these services naturally and what would be the cost if humans would start producing such (TEEB, 2010). An example of such an instance would be the replacement cost for treating stormwater in a wastewater plant compared to by BGI.

Whenever there is an ecosystem service that can be exchanged by engineered systems, it is assumed to give a fair estimate of the cost for a service. When services cannot be exchanged, it is however difficult estimating such costs (TEEB, 2010).

Avoided damage-cost

Another way of estimating the cost or benefit of an ecosystem service is to presuppose the protection against various natural events the ecosystem contributes to. Difficulty lies with defining the extent of protection a certain ecosystem service provides. Plantation of trees within coastal areas limits erosion and the effect of storm surges and could thereby be estimated by the cost for restoring such areas (TEEB, 2010). Another measure would be through the resilience ecosystem services provide towards extreme weather events by the avoided damage-cost of a natural disaster.

Hedonic price method

In some cases when not being able to define a market price of an ecosystem service, the market price of other items can alternate by the implementation of ecosystem or new infrastructure. A widely used example is the effect of presence to water or green space for house prices. Market prices of households are generally increasing by such features and can estimate the effect of implementation of blue-green infrastructure (TEEB, 2010; Barbier et al., 2009).

By using the hedonic price valuation, a relationship between the price of a particular good and the change in alternating the surrounding nature could be established. In order to single out the effects of a certain factor, its correlation to the price could be estimated and hence the value (Mattson, 2006). Surrounding factors that could implicate a change in house prices could be increased noise, proximity to recreational land or a change in air quality (Mattson, 2006). The hedonic pricing method can be complicated due to isolating characteristics implicating the market price. The methodology generally requires a large data set to extract the differences that is making it difficult (TEEB, 2010).

Travel cost method

For certain solutions, the implementation of blue-green infrastructure could develop into a meeting place for social activity or aesthetic value. Calculating the travel-cost to the location could do estimating the value for the specific ecosystem service. That would indicate the willingness to use a certain facility. How much are the cost for travelling back and forth and their investment during the stay. Extracting this information could be done by interviews and questions about people's interests. The result would be a demand curve where the demand is likely to decrease with price (TEEB, 2010).

The travel cost method is built upon the cost of travelling to make use of a service. An example is the entrance fee for a national park, which could be considered as the market price for attending the park. However the costs of "staying" within the area could also be included such as the livelihood of purchasing food and beverages during the visit (Mattson, 2006). Difficulties using this method relates to the exclusion of other reasons for travelling to using the service. Visiting the national park could be a part of a longer period of travelling where the main reason is to visit friends or relatives, implying that they would not be paying for the park visit exclusively (Mattson, 2006). The willingness-to-pay for visiting is area specific which means that it is not feasible to transfer the travel cost to other areas where the good for consumption is different (Mattson, 2006).

Also, the act of travelling to certain places might be impossible for people but the area of interest could nevertheless have a value for that group of people (Mattson, 2006).

Contingent valuation method

This method is subjectively based on the "willingness-to-pay" of people. By having questionnaires regarding certain environmental issues or implementation sets for different investments.

Problems can arise due to the hypothetical nature of these questions. People can over or underestimate the amount compared what they would be willing to pay in real life. The format of asking questions regarding the amount could also inflict with what the "real" result would be paying for.

The contingent valuation method is based on a hypothetical valuation of a certain change. It is conducted by interviewing a representative assembly of people to achieve a realistic valuation (Mattson, 2006).

Benefit transfer

This methodology is based on examining earlier studies of monetary estimation of ecosystem services. It can be applied both for tradable and non-tradable assets. For the most accurate result, a study corresponding to the site characteristics should be identified. It is important to adjust the value of the goods to a specific time. For the most accurate result when applying this method is to identify a study that well correspond to the site characteristics of interest. Importance is to identify how transferable the goods are and adjust values to the specific time (TEEB, 2010; Naturvårdsverket, 2015b).

3 COST-BENEFIT ANALYSIS

3.1 FRAMEWORK

Cost-benefit analysis serves as a decision-making tool in the process of considering multiple options for a proposed investment. It accounts for the costs of implementing a certain operation and the economic benefits provided for society throughout the lifespan of the investment (Naturvårdsverket, 2015a; EC, 2014). The European Commission have through initiatives of a more efficient use of natural resources implied implementation measures to incorporate economic analysis into water management and water policy decision-making (EC, 2014). Within this policy lies the use of cost-benefit analysis as a decision-tool. Furthermore the initiative; The Economics of Ecosystems and Biodiversity (TEEB) has assigned a framework for the conduction of cost-benefit analysis for planners and policy makers valuing the environment (TEEB, 2010). Below follows the suggested methodology in six steps:

- **Project definition**: What is the project's scope and who are the stakeholders?
- **Classification of impacts**: What are the expected incremental costs and benefits of the project (such as administration and implementation) and when are they likely to occur?
- **Conversion of physical impacts into monetary values**: How can non monetized services be described in monetary terms?
- **Discounting**: A process that puts more weight on costs and benefits that arise earlier in the project.
- **Net Present Value assessment**: Given the informaiton gathered, is this project economically advantageous?
- **Sensitivity analysis**: How reliable are the numbers used in the study?

The change in economic welfare can be calculated by the net present value (NPV) for the lifespan of the investment (Hanley & Barbier, 2009). A calculation of NPV is the most common method used when assessing business investments in general and concerning valuation of environmental benefits (Hanley & Barbier, 2009; TEEB, 2010; Naturvårdsverket, 2015; OECD, 2006). Conversion of future costs and benefits into present value is based on the foundation of time dependency of money's value. The value of money today is greater than it is in the future. The net present value is calculated based on the fact of discounting future cost and benefits which is described in equation 1,

$$NPV = \sum_{n=1}^{t} \frac{B_t}{(1+s)^t} - \sum_{n=1}^{t} \frac{C_t}{(1+s)^t} \tag{1}$$

where B_t (SEK/year) equals the annual benefit of the investment, C_t (SEK/year) equals the annual costs, s (%) equals the annual discount rate and t (unit of time) equals the time horizon of the project. If the NPV is a positive number, the investment can be considered as contributing to an increase in welfare in society. The alternative realizing the greatest value of NPV should be considered the most profitable and thus implemented.

3.2 TIME HORIZON

Costs and benefits should be estimated over the time span of the functioning of the investment. It is thus of importance to identify the time horizon of the options considered in the analysis.

The European Commission has directed time benchmarks for different sectors, based on internationally accepted practice. As for investments within water supply and waste management, the time horizon is considered to be 25-30 years (EC, 2014). The database for information regarding water, VISS, is established by Swedish authorities and has suggested a service life of 20 years for different measures of BGI (VISS, 2015). Literature suggests a ranging lifespan for green roofs and rain gardens between 40 and 50 years (Magnussen et al., 2015). Previous studies on CBA for BGI have varied regarding the time horizon. A CBA on implementation of green roofs used a timespan of 39 years (Falk, 2016). A study in Sweden used a reference period of 100 years assuming that the functioning of the BGI is similar to the use of conventional/underground stormwater management (Karras & Read, 2016; Svenskt Vatten, 2016). The lifespan of underground stormwater solutions such as pipes and geocellular storage systems are considered to be 100 years if maintained properly (Göteborgs Stad, 2015).

In this study, the service life of BGI was estimated to vary between 25 and 50 years. The service life of underground stormwater management is assumed to be 100 years. In order to compare the NPV over the same time span, 100 years, the alternative considering BGI will include a reinvestment every 50 years estimated as a new capital cost.

As a measure of considering the sensitivity of investments in BGI is a service life of 25 years to be estimated for comparisons. For the alternative of a considered service life of 25 years are reinvestments needed every 25 years estimated as a new capital cost.

3.3 DISCOUNT RATE

In order to take account for future costs and benefits into a present value, a discount rate is applied. Discounting is based on the weighting of a lowered value of costs and benefits over time (Barbier et al., 2009). By using a discount rate, cost and benefits at various times can be estimated by the same measure and added as a present value (Stern, 2007). The discount rate being defined on a yearly basis, hence the effect of discounting increase over time (Söderqvist, 2006). An example of the effect of a varied discount rate into an investment analysis is shown in table 4.

Table 4: The impact of a change in discount rate for an annual benefit of 100 SEK.

	Discount rate	
Year	3.5 %	1.4 %
0	100	100
1	97	99
2	93	97
3	90	96
4	87	95
5	84	93
Total	552	580

The European Commission has established a benchmark discount rate of 4 % for long-term investments during the time period of 2014-2020. However the discount rate may be altered under justified conditions depending of the specific sector and the national guidelines (EC, 2014).

A study from 2010 compiled discount rates used for various Swedish Authorities and indicated proposed time horizons for the analysis indicated in table 5 (Lilieqvist, 2010).

Table 5: A range of Swedish Authorities suggested discount rates for economic analysis (Lilieqvist, 2010).

Authority	Discount rate (%)	Time horizon (years)
Environmental Protection Agency	4	No defined horizon
Swedish Forest Agency	3-4	80
National Board of Housing, Building and Planning	4	40
Swedish Transport Administration	4	40

The Swedish Transport Administration proposed a new yearly discount rate of 3.5 % in 2016 (Trafikverket, 2016c). Lilieqvist (2010) argues that national authorities in general is strongly influenced by the direction of ASEK in the use of discount rate in economic analysis and thus proposed discount rates for other authorities may alter.

In order to take account for long-term effects due to a changing climate, suggestions of a decreasing discount rate over time have been raised (Barbier el al., 2009; Söderqvist, 2006). Stern (2007) argues that due to increasing effects of climate change, a lowered discount rate at 1.4 % should be applied to imply the need for climate adaptation measures.

In this study, a discount rate of 3.5 % in accordance by ASEK was applied. Due to the uncertainty and variation in applied discount rates, a way to identify the sensitivity is by altering the discount rate. Thus will the discount rate of 1.4 % be altered as a sensitivity test of the NPV.

4 CASE STUDY - MASTHUGGSKAJEN, GOTHENBURG

Masthuggskajen is an area in Gothenburg, which is targeted for development from a former industrial into a residential and business area. Masthuggskajen is to be developed in line with CityLab Action (SGBC, 2017), which aims for sustainable construction of new districts. Within Masthuggskajen, two alternatives of stormwater management are considered. One alternative considering implementation of BGI according to a stormwater investigation conducted by Ramboll, from now on denoted as Alternative 1. The second alternative serves as a reference, consisting of underground stormwater management, which further on will be denoted as Alternative 2. All costs and benefits are estimated and applied in the NPV assessment that determines the profitability of alternatives for stormwater management. The framework for conducting a cost-benefit analysis will proceed as suggested in figure 2 and previously described in section 3:

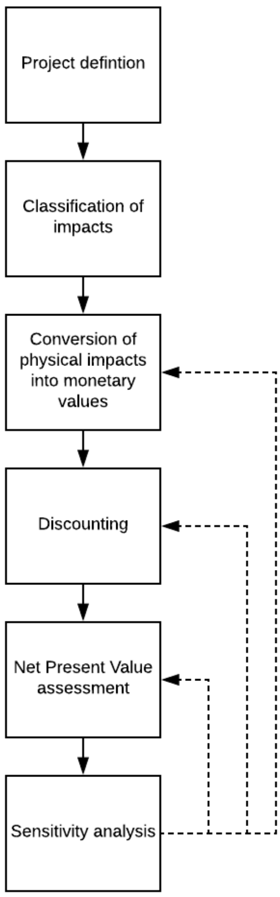

Figure 2: Approach for the conduction of a cost-benefit analysis in Masthuggskajen. The dashed lines indicate an iterate approach in determining the sensitivity of the NPV (TEEB, 2010).

4.1 PROJECT DEFINITION

4.1.1 Current state

Masthuggskajen is a district of approximatly 18 ha, along the *Göta* river in central Gothenburg. The area mainly consists of impervious land. Through previous mapping of natural values in the area, 83 trees were identified along by a few grass surfaces (COWI, 2015). A presentation of the current area can be seen in figure 3.

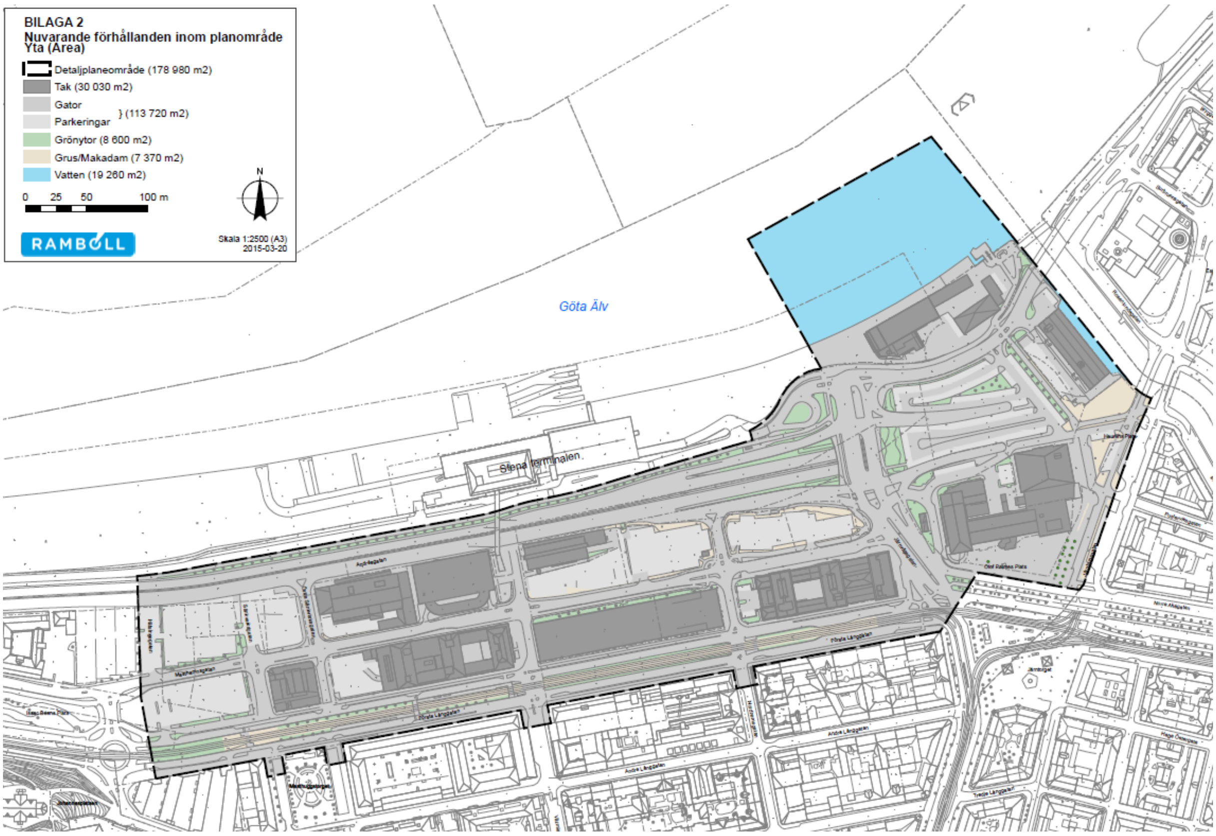

Figure 3: Present area of Masthuggskajen and the project area within the dotted lines (Ramboll, 2015).

The City of Gothenburg has a joint vision of developing its onshore areas from former industrial areas into sustainable built residential and business areas. Masthuggskajen is one of the proposed areas for development. The reconstruction of Masthuggskajen is part of Citylab Action, which is directed by the Swedish Green Building Council (SGBC), serving the purpose of creating sustainable city development through guidance and sustainable certification of urban districts (SGBC, 2017). Approximately 1200 apartments and an increase in people within the area by 4500 are proposed. The population is for the aim of this project assumed to be 3000 after the development.

Due to the location close to the outlet of *Göta* river, which provide water from inland and the proximity to the ocean, there is a risk of flooding due to sea level rise. A CBA of measures to withstand sea level rise due to climate change have been conducted for the city of Gothenburg (Ramboll, 2014; SWECO, 2016). The measures considered were barriers to regulate the sea level in central Gothenburg.

The City of Gothenburg and a consortium consisting of construction and real estate companies develop the area. Elof Hansson Fastigheter, Folkets Hus Göteborg, NCC, Riksbyggen, Stena Fastigheter Göteborg and Älvstranden Utveckling make up the consortium.

4.1.2 Prerequisites for stormwater management

Masthuggskajen is in the bottom of a greater catchment area, which imply the need of effective drainage to withstand heavy precipitation. To effectively handle and divert stormwater, different solutions are considered. The City of Gothenburg provide guidelines for diversion of heavy rainfall, stating a need of detention of 10 mm/m^2 reduced area within residential grounds (Göteborg Stad, 2017). The drainage capacity within the area is considered to sustain a rain with the return period of 5-10 years. Furthermore the project area is designed to provide diversion of stormwater to exclude the effects of pluvial flooding in the case of heavy precipitation by a return period of 100 years (Ramboll, 2017).

For the most part within Masthuggskajen, stormwater is diverted in a separated stormwater network to *Göta* river. However is the existing pipe network along *Första Långgatan*, *Järnvågen* and the eastern parts of *Masthamnsgatan* diverted to the combined sewage network.

4.1.3 Action proposals for stormwater management

By the above stated prerequisites, two options for treatment and detention of stormwater within the area was considered. Alternative 1 considers the use of BGI with an estimated service life of 50 years. Alternative 2 considers underground grey stormwater management with an estimated service life of 100 years. The two alternatives are further described below.

Alternative 1

The first alternative considers measures of stormwater management according to the stormwater investigation conducted by Ramboll (2017), figure 4. Green roofs are implemented as a measure of detention of stormwater during rainfall of low intensity. The greatest pollutant load is accumulated along streets, whereby rain gardens are implemented as measures for treatment along *Masthamnsgatan* and *Första Långgatan*. To enhance the capacity for treatment and infiltration within rain gardens, trees are integrated in the stormwater management by an underlying macadam structure, enabling increased infiltration. During increased rain intensities, water is diverted along main routes to the stormwater network. Additional water is diverted into detention basins designed as park areas to be naturally inundated during extreme weather events. The detention basins have a capacity of storing 600 m^3 each during intense rainfall. Assumptions regarding the extent of solutions were conducted through available documentation and in contact with responsible people at Ramboll. Throughout the area, four different solutions regarding blue-green infrastructure are proposed and their respective surface area presented in table 6.

Table 6: Properties of the measures of BGI implemented.

Facility	Extent
Green roofs	3 340 m^2
Rain gardens	4 665 m^2
Detention basin	14 745 m^2
Trees	100 trees
Total	22 750 m^2

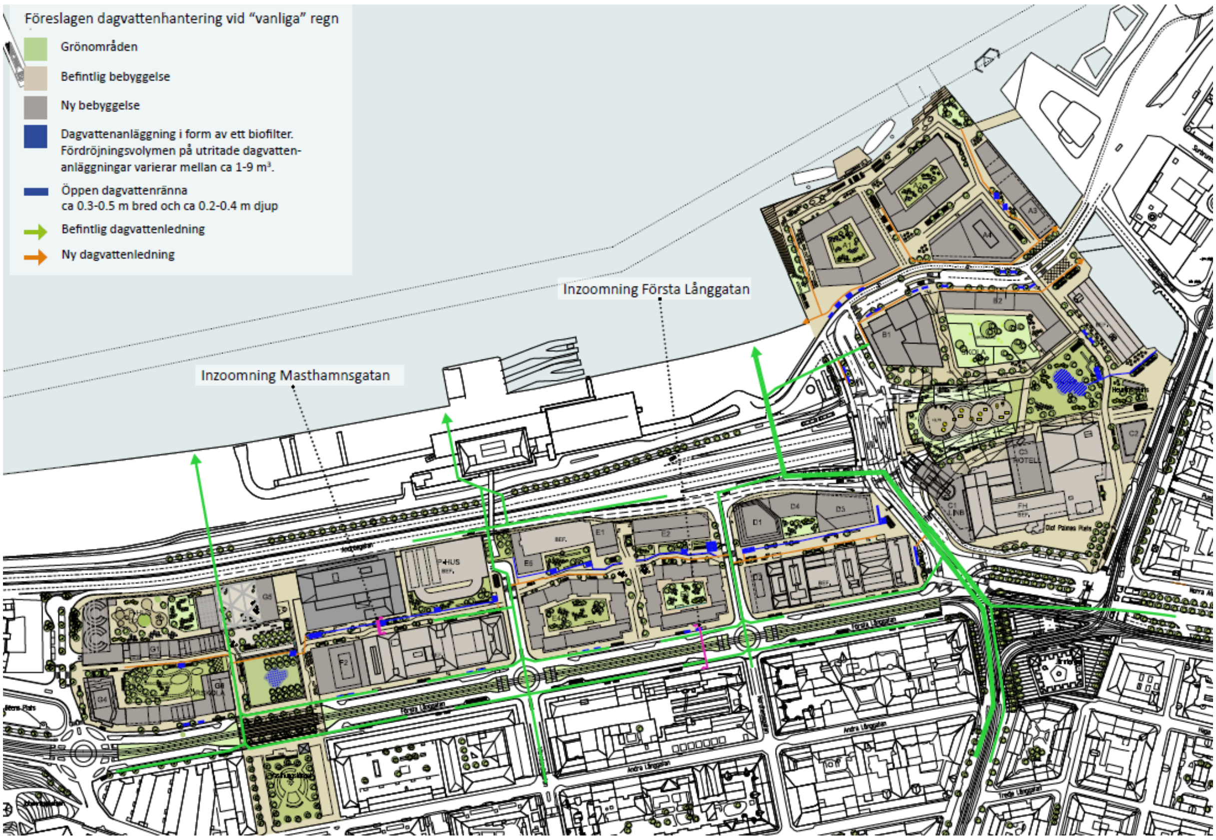

Figure 4: The proposed area of Masthuggskajen after development (Ramboll, 2017).

Alternative 2

The second alternative, also the baseline, is to replace all BGI features with underground storage spaces for detention and filters for stormwater treatment. Underground storage solutions would be implemented to achieve the same functionality as the open detention basins in the case of intense rainfall. The costs of underground stormwater features were presented previously in table 2.

4.2 CLASSIFICATION OF IMPACTS

The project aim is to detain, divert and treat stormwater according to the regulatory standards of the City of Gothenburg. In order to monetary estimating costs and benefits, a classification of impacts is crucial. Benefits are estimated as ecosystem services provided through the implementation of BGI. Costs are considered to be capital and operational costs for the investment in stormwater management solutions. Thus, this section first targets the identification of ecosystem services in Masthuggskajen. Secondly, costs are approximated for the different alternatives of stormwater management.

4.2.1 Identification of ecosystem services

Identification of urban ecosystem services in Gothenburg has previously been concluded by Andersson-Sköld et al., (2017). The scope was to value and identify ecosystem services provided by urban greenery such as urban trees and green areas. Table 7 show the estimated provision of ecosystem services in Gothenburg.

Table 7: Compilation of ecosystem services provided within the area of Gothenburg by urban greenery(Andersson-Sköld et al., 2017)

Biophysical component	**Function**	**Ecosystem service**
Urban trees	Leaves can reduce wind and provide cooling through provision of shade	Local climate regulation
	Leaves contribute to regulation of air quality through deposition of pollutants on leaves	Air quality regulation
	Noise scattering and absorption through leaves	Noise reduction
	Increased effect of transpiration	Water regulation
	Audial contribution to increased wellbeing through ruslting of trees	Recreation and mental and physical health
Green areas	Permeable surfaces provide water storage	Water regulation

Above-mentioned information along with a site visit and available documentation was the foundation for identification of ecosystem services provided in Masthuggskajen. The available documentation for Masthuggskajen are stated below:

- Stormwater investigation (Ramboll 2015; Ramboll, 2017)
- Air quality investigation (COWI, 2017)
- Noise investigation (Akustik Forum, 2015)
- Proximity to recreational areas (Ramboll, 2017)
- Natural values assessment (COWI, 2015)

Below follows a description of the provided ecosystem services within Masthuggskajen:

Flood protection

The main incentive for introducing BGI is to enable soil infiltration, regulate water flow and provide flood protection. Detention basins are providing overflow storage spaces during extreme precipitation events lowering the risk of inundation. Thus, the implementation of BGI was considered to be contributing to the ecosystem service flood protection.

Water treatment

Presence of vegetation, microorganisms in soils enable removal of pollutants from stormwater and groundwater through a range of processes; physical sedimentation, reducing water speeds to increase surface infiltration, absorbing nutrients and dilutes contaminated water (TEEB, 2010). Rain gardens provide biological treatment of water through filtering by vegetation and interception by filter material. Considerable reduction of metals, nutrients and particles can be concluded (Blecken, 2016). Thus, the implementation of rain gardens and trees are considered to be contributing to the ecosystem service water treatment.

Air quality regulation

Regulation of air quality can be provided within different ecosystems. In urban areas, implementation of vegetation can improve air quality due to removal of a range of pollutants among ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (CBO, 2013). Implementation of trees rather than lower vegetation has served as a better mean of adsorption and deposition of air pollutants to produce a better air quality (Naturvårdsverket, 2012). The implementation of trees within Masthuggskajen is considered to be contributing to the ecosystem air quality regulation.

Noise regulation

Soft surfaces limit the distribution of noise and reduce sound levels in urban areas (Bolund & Hunhammar, 1999). Soil and plants can act as a noise reducing measure due to attenuation through reflection, deviation, absorption and refraction of sound waves (CBO, 2013).

The implementation of trees, rain gardens along with green areas in Masthuggskajen are considered to be contributing to the ecosystem service noise regulation.

Recreation

Urban features as parks, forests, lakes and rivers enable recreational activities that improve human health and well-being. It may help reducing stress levels and provide a sense of peacefulness. The recreational value of green areas is however not fully dependent on the surrounding ecosystems, built infrastructure like benches and sport facilities are also important (CBO, 2013). The introduction of detention basins as park areas is considered to be contributing to the ecosystem service recreation.

Local climate regulation

Green areas with vegetation and parklands regulate the effect of the urban heat island due to altering of albedo and assimilation of carbon dioxide (Alexandri & Jones, 2007). Green areas can also have the ability to provide a protection in the form of shadow during hot spells and linger heavy winds (Naturvårdsverket, 2012). Trees and urban vegetation through implementation of rain gardens can reduce wind speeds and provide a cooling effect in Masthuggskajen. Green roofs and green areas have the ability of mitigating the effect of urban heat island and thus regulate the local climate in Masthuggskajen. The impact of mitigation of urban heat island and assimilation of carbon dioxide was however to be limited considered the small district of Masthuggskajen. Thus, this ecosystem service was not monetarily evaluated within the scope of this thesis.

Additional ecosystem services was considered to have an affect within Masthuggskajen but was not further evaluated within this project. The services considered were erosion prevention, social services along by biodiversity. These services were not taken into consideration due to time constraint and the limited extent of previous monetary estimates within an urban context.

A summary of the BGI features contributing to ecosystem services can be viewed in table 8.

Table 8: Ecosystem services considered to generated by different features of stomwater management solutions.

	Green roofs	Swales	Rain gardens	Trees	Detention basins	Detention ponds	Attenuation storage tanks
Flood protection	X	X	X	X	X	X	X
Water treatment		X	X	X	X	X	X
Air quality regulation	X			X			
Noise regulation	X			X	X		
Recreation			X	X	X	X	

4.2.2 Capital and operational costs

Within the aim of this project, costs for complementary infrastructure for implementation of stormwater solutions were not considered. Cost estimations are based on available literature stated in section 2.1.3. Below follows a summary of the capital and operational costs associated by Alternative 1 and Alternative 2.

Alternative 1

The properties of the stormwater facilites were estimated from the stormwater investigation and of guidance by people at Ramboll. The total cost for the full measure can be viewed in table 9.

Table 9: Investment and operational costs for the BGI implemented in Masthuggskajen.

Facility	Extent	Investment cost (SEK/unit)	Operation cost (SEK/year)
Green roofs	3 340 m^2	2 338 000	16 700
Immersed rain gardens	3 235 m^2	4 552 500	48 500
Elevated rain gardens	1 430 m^2	4 576 000	35 800
Detention basin	14 745 m^2	7 372 500	88 500
Trees	100	1 500 000	45 000
Total	22 750	20 639 000	234 500

Alternative 2

The properties of the conventional stormwater features was selected to correspond to the prerequisites determined in the project definition which can be described in table 2. The total cost for the underground system can be viewed in table 10.

Table 10: Investment and operational costs for the underground stormwater management.

Facility	Extent	Investment cost (SEK)	Operation cost (SEK/year)
Geocellular storage systems	600 m^3	3 000 000	39 000
Oversize plastic pipes	600 m^3	2 550 000	42 000
Filter	70 pieces	420 000	24 500
Total		5 970 000	105 500

4.3 CONVERSION OF PHYSICAL IMPACTS INTO MONETARY VALUES

In this section, benefits are valued as the provision of ecosystem services. The available site specific documentation for Masthuggskajen is stated in section 4.2.1.

4.3.1 Flood protection

Flood protection can be monetarily estimated by the avoided damage-cost of a flooding event. The disbursed insurance money most commonly estimates the cost of a flooding event by that certain event. Damages due to pluvial flooding can be divided into tangible and non-tangible costs. Tangible damage can be described by physical damage of buildings, infrastructure and disturbances in traffic. Intangible costs can be defined by damage in health, inconveniences and loss in ecological and cultural values (Skovgård-Olsen et al., 2015; Grahn, Nyberg & Blumenthal, 2014).

Method

A framework for conducting an economic flood risk analysis can be divided into a hazard and vulnerability assessment (Skovgård-Olsen et al., 2015). The hazard assessment serves as a measure of identifying the areas of potential risk of inundation. In order to assess the areas of special concern, hydraulic modeling of rain events of different return periods can be simulated. It is of importance to take into consideration the dimensioned capacity of the present sewage network to accurately determine the extent of pluvial flooding. In figure 5, the hydraulic modeling result of a design storm event with a return period of 100 years is presented for Masthuggskajen and its surrounding catchment area.

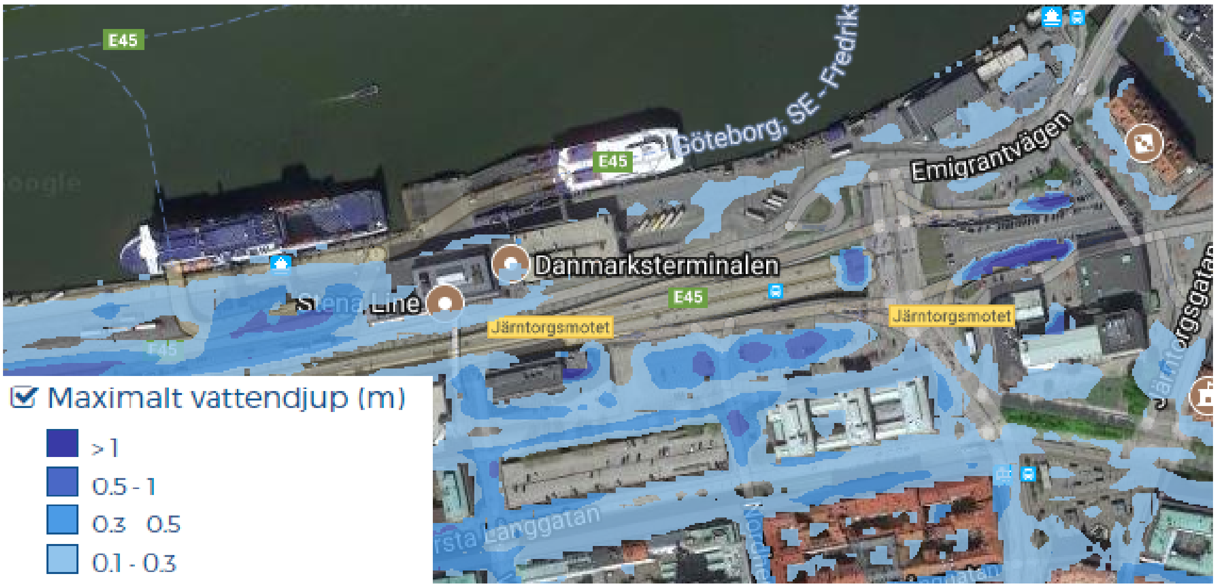

Figure 5: Simulation result of a rain by return period of 100 years for Masthuggskajen (Göteborgs Stad, 2015a).

The vulnerability assessment combines the hydraulic modeling results by visualizing the known depth of inundation of targeted areas. The aim is to highlight areas affected by inundation. The damage cost for inundated infrastructure can be estimated by the use of unit prices for ranging units (Skovgård Olsen et al., 2015). Depending on the activity within the area, a variation of unity costs can be applied. The City of Gothenburg have compiled a list of unit prices based on insurance cases for inundation which can be seen in table 11.

Table 11: Unit prices based on estimations by the City of Gothenburg (Göteborgs Stad, 2016).

Object	Price (SEK)
Commerce	180 000/building
Industry	195 000/building
Public	180 000/building
Apartments	190 000/building
Tram way	3 000/m
Highway	$150/m^2$
Main road	$130/m^2$
Local road	$110/m^2$

Throughout the scope of this project, damage-costs were delimited to damages on properties and affected roads. To determine the annual avoided damage-cost of pluvial flooding, were estimations of the extent of damage to separate rain events by defined return period considered. Damage-cost estimations were concluded through the use of unit prices of inundation and the number of inundated objects. Estimation of inundated objects was concluded through overlooking the extent of available modeling results and approximating the number of inundated objects and meters of inundated roads. An object was considered damaged if in connection to a standing water level of a minimum of 0.2 m.

In order to conclude the yearly monetarily estimated value of pluvial flooding, a log-linear relationship is assumed between the return period of defined rain intensities and the avoided damage-cost (Skovgård-Olsen et al., 2015; Skovgård-Olsen et al., 2017). Increased amount of simulations increase the accuracy of the linear approximation, thus hydraulic modeling of a wide range of return periods are of importance. The equation for the linear approximation can be viewed in equation 2.

$$D(T) = a * ln(T) + b \tag{2}$$

where *D(T)* equals the damage cost at the defined return period T. a and b are linear coefficients used in the valuation of the expected annual damage (EAD) in equation 3

$$EAD = a * e^{\frac{b}{a}} \tag{3}$$

The return periods of 5, 10, 100 and 500 years were plotted against the cost of those events according to figure 6. The capacity of the drainage network was altered between return time of 5 and 10 years due to the variety of network capacity throughout the area and thus the damage-cost was set to 0 for each of those instances.

Result

The log-linear relationship with the scenario of a drainage capacity of a 5 year design storm are represented by figure 6. The result for the drainage capacity can be seen in figure 11 in Appendix.

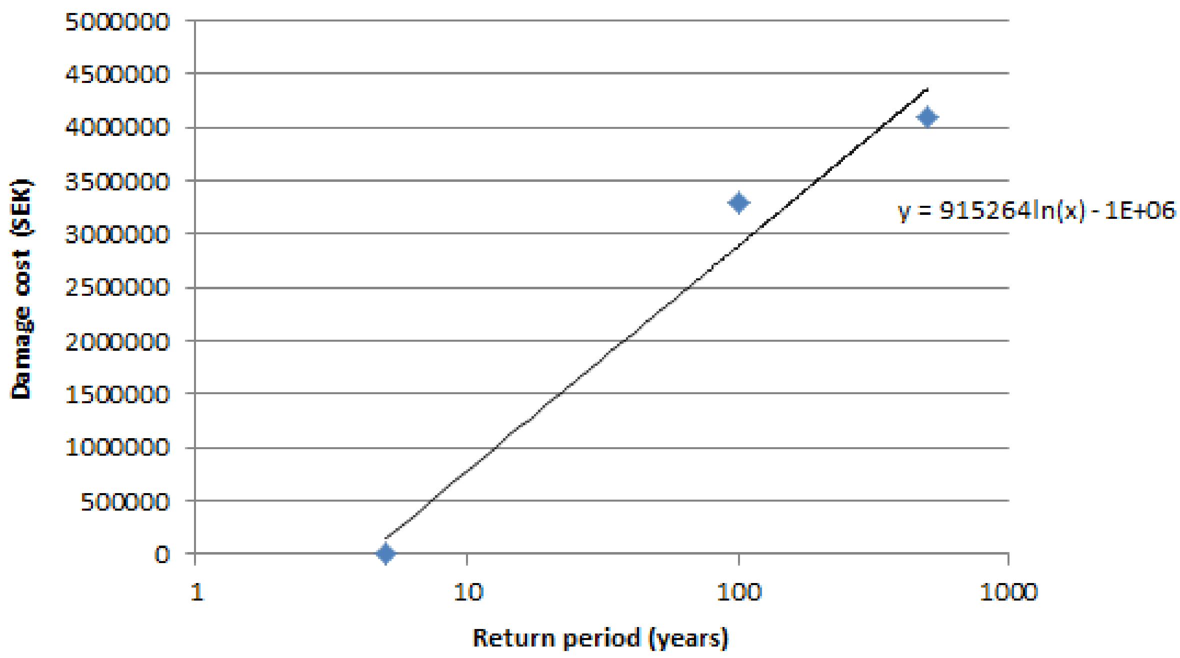

Figure 6: Log-linear relationship between damage cost and return period when defined for a drainage capacity for episodes with a return time of 5 years.

The EAD are calculated by using the coefficient from the log-linear relationship. The ranging result depends upon the variation in defined drainage capacity. By a lowered drainage capacity, the value of EAD increases.

EAD = a*$e^{\frac{b}{a}}$ = 135000-307000 SEK/year

4.3.2 Stormwater treatment

The value of treatment of water by ecosystem services can be calculated by the replacement cost method. The Swedish Environmental Protection Agency has developed economic estimations of the effects in determining the ecological status of recipients. If an area of great impact could be restored and lower the emission to such a recipient, interest could be put to evaluate such cost or benefit. Valuation consider the alternating cost of maintenance and protection measures as the use of pH-adjustment for increased water quality.

Estimating the volume of water treated within the project area could do an alternative approach. This volume is then multiplied by the cost of treatment per unit at a sewage treatment plant (Liu et al., 2016, Karras & Read, 2016). Major cities in Sweden demands treatment of stormwater in order to maintain or enhance the water quality of the downstream water body/recipient. The degree of treatment depends on the site characteristics (Göteborgs Stad, 2017). Treatment of stormwater can either take place at a wastewater plant, in the case of a combined sewage network, or by treatment capacity within the stormwater system.

Method

Within Masthuggskajen, the distribution network consists of a mix of combined pipes along with separate pipes for stormwater. Along the main streets considered, the existing pipe network is combined. Within this valuation, stormwater assumes being diverted into the combined sewage network. Costs for treatment at a wastewater treatment plant was used for replacement cost. The cost of treatment for a specific volume would correspond to the operating cost of the treatment plant. The trade organization for water in Sweden has compiled cost estimations for the volume of treated water.

To determine the yearly volume of stormwater being treated within the area, the net run off and the size of the catchment area was of importance. The net runoff is dependent on the annual precipitation, transpiration and the soil infiltration leading to groundwater recharge, equation 4 (SMHI, 2017),

$$R = P - E - \Delta S \tag{4}$$

where R (mm) equals the runoff; P (mm) equals the precipitation; E (mm) equals the transpiration and $\Delta\ S$ (mm) the change in groundwater storage. Due to the urban environment $\Delta\ S$ was assumed to be 0.

Through the stormwater investigation the contributing impervious area to the runoff to rain gardens could be determined.The treated volume was estimated by equation 5

$$V_{treated}(m^3/year) = R * A \tag{5}$$

To determine the monetary value of the treatment, the operating cost for treatment was multiplied by the treated volume annually according to equation 6

$$B_{watertreatment}(SEK/year) = V_{treated} * C_{operating} \tag{6}$$

Result

The operating cost has been estimated to 2-3 SEK/m^3 (Balmér & Hellström, 2011). The contributing area was estimated to 36500 m^2 and the precipitation in Gothenburg to 945 mm/year considering the last 15 years of measurements from *SMHI Öppna data*(SMHI, 2017a). The transpiration was estimated to 500 mm/year (SMHI, 2017b). The result of the benefit of water treatment can be viewed in table 12.

Table 12: Overview of the result of the benefit drawn by the ecosystem service annualy.

Run off (m/year)	Area (m^2)	Operating cost (SEK/m^3)	Total benefit (SEK/year)
0.445	36500	2-3	32 500-48 700

4.3.3 Air quality regulation

Air pollutants are an increasing problem within an urban context. The main source for increasing concentrations of air pollutants is anthropogenic activities such as traffic and construction. Gaseous pollutants as nitrogen oxide (NO_x), sulphur dioxide (SO_2) and ozone (O_3) originate from combustion of fossil fuels largely due to traffic. Particulate matter (PM), consists of suspended particles in air and is defined by the diameter of particles. PM is commonly divided between the categories PM2.5 and PM10 which is referring to the particle diameter of 2.5 micrometer respectively 10 micrometer. Air pollutants mainly affect the respiratory system and can cause premature mortality due to both short- and long-term exposure to exceeding high concentration levels of air pollutants (Kampa & Castanas, 2008).

Blue-green infrastructure through practices of green roofs, trees and vegetation has the ability to clean air through deposition, absorption and thus enhancing the local air quality. Deposition of small particles on vegetated surfaces has been recorded to be up to 30 times faster than on cement surfaces (Janhäll, 2015).

Method

The Swedish Transport Administration has compiled general values for the monetary values of change (increase or decrease) in pollutant levels. Those values are to be used in economic analysis of a proposed action. The monetary values are estimated through individuals willingness-to-pay to lower the levels of air pollutants (Trafikverket, 2016a). Monetary values are estimated for local or regional scale, costs for various air pollutants can be viewed in table 23 in Appendix.

The rate of exposure by local effects are estimated by a methodology proposed by the Swedish Transport Administration and is based on the population density of a certain and the ventilation factor according to equation 7,

$$Exposure = 0.029 \cdot F_v \cdot B^{0.5} \tag{7}$$

where B equals the population of the metropolitan city of interest and F_v the ventilation factor. By taking into consideration the cost per unit of exposure, the cost per kg deposited pollutant can be achieved within the local area. The cost per unit of exposure can be seen in table 23 which can be seen in Appendix. The monetary value of air quality regulation is calculated by the deposition and absorption of pollutants by green infrastructure. The deposited amount is described by equation 8

$$M(kg) = v_d \cdot C \cdot t \cdot A \tag{8}$$

where v_d is the deposition velocity (m/s); C the concentration of air pollutant (μgram/m^3), t is the time, A the surface area of vegetation (Nowak, 2006; Karras & Read, 2016). As the deposition velocity is dependent on the vegetated surface, the deposited amount of pollutants was calculated for the time of existing vegetation, approximated to be 6 months within this project. Examples of deposition rates have been found for green roofs and trees through previous studies which can be sen in table 13.

Table 13: Mean dry deposition velocities of a range of pollutants according to (Yang et al., 2008; Janson & Hansson, 2003).

Pollutant	v_d decidous trees (cm/s)	v_d green roofs (cm/s)
SO_2	0.31	0.22
NO_x	0.3	0.2
O_3	0.33	0.22
PM10	0.25	0.15
PM2.5	0.25	0.25

The total amount of deposited air pollutants is decided by the total tree canopy coverage and surface area of green roofs in m^2. An approximation of an average tree canopy radius of 2 meters was multiplied with the change in number of trees within the area. The area of green roofs were determined by table 6

Within the area of Masthuggskajen lies a major road, which contributes to occasionally high concentrations of air pollutants. According to simulations from previous studies, levels of NO_2 and PM10 were exceeded by the main road (COWI, 2017). An average concentration of the modeled pollutants was estimated as the concentration of pollutants in vicinity to green elements as trees and green roofs.

Within Gothenburg, monitoring of air quality is conducted on a regular basis. Monetary estimates and concentration levels were also found for SO_2, O_3 and PM2.5. Concentration levels were considered within the range of two adjacent gauging stations (Miljöförvaltningen, 2017).

PM10 includes the smaller fraction denoted PM2.5 which is valued much greater than the larger fraction of particles. Trafikverket argues that adding another component of monetary value to PM10 not being necessary (Trafikverket, 2016a). Thus, the cost for deposition of PM2.5 was taken into consideration within this project and not the larger fraction of PM10.

Result

The exposure rate was concluded by defining the ventilation factor and population of Gothenburg. The ventilation factor was assumed to be 1 for Gothenburg (Trafikverket, 2016a). Moreover, the current population of Gothenburg was estimated as 562748 people (SCB, 2017). The exposure rate was calculated to 21.8.

In table 14, cost estimations for ranging air pollutants can be seen. NO_x, SO_2, and PM2.5 calculated through the methodology presented by (Trafikverket, 2016a). Cost estimation of O_3 was transferred from a study by Karras & Read (2016).

Table 14: Exposure rates and estimated marginal costs for the city of Gothenburg and through literature (Karras & Read, 2016).

Pollutant	Cost (SEK/kg)
NO_x	44
SO_2	374
PM2.5	12746
O_3	65

Table 15 display the concentration levels, deposited amount and the monetary estimate of each air pollutant. It can be seen that the largest impact on the monetary estimate of air quality regulation is the deposition of small particles, PM2.5.

Table 15: Overview of the monetary valuation of the ecosystem service air quality regulation within Masthuggskajen.

Pollutant	Concentration (μgram/m^3)	Deposited amount (kg/year)	Cost (SEK/year)
SO_2	0-2	0-0.35	0-130
NO_2	20-25	3.3-4.1	150-180
O_3	41-55	7.4-10	480-650
PM2.5	6-8	1.1-1.4	14 000-18 000
Total			15 000-19 000

$B_{airquality}$ = 15 000-19 000 SEK/year

4.3.4 Noise regulation

In an urban environment, there are many sources for noise pollution. A key component in the estimation of the effects of noise disturbance is the distance towards the source of noise. A doubling in distance lower the sound level by 3 dB(A). Also, softer surfaces contribute to lower sound levels compared by harder surfaces such as concrete (Bolund & Hunhammar, 1999).

Method

The Swedish Transport Administration has compiled general monetary values describing the estimated effect of a change in sound levels due to traffic. Noise from road traffic is estimated differently than noise from rail traffic. The monetary values are based on the hedonic and the avoided-damage cost method. The estimation is based on the impact on real estate prices due to disturbance and the health effects caused by longterm exposure to high noise levels. The general values are used in economic analysis through the evaluation of the change in noise level and consideration of the marginal cost of the explicit change in dB(A), according to figure 9 in Appendix. In addition to identifying the marginal cost of noise, the number of affected people are needed to be estimated (Trafikverket, 2016b). The number of affected people is estimated by the number of residents within the area that are affected by the change in noise levels. Another foundation for valuation is the assumption of people spending time indoor and outdoors within the area (Trafikverket, 2016b).

To acknowledge a representative noise level throughout the area, the sound level was estimated as the modeled noise level within the area. For the two park areas the noise level was approximated to range between 50-55 dB(A). Along Masthamnsgatan, the sound level was assumed to range between 55-60 dB(A) (AkustikForum, 2015).

Parks and open green surfaces have an effect to mitigate the sound propagation through absorption of sound compared to hard surfaces. A soft surface has been considered to decrease the sound level of 2-3 dB(A) (Bolund & Hunhammar, 1999). Inclusion of surrounding residential areas close to the park were given a decrease by 2-3 dB(A) in this project. Trees in street canyons are assumed to scatter of sound in tree canopies. The effect was considered to be up to 2 dB(A) (HOSSANA, 2013). An altering sound level along streets was assumed to be between 1-2 dB(A) in this project.

Due to the importance of distance for the sound propagation have the affected residents within the area, an assumption that the reduction are limited to the residents in close connection to roads were concluded. Throughout the whole area 10 % of the population were assumed to be affected by lowered sound levels through implementation of trees and parks, a total of 300 people based on site characteristics. 200 were assumed to be living near park areas and 100 along Masthamnsgatan. The effects of green roofs were not evaluated in this project due to the risk of double counting the effects of other measures.

The benefit provided by noise regulation was calculated by equation 9 (Trafikverket, 2016b). The level of reduction in sound level was multiplied by the marginal cost estimated by the Swedish Transport Administration and the number of affected persons according to equation 9,

$$B_{noise}(SEK/year) = C_{dB(A)} * N \tag{9}$$

where $C_{dB(A)}$ equals the marginal cost of a change in noise level and N the number of affected people.

Result

The results of the impact by noise reducing measures can be seen in table 16. The monetary estimation of noise regulation varies within a large span depending of the assumed marginal cost of a change in noise levels.

Table 16: Overview of the monetary valuation of noise regulation. Mean values are aggregated for the two locations of Masthamnsgatan and the park areas.

Location	dB(A) prior	dB(A) after	$C_{dB(A)}$ (SEK/year*persons)
Masthamnsgatan	55	54	1021
	60	58	3739
100 people			238 000
Park areas	50	48	0
	55	52	2544
200 people			269 900
Total			507 900

$B_{noiseregulation}$ = 507 900 SEK/year

4.3.5 Recreational values

The proximity to recreational areas can be valued in a range of ways. One approach is to estimate the travel-cost to attend the location of interest. Alternative approaches are to extract the health benefits achieved associated with green space.

To identify the monetary value in an urban context, the method of hedonic pricing is used. Studies shows a positive correlation between the distance to urban green space in relation to increase in house prices. By estimating the distance within the area to recreational areas, different ranges in property increase can be showcased. By indicating the amount of households or offices within the area, taking the average price and then multiplying it by the percentage of increase in value would imply the recreational benefits by the green space in the area. In order to account assessing the value increase, a threshold value for the surface of the green space need to be assigned.

Research have indicated an increase in property prices due to existing or further implemented green areas. Research in Portland, US; suggest that the positive effect in property sales prices can outweigh the extra cost of green infrastructure (Neutsil et al., 2014). Further research within Portland also indicates positive effects for rental prices due to inclusion of trees in vicinity to households (Donovan & Butry, 2011).

Method

Calculations were based on a combination of hedonic pricing. When using the benefit transfer methodology between estimations it is of great importance to identify similarities of the initial study area compared to the area to be using the benefit transfer. A study (Panduro & Veie, 2013) conducted in Aalborg, in northern Denmark, close to Gothenburg distinguished the effects of the proximity to various types of green areas. They looked upon the change in house and apartment prices due to the proximity to park areas. They saw a correlation between the distance to parks, and an increase in apartment prices (Panduro & Veie, 2013). The impact of increased proximity by 100 m to parks was considered to be an average of 0.35 % for apartments (Panduro & Veie, 2013).

In this project, the effect in price due increased proximity to parks was estimated for new built apartments. All apartments were assumed to increase their proximity by 100 m. The total invested area in apartments are estimated to 118 900 m^2 and the price for each square meter within the area was 61 050 SEK (Mäklarstatistik, 2017).

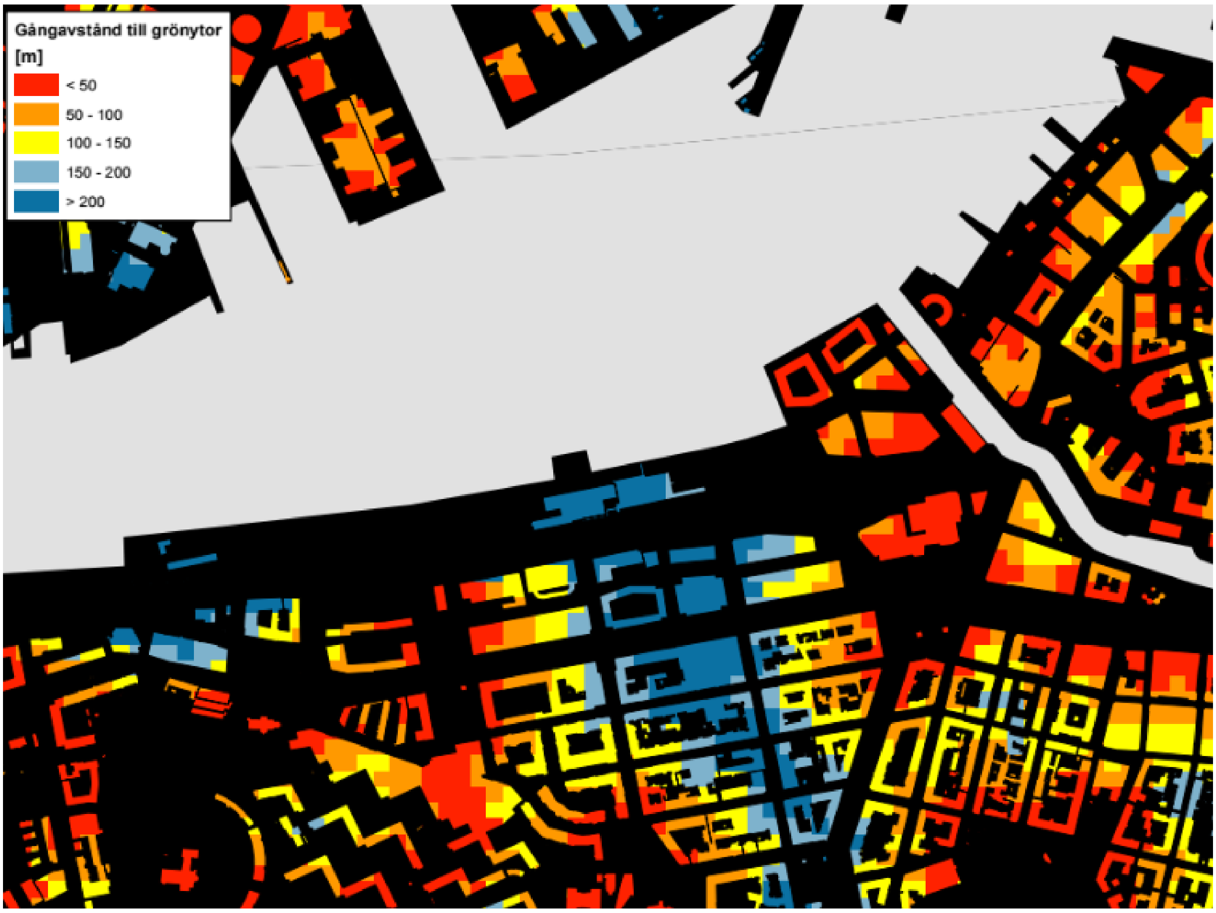

Figure 7: Walking distance to open greenspace after the proposed development (Ramboll, 2017b).

Result

In table 17, the monetary estimate of the ecosystem service added recreational values can be seen. The value increase is considered to be valid over the lifespan of the investment and thus added value is considered as a one-time benefit by the increased apartment prices within the area. It is not considered to be a benefit generated continuously over time.

Table 17: Overview of the monetary valued benefit by recreational in Masthuggskajen.

Δ Distance (m)	Area (m^2)	Price (SEK/m^2)	Δ Price (%)	Δ Price (SEK)
100	118 900	61 050	0.35	25 406 000

4.4 DISCOUNTING

Due to the application of multiple monetary estimates by the Swedish Transport Administration and their influence on recommendation of discount rates to national authorities was a discount rate of 3.5% applied (Trafikverket, 2016c). As a reference value to implicate the sensitivity of the analysis was a discount rate applied of 1.4% according to Stern (2007) and in line with previous cost-benefit analysis of sustainable stormwater management (Karras & Read, 2016; Falk, 2016).

Capital costs were discounted for an estimated implementation period of two years. The same assumption were made during reinvestments of BGI under the total period of 100 years. During the implementation period, neither benefits nor maintenance costs were accounted for.

Annual costs and benefits were discounted for all years except during the years of implementation. The added value for recreation was only discounted for the initial implementation period.

4.5 NET PRESENT VALUE ASSESSMENT

Costs and benefits over the lifespan of the investment are calculated to the NPV. An overview of the annual benefits can be represented in table 18. The mean value was adopted for the NPV assessment.

Table 18: Summary of the monetary estimates of ecosystem services.

Ecosystem service	Monetary estimate (SEK)
Flood protection	140 000 - 310 000/year
Water treatment	32 000 - 49 000/year
Air quality regulation	15 000 -19 000/year
Noise regulation	130 000 - 880 000/year
Recreation	25 000 000 / 100 years

In figure 8, the result of the NPV assessment can be viewed with an applied discount rate of 3.5 % over the time period of 100 years. It is shown that the benefits exceeds the costs for Alternative 1 considering implementation of BGI. The inclusion of underground infrastructure in Alternative 2 was not considered profitable.

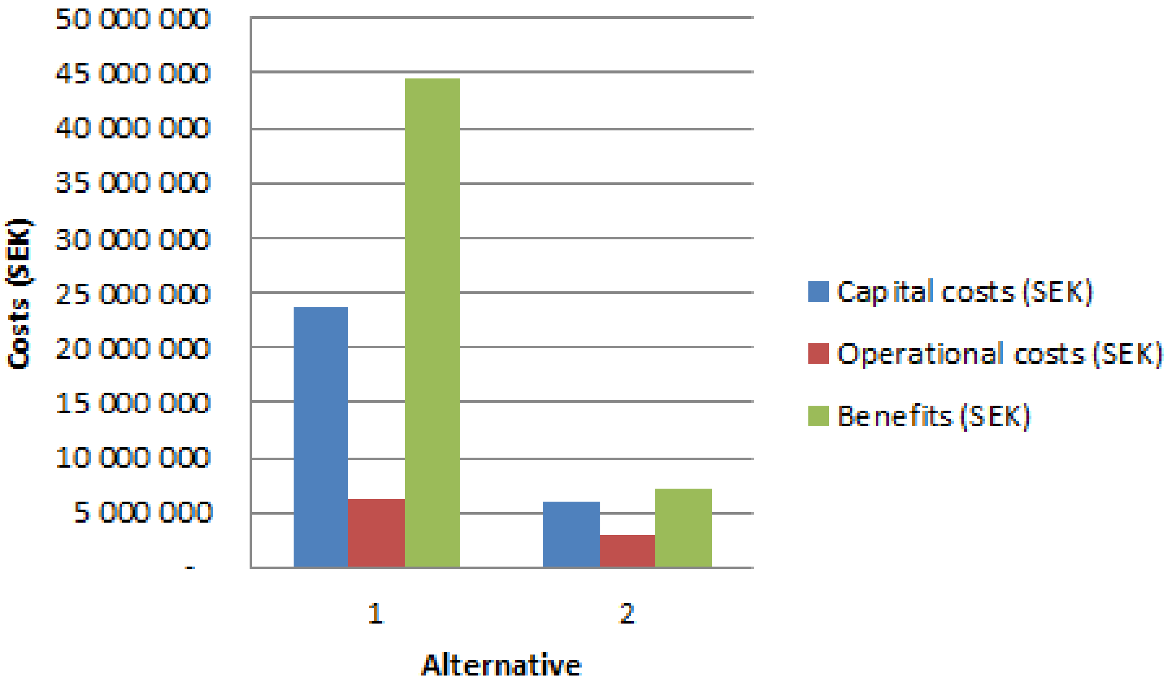

Figure 8: NPV assessment for the implementation of alternative 1 (BGI) and alternative 2 (underground storage tanks) for stormwater management with a discount rate of 3.5% for the time horizon of 100 years.

In table 19, the numeric representation of the NPV assessment can be viewed. It can be seen that the investment in BGI yield a profit over the time horizon of 100 years of 14 469 029 SEK.

Table 19: Overview of the NPV assessment with an applied discount rate of 3.5%.

Scenario	NPV (SEK)
Alternative 1	14 569 029
Alternative 2	-1 585 554

4.6 SENSITIVITY ANALYSIS

To determine the sensitivity of the NPV, costs and benefits were altered 10% respectively. The negative 10% corresponds to a decrease in all benefits by 10 % and an increase in capital and operational costs by 10%. The opposite was applied for the positive change. This was completed for both alternatives and the results can be seen in table 20.

Table 20: Overview of NPV by positive and negative change in costs and benefits by 10 %.

NPV	-Δ 10 %	+Δ 10 %
Alternative 1	7 132 874	22 040 885
Alternative 2	-3 159 317	-1 488

It can be seen that Alternative 1 is considered profitable for an alteration of both a negative and positive alteration of 10 %. The costs for Alternative 2 exceeded the benefits for both cases for the sensitivity analysis. It can be seen that the altering of 10 % have greater impact of the investments considering BGI (alternative 1). Thus, it is of importance in identifying the most contributing variables for the monetary estimations of BGI.

The effect of discounting imply lowered value of costs and benefits extracted in future time. Thus, the impact of capital costs and the benefit by added recreational values are contributing greatly to the results since they are discounted only during the time of implementation. For future analysis it is important to carefully estimate these effects. The estimation of service life for different features of BGI is difficult, it was thus considered as a good measure for identifying the sensitivity in the investment to assume a shorter lifespan. The service life was estimated to 25 years as a comparison to 50 years. In table 21 can the result of Alternative 1 be seen by two different estimations in service life. The investment appears to be profitable for both cases. Calculations with an applied discount rate of 1.4 % can be seen in table 22.

Table 21: NPV assessment of implementation of BGI by two different considered service life by an applied discount rate of 3.5%.

Scenario	NPV (SEK)
Alternative 1 - 25 years	4 489 889
Alternative 1 - 50 years	14 569 029

Table 22: Overview of the NPV assessment by an applied discount rate of 1.4% for Alternative 1 by varying service life (25 & 50 years) along by Alternative 2 with an estimated service life of 100 years.

Scenario	NPV (SEK)
Alternative 1 -25 years	554 578
Alternative 1 - 50 years	22 760 707
Alternative 2 - 100 years	2 492 490

With a lowered discount rate, all costs and benefits are valued higher compared to when applying a higher discount rate. It can be seen in table 22 that the lowered discount rate has a positive effect in the NPV for investments with no or limited reinvestment costs which constitutes to a large sum of the total investment. However, the implementation of BGI by a service life of 25 years is prone for higher reinvestment costs contributing to a lowered NPV.

5 DISCUSSION

5.1 URBAN ECOSYSTEM SERVICES

The Swedish government has established an aim of highlighting the value of ecosystem services (SOU 2013:68). A partial aim of this project was to identify and monetarily evaluate urban ecosystem services in Masthuggskajen.

Importance through the identification process was to consider the site-specific conditions. Ecosystem services such as erosion prevention are highly dependent on vegetation through the root systems functioning of holding the soil in place. Within Masthuggskajen, a district of urban character, provision of erosion prevention was not considered to be a factor. The ecosystem services generated in Masthuggskajen are depending on the features implemented as BGI. For example, the implementation of other BGI features as detention ponds could create additional values within an urban environment than the ones discussed in this thesis. The inclusion of blue elements within the district such as a detention pond could increase the recreational value within the area and enhance the conditions for biodiversity. Thus, the possible synergy effects regarding implementation of multiple natural values are important to consider when evaluating the ecosystem services within an area.

The complex relationship between ecosystem services, implicate the difficulty in identifying services within a defined area. Consideration of a greater area is recommended to better understand existing natural values and the ones that might be generated.

5.2 UNCERTAINTY IN MONETARY ESTIMATES

The monetary valuation of ecosystem services is based on previous studies and guidelines. Documentation for Masthuggskajen present estimations of the extent of various features of BGI, along by modeling results of various measures. One of the objectives of this thesis was to evaluate whether the supporting documentation for Masthuggskajen was adequate for input to monetarily value ecosystem services. Throughout the project was benefit transfer used in establishing monetary values. When using the benefit transfers methodology, Naturvårdsverket recommends considering an allowance for a level of uncertainty of 25-40 % (Naturvårdsverket, 2014).

The ecosystem services contributing most to the result were added recreational values, noise regulation and flood protection as can be seen in table 18. The limited extent of previous studies concerning evaluation of the physical functioning of urban ecosystem services creates uncertainty in the estimations of its monetary value. For example, there are considerable uncertainties in the estimation of the noise level at which health effects start to be noted (Trafikverket, 2016b). The value of noise regulation was calculated by the impact of trees and green areas to lower noise levels. The magnitude of impacts was concluded from a research project within the EU (HOSSANA, 2013), along by past research (Bolund & Hunhammar, 1999). It was considered difficult to determine which impact noise regulation measures would have in Masthuggskajen, due to the limited information regarding spatial design of trees and vegetation within the area. High marginal cost for a change in noise levels estimated by Trafikverket (2016b) contribute to large variations in the estimate of noise regulation. The marginal cost of a change in noise levels is based on the individual willingness to pay for a decrease in noise levels along by the health effects by exposure to noise levels. The willingness to pay is expressed by the increase in real estate prices due to lowered noise levels. Thus, there is a risk of double counting the value of ecosystem services noise regulation and recreational value since both are estimated in the change in real estate prices. The marginal cost also increase by noise level, table 9 in Appendix. The estimated initial value is therefore of special concern. For this project, a range of 5 dB(A) was considered based on the modeling results of the area. To increase the reliability of the results, further modeling of sound propagation could be concluded by integration of the impact of vegetation. The number of people affected was difficult to determine since the area is yet not developed and lack of the distribution of residential areas. An approximation of 10 % was estimated but further information regarding the design and spatial distribution within the area are crucial for better estimations of the monetary value by noise regulation.

The recreational value was estimated as the increase in real estate prices due to further proximity to green areas. The methodology was adopted by a previous study in Aarhus, Denmark, which was considered to host the same urban characteristics as Gothenburg. As the added recreational value was considered by the time of implementation, this value was discounted only during the period of implementation and therefore having a large effect on the NPV. For future analysis, the extracted benefit by recreational values is recommended to be calculated on an annual basis to better compare the value of different ecosystem services. A study by Karras & Read (2016) concluded the recreational value on an annual basis which was based on a hedonic pricing method by the benefit generated by green facades and roofs. However, it is difficult to conclude whether the added value in apartment prices consider the total recreational value. The added value for people visiting or working within the area have not been taken into consideration within this study, nor the possible health benefits by further proximity to green areas. This concludes a possible underestimation of the recreational value by implementing green elements in Masthuggskajen.

The provision of flood protection was concluded through the estimated annual damage-cost. The cost of damage was based on inundated infrastructure as buildings and roads.

Intangible damages such as delay in traffic and absence to work was not taken into consideration and creates uncertainty in the monetary estimate of damage to pluvial flooding. Due to limited amount of modeling results for Masthuggskajen (100- and 500year return period), and the assumed drainage capacity of between 5 and 10 years years is it difficult to conclude the uncertainty within the results. To increase the accuracy, multiple estimations of the extent of flooding are in need to better approximate the linear relationship between damage-cost and return period of rainfall. This could be done through modeling of multiple return periods by a shorter than 100 years. However, assessments of damage-costs due to inundation are widely used and an integral part in estimating mitigation measures towards climate change (Skovgård et al., 2015).

As can be represented in table 18, it is important to consider the monetary value of defined ecosystem services as an estimate, and it is not recommended to conclude an explicit value which ecosystem services provide. It presents an indication of the value different services provide, but due to synergy effects between implementation of green elements in urban areas, along by changing conditions over time, it is most likely an underestimation.

The provision of ecosystem services is generated locally whereby it is of importance in establishing a solid foundation for monetary estimates in the assumption of physical conditions. The limited extent of previous studies concerning evaluation of the physical functioning of urban ecosystem services, create uncertainty in the estimations of its monetary value. This is concluded to be of significant importance for future use in integrating monetary valuation of ecosystem services in a CBA (Bateman et al., 2010).

5.3 COST-BENEFIT ANALYSIS

By evaluating the results in figure 8, the implemented measures of BGI was considered profitable over a time horizon of 100 years. Due to the short history of installments of BGI and ranging types of solutions, two various time spans for the service life was considered. The literature suggests that after 25-50 years, major rebuilding is needed and was throughout this project viewed as a new capital cost. This study highlights the need for careful estimations in the expected service life of BGI since it contributes greatly to the result of the NPV. By an increased number of implemented BGI features, the life span through empirical data can be better estimated. The study conducted by Karras & Read (2016) assumed the service life to be equal to the use of conventional management, 100 years. Their result indicated the profitability for implementation of BGI with an applied discount rate of 1.4% but not with an applied discount rate of 3.5 %.

An increased timespan cause further uncertainty through the possibility for external events, such as reconstruction within the area and effects of climate. The applied discount rate was set to 3.5 % according to the recommendation of the Swedish Transport Administration. However, a decreasing or generally lowered discount rate are proposed for longer time spans due to increased uncertainty of external effects affecting investments in future time (Stern, 2007; Barbier et al., 2009). The foundation for an applied discount is the time preference of money. The value of money or benefits is considered to be higher today than in the future. However, when considering climate adaptation measures, the benefit in future time could be argued to increase. The benefit provided by flood protection could be argued to increase over time if the probability for flooding events increase (Naturvårdsverket, 2006). Thus, the application of monetarily valued benefits for the use of a CBA is controversial. However, the monetary value of ecosystem services as benefits provided by ecosystems highlights the value in the conduction of a CBA.

Through the difficulty in capturing the full extent of generated ecosystem services, the results are considered to be an underestimation of the full value of implementing BGI in Masthuggskajen. The failure in monetarily estimating all provided ecosystem services indicate the need of complementary valuation methods for decision-making. Saarikosi (2016) argues that alternative frameworks for assessing the value of ecosystem perform better in capturing the full extent of values. However, it could be seen that the impact of integrating ecosystem services in a CBA for stormwater management has a great impact when considering the societal benefit of a project. Further estimation of ecosystem services can increase the knowledge and understanding in which services best can be estimated and if to be integrated in a CBA.

Of importance to highlight within the identification of benefits provided by ecosystem services, is the alternate cost of land use. Within urban environments is available land often a constraint for considered developments and highly valued. This has not been taken into consideration within this project.

5.4 CONTRIBUTION AND FUTURE RESEARCH

The limited extent of integration of urban ecosystem services in economic assessments regarding stormwater management was the foundation of the project. The scope was to make use of available information regarding an area during development as Masthuggskajen, for integration of ecosystem services in a CBA. The available information provided modeling results of current and future conditions, contributing to good measures of estimating site conditions. That is of importance due to ecosystem services being generated on a local scale within the area.

Research regarding the ability for BGI features to impact the surrounding environment is of importance for future monetary estimations of ecosystem services. The limited extent of economic modeling on environmental effects as ecosystem services command further research of the economical impacts of natural elements.

6 CONCLUSIONS

It can be concluded that in order to enhance the accuracy in monetary estimation, great understanding in the physical processes of ecosystem services are in need. Considering the great contribution to the result of the CBA, special regard to monetary estimations of added recreational value and noise regulation are of importance for future studies.

Multiple ecosystem services were identified by implementing BGI in Masthuggskajen. By the use of existing guidelines and literature, it was possible to include monetary estimates of ecosystem services in a CBA. By including the benefits generated by ecosystem services, the investment in BGI was considered profitable for the case of Masthuggskajen. Further analysis regarding the uncertainty in the monetary estimations would strengthen the results.

Further research concerning the impact of urban ecosystem services is of importance in strengthening the results and for future valuation of ecosystem services. However, by identifying monetary estimates, the value of ecosystem services can be highlighted and act as foundation for future decision-making.

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8 APPENDIX

Appendix A

Urbana miljöer, boendemiljö				
Bullernivå (Db)	Kostnad för buller från vägtrafik (kr/person/år)	Marginalkostnad vägtrafik (kr/person/år)	Kostnad för buller från tågtrafik (kr/person/år)	Marginalkostnad tågtrafik (kr/person/år)
50	155		62	
51	483	328	192	130
52	985	502	389	197
53	1 660	675	653	264
54	2 508	848	985	332
55	3529	1021	1 383	398
56	4 723	1194	1 849	466
57	6 091	1368	2 383	534
58	7 700	1609	3 051	668
59	9 469	1769	3 774	723
60	11 439	1970	4 591	817
61	13 595	2156	5 489	898
62	15 952	2357	6 481	992
63	18 509	2557	7 568	1087
64	21 254	2745	8 737	1169
65	24 185	2931	9 986	1249
66	27 317	3132	11 329	1343
67	30 649	3332	12 767	1438
68	34 182	3533	14 300	1533
69	37 905	3723	15 917	1617
70	41 845	3940	17 645	1728
71	45 972	4127	19 454	1809
72	50 300	4328	21 358	1904
73	54 828	4528	23 356	1998
74	59 557	4729	25 449	2093
75	64 500	4943	27 650	2201

Figure 9: Cost estimations of noise regulation by the Swedish Transport Administration (Trafikverket, 2016b).

Appendix B

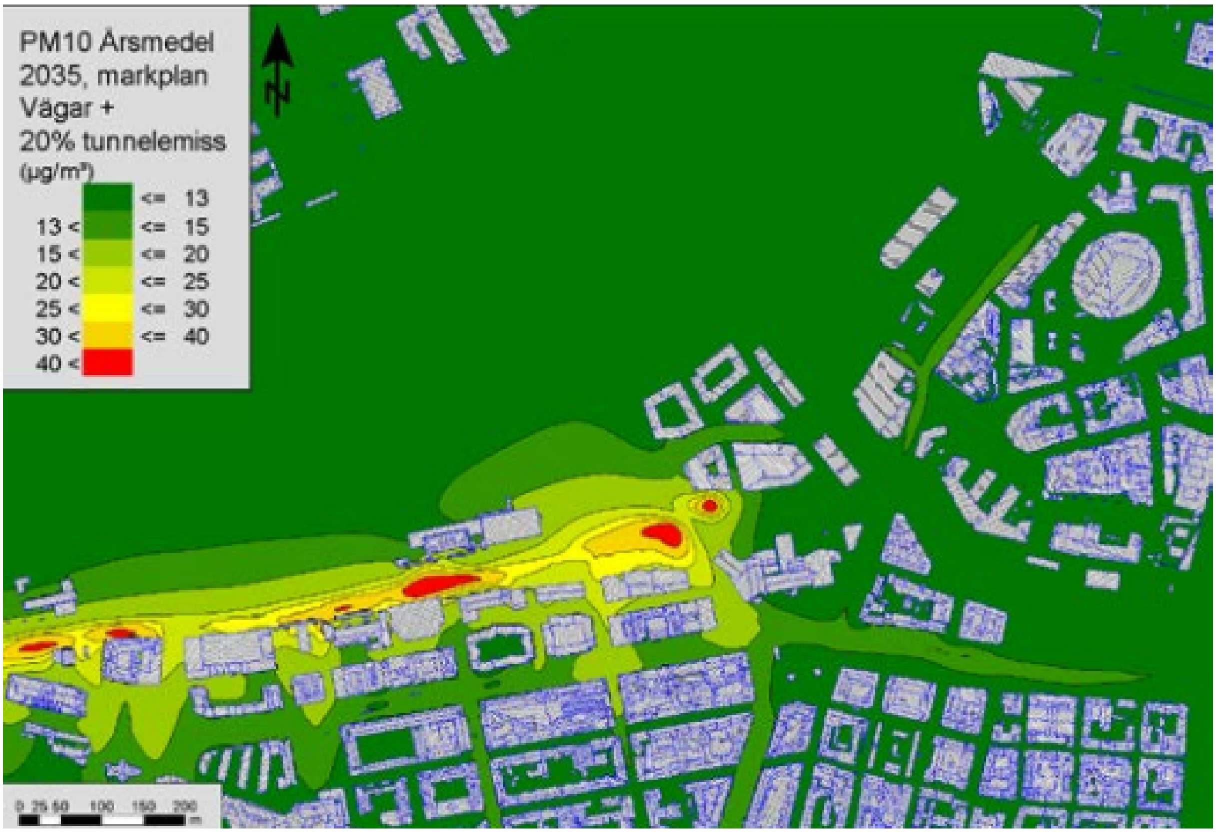

Figure 10: Concentration levels of PM10 after development (COWI, 2017).

Appendix C

Table 23: Cost of local effects by air pollutants estimated by the Swedish Transport Administration in (SEK/unit of exposure) (Trafikverket, 2016a).

Air pollutant	Cost (SEK/unit of exposure)
Nitrogen oxide (NOx)	2,0
Volotile organic carbon (VOC)	3,4
Sulphur dioxide (SO2)	17,2
PM2,5	585,9

Appendix D

Table 24: Gross defined list of ecosystem services. Used for foundation in identification of ecosystem services.

Category	Ecosystem service	Source
Provisioning	Food	MA/TEEB/CICES
	Fresh water	MA/TEEB/CICES
	Raw materials (incl. fuel)	MA/TEEB/CICES
	Genetic resources	MA/TEEB/CICES
	medicinal resources	MA/TEEB
	Ornamental resources	MA/TEEB/CICES
Regulating	Air quality regulation	MA/TEEB/CICES
	Climate regulation	MA/TEEB/CICES
	Moderation of extreme events	MA/TEEB/CICES
	Regulation of water flows	MA/TEEB/CICES
	Waste treatment	MA/TEEB/CICES
	Erosion prevention	MA/TEEB/CICES
	Mainteneance of soil fertility	TEEB/CICES
	Pollination	MA/TEEB/CICES
	Seed dispersal	CICES
	Biological control	MA/TEEB/CICES
	Water treatment	MA/TEEB/CICES
	Noise regulation	CICES
Cultural	Aestethic values	MA/TEEB/CICES
	Recreation	MA/TEEB/CICES
	Tourism	MA/TEEB
	Inspiration for culture, art & design	MA/TEEB
	Spiritual experineces	MA/TEEB/CICES
	Education	MA/TEEB/CICES
	Cultural heritage	MA/TEEB/CICES
	Social relations	MA
	Sense of place	MA/CICES
Supporting	Maintenance of biodiversity	TEEB
	Photosynthesis	MA/TEEB
	Priamry production	MA/TEEB
	Soil fertility	MA/TEEB/CICES
	Nutrient cycling	MA/TEEB

Appendix E

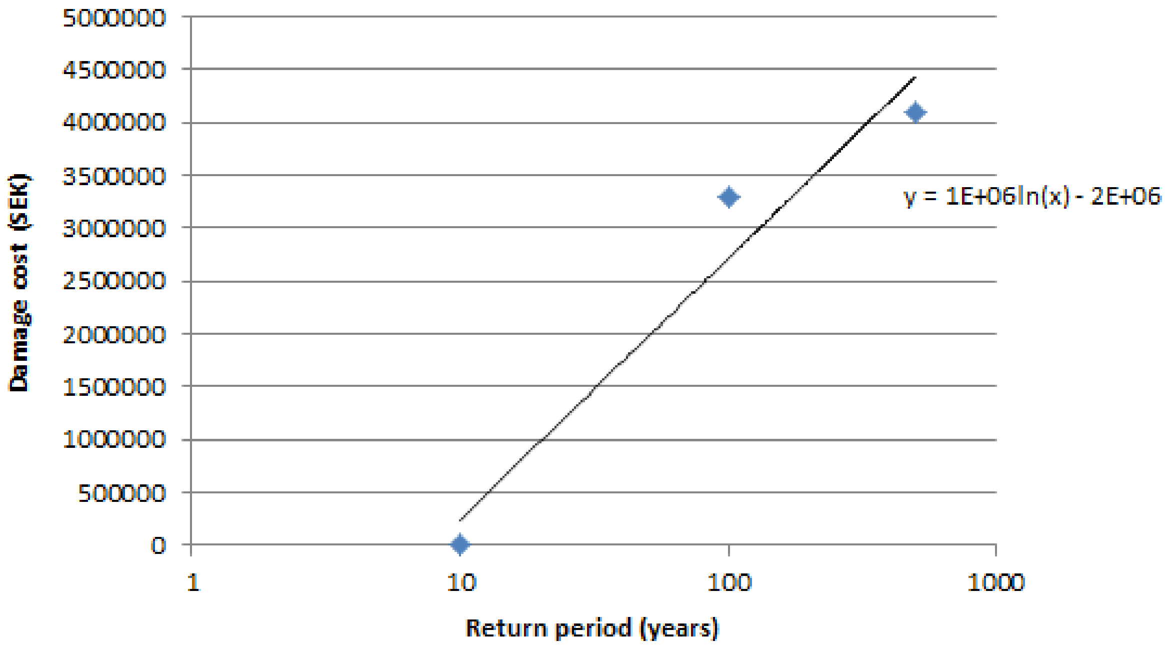

Figure 11: Log-linear relationship between damage cost and return period when defined a drainage capacity of 10 years.