CHALMERS
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Design of Bioretention Planters for Stormwater Flow Control and Removal of Toxic Metals and Organic Contaminants

Challenge Lab 2015 Sustainable Urban Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

In this project a bioretention planter (BP) that retain stormwater and reduce nickel (Ni), copper (Cu), zinc (Zn) and polycyclic aromatic hydrocarbons (PAHs) is designed for use in Gothenburg. Initially the research question was defined following the Challenge Lab process. As the maximum capacity is reached at the wastewater treatment plant (WWTP) in Gothenburg, stormwater has to be bypassed the treatment plant at heavy rains, and sustainable solutions to treat the stormwater closer to the source is needed. Green infrastructure, where water infiltrate in green areas, was identified as a solution to the stormwater over-flow pipe problems, but it gives a new environmental concerns when the contaminants accumulate in the soil. A combination of BPs and phytoremediation, a technology where plants are used to treat polluted soils, is a solution where both problems can be addressed. In addition to literature and design manuals of BPs, interviews has been carried out with stakeholders in the city. The result show that a BP with the depth of 1.5 m and surface area of 14.2 m^2 can treat a volume of 9.5 m^3 that is equivalent to water from an area of 200 m^2 with a 50 mm rain in 24 hours. Suitable plants for treatment of Cu, Ni, Zn and PAHs are *Populus deltoides x populus nigra L*. (poplar), *Salix* (willow), *Helianthus annuus* (sunflower), *Secale cereale L*. (winter rye) and *Medicago sativa* (alfalfa). If the whole planter was filled with sunflowers, 154 mg of copper could be accumulated in the plant tissue per year, but in order to remediate PAH as well some space would have to be left for other plants. The cost to treat stormwater in BPs is calculated to 3.5 SEK per cubic meter, which is cheaper than the WWTP with a cost of 5.6 SEK per cubic meter. The Challenge Lab group process also included defining sustainability criteria for nature, society, economy and well-being, and the evaluation of the BP according to these criteria show that the solution is more sustainable than most alternatives.

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1. Introduction

Cities worldwide are facing the problem of too large flows of storm- and wastewater (Phillips et al., 2012). Both the system of combined and separated pipes for storm and wastewater are problematic in some way. In combined sewer systems times of long or intensive rains cause combined sewage overflow (CSO) with sewage flooding in the cities and entering the natural waters without any treatment (Phillips et al., 2012). According to Ellis (1991) this is one of the major polluters to aquatic life. In separated pipe systems where the stormwater is lead straight into the natural waters without any treatment it is the fact that the stormwater is polluted that is of concern (Gasperi et al., 2008). The stormwater contain nutrients, toxic metals, suspended solids, petroleum hydrocarbons, PAHs and other organic pollutants, pathogens and salts (Weiss, 2008).

The problem of both sanitation and pollutants in waters are highlighted in the sustainability goals developed by the United Nations (UN) (2014) where two of the goals are to:

- Ensure availability and sustainable management of water and sanitation for all.
- Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

Out of the 17 goals developed by UN, several of them are related to the two already mentioned for example:

- Ensure healthy lives and promote well-being for all at all ages.
- Promote the ecosystems on land to reverse land degradation and stop biodiversity loss.
- Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- Take action of climate change now.

Water and sanitation is strongly connected to climate change since the climate determines when and where it rains, which is strongly linked to freshwater availability and sanitation. Rockström (2009) points out that the planetary boundary for climate change has already been passed together with the biodiversity loss. United Nations (2014) acknowledge that the ongoing mitigation of climate change is slow compared to what is needed to reach the 2 degree target, so many places can expect more intensive and higher amounts or rainfall that has to be controlled in the cities.

Urbanization is another factor that increase the pressure on the current waste- and stormwater systems and will be a challenge for the future. Today 54% of the world population lives in cities and in 2050 it is expected to be 66% (UN, 2012), meaning not only greater quantities of sewage in the city, but also larger areas of impermeable area creating more stormwater runoff.

During the last decades local solutions to handle stormwater have increased in popularity. By increasing the green areas in the city more water is infiltrated in the soil and taken up by plants reducing the need for pipes. Green infrastructure (GI), Low Impact Development (LID) or Best Management practices (as it also can be called), can add value by its appearance and contribute to landscape diversity (PGC, 2007). It can also increase biodiversity in the urban environment by being a habitat for wildlife. It is therefore a good example of how the solution of stormwater also address other of the UN sustainable development goals like biodiversity and human wellbeing.

The sustainability issues are connected, complicated and complex. In order to give students tools to work with these issues Challenge lab was developed by Chalmers University. Students gain leadership skills and use the backcasting methodology to identify leverage points in the system and create solutions. Backcasting means that a desirable future is defined and thereafter policies and programs that will connect the future to the present are identified in a backward process. In challenge lab it is recognized that problems cannot be solved by themselves but there have to be an integrated solution.

To disconnect the stormwater from the pipe system and use green infrastructure have many benefits, but the problem with the contaminants in the stormwater from urban areas remain. If the stormwater is infiltrated without control there is a possibility to degrade the quality of the soil progressively (Weiss, 2008). Soil and water contaminated with metals and organic pollutants pose a major environmental and human health problem that is still in need of an effective and affordable technological solution (Raskin et al., 1997). Contaminated soil is usually treated by expensive physical and chemical methods but there is interest in identifying low-cost, mild, green technologies. Phytoremediation is an opportunity with great potential to remediate organic and inorganic contaminants (Lasat 2002; Ernst 2005).

With help of the methodology and tools of Challenge lab the potential solution of combining phytoremediation technique, for soil treatment, with bioretention planters, for stormwater control, was identified. It is recognized to be only a small part of the solution but as the motto for challenge lab is:

“Think big, start small, act now” (Andersson, 2015)

1.1. Aim and objectives

The overall aim of this project is to suggest a design of a bioretention planter (BP) that control water flow and treat toxic metals and organic pollutants in stormwater, but also to reflect over the possibilities to implement these planters in the urban area of Gothenburg. The work should be done with the tools learned, and evaluated according to the criteria set up within Challenge lab.

Within the overall aim, there are some objectives defined to:

1. Study BPs for treatment control of toxic metals like zinc (Zn), copper (Cu), and nickel (Ni), and the organic pollutants polycyclic aromatic hydrocarbons (PAHs) in stormwater.
2. Investigate which plant species are suitable to cultivate in BPs in Gothenburg, i.e. Phytoremediation plants, suitable for this climate.
3. Estimate how BPs in Gothenburg can contribute to lower the stormwater flows to the wastewater treatment plant.
4. Evaluate BPs sustainable feasibility using the Challenge Lab criteria for nature, society, economy and well-being.
5. Suggest recommendations of further research.

1.2. Scope and Limitations

The study will only be performed during a limited time, February to June 2015. Due to time restraints, the outcome of the project will stay on a design sketch and analysis, not under production. There will not be laboratory analysis, and the study is based on literature and stakeholders feedbacks.

Due to restrictions in time, this study will focus on punctual flooding areas in the city and near surroundings, a treatment method for toxic metals and organic pollutants will be suggested but not developed further, nor a method for retention of stormwater. In addition, the system will be design under Challenge Lab criteria as an aggregate value for the city´s development.

The focus in the thesis is on retaining and treating stormwater with bioretention planters. Snow or wastewater will not be discussed. The planters will be designed for a ten year rainfall event. The design of the system will be limited to the BPs and no details will be provided about other infrastructure such as pavement designs, pipe distribution, water channel design, etc. The focus will be on the BPs and there will be no details about prior treatment methods as green roofs, permeable paving, and stone fillings nor post treatment methods as swales, creeks, canals, and discharge to the river.

Due to time restriction not all contaminants can be studied. The focus in this report are on nickel (Ni), copper (Cu) and zinc (Zn) and they are chosen because of their toxicity to biological systems and their high presence in stormwater (Chandra, 2009). PAHs was considered as one of the most important organic pollutant to study because of its carcinogenic properties and frequent occurrence in stormwater from roads (Björklund, 2011).

1.3. Outline of the thesis

The first part of the report Chapter 2 describe the Challenge Lab. After an introduction of the concept a description of “the change agent, the structure of the challenge lab is provided. The heading 2.4 Perspectives for sustainable transitions present the tools and methods used in the Challenge Lab. Heading 2.5 The procedure explains the sustainability criteria, used to evaluate the BPs in the analyses, and how they were developed. The heading 2.6 Formulation of Research Question is about how the research question was identified.

The second part of the report (Chapter 3 Bioretention planter and onwards) focus on the bioretention planters. It starts with an introduction to the problem and is followed by the theory of the BP in heading 3.1 and phytoremediation in heading 3.4. The methodology is explained in Chapter 4 Design of a bioretention planter prototype and is followed by results in Chapter 5. The justification and explanation of the result are described in Chapter 6 Analysis of the results and recommendations, together with the evaluation of BPs according to the challenge lab criteria. The report ends with conclusion and further work in Chapter 7.

2. Challenge Lab

Challenge Lab is a new arena instituted by John Holmberg, vice-president of Chalmers. The initiative is inspired by Chalmers vision “Chalmers for a sustainable future”, and is a place where students work with not only universities but also collaborating partners, funding agencies and other organizations to embrace collaborative and transformative actions on world challenges (Holmberg, 2014). The collaborative involvement of academia, industry and government is called the triple helix model (See Figure 1) (Leydesdorff & Etzkowitz, 1996).

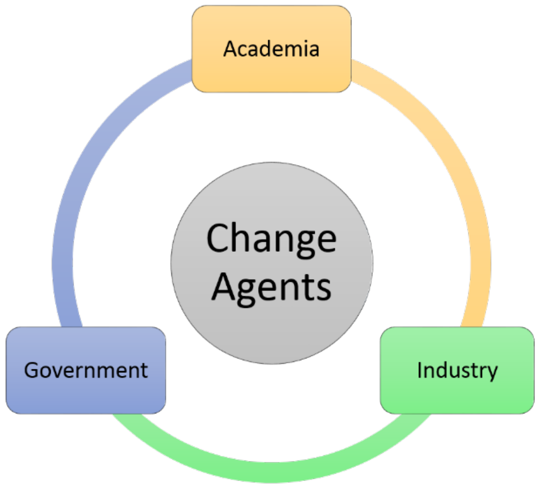

Figure 1 Triple helix model

The society stands in front of difficult challenges such as resource shortages, water scarcity and land use, but they can be addressed with collaboration between organizations and countries (Senge 2015). In the Challenge Lab interaction and participation between different sectors can increase. It is meant to be a place where trust is built and where students gain the necessary skills to address the most complex global challenges that will transform the way we live together on the earth.

In Challenge Lab, master thesis students will start the needed transformation on how we interact with the planet. The common ground for 2015 thesis is Sustainable Urban Development and the students will choose specific thesis topics and research questions within this area.

2.1. The change agent

The MSc. students in the Challenge Lab are called "change agents" and 2015 there are 13 students with different backgrounds, diverse in terms of studies and culture. The students are prepared to be facilitators of change in complex systems to address global challenges. Senge (2015) call these persons systems leaders and argue that there is a need of them to handle the coming challenges:

“Ineffective leaders try to make change happen. System leaders focus on creating the conditions that can produce change and make it be self-sustaining” (Senge 2015).

By bringing together different actors in society for co-creation and to challenge existing believes, the students can create the right conditions for a sustainable transition. To accomplish that transition, student's leadership skills are enhanced during a preparatory module called "Leadership for Sustainability Transitions" and by adding a research focus according to their background perspectives (see Table 5). Change agents must open their perspectives in order to build trust within the group, this is important since the students have different backgrounds in terms of education as well as culture and country (Holmberg 2014).

The Challenge Lab work multidisciplinary to create as big impact in the society as possible. Students are chosen to become change agents under the belief that they have the ability to "go beyond", act from a neutral position in society, and be open minded (Holmberg 2014).

2.2. Overall C-Lab organization

The Challenge Lab organization is being headed by the examiner, project leader and project coordinator. Spring 2015 is the second academic semester for the Challenge Lab, and in the team there are 13 change agents (13 master students) doing their master thesis focused within the principles and objectives of the Challenge Lab (See Figure 2).

Figure 2 Challenge Lab organization structure

2.3. Structure of the C-Lab thesis

Challenge Lab thesis is a new and different way to carry out a master's thesis in Chalmers. The traditional Chalmers master's thesis is performed in one of two cases: it can be connected to one department/professor or to a company. In the latter case, there is a supervisor in the company and an examiner at Chalmers. In either cases, the thesis objectives or research question are linked to an existing or newly design project by different interests. Challenge Lab thesis structure is open to students perspectives and driven by their exploration.

Challenge Lab is divided in two phases. (Holmberg 2014)

Phase 1, where the students work together to establish a common vision and understanding of the current world's trends. During this phase the students also identify their own interest and search for leverage points to intervene in the system. Phase 1 is crucial because of the effort put into finding a highly relevant and thought research question.

Phase 2, is the part where the identified specific topics are in focus and the students take action and initiate solutions.

Central in Challenge lab, and specifically in Phase 1, is the backcasting process. Backcasting is a tool that frees the mind from the current trends by visioning the future, it will be described more into detail in the heading Backcasting part of chapter 2.4.

2.4. Perspectives for sustainable transitions

A system perspective is meant to be holistic thinking and a learning approach to coping with issues, stemming from complex and dynamic societal systems (Hjorth & Bagheri, 2006). For this thesis purpose, a perspective is an open wide point of view, perceived in two ways, from, and to the users, with the objective to solve difficult dynamic issues on society.

Conventional scientific thinking is fragmented and rather mechanistic, cannot solve the current global issues, e.g. sustainability (Hjorth & Bagheri, 2006). The traditional way of thinking tries to solve the problems by splitting them into several parts, then studies those single parts and finally intend to give a common conclusion. However, global challenges are very complex to address in that way.

Challenge Lab is based on two perspectives for sustainable transitions. The Outside-In perspective makes the students understand the system and the context of sustainability in the society. In the Inside-Out perspective the students are guided to understand their own values and strengths to be able to interact with others. To create change agents a personal drive, engagement and interest in the topic is needed and this is taken into account in the inside out perspective. Senge (2015) points out that in successful examples of transitions there is an understanding that the inner and outer dimensions are connected.

Outside-In perspective

The outside in perspective is the information and experience we get from an external point of view. The methods and concepts bring new ways to see and understand the present challenges. Methods like backcasting, systems thinking, design thinking, the funnel, and compass were introduced during the sustainable leadership course and used in the first phase. In this section the methods we have used the most, backcasting and the compass, will be described more (Holmberg 1998).

Backcasting

Forecasting aims to reveal the future by studying the past and extrapolate the trends into the future (Robinson, 1990) but when the trends are part of the problem another method is needed (Holmberg and Robèrt 2000). Backcasting focus on how to attain a desirable future by setting up a vision (Robinson, 1990). It is important to look at the future before assessing the present state (Stewart 1993)

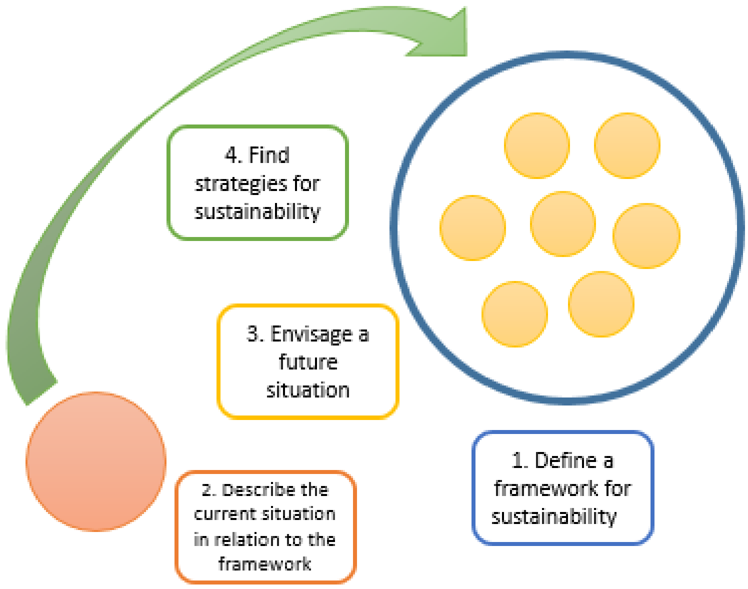

Figure 3 Backcasting methodology

Backcasting is a suitable method when the problem is complex, the scope is wide and the time horizon is long (Holmberg and Robèrt 2000). This is the case with sustainability issues and backcasting is therefore a suitable method (Dreborg 1996). Several big companies have used the method to work successfully with sustainability, some examples are Ikea, Electrolux, and Ica, (Holmberg 1998). It has also been applied by regions like "Västra Götalands Regionen" who used it for their traffic strategy (Västra Götalands regionen, 2013).

With backcasting it is possible to find parts of the system that needs change and identify leverage point. Another advantage with backcasting is that the future is envisioned but expresses in terms of actionable concepts (Stewart, 1993).

Holmberg (1998) describes four steps of backcasting (See Figure 3) that will be described below.

A. Defining a framework for sustainability

The first step is to define criteria for a sustainable future. The criteria are set unrelated to possibilities of today and focus solely on the desired state (Holmberg 1998). A framework of criteria gives indications to what is possible in the sustainable future. It is important to keep the criteria on a general level and not go into specific solutions at this point (Holmberg and Robèrt 2000). Robinson (1990) defined criteria that have developed over the years (Holmberg 1998). The criteria states that in a sustainable society nature is not subject to increasing concentrations of substances extracted from earth’s crust or produced by society. Nor is nature impoverished or manipulated ecosystems. The fourth criteria states that the resources are used fairly and efficient to meet human needs everywhere (Holmberg and Robèrt, 2000). The criteria are highly relevant but should be seen as guidance and base for discussion (Homberg 1998). It is important that the participants of a backcasting process have the same vision, understanding and a common intention so everyone should be included in the process of defining criteria (Scharmer 2009).

B. Describing the current situation

The second step is to map and describe the current activities and trends. The ongoing activities are compared to the criteria from the first step to see if they are within the sustainability criteria. This step helps understanding what parts of the present situation are sustainable and what needs to be adjusted to be within the criteria. (Holmberg, 1998)

C. Envisioning and discussing the future

In the third step future possibilities are understood better by a deeper comparison between the current situation and the sustainability criteria from step 1 (Holmberg, 1998). The role of the organization in a sustainable future is envisioned. Reflection over the values the organization create can open the mind and help finding other solutions than the current products, business models and methods (Holmberg, 2014).

D. Strategies for sustainability

The fourth step is to develop strategies that lead from the current situation to a sustainable future (Holmberg, 1998). One way to do this is to think through decisions to make sure that they will; lead closer to a sustainable situation, lead to a flexible point where alternatives still are open, the investment will pay off soon enough and help the society to change fast enough without too much losses. All of them have to be fulfilled for it to be a good decision as it is equally important to consider all three parts of sustainability; nature, social and economic (Holmberg, 1998).

The sustainability compass

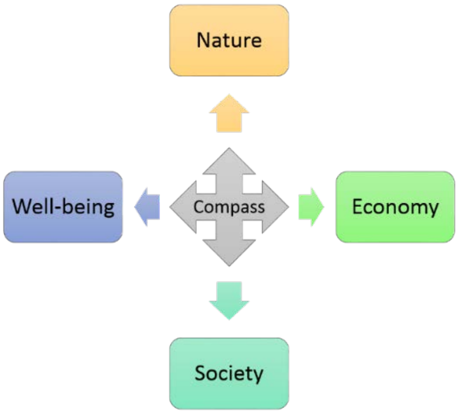

Figure 4 Sustainability compass

The sustainability compass (See Figure 4) was developed by Atkisson (2010) as a tool to work with sustainability. In the sustainability compass the cardinals have been replaced with perspectives of sustainability; north is replaced with Nature, Economy is instead of east, Society instead of south and west is replaced with wellbeing.

The different perspectives came from Daly's triangle see Figure 5, but the compass was seen as a better symbol since different cultures have different priority to what is ultimate ends and intermediate means. The compass can work as a framework for sustainability indicators to make sure all perspectives are covered (Atkisson, 2010).

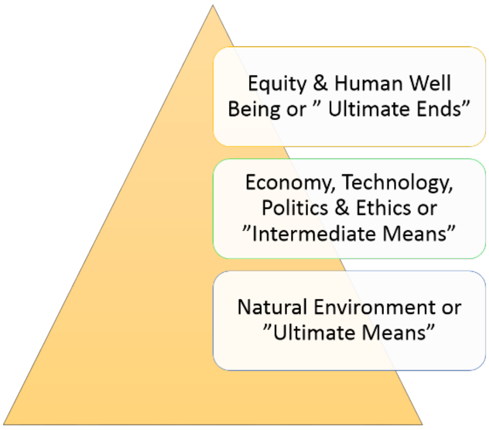

Figure 5 Daly's triangle

Inside-Out perspective

Research shows that motivation comes from three things; competence, autonomy and relatedness. Competence means that the person have the capability and the knowledge to do a task. Equally important is to feel that the task is determined by oneself and to have the support from others (Ryan and Deci, 2000).

To create motivated change agents Challenge Lab supports all three parts. The students have the competences from their master's programs, and get supervision from researchers in the relevant fields. Exercises to highlight the student's different strengths are also included in the first phase of challenge lab.

The next step; support and relatedness, comes from being a group of students working together in a defined context and at the same location Kuggen, Lindholmen. The students are trained in dialogue to create a good environment between them but also to use in contact with stakeholders.

The last part to motivate the students is to create autonomy. In challenge lab it is done by giving the students the freedom to choose the topic and the research question that engage them. Exercises that reveals the participants values are part of phase 1 and helps to find a relevant topic. The next sections will describe the theory and practice in challenge lab of self-leadership and dialogue.

Self-leadership – value and strengths workshop

Collaboration between organizations and countries are needed when addressing big and complex challenges. A system leader can enable collective leadership and collaboration. The system leaders are characterized by their ability to see the bigger picture, they foster reflection and conversation and they co-create the future instead of seeing the problems. The systems leaders have an open heart, mind and will and they create places for truth, listening and reflection. (Senge, 2015)

In order to open their heart and minds the students took part of a self-leadership workshop where their strengths and values were highlighted. Prior to the workshop the students prepared by doing online questionnaires where they should prioritize between statements.

The online value exercise resulted in a “meaning map” where the prioritized values were put into the categories of foundation, focus and vision. The students then had to find patterns and similarities between the three categories.

One of the exercises in the workshop was to identify strengths in the other students. In small groups each student should explain 3 strengths about all the others. Then the individual explained and gave examples of strengths they identified themselves. Kaplan and Kaiser (2009) report that the focus on strengths rather than on faults or weaknesses can improve a person even more. Strengths can however also be overdone, meaning that a strength done too much can have negative impact (Kaplan, and Kaiser, 2009). An exercise was done during the workshop to illustrate what happens if our individual strengths are overdone and how other strengths can balance it.

In another exercise the students should stand at different places in the room depending on the level of agreement on statements. After some statements clear patterns could be seen. This was explained by theory of four different kinds of people;

the altruistic- nurturing, the assertive-directing, the analytic-autotomizing and the flexible-cohering (Leadership Development, 2015). The idea was not only to give an understanding of each other's strengths and values but also to respect a different way of thinking and see who would be a good partner that would complement us when teaming up for the second phase of the master thesis.

By listening to each other and getting to know each other's strengths and values the trust is increased which is as important small groups as in society (Sandow and Allen, 2005)

Dialogue

Dialogue is an important tool for creating a common understanding and reaching conclusions. In a dialogue the participants listen actively to each other without interrupting. A common mistake is to think you already know what the other person is going to say. By taking the time to actually listen properly it can lead to mutual acceptance instead of conflict (Sandow and Allen, 2005).

There are four ways to act in a conversation (Isaacs 1999):

- Movers - that initiate the ideas
- Followers - that support the ideas, they mainly listen
- Opposers- Ask questions (to make sure it is correct)
- Bystanders - Look from an outside perspective to get the systems perspective

During a normal dialogue each person change between all of them. Some of them might feel more natural to certain people, but all are needed. Do not accuse the bystander to be passive or get irritated on the opposer because their input validates and improves the ideas, and the followers give support so the movers get mandate to take things into action. If a person only acts in one of the ways above the conversation tend to get stuck (Isaacs 1999).

2.5. The procedure

As mentioned before, Phase 1 followed the steps of backcasting interspersed with exercises from the inside out perspective. This section will describe the sustainability criteria and how they were created. It will be followed with a part about the global challenges connected to the trends in society and local sustainability initiatives.

Generation of sustainable criteria

The first step in the backcasting process is to create criteria for a sustainable future. With criteria it is possible to say when sustainability is achieved. It is important that the criteria are general and not solution based in this first step of backcasting. This is to make sure all possible sustainable futures are included in the frame of criteria (Holmberg, 1998).

Wellbeing, human health and happiness are, according to some, the ultimate end to strive for and nature, society and economy should be seen as means for reaching well-being (Atkisson, 2010) (See Figure 6).

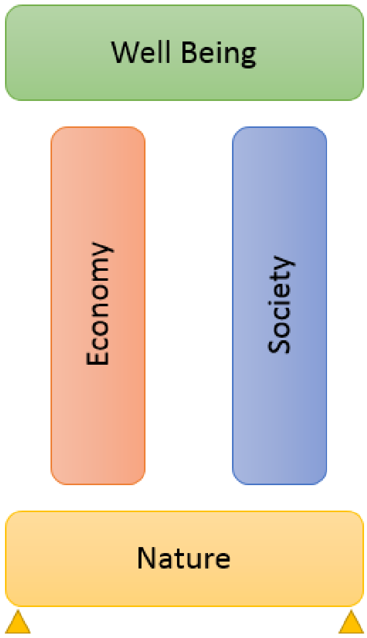

Figure 6 Pillars for sustainability

Since all four aspects from the sustainability compass are equally important, Challenge Lab created sustainability criteria for all of them. The criteria were developed by the whole group of students in an iterative process. The first step was a literature research to understand the challenges and what to aim for in society, nature, economy and wellbeing. A short presentation was held about the areas to assure everyone had the same knowledge and perception.

Based on this research discussions were carried out in groups of 3-4 persons. The groups were rotating through the areas and to make sure the knowledge of the last group was understood correctly one person stayed each round. During these discussions the major points to include in the criteria were highlighted. Formulations of criteria were done in the whole group together. This resulted in more discussions and further literature research to study formulations etc. The result was a draft that was reviewed some weeks later together with the examiner. After that the criteria were updated one last time before everyone could agree upon them. When the criteria were set the vision of last year were reviewed and accepted after some minor changes.

Sustainable development criteria

The result of the research and discussions were 13 criteria within society, environment, economy and wellbeing.

The criteria are based on existing theories and knowledge but combined and reformulated. The author references in this section should therefore be seen as a guide of where to find information rather than quotes.

Nature criteria

The inspiration to the environmental or nature criteria comes from the sustainability principles Holmberg and Robèrt (2000) presented in their paper. In a sustainable future, all activities should:

Table 1 Nature criteria

Not increase the concentration of substances from the lithosphere in the ecosphere.
Not increase concentration of human made substances in the ecosphere.
Not systematically deteriorate the resource base; such as fresh water, fertile land, and biodiversity through manipulation, mismanagement, or over-exploitation.

Economy criteria

Today the economy has huge influence on the world rather than being a mean of reaching well-being. The review of Atkisson (2010), Sen (1999), Anand and Sen (2000), Simmi and Martin (2010) and Pisano (2012) resulted in four economic criteria for a sustainable future:

Table 2 Economy criteria

The economic system enables us to meet the other criteria efficiently and effectively. The economic system should be influenced by the other dimensions (society, well-being, nature) and not the other way around.
The economic system is resilient in a way that it functions as a buffer against destructive disturbances, such as environmental catastrophes or economic mismanagement.
The economic system enable further use of resources and avoid dissipative use of materials.
The economic system has an inherent mechanism of maintaining and serving societal infrastructure and institutions that permits human well-being to be met over time.

Society criteria

To differentiate between well-being and societal criteria was at the start difficult but after studying the literature it was decided the societal criteria are about the societal institutions and how we live together. The criteria are inspired from; the human rights (UN 1948) and Open Working Group on Sustainable Development Goals (2014).

Table 3 Society criteria

Societal institutions are built on transparency, accountability, and mutual trust. They enable the well-being of the individuals in society
The societal system is an instrument for individuals to live together within the other criteria.

Wellbeing criteria

Well-being is about the individual needs and satisfactions to have a safe and happy life. The base for well-being can be found in the human rights (UN 1948). Max-Neef (1992) specified the human needs and the equality was discussed by Rawls (1971).

Table 4 Wellbeing criteria

Everyone has basic needs fulfilled such as food, water, health, energy, shelter, and safety.
Human life includes affection, understanding, morality, participation, leisure, empowerment, creation, identity, and knowledge
Each person has an equal right to the most extensive basic freedom, compatible with a similar freedom for others. This includes freedom of opinion
Economic inequalities are not justified unless they are to the benefit of the less-advantaged members of society

The vision

"A sustainable future where we (~10 billion) people are able to meet our own needs within the planetary boundaries without compromising the ability of our future generations to meet theirs"

Global challenges – trends

The second step of backcasting is to study the present situation in relation to the criteria (Holmberg, 1998). The global trends are many but in this chapter some of them will be presented.

The world population has been rising fast, and even if the growth rate in Europe and America and have stabilized it is still high in most parts of Asia and Africa. The expectation is that the trend will flatten off at 10 billion people around 2050 (UN 2012)

A current trend that goes in line with the sustainability criteria are the global increasing health and life expectancy (OECD 2005). As many diseases are coupled to clean water and sanitation (Prüss-Ustün et al. 2014) water and wastewater infrastructure and technology is an important part of this trend.

Urbanization is a global trend that can be seen in Sweden as well (United Nations, 2014). 54% of the world population lived in cities 2014, and this number is expected to increase to 66% in 2050.

Ongoing projects in Gothenburg Sweden

Challenge Lab work for transition in the society and the best place to start is local. By focusing on a specific place concrete examples both of problems and solutions can be highlighted. Gothenburg is chosen because it is the city Challenge Lab is located in and the proximity is an advantage.

In the first phase several stakeholders were invited to Challenge Lab to describe ongoing project at Chalmers and in the city/region. The idea is to get inspiration and possibly connect to an ongoing local project. To work together with an ongoing project increases the potential of action as there are already stakeholders in the society interested in the topic. The idea is not to work for a project but rather evaluate them according to the sustainability criteria or try to influence them in the right direction.

District Factor 10

Leonardo Rosado, researcher on Chalmers in built environment and urban metabolism analyses, introduced the project Johanneberg District Factor 10 (Chalmers, 2014). The goal is that the district will reduce its climate impact with a factor 10. In order to do this many things are needed. One part of the project was to evaluate how well rain gardens handle stormwater in terms of decreasing climate impact and increasing wellbeing with a greener environment.

HSB – Living Lab

HSB Living Lab is a test arena where new ways to build and shape the future of housing will be developed. Shea Hagy, Living Lab project leader and Larry Toups, associate professor from NASA, explained the inputs and outputs of this housing project located on Chalmers. The building construction started by the end of March 2015, and has the objective to be more than a house, it is a living laboratory where research can be conducted in ways it never did before.

HSB Living Lab initiative is the perfect example of how the Triple Helix approach can be operate, an innovative blend between HSB Group, Chalmers University of Technology and Gothenburg city.

Chalmers Sustainable Campus

Chalmers is working towards a sustainable campus and are open to try new environmental solutions. Anna Ekerstig from Chalmers Fastigheter (housing company), Jennika Källstrand environmental manager at Chalmers, Magnus Wennegren environmental coordinator, Ulf Östermark from the area of advance energy and the Johanneberg science park and Alf-Erik Almstedt, vice president and responsible for the campus development visited Challenge Lab. The different parts presented their perspective and part in developing a sustainable campus. The students were invited to come with initiatives and projects that could be tested on the campus.

2.6. Formulation of Research Question

Discovering the research area

Discovering the research area was a process conducted by John Holmberg in order to select on which scientific area the students would work on the next step of the thesis (Phase 2). Students were gathered with the objective of converging all the information acquired during the first phase. The development of the different perspectives, comprehension of the sustainable criteria and personal interest were all taken into account. Two crucial decisions were made during this process, the research area and the thesis pairs.

The exercise started with the selection of one of five big areas such as energy, built environment, water, participation, open innovation. The selection of the area was inspired on the different professional backgrounds and personal profiles and also if the students had common interests according to their experience, academic studies, personal and future development on the chosen area.

The research area selected is “Water”, most specific Stormwater treatment. This thesis is been held by Andres Cuaran and Linnea Lundberg. Information about their backgrounds is on Table 5.

Table 5 Change agents (Authors) backgrounds and interests

Change Agent	Background
Andres Cuaran	Bachelor in Civil Engineering with emphasis on Hydraulics and Water Sanitation. Master in Infrastructure and Environmental Engineering focused on sustainability management and stormwater treatment. As personal interest, water subject is also abroad from the political point of view, based on regulation, water as a fundamental need and develop wellbeing.
Linnea Lundberg	Bachelor in Energy and Environmental Management. Master in Water and Environmental Management. My motivation comes from protection and preservation of the habitats and biodiversity in the fresh and marine waters but also to support all humans’ basic needs and well-being.

Development of our research question

With our interest for water the rain garden concept mentioned during the District Factor 10 presentation caught our attention and we booked meetings with Leonardo Rosado and Greg Morrison.

The project was developed by Greg Morrison and Sebastien Rauch at Chalmers, they have the idea that the stormwater can treated onsite. They plan a project to model the quantity, quality of the flow, but also to include, socioeconomic and biodiversity models.

The idea that green areas could solve more than one problem at the time is attractive as it will reach several of the sustainability criteria at the same time. We imagined a pond, cleaning the water, with green areas around it, used for leisure, play, recreation of humans but also for breeding and living for plants and animal. To find out more about how such a pond could work, Ann-Margret Strömvall, an expert in treatment ponds working at Chalmers, was contacted.

The interview with Ann-Margret was a turning point as she described treatment ponds as too contaminated and hazardous for both nature and humans. Instead of creating wellbeing such a pond could decrease the wellbeing and contradict the environmental criteria by concentration substances into the biosphere (Nature criteria). The idea had to be reconsidered.

After some research on local stormwater solutions (swales, ponds, rain gardens etc.) a conclusion could be drawn; none of them followed the first or second environmental criteria. Local solutions are based on the idea that the water is treated locally instead of flowing through a pipe system to a wastewater treatment plant (or direct out to open waters). Many of these solutions imitate the natural treatment by using infiltration in the soil. Whereas the water is cleaned when filtered through the soil the pollutants stay in the soil. By looking from a systems perspective including the whole system instead of just water there is no gain, the problem has just been shifted from polluted water to polluted soil instead.

With a vision of leaving the planet for future generation, it is easy to see that a whole city with contaminated soil does not fulfill the vision. A wider perspective is needed that take both the water and the contaminants in the soil into consideration. This is what our master's thesis will be focusing on. How to clean the water locally in the city without increasing levels of contaminants in the soil.

Our research inspiration

As a special and very motivational experience, this part we will dedicated to a special place located in Chalmers Student Union; the Chalmers pool.

Since the two of us loves water, a natural place to meet were the swimming pool in the Chalmers student union building. There, exercise, and work was combined with getting to know each other better. It was during the process of developing a research question and the pool worked as inspiration. The pool has illustrated a local pond, the curb on the streets full of waters etc. It was in conjunction with a session in the pool we realized that we need to have a holistic perspective and focus not only on the water but to see the whole picture to avoid problems shifting.

3. Bioretention planter

3.1. Background of the problem

Gothenburg is the second largest city in Sweden with 537 000 inhabitants in 2014 (SCB, 2014), and the ambition is to grow with 100 000 more inhabitants in the coming decades (Trafikkontoret Göteborgs stad, 2012). The rising population entails an increment of wastewater and adding that to the increasing storm periods, water quantity elevates and it is difficult to control.

The wastewater system is a collaboration between several municipalities, and the wastewater flows through pipes to the wastewater treatment plant (WWTP) Ryaverket owned by Gryaab. There are 2 478 km of different wastewater pipes in the Gothenburg region of which 882 km (35%) are stormwater pipes leading straight to open water without any treatment. There are 990 km (40%) of wastewater pipes and 397 km (16%) of combined pipes for both wastewater and stormwater (Kretslopp och Vatten Göteborgs stad, 2015). Combined pipes increase the flow to the WWTP during long or intensive rains. Around 70 days per year the incoming flow to the WWTP exceed the maximum capacity of 7 m^3/s. Higher flows will partly not be treated in all steps. Around 10 days per year the flow is so high that parts of it have to be bypassed the treatment plant and into the river without any treatment (I'ons, 2015).

The combined pipes, putting high pressure on the WWTP, are one part of the problem but it also affect the rest of the city. When the capacity of the pipes are reached there is no way for the rainwater to drain and it floods into the city areas. The flooding problem can be seen at roads (Lundskog, 2015), but it also affects the green areas when large amounts of water from impermeable areas flows into the parks when flooded, and if they are not built for that the plants can drown (Offerman, 2015).

The benefit with a separate system is less water flowing to the WWTP but it also means that the stormwater flows untreated to the lake and river systems. The stormwater flooding problems will increase over the years as the urbanization of Gothenburg (Ylander, 2015) will increase the quantity of wastewater. Climate change with more intensive rains will also cause more stormwater that needs to be treated. A new system to treat water would improve the quality of the stormwater reaching lakes and rivers and would be beneficial for the environment but also for the WWTP that becomes less pressured.

A BP could be a part of a new stormwater treatment system in Gothenburg that may solve the flood and contamination problems. If placed in an area of the city with a combined system, less rainwater will flow to the WWTP. If the BPs are placed where the pipe system is separated less untreated water would enter the lakes and rivers.

This report will investigate how a BP in Gothenburg could be designed and evaluated in accordance to the Challenge Lab criteria and the perspectives of the sustainability compass: nature, well-being, society and economy.

3.2. What is a bioretention planter?

BPs are also known as: bioretention cell, bioretention planter, above-ground planter, flow-through planter, or stormwater planter.

BPs are part of green infrastructure (GI) that also includes concepts like green roofs, swales, rain gardens and permeable surfaces. They are all designed to retain the stormwater at the source by maximizing the infiltration (Davis et al., 2003). GI aims at preserve the natural conditions and leave nature as undisturbed as possible. The popularity of local solution have increased over the years and results from GI studies are promising (Dietz, 2007).

Figure 7 Stormwater planter in the public way, Portland, Oregon (Dietz, 2007)

Bioretention require different layers of gravel, soil, mulch and plants to maximize the retention and treatment of stormwater (Davis et al., 2003). Plants fill the function of evapotranspiration, biotransformation mechanisms, keeping the soil in a good shape. The plants can vary from shrubs trees to perennials, see Figure 7 There have been doubts about the applicability of BPs in cold climates with snow and a frozen ground, but according to Dietz (2007) it works as long as they are installed and designed properly.

Filtration based planter (Flow-Through)

In a filtration-based bioretention planter, the stormwater flow through all the layers of the system, and is then collected in a pipe which transport the treated water to a disposal point. Filtration planters are used when the infiltration rate of the underlying material is slow or when the planter is too small to infiltrate all water fast enough (Cahill et al., 2011). Pollutant removal efficiency of filtration planters is high, while the volume reduction and peak flow reduction are moderate, see Figure 8.

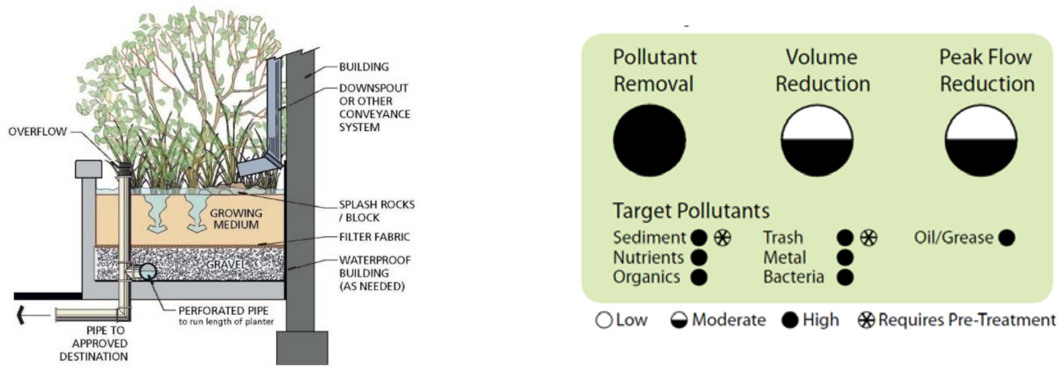

Figure 8 Flow-through planter layout and efficiency (Source: Portland Bureau of Environmental Services and San Francisco Stormwater Design Guidelines)

Infiltration based planter

In an infiltration-based planter the water flows through the layers of mulch, soil and rock in the planter and then continues to infiltrate in the underlying soil, see Figure 9. With this construction there is no need for pipes between the planter and the receiving waters as the water flows through the soil instead. It also means that there is no need for an underdrain pipe in this retention system (Cahill, 2011). The infiltration based planter have high efficiency for both volume reduction and pollutant.

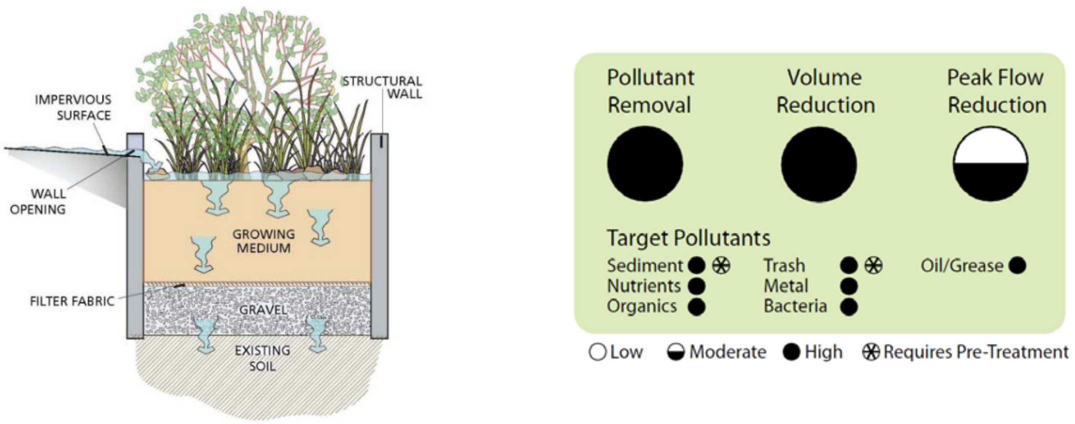

Figure 9 Infiltration based planter layout and efficiency (Source: Portland Bureau of Environmental Services and San Francisco Stormwater Design Guidelines)

The University of New Hampshire has a rain garden installed with a pea-gravel layer on top of a coarse sand layer that has been successful, and the infiltration test made on the natural soil showed an infiltration rate of more than 0.0381 meters per second that is more than the recommended rate. Figure 10 shows how it looks in the landscape.


Figure 10 New Hampshire Rain garden and infiltration test (Source: Hebert, 2013)

Location

BPs are usually small and can therefore be applied in many different contexts like parks, parking lots, courtyards, residential yards and other urban areas (CSF, 2009). The bioretention systems can be applied on the commercial, industrial and residential level (PGC, 2007).

When choosing a location for the BP the City of San Francisco (CSF, 2009) have some guidelines:

- Not to place infiltration planters too close to property (flow through suitable).
- Not too close to water wells.
- At least 90 cm above the groundwater table.
- Location with less than 5% slope.
- Not place the BP near big slopes (more than 15% gradient).
- Consider pre-treatment if it is close to heavy traffic.
- Have more than one inlet if the drainage area is more than 200 m^2.

Benefits and limitations

The benefits with BPs are many and the common benefits and limitations are presented in Table 6. The possibility to have BPs in different sizes and locations is one of the benefit that together with the easy and inexpensive installation make them suitable in many contexts. The maintenance of the vegetation is a limitation that is acceptable with the additional value of green area with habitats for wildlife and potentially increased biodiversity. Another benefit with the BPs is that they improve not only water but also air quality through dry deposition.

Table 6 Benefits and limitations of Bioretention practices

Benefits	Limitations
• Easy and inexpensive to install. • Wide range of scales and site applicability. • Reduces runoff volume where infiltration is feasible and attenuates peak flows. • Improves water quality and air quality. • Increases effective permeable surfaces in highly urbanized areas. • Creates habitat and increases biodiversity in the city. • Provides aesthetic amenity. • Facilitates groundwater recharge (infiltration-based systems only). • Facilitates evapotranspiration. • Reduced TSS (Total suspended solids). • Reduced pollutant loading. • Reduced runoff temperature. • Groundwater recharge (if soils are sufficiently permeable). • Habitat creation. • Reduced heat island effect.	• Requires relatively flat site and sufficient hydraulic head for filtration. • Vegetation requires maintenance and can look overgrown or weedy; seasonally it may appear dead.

(Source: Portland Bureau of Environmental Services and San Francisco Stormwater Design Guidelines)

3.3. Bioretention planter design

BPs are designed to drain the water in maximum 24 hours. In order to achieve this it needs to have the right infiltration rate, composition of the layers, area and volume.

Structure and Materials

The BPs are structured by several layers with different properties and functions. The top layer is usually of mulch and below are bioretention soil and gravel. The soil cover and filter media are important for the performance of the BP over time (MGNDC, 2012). The planter should have room to retain water above the top layer and this space is called the ponding area. There should also be an overflow control and flow-through planters needs an underdrain pipe. The ponding area gives room for storage of large quantities of water from storm flows; the area should drain within 24 hours. (DPDS, 2010)

Mulch

The top layer of mulch have several functions like pre-treating the runoff, limit weeds and support the plants. Other positive impacts are keeping the soil moisture and reduce compaction from heavy rains. Wood chips and chopped green waste are examples of organic mulch that also contribute with nutrient when it break down. It is however also possible and sometimes even favorable to have inorganic mulch like gravel, pebbles or decomposed granite. (MGNDC, 2012). Pea gravel have showed good result in the rain garden at the University of New Hampshire (Cahill, 2011).

Filter Media/bioretention soil

The soil layer should both filter and retain the water, and therefore it is very important that the soil have the right characteristics. According to the Metropolitan Government Nashville and Davidson County (MGNDC, 2012) it should have the composition of:

- Maximum 60% sand
- Less than 40% silt
- 5% to 10% organic matter
- Less than 20% clay

This is the plant media and the depth depends on the plants used in the bioretention planter. Tree roots needs bigger volumes than shrubs and perennials, so if trees are planted the depth needs to be bigger (MGNDC, 2012).

Gravel

Gravel at the bottom of the planter provide a layer for storage (MGNDC, 2012). The Department of Planning and Development, Seattle (2010) suggest 15–10 mm crushed rock for this layer. In a flow through layer the underdrain is placed in this layer and in that case the material also have a protective role of the drain. To avoid the soil and gravel to mix, a layer of crushed rock or a filter fabric can be applied between them (Cahill, 2011). Geotextiles can get blocked so the crushed rock are recommended. In flow-through planters the infiltration to underlying soils are stopped by an impermeable liner, usually 60 mm thick. Some literature suggested a liner of PVC but as they often contain organic pollutants, eg softening agents as phthalates, which will leach out to the surrounding environment, other materials should be considered.

Drainage pipe and overflow control

A flow-through BP needs to have a drainage pipe that transport the water to an approved discharge point. The city of Department of Planning and Development, Seattle (2010) recommend a pipe with a minimum diameter of 10 cm surrounded by aggregate reservoir material. BP also need an overflow control if the storm events are more voluminous than the planters are designed for.

3.4. Design considerations

Infiltration Rate

The infiltration rate in the BP should be 25–50 mm/h, and if the BP is an infiltrate based type, the underlying soil should have at least 13 mm/h infiltration rate (PGC, 2007). The infiltration rates presented by Natural Resources Conservation Service (2008) are found in Table 7; the rates are lower than what is required for bioretention planters, therefore to get the required infiltration different soil types are mixed.

Table 7 Soil textural classification

Texture class grouping	Infiltration rate mm-hour
Sand	20
Loamy	5 – 10
Clay	1 – 5

Sizing procedure

The size of a BP is dependent on the stormwater volume, the depth and the surface area of the planter. The stormwater treatment volume is calculated with a runoff coefficient, the catchment area and the depth (PGC, 2007). The planter size area is calculated from the treatment volume over the equivalent storage depth (MGNDC, 2012). In this section the sizing process is developed in five steps, deciding the depth of the layers, calculation equivalent storage depth, calculating runoff coefficient (Rv), volume and area.

Step 1: Selecting layer thickness

The BP have several different layers and the total depth depend on the composition, see Figure 11. The design guidelines differ slightly in the depth of the layers, as can be seen in Table 8. The total depth is however very similar with a minimum of just over a meter and a maximum around one and a half meter (MGNDC, 2012; PGC, 2007; DPDS, 2010).

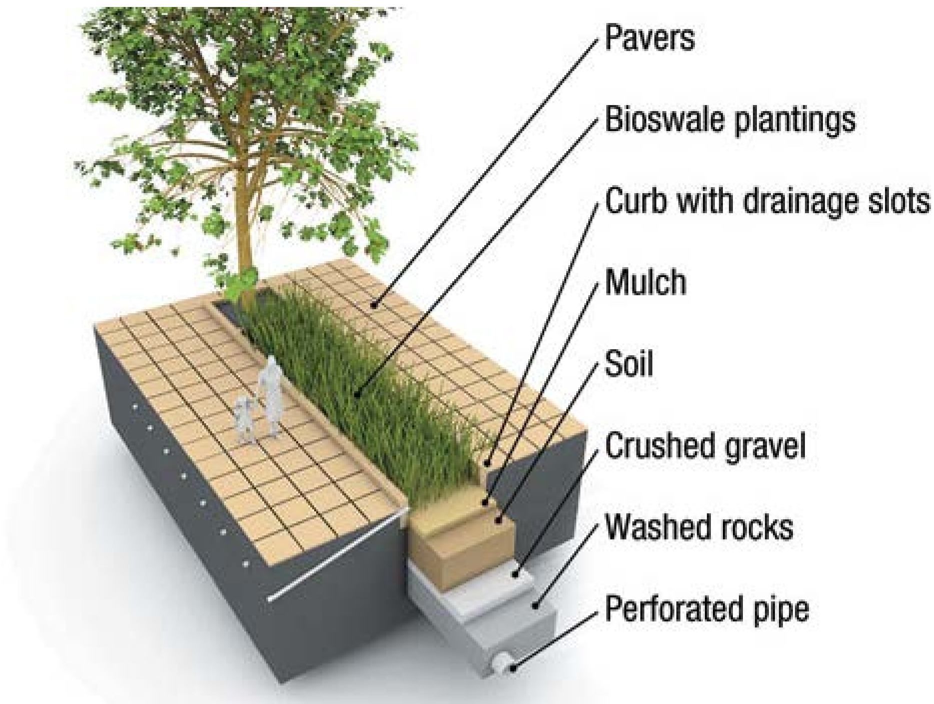

Figure 11 Bioretention planter layers (Source: Mithum Architects, 2015)

Table 8 Diverse layer thickness for bioretention manuals

Layer	The Prince George's County 2007	Metropolitan Government Nashville and Davidson County 2012	Department of Planning and Development, Seattle 2010
Ponding depth	30 cm	15 cm	30 cm
Mulch	7-10 cm	-	5-7 cm
Bioretention soil/ planting soil bed/ filter media	76-122 cm	76-122 cm	46 cm
Gravel	-	15 cm	30 cm
Sum	113 -162 cm	106-152 cm	111-113 cm

Step 2: Equivalent Storage Depth

When the different depth of the media are decided the equivalent storage depth can be calculated by adding the depth of each media times the void ratio for the media, see Equation 1 (MGNDC, 2012). The porosity for each layer has to be included since it is a difference of how much water that can be stored in sand compared to gravel.

Equation 1 Bioretention Equivalent Storage Depth

$$D_e = n_1 * d_1 + n_2 * d_2 + n_3 * d_3 + \cdots$$

Where:

n_1 and d_1 are for the first layer, etc…

n is the porosity

d is the depth of the layer

The porosities (n) for different media can be seen in Table 9 (MGNDC, 2012):

Table 9 Porosities recommended for bioretention planters

Ponding	n= 1.0
Bioretention Soil Media porosities	n = 0.40 (sandy loam, loamy sand, or loam)
Gravel	n = 0.40

Example. The equivalent storage depth for an urban bioretention facility in Nashville with a 15 cm ponding depth, a 76 cm media depth, and a 15 cm gravel layer is therefore computed as:

$$D_e = (1 * 0.15m) + (0.40 * 0.76m) + (0.40 * 0.15m) = 0.514m$$

Step 3: Runoff coefficient RV

The runoff coefficient (Rv) takes into account the composition of the catchment area to compensate for the amounts of permeable and impermeable parts (PGC, 2007). The runoff coefficients can be found in Table 10, so for example if the whole area is impervious Rv = 0.95 (Metropolitan Government Nashville and Davidson County 2012).

Table 10 Site cover runoff coefficients

Soil condition	Volumetric Runoff Coefficient (Rv)			
Impervious cover	0.95			
Hydrologic soil group	A	B	C	D
Forest cover	0.02	0.03	0.04	0.05
Turf	0.15	0.18	0.20	0.23

Note: Hydrologic soil group data are based in the following factors: intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet), soil not frozen, bare soil surface, maximum swelling of expansive clays. (United States Department of Agriculture 2007).

If the area has forest cover or turf there is a need to know the hydrological soil group at the site to be able to find the right value for Rv. In case this information is not available the Equation 2 can be used. It is simpler and do not take the different soil types into account and focuses on the percent of the area that is impermeable (PGC, 2007).

Equation 2 Runoff coefficient (simple)

$$R_{vs} = 0.05 + 0.009\ (I)$$

Where:

I= Percent of total area that is impermeable (%)

If the information about forest cover or turf is available, the runoff coefficient is calculated as a weighted calculation, taking into account the particular runoff coefficients of different soils, see Equation 3 and Table 12.

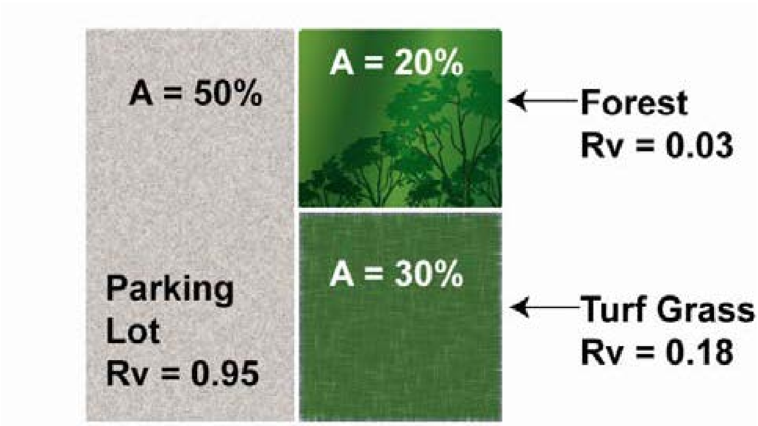

Figure 12 Example of runoff coefficients for different land uses

Equation 3 Weighted Runoff coefficient Rvw

$$R_{vw} = \frac{[(R_{v1} * A_1) + (R_{v2} * A_2) + \cdots]}{(A_1 + A_2 + \cdots)}$$

Example

Assuming the 100% of the area is impervious, the runoff coefficient is:

$$R_{vs} = 0.05 + 0.009\ (100) = 0.95$$

Step 4: Calculating the Treatment Volume T_v

The total storage volume, water quality volume or treatment volume as it also can be called are calculated from the precipitation and the impermeable drainage area (PGC, 2007). The formula to calculate the volume can be seen below:

Equation 4 Treatment volume

$$T_v = (P)(R_v)(A)$$

Where:

T_v = the required treatment volume (Cubic meters)
P= precipitation at the location (meters/day)
A = the contributing drainage area (Square meters)
R_v = runoff coefficient (Rv simple or weighted)

Assuming an impervious cover the runoff coefficient is 0.95, no maintenance, 25.4 mm precipitation and a maximum contributing area of 200m² (square meters) for one planter cell, the treatment volume is computed using Equation 4:

$$T_v = (0.0254m)(0.95)(200m^2) = 4.83\ m^3$$

Step 5: Sizing Area

The required surface area of the BP is calculated by dividing the Treatment Volume by the Equivalent Storage Depth as can be seen in Equation 5 (MGNDC, 2012).

Equation 5 Surface area of the bioretention planter

$$SA = \frac{T_v}{D_e}$$

Where:

SA = the surface area of the urban bioretention facility (in square meters)
D_e = Equivalent storage depth (in meters)
T_v = the required treatment volume (in cubic meters)

Example

Using the values for the Equivalent depth and Treatment volume examples, the Surface area is:

$$SA = \frac{4.83\ m^3}{0.514\ m} = 9.4\ m^2$$

Phytoremediation

The term Phytoremediation consists of the Greek prefix φυτο (phyto) meaning "plant", and Latin root (remedium), meaning "to correct or remove an evil" (Cunningham et al., 1996). Phytoremediation is defined as a technology using plants to clean up contaminated soils to improve the environment quality (Tangahu et al., 2011). For the thesis research, phytoremediation consists of mitigating toxic metals and organic pollutants in soils with contaminated water, with plants which are able to contain, degrade, or eliminate the contaminants (Hinchman et al., 1996).

Application

It is not possible to say at what point in history the idea that plants can remove pollutants were initiated, but recent scientific research are turning it into a promising remediation technology (Raskin et al., 1997). The technology has increased in popularity over the last two decades and there are today several successful projects. Phytoremediation is a treatment method done “on site” and can be used at previous contaminated sites or where the contamination is ongoing. The use of plants make the technology slow but solar driven and environmentally friendly (Erakhrumen, 2007).

Plants are unique and have processes to selectively take up, transport and store nutrients and pollutants (UNEP, 2015). Some plants are called hyper accumulators because of their capacity to concentrate pollutants in their tissue (Raskin et al., 1994). Plants especially trees, can also take up large amounts of water a useful feature for hydraulic control (UNEP, 2015).

Benefits and limitations of phytoremediation

There are numerous benefits and limitations with the use of phytoremediation and Table 11 show a general list of them with the most important benefit of treatment on site being cost effective but the limitation of taking long time.

Phytoremediation also has several benefits compared with other engineering technologies. In Appendix I Comparison between other remediation techniques to phytoremediation other remediation techniques are compared to phytoremediation. .

Table 11 Benefits and limitations of phytoremediation

Benefits	Limitations
• The cost of the phytoremediation is lower than that of traditional processes both ***in situ*** and ***ex situ***. • Does not require expensive equipment or highly specialized personnel. • The plants can be easily monitored. • The possibility of the recovery and reuse of valuable metals (by companies specializing in "phytomining"). • It is potentially the least harmful method because it uses naturally occurring organisms and preserves the environment in a more natural state.	• Phytoremediation is limited to the surface area and depth occupied by the roots. • Slow growth and low biomass require a long-term commitment. • With plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the groundwater (without the complete removal of the contaminated ground, which in itself does not resolve the problem of contamination). • The survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil.

Phytomining

The contaminants accumulated in the plants can be separated by harvesting, drying, ashing or composting (Singh, 2005). Metals can be separated from the ash and recycled at the same time the amounts of hazardous waste is lowered (Karlfeldt Fedje, 2010; Raskin, 1997)

Pollutants

Pollutants that are found in stormwater are nitrogen, phosphorous, suspended solids, BOD, COD, acids, PAH, petroleum hydrocarbons and metals and a long list of different organic pollutants (Björklund 2011; Eriksson et al., 2007). In this study PAH and Cu, Ni and Zn will be investigated further.

Toxic metals

Heavy metals are elements with metallic properties and an atomic number higher than 20. They are of concern because of their toxicity and accumulation in the environment. In this report copper (Cu), zinc (Zn) and nickel (Ni) will be studied because of their environmental concern and high concentrations in stormwater. Nickel is also on the European commission list of priority substances (European commission, 2008).

Organic contaminants

A study showed that 600 specific pollutants had been found in runoff worldwide and many of them are different organic pollutants (Eriksson et al., 2007). This report will focus on the organic group polycyclic aromatic hydrocarbons (PAHs) due to its persistence in the environment (Huang, 2004). PAHs are on the EU list of priority substances (European commission, 2008).

PAHs are stable compounds with poor solubility and strong affinity to soil particles, they are also persistent to degradation by microorganisms which make them accumulate in the soil (Ouvrard, 2013). This is problematic when some of the PAHs are carcinogenic, mutagenic and teratogenic (Boström et al, 2002). PAHs are formed in incomplete combustion of organic compounds and common sources are creosote, petroleum and coke products (Huang, 2004). PAH are widely spread and are found in high levels on industrial sites and near roads (Ouvrard, 2013).

Phytoremediation processes

Phytoremediation is a method were plants are used to clean soil or water from contaminants, but there are several different processes on how this can be done. The processes are able to handle different contaminants; some of the processes take place in the soil and others in the plant or atmosphere. A list of the types of contaminants the processes can treat and in which medium they work in can be seen in Table 12 (The ITRCPT, 2009)

The different categories are shortly described below (Chandra et al., 2009), and their plant location can be seen in Figure 13.

Table 12 Phytoremediation processes and contaminants treated

Process	Medium	Organic	Inorganic contaminants
Phytovolatilization	Atmosphere	X	X
Phytodegradation	Plant	X	
Phytoextraction/ Phytoaccumulation	Plant		X
Rhizofiltration	Soil	X	X
Rhizodegradation	Soil	X	
Phytostabilization	Soil	X	

Phytovolatilization

Phytovolatilisation is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant from the plant to the atmosphere.

Phytodegradation

Phytodegradation is when plants take up and break down contaminants. The plants produce enzymes that speed up chemical reactions so that complex organic pollutants can degrade to simpler molecules.

Phytoextraction/phytoaccumulation

Phytoextraction refers to the uptake and accumulation of metals in plants. This can be used to remove contaminants from a site by harvesting the plants after some time. Metals like nickel, zinc and copper can be removed in this way.

Rhizofiltration

Rhizofiltration is similar to phytoextraction where the contaminants were taken up and translocate in the plant. In rhizofiltration the contaminants accumulate in the root. The root is then harvested and the contaminants removed. It can be used to clean contaminated water.

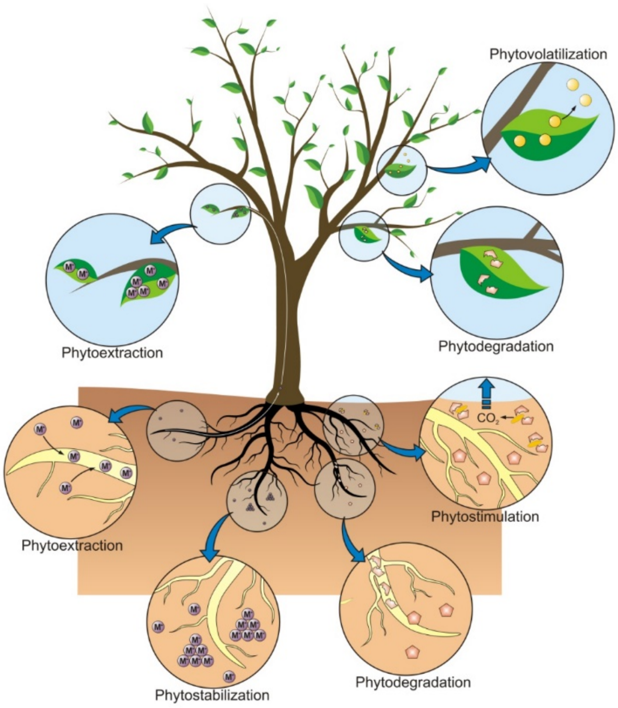

Figure 13 Phytoremediation processes in a plant

Phytostimulation/Rhizodegradation

The rhizosphere is the soil around the roots and the home of microorganisms. The roots release sugars, alcohols and acids that stimulate the micro activity so they degrade the contaminants. It is a symbiosis between the roots and the microorganisms.

Phytostabilization

Phytostabilization is when plants reduce the mobility of the contaminants in the soil or groundwater. The ability for plant to take up metals from the soil is dependent on pH, cation exchange capacity, metal content, solubility sequence and plant species (Chandra et al. 2009).

Use of phytoremediation to treat toxic metals and organic contaminants

Toxic metals

At sites contaminated with metals, plants can be used to either stabilize or remove the metals from the soil and groundwater through three mechanisms: phytoextraction, rhizofiltration, and phytostabilisation. The phytoremediation of metals is a cost-effective 'green' technology based on the use of metal-accumulating plants to remove toxic metals, including radionuclides, from soil and water. (Raskin, 1997)

The ratio between the accumulation of metals in the plant and the soil concentration defines if the plant is an accumulator and thereby can be used for phytoextraction (Chandra et al., 2009). Plants that are not accumulators can be used for phytoextraction if they are accumulating biomass fast and is combined with technologies to mobilize metals in the soil (Van Ginneken el al., 2007).

Organic materials

Phytodegradation, rhizodegradation, and phytovolatilization can be used for the treatment of organic contaminants.

PAH are resistant to biodegradation (Muratova 2010, Ouvrard 2014). Degradation of PAH in the rhizosphere is not as effective as expected or interpreted in some studies. Instead it is argued that a long term stabilization in the soil is a better remediation. Alagic (2015) concludes that plants have not developed a system for complete degradation of PAHs and other complex organic molecules but the plant roots in the rhizosphere stimulate the degradation by microorganisms. Phytoremediation is accepted as an environmentally friendly method for treatment of PAH contaminated soil but to get the best results it should be done in combination with other treatments at the site like, soil cultivation, fertilization etc. (Alagic, 2015).

Phytoremediation plants

Tangahu review (2011) have been used to get an overview of the plants commonly used for phytoremediation of metals. The plant suitable to treat Cu, Ni and Zn have been studied into more detail. It can be noted that many plants can be used to treat several metals. Studies of phytoremediation plants for Cu, Zn and Ni also often include treatment of Cd, Cr, Fe, Mn and Pb (Chandra et al., 2009). PAH are more resistant to degradation some plants have shown good results.

Operation and Maintenance

BPs need pruning, mulching and watering before the vegetation is established. It is also recommended with weeding and replacement of dead plant semi-annual. (CSF, 2009).

Mulch and compost improve the soil's ability to capture water. Because some of the sediment that enters the planters may form a crust on the soil surface, limiting the porosity of the soils, some raking of the mulch and soil surface may also be necessary to maintain high infiltration rates. Periodic trash removal may also be necessary. The Table 13 provides more information on typical post-construction inspection and maintenance activities.

Table 13 Typical inspection and maintenance activities for Bioretention

Inspection Activity	Schedule
After first storm event, inspect for proper drainage, erosion, and proper inlet and outlet functioning.	Post-construction
Monitor vegetation to ensure successful root establishment.	Semi-annually (beginning and end of rainy season)
Inspect for erosion, clogging, and vegetation damage.	

Maintenance Activity	Schedule
Regularly water during the first three months as vegetation establishes roots.	Post-construction
Trim vegetation as needed to maintain desired appearance.	Monthly or as needed
Remove debris from inlets and outlets to avoid clogging.	Semi-annually (beginning and end of rainy season)
Add mulch to bare areas.	
Replace dead or diseased plants.	Annually
Re-grade soil surface if erosion or scouring has occurred.	
Till soil and replant if the system does not infiltrate within the designed drain time.	As needed (expected to be 3 to 5 years)

3.5. Costs

Costs of bioretention planters

BPs can be a low-cost method to manage small volumes of stormwater. Multiple planter cells can be used to treat stormwater from larger contributing areas. Beyond the cost of plant purchase, capital costs are minimal since BPs do not typically require a filter fabric or other man-made devices. The more elaborate the planter, the more expensive the installation becomes.

The costs of installing and maintaining a BP vary depending on size, materials, and maintenance requirements of selected plantings (CSF, 2009). Installation cost for one 45 square meters concrete planter box with a 10 cm underdrain was estimated at $4,000; maintenance costs for the same planter are estimated at $500 per year. Construction of another planter bed was estimated at a cost of $23 per square meter of impervious surface area, or $350 per square meter of planter bed (CSF, 2009).

The Table 15 show the costs for five different bioretention scenarios (PGC, 2007); the average cost of a BP is almost 8000 USD.

Table 14 Costs for different scenarios of bioretention planter projects

Scenario	Residential Bioretention Planter	Residential Lot in Subdivision	Residential Single Lot	Commercial New	Commercial Retrofit
Cost	1075	3790	7775	10357	12355

Community and environmental concerns

The following is a list of several community and environmental concerns that could arise when BPs systems are proposed.

Nuisance Conditions

Poorly designed bioretention practices can generate potential nuisance problems such as poor drainage and standing water. In most cases, these problems can be minimized by soil testing and pretreatment requirements (MGNDC, 2012).

Mosquito Risk

Infiltration practices have some potential to create conditions favorable to mosquito breeding, if they clog and have standing water for extended periods. Appropriate installation and maintenance of the bioretention area will prevent these conditions from occurring (MGNDC, 2012).

4. Design of a bioretention planter prototype

The method used to design the BP was a literature review of articles and design manuals in combination with stakeholder interviews, see Figure 14.

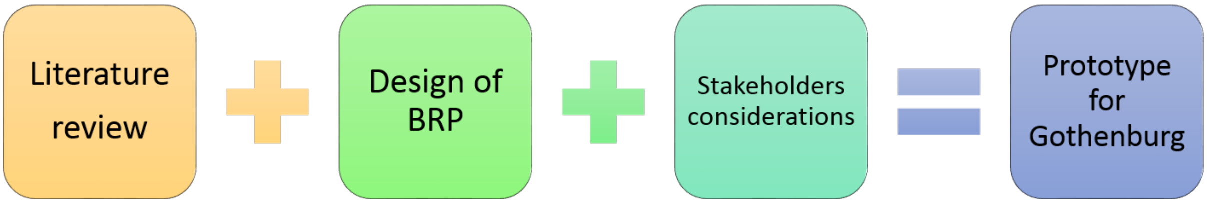

Figure 14 Bioretention planter prototype design for Gothenburg

4.1. Literature review

The first step in the methodology was to study the current literature on BPs and phytoremediation. Primary sources and peer reviewed articles have been prioritized. Search engines like *Web of Science* and *Chalmers library* were used as sources. The snowball method (Goodman, 1961), where references from some identified articles are used to find further information was also used for this research. There were many articles about both BPs and phytoremediation and the idea was not to identify and summarize all of them, but to find the information needed to answer the research question.

There are several articles written about bioretention planters, but very few of them explain the structure and the design of the planters. Instead, most of the articles refer to Green Infrastructures (GI) and Best Management Practices (BMP), instead bioretention design manuals produced by diverse departments and states across United States of America had accurate design information.

The manuals presented in Table 15 were studied for the present research; they define different aspect such as sizing, maintenance, costs and others, and all of them combined give an ideal framework for the design of the Bioretention planter.

Swedish statistics were used to find information about the local conditions in Gothenburg, further sources such as SMHI - Swedish Meteorological and Hydrological Institute and by Gothenburg municipality were also studied.

Table 15 Design manuals for bioretention planter

Name	Location	Year
San Francisco Stormwater Design Guidelines	San Francisco, California	2009
Green Streets Design Manual	Philadelphia, Pennsylvania	2014
Low Impact Development Stormwater Management Manual	Nashville, Tennessee	2012
Green Stormwater Infrastructure	Seattle, Washington	2010
Bioretention Manual	Prince George's, Maryland	2007
Portland Stormwater Management Manual	Portland, Oregon	2008

4.2. Bioretention planters design process

In Table 16, a step by step of the BP design process for Gothenburg is presented. The first step is to choose type of planter and then to calculate the drainage area. The sizing includes deciding the depths of layers as well as calculating the volume and the area of the planter. The last step is to choose plants suitable for the site and contaminants.

Table 16 Bioretention planter design process

Step 1	Choose type of bioretention planter	Choose between a flow-through planter with underdrain or infiltration planter where the water infiltrates in underlying soil.
Step 2	Considerations prior sizing	Drainage area: pick an area according to Gothenburg city requirements, not to exceed the maximum for one planter cell.
Step 3	Sizing	Layers decide depth of mulch, retention soil, gravel, Equivalent depth – calculated from formulas in theory, Treatment volume – calculated from formulas in theory, Sizing area – calculated from formulas in theory.
Step 4	Plants	Select phytoremediation plants for a Gothenburg climate that can remediate toxic metals and organic contaminants

4.3. Interview dialogue for prototype design consideration

Interviews were carried out in order to improve the bioretention planter. By involving interested actors in the identification of problems and solution it is more likely that the implemented changes will be followed (Kemmis and McTaggart, 2005). Involving as many stakeholders as possible in the data collecting process catalyzes reflection

(Scheinberg and Alänge, 2014). The stakeholders were asked to give their opinion of the BP which was considered when creating the final version of the BP suitable for Gothenburg.

Selection of the stakeholders

Identifying the stakeholders was an iterative process. New stakeholders were added as the procedure progressed, and some stakeholders identified in an early stage were later deemed irrelevant.

The stakeholders were chosen according to their relevance to the issues of increasing stormwater in Gothenburg. Stakeholders who are affected directly and are working with future planning, mitigation or handling were selected.

Data collection

Primary data sources consisted of interviews with stakeholders identified as relevant for the study. A structured interview method was considered too strict, as it was considered desirable to let the interviewee speak freely around the questions asked. The interviews were instead conducted in a semi-structured manner as it gives the interviewee enough freedom, while still providing enough structure for the interviewer to acquire information on specific predetermined topics (Dalen, 2007). The structure provided by the method also allowed for comparison of the result from the different interviews. The questions asked and the selected stakeholders can be found in Appendix III Interview questions.

5. Results

To decide the design and size of a BP in the Gothenburg urban context, several aspects have to be taken into consideration. To retain and treat the largest possible stormwater volumes, the sizing will be based on the engineering and technical solutions described in 3.3 Bioretention planter design, but when applied to a context the local considerations and views of different stakeholders are also taken into account.

5.1. Considerations prior bioretention planter design for Gothenburg

Legislation

Stormwater policies in Sweden state that stormwater shall be taken care of in such a way that threats to human health, water and the soil environment, and the risk for damage to buildings is minimized (Vattenverket, 2001). Pollutants shall not be diffusely emitted, and measures should be taken as close to the source as possible. Measures should be taken as far as technically, economically and legally possible.

Gothenburg have a green strategy stating that the city should be greener to have a rich plant and animal life and healthy citizens (Jögård, 2014). The green strategy suggests that the blue and green areas in the city should be strengthened and the city should be open to gain new knowledge about ecosystem services. As an example of ecosystem services mentioned is infiltration and wetlands to treat water

Precipitation

The average yearly precipitation in Gothenburg is 758 mm (SMHI, 2014). The one in a ten year rain event is 40–45 mm/24 hours in the Gothenburg region, but heavy rain falls will probably increase by 10–30% at the end of the century due to climate change (Persson et al., 2011). The BP will be designed to cope with 50 mm of rain in 24 hours which is higher than the one in a ten year rainfall event because of increased precipitation levels from climate change.

Sizing and soil type

In urban areas the usual maximum depth for planting trees is 1.5 meters and a minimum of 16 m^3 for their roots, the area is wider under the surface than what is seen above ground (Offerman, 2015). Sweden and Gothenburg are seated on rock and clay water infiltration is very slow on this type of soil. (Rankka et al., 2004)

5.2. Plants suitable for bioretention planters

In the studied articles the plants with the highest uptake of the different metals can be seen in Table 17. More specific information, and photos of the plants can be found in Appendix II Vegetation Palette.

Table 17 Best studied plants worldwide for phytoremediation mg/kg

Plant (lowest levels)	Cu	Zn	Ni	References
Wheat *(Triticum aestivum L.)*	4.0	18	4.1	(Chandra et al., 2009)
Indian mustard (*Brassica campestris L.)*	4.6	26	3.2	(Chandra et al. 2009)
Hybrid poplar Populus deltoides x populus nigra L.	9.0	85	7.0	(Liphadzi, 2003)
Sunflower *(Helianthus annuus)*	11	20	6.7	(Liphadzi, 2003)
Willow group 1 *(Salix)*	8.0	120	5.5	(Pulford, 2002)
Willow group 2 *(Salix)*	13	98	6.5	(Pulford, 2002)
Brachythecium populeum *(Brachythecium populeum)*	20	240	31	(Sharma, 2009)

In all plants Zn shows the highest levels of uptake, but it also had the highest levels in the ground. Studies show that the uptake is dependent on the levels in the ground.

According to Table 17, the best plant for removal of metals would be the tree *Brachythecium populeum*, see Figure 15, more information can also be found in Appendix II.

Of the studied plants for PAH remediation, the combination of winter rye and alfalfa proved to be the best with a removal of 70% of the oil. The comparison between the plants for PAH removal can be seen in Table 18.

Figure 15 Popoleum tree (Demox, 2015)

Table 18 Plants efficient for removal of organic contaminants as PAHs.

Plant	Efficiency (removal) of PAHs	Reference
Winter rye (*Secale cereale L.*) and alfalfa (*Medicago sativa*)	70%	(Muratova 2011)
Tall fescue (*Festuca arundinacea*)	55%	(Huang, 2003)
Rye grass (*Lolium multiflorum*)	15%	(Parrish 2004)
Yellow sweet corn (*Melilotus officinalis*)	9%	(Parrish, 2004)

Plants mentioned above (Table 18 and 19), and selected to be suitable for the Gothenburg climate, are ranked as seen in Table 19

Table 19 P plants suitable for bioretention practices in Gothenburg

Cu	Zn	Ni	PAH
Willow group 2	Willow group 1	Poplar	Winter rye and alfalfa
Sunflower	Willow Group 2	Sunflower	Tall fescue
Poplar	Poplar	Willow Group 2	Rye grass
Willow Group 1	Indian Mustard	Willow Group 1	Yellow sweet corn
Indian Mustard	Sunflower	Wheat	Winter rye and alfalfa
Wheat	Wheat	Indian Mustard	

5.3. Quantity of total metal uptake

The value of the metal uptake in mg/kg, presented in Table 17 is good as a comparison between the different plants but it is difficult to grasp the total uptake. In order to get the total uptake the values needs to be multiplied with the biomass production per season of the different plants. An example of this is given below:

According to Liphadzi (2003) sunflowers grow 1 kg per m^2 when planted 4th of July and grow to 6th of October. Meaning that a BP of 14 m^2 can support a biomass of 14 kg of sunflowers. Sunflowers accumulated 11 mg copper/kg biomass (Liphadzi 2003), the total uptake of copper in a BP of 14 m^2 is 154 mg per season.

5.4. Stakeholder considerations

Selected stakeholders

All selected stakeholders and their organizations are presented in Appendix IV Stakeholders. To include Gryaab in the process was evident as they are responsible for the WWTPin Gothenburg, and therefore both affected and knowledgeable in the topic. Park and Nature office in Gothenburg were involved because of the inclusion of green areas (BPs) in the solution. Kretslopp and Vatten are the owners of the pipe system and have great knowledge about the flooding problems and local conditions. The traffic office were involved because of the important role roads and traffic have for the contamination and impermeable area in the city.

Stakeholders interest in the stormwater question.

All of the stakeholders are well aware of the stormwater problem in Gothenburg and the challenges faced in the future. Most of the stakeholders are also involved in project for mitigation.

Kretslopp and Vatten are working with the ecosystem services of infiltration of water to reduce runoff in their pilot project of a rain garden by a carpark in Kviberg (Nivert and Ander, 2015). Park and Nature are also involved in the process to choose suitable plants (Offerman, 2015).

The Traffic office work with a pond that can hold the water after heavy rains to reduce the flooding of Mölndalsån (Lundskog, 2015). Apart from the involvement in the rain garden, Park and Nature also thinks that designing all new park and nature areas to cope with large amounts of water is part of the future (Offerman, 2015).

Improvement of the bioretention planter design

All stakeholder liked the idea of BPs as it would increase the green area in the city. The comments on the design and implementation possibilities have been divided into six different categories that were raised on several of the interviews. When all actors had the same view no one is pointed out in the text.

Aesthetics

The aesthetics of the plants and that they fit into the local context is vital. The importance of this is also highlighted in the Bioretention Manual from The Prince George's County (PGC, 2007). There is a big difference in the perception if the BP has large trees, small colorful flowers or is a field with high grass. Different plants could be used for different locations in the city and the people living in the area should be part of the decision to create acceptance.

Examples of what the stakeholders believed could be attractive was: colorful flowers and plants attracting butterflies and birds.

Season

The performance during the winter was raised during the interviews, both how well it is working, to make sure it is resistant to frost and the salt from the roads, but also that there is room for the snowplow. This is an important part of producing a complete and working concept, it is however outside our scope and even if Dietz (2007) states that it works in cold climates as long as installed and designed properly further research should be done to support this.

Area

In urban environments there is often a limited space, buildings, roads, footpaths, trees and flowerbeds all compete for the same land. The pipe system have the advantage of being underground so to fit solutions like BPs that take up space can therefore be difficult. Central parts of the city where buildings and infrastructure is already in place are the most difficult parts to implement these kinds of solutions (Lundskog, 2015). In new areas it can be introduced in the planning stage which enables implementation (Lundskog, 2015). As Offerman from Park and Nature mentioned, parks will probably in the future be designed to be able to handle large amounts of water (Offerman, 2015).

Park and nature, are used to plant in the limited space of the city and know about the limitations. The usual depth for their plantations are 1 meters and in order to get enough space for the 16 m^3 the trees requires they use the space under the footpaths etc. So the “planted area” under the ground is much bigger than can be seen above ground (Park och Natur Göteborg stad, 2014).

Safety

Safety has been raised as a concern from different aspects. Parents can be worried to have open water tables for the safety of their children. But on the other hand it could also be seen as a way to get the footpath further away from the road which could increase the safety for pedestrians (Offerman, 2015). Traffic office mentioned that there are regulations around construction design close to roads that are important to consider to reduce injuries if people drive into them (Lundskog, 2015).

Operation and Maintenance (costs)

Plants needs to be replaced, harvested and maintained continuously so this require long term funding or to be included in the budget. To plan for this it was highlighted as a very important part of a successful project. In the public sector the budget is usually tight and filled with important tasks that has to be attained. To choose plants with as little maintenance and need for harvest are therefore of interest. It is natural that Park and Nature take care of the plants. They might have to gain knowledge about new species or learn new machines but as long as they have the money for it they did not see it as a problem (Offerman, 2015). The plants are however just one part of the BP and the knowledge about layers underground and the flow control are not within Park and Nature so a cooperation with others might be needed.

Responsibility and ownership

The question of responsibility and ownership was raised during almost all interviews. The flooding problem affects everyone but who is responsible? Who would invest in, and take care of the BPs, and who would benefit from them? There is an ongoing dialogue within the region about everyone's responsibility to take care of their own stormwater. This would for example mean that the traffic office is responsible for the water from the roads.

With the agreement that everyone should take care of their own stormwater it is important not to mix the runoff from roads with for example the runoff from the buildings as different actors are responsible. This should be taken into account when designing solutions like the BP. In other words, a specific BP should only take water from roads or buildings. Most stakeholders agreed that the communication between them could be improved and cooperation might be needed in order to get the money and knowledge to implement such a project.

The budget and tasks for the public sector is decided by politics so the room for own initiatives is limited. Politics is therefore an important factor for the possibility of a public body to invest in a solution.

During several of the interviews the alternative that BPs could be placed near buildings and paid by the builders or owners were mentioned. Gryaab saw the possibility that the house owners could get a reduction in the water and sanitation fee (VA taxa). This would be a way for Gryaab to support the initiatives economically without doing the implementation or the maintenance (I’ons, 2015).

5.5. Final design

The information from the design manuals were combined with the local conditions and stakeholders considerations in order to create the final design of a BP for Gothenburg. In Table 20 the sizing, layers, media and plants can be seen.

Design table

Table 20 Bioretention planter design table for Gothenburg city

Item	Observation
Sizing	Area: 14.2 m^2 Volume: 9.5 m^3 Equivalent depth: 0.95 m
Drainage Area or Contributing Drainage Area	200 m^2
Maximum Ponding Depth	15 cm
Filter Media Depth	100 cm
Gravel Layer Depth	30 cm
Media & Surface Cover	The final composition should be: Max 60% sand; less than 40% silt; 5% to 10% organic matter; and less than 20% clay by volume
Underdrain (Flow Through planter)	Corrugated HDPE with clean outs, and a minimum 12-inch stone sump below the invert
Plants	Alternative 1: Rye, alfalfa, poplar and willow Alternative 2: Willow and sunflowers

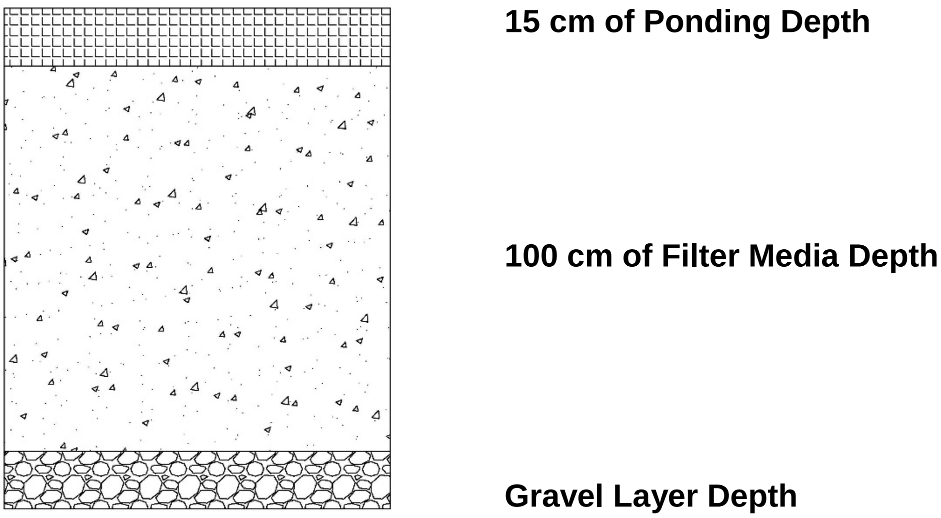

Figure 16 Sketch of the layer design

6. Analysis of the results and recommendations

6.1. Chosen design for Gothenburg

The flow through planter was chosen because of the soil properties with weak infiltration in Gothenburg. A drainage area of 200 m^2 is the maximum recommended just for one planter cell and it is also the example of how the calculations and design of a retention planter are carried through.

The total depth of the BP was chosen in accordance to the usual planting depth in Gothenburg, and then the depth was divided between the layers. Since the soil has the important functions of both retaining and filtering the water, priority has been given to the depth of this layer so that the volume for the plant roots are as big as possible. Gravel also store and retain water and have been given a big depth.

The phytoremediation plants were mainly selected according to treatment performance and aesthetics. Other things to take into consideration could be the investment cost, and the need of maintenance, planting and harvesting. Accumulators will always need to be harvested to remove the pollutants from the system but for plants using phytodegradation or phytostimulation there is no such need. It could therefore be a better investment, requiring less attendance. It is however important to remember that not all phytoremediation processes can handle all types of contaminants so in order to reach the highest total removal of pollutants a mix of different plants is likely to be the best.

Not all phytoremediation plants for organic pollutant treatment have been investigated in this study. To find the perfect plants for Gothenburg a study with more plants and more information about them is needed.

The size is a critical factor for solutions in an urban environment. In this study the assumption of a 200 m^2 drainage area was done and resulted in a surface area of 14.2 m^2 for the bioretention planter. BPs can off course be smaller if the drainage area is less or if there are many of them. One strength with the BPs is that they are possible to design in different sizes to fit in the local context. If there is only room for something small or narrow it is possible to get. It is also important to point out that the BPs are not supposed to take room instead of nature but create green areas. As Park and Nature mentioned in the future most parks will probably be designed as green gardens to be able to handle large amounts of water. To focus on the fact that BPs bring green areas to the city rather than being a structure for the stormwater is important for the implementation. The city planners today are well aware of the effects on wellbeing green areas have and it is part of the process to design for parks in new areas.

6.2. What would it mean for Gothenburg?

Cost per cubic meter

The following cost example shows how much it will cost a cubic meter for a bioretention with an area of 14.2 square meters and a treatment volume of 0.95 m^3 /24 hours

Assuming an average construction cost of almost 8000 USD ~ 80000 SEK, a maintenance fee of 500 USD ~ 4000 SEK/ year and a performance lifetime of 10 years, the result and cost for 10 years is 120 000 SEK.

With a treatment volume of 9.5 m^3 /24 hours for 10 years the treatment volume is 34 200 m^3.

The result and cost per cubic meter of this calculation is approx. 3.5 SEK / m^3. The cost per cubic meter in Gryaab is 5.68 SEK / m^3 (Gryaab, 2015), a BP is suitable for 10 years and even more.

Gryaab Wastewater treatment plant overflow

According to Gryaab WWTP they have a water bypass (zero treatment) of 2 000 000 m^3 a year.

A BP of 14 m^2 can theoretically handle 9.5 m^3 /24 hours stormwater. If the city only uses BPs to fulfill the bypass demand more than 21000 BPs are needed all over the city.

That amount of BPs is extremely massive. To avoid the only use of BPs, there must be a complete green infrastructure to handle that amount of stormwater.

Bioretention planters at Rosenlund car park

Rosenlund car park, located in central Gothenburg, has an area of 1400 m^2 see Figure 17, so in order to retain and treat all water from the area 7 BPs (each taking water from 200m^2) would be needed.

Figure 17 Rosenlund car park has 104 parking lots and an area of 1400 m2.

This would mean approximately 100 m^2, of surface area with BPs, equivalent of 7-8 parking lots, an area marked in Figure 18. To reduce the already limited amounts of parking lots in the city would most likely not be popular, but as can be seen on Figure 18 the parking lot is already surrounded by green area that if it was transformed into BPs would be more than enough to take care of the water from the carpark.

Figure 18 An area of 100 m2 of bioretention planters are needed to handle the water from the car park

6.3. The bioretention planter additional value evaluated with the Challenge-lab criteria.

In this section the BP will be discussed in relation to Sustainable development criteria in heading 2.5 from the first phase of the Challenge Lab process to evaluate the idea.

Nature criteria

The ideal situation would be if the stormwater was not contaminated and could be infiltrated in any green area without risk of contamination. One part of the work must therefore be to start with the problem at the source and reduce the contamination. Traffic have a big environmental impact on stormwater contamination but road construction materials, roof materials, buildings, bikes, plastic, shoes etc. also contribute to the contamination.

The idea to include the phytoremediation in the BP was to fulfill the first two environmental criteria of not increasing any elements from the earth's crust or manmade contaminants in the biosphere. The plants can only take up or degrade a certain amount of toxic compounds so 100% efficiency is not guaranteed. It is however an improvement compared to infiltration without phytoremediation. An additional improvement of the system could be to have several different natural treatment steps following each other.

The third environmental criteria is about not manipulating the ecosphere. BPs placed in the urban area where it previously was impermeable paving will increase the natural mechanisms in accordance with the criteria. As an example the groundwater recharge through infiltration will come back to its natural state. Increased green areas can possibly also increase biodiversity.

Economy criteria

The normal way to see economy is to compare different alternatives and choose the lowest price for the same service. According to the calculations the cost per cubic meter for BPs is cheaper compared to the cost in Gryaab WWTP.

To implement BPs is to invest in an option that enables the other criteria (well-being, nature) to be fulfilled, like the economic criteria states that it should. A WWTP fill the same purpose of reducing contaminants in the nature but do not produce well-being in the same way as green areas in the city can do. One of the purposes of a BP is to reduce peak flows to diminish flooding and their impacts. This lower costs and ease the recover after flooding and is therefore a resilient system that buffer against destructive disturbances like environmental catastrophes in the economic criteria.

Another of the economic criteria is about enabling future use of resources and dissipative use of materials. The BPs can be used for urban mining by harvesting accumulating plants that concentrate materials. Compared to infiltration in any green area BPs are better not only because the soil is not polluted but also because the contaminants can be separated and recycled. The economy for this process is not discussed here.

The operation and maintenance was raised during the interviews and continuous costs were seen as a problem. The best would of course be with a system taking care of the water naturally without need of maintenance but it is not realistic as long as the stormwater is polluted. It is important to remember that all alternatives also have big maintenance costs including a new WWTP.

Well-being criteria

More green areas in the city can enhance walking, jogging, recreation and can thereby both increase the leisure, health and the wellbeing of the inhabitants. Feeling safe is part of well-being and is therefore an important parameter to take into account when designing the BPs. As the stakeholders mentioned it is both about the safety for parents and their children and for pedestrians and drivers. It can also be about the lightning in the area and to avoid blocking the view with bushes and trees. By thinking about this in the designing state there is no reason to feel unsafe near the BP.

It is also important to take into account that some plants will need to be harvested and to give clear information to the public so they understand the purpose when their nice green trees are cut down. Stormwater systems above ground are easier to follow and understand and it is therefore a good opportunity to create knowledge about the infrastructure systems in the city.

The interviews show there is a concern that the plants will not fit in the urban context. If the people in the area are involved in the process of designing or choosing the plants this problem can be solved and might also make the citizens to feel included free and empowered. It can be a place for creativity and strengthen the feeling of identity in the area. To involve the citizens could also be a solution for the maintenance as many people enjoy taking care of plants and it would increase the participation in the city and society.

Societal criteria

Societal institutions are built on transparency, accountability, and mutual trust. They enable the well-being of the individuals in society. The societal system is an instrument for individuals to live together within the other criteria.

The society should be an instrument for living within the criteria of economy, well-being and nature. The difficulty for individuals to handle stormwater make cooperation needed and therefore a societal matter.

As the interviews have shown the flooding affects many parts of society and several stakeholders are working with it. The cooperation between the different actors could however be increased. Everyone liked the idea of a BP but no one took the initiative to be responsible. It is natural that no one takes the overall responsibility in a system where the responsibility is divided. A positive aspect about having a divided responsibility is the fact that everyone reflect over, and tries to limit their own contribution to the problem. The BP solution are applicable in many contexts as it can be done in different sizes and settings. It is possible for different actors to see it as an economical viable option and invest in it. Even if an option is economically viable there is no guarantee it will be implemented.

By cooperation sub optimization can be avoided. A cooperation and combination of different actor's knowledge, money, expertise and energy would be beneficial. Cooperation is difficult, and many of the interviews actors agreed that the communication and cooperation between them could be improved. Since stormwater affects all of them it could be a good project for collaboration.

In order to do this cooperation someone needs to take the initiative and gather the stakeholders. Maybe there is need of an institution with the overall responsibility that could take such an initiative. Either a new flooding institution could be created or an existing one like Havs och Vattenmyndigheten or Värstra Götalands regionen could be responsible. At the moment this is not under question and one should not wait but act now. Everyone should start here and take their little piece of responsibility and create something good with it.

7. Conclusions and future work

It can be concluded that a BP in Gothenburg can be designed in a way that it both treats and retains stormwater. A BP of 14 m^2 can take care of water from a 200 m^2 drainage area up till storm events of 50 mm/24h. Suitable plants for Gothenburg is poplar (*Populus deltoides x populus nigra L.*), willow (*Salix*), sunflower, winter rye (*Secale cereale L.*) and alfalfa (*Medicago sativa*) but care should be taken so that the design and choice of plants in the BP is suitable for the local context. If the whole planter was filled with sunflowers, 154 mg of copper could be accumulated in the plant tissue per year, but in order to remediate PAH as well some space would have to be left for other plants.

The power of the BP is to reduce flooding and benefit the environment by treating stormwater, but it will at the same time create well-being by increasing green areas in the city. By involving citizens in the development process it can also strengthen the feeling of identity and cooperation in the society.

The cost to treat stormwater in BPs is calculated to 3.5 SEK per cubic meter, which is cheaper than treatment in the WWTP with a cost of 5.6 SEK per cubic meter.

Further research should be done about phytoremediation to evaluate all possible plants for Gothenburg. A study about the effect of pretreatment and the design of channels, inflow and outflow would also be needed. Suitable location for the BPs in Gothenburg should be identified. Before implementing in a big scale the winter performance needs testing. Another important part for further work is to include more stakeholders in the dialogue.

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Appendix

Appendix I Comparison between other remediation techniques to phytoremediation

Table 21 Other remediation techniques compared with phytoremediation

Treatment name	Benefits compared to phytoremediation	Limitations compared to phytoremediation
Solidification / Stabilization	Not seasonally dependent; well established, rapid; applicable to most metals and organics; simple to operate during treatment.	Site is not restored to original form; leaching of the contaminant is a risk; can result in a significant volume increase.
Soil Flushing / Soil Washing	Not seasonally dependent, except in cold climates; methods well established for several types of sites and contamination.	Removal of metals using water flushing requires pH change; additional treatment steps and chemical handling add complexity and cost; possible lengthy period of treatment.
Bioremediation	Established and accepted; a bioreactor can be utilized for existing work; may be faster than phytoremediation	Requires nutrient addition at a much greater level than phytoremediation; applicable to organics only.
Electrokinetics	Not seasonally dependent; can be used in conjunction with phytoremediation to enhance rhizosphere biodegradation.	Useful for soil only, not wetlands; uniformity of soil conditions is required
Chemical Reduction / Oxidation	Not seasonally dependent; relatively short treatment time frame; usually off site.	Requires excavation; uses chemical additives; fertility of the soil after treatment may be damaged
Excavation / Disposal	Rapid, immediate solution for site owner.	Transfers contaminants to landfill; does not treat

Appendix II Vegetation Palette

The following vegetation palette merge data from several plant databases and major reference books to generate a varied palette specific to the Gothenburg area. The plants can be combined with non-native plants not listed, depending on their growing conditions and cultural requirements. The criteria for including these plants in the report include the following characteristics:

• Well-suited to bioretention planters
• Attractive to wildlife and beneficial insects
• Locally appropriate

Plants are listed by both scientific and common names and plant type. The palette includes information on treatment preferences: toxic metal and organic contaminants remediation.

Wheat plant *(Triticum aestivum L.)*

Wheat is an annual grass that grows approximately 1 meter tall. It can be found wild but is mostly found on agriculture land in the southern parts of Sweden (Anderberg, 2015).

Chandra et al. (2009) showed that the concentration of metal in wheat differs between the parts of the plant. None of the parts in wheat had higher levels than were found in the soil, see table XX. The levels of Ni were highest in the roots 16.80 mg/kg, but Zn were highest in seeds with 28.26 mg/kg. Cu had the highest levels in the leaves 7.06mg/kg (Chandra et al. 2009).

Figure 19 Wheat plant (Cherepanov 1995)

Table 22 Maximum metal (mg/kg dry weight wheat) accumulation during 90 days

	Root	Shoot	Leaves	Seed	Soil
Cu	5.16 ± 1.02	4.02 ± 0.87	7.06 ± 1.24	5.06±0.63	40.83 ± 2.24
Zn	21.04 ± 3.76	19.14 ± 2.16	18.26 ± 2.24	28.26±3.18	143 ± 4.16
Ni	16.80 ± 2.08	4.18 ± 0.92	5.14 ± 1.02	4.12±1.03	42.24 ± 3.31

Source: Chandra et al. 2009

Indian mustard *(Brassica campestris L.)*

Indian mustard is a plant with yellow flowers that naturally grows in Sweden. In the past it was common all over Sweden but today it is seen as weed and is less spread (*Anderberg, 2015*).

Most of the metals Indian mustard takes up stays in the roots where it had 12.4 mg/kg of Cu, 61.26 mg/kg of Zn and 7.28 mg/kg of Ni in a study by Chandra et al (2009), see table 24.

Figure 20 Indian mustard (Sharma 2012)

Table 23 Maximum metal (mg/kg dry weight mustard) accumulation during 90 days

	Root	Shoot	Leaves	Seed	Soil
Cu	12.4 ± 41.06	4.60 ± 0.56	7.18 ± 1.53	5.26 ± 1.23	40.83 ± 2.24
Zn	61.26 ± 4.06	26.12 ± 3.15	48.24 ± 2.86	28.16 ± 3.06	143 ± 4.16
Ni	7.28 ± 1.16	5.56 ± 1.0	3.16 ± 0.53	4.08 ± 0.82	42.24 ± 3.31

Source: Chandra et al. 2009

Alpine Penny-cress *(Thlaspi caerulescens)*

Alpine Penny-cress is a small flower that grows naturally over all but the most northern parts of Sweden (Anderberg, 2015).

Alpine Penny-cress accumulate Zn and Cd. Robinson (1998) found that 60 kg of Zn could be removed yearly from one hectare planted with it (1.16% dry weight of Zn and 2.6 t biomass per ha).

Figure 21 Alpine Penny-cress (Biopix 2015)

Hybrid Poplar *(Populus deltoides x populus nigra L.)*

Populus nigra origins in the Mediterranean area but have been planted in Sweden for centuries. Popular are deciduous trees (Anderberg, 2015).

Figure 22 Poplar tree (Demox 2015)

Liphadzi (2003) found that popular did not accumulate Ni to any high extent, the leaves had 7mg/kg in a soil with 9 mg/kg. The same result were found for Cu that had the highest level in the steams (9 mg/kg) in a soil that had 16 mg/kg. Zn was different and as much as 85 mg/kg was accumulated in the leaves of the plant where only 60 mg/kg of Zn was in the soil Liphadzi (2003).

Sunflower *(Helianthus annuus)*

Sunflower is a cultivated plant in Sweden but at some places it has spread and is found in the wild. It can reach 3 m tall and have big yellow flowers between augusti to september (Anderberg, 2015).

Figure 23 Sunflower (Mullerseed 2015)

Research by Liphadzi (2003) showed that the dry weight of Ni in sunflowers was 6.7 mg/kg in contaminated soil. By adding the salt EDTA the accumulation of Ni could be increased to 19.2 mg/kg which was considerably more than the 8 mg/kg that was in the soil (Liphadzi, 2003). In the same study Cu was found at the highest concentration in the leaves with 11 mg/kg which increased to 17.5 mg/kg when the salt EDTA was added. Zn was not concentrated in the sunflower tissue as it only showed around 20 mg/kg compared to the soil with 55 mg/kg. (Liphadzi, 2003)

Willow *(Salix)*

There are many kinds of Salix. Salix viminalis is a bush/tree that can be 5 meters high, it occurs naturally in Sweden (Anderberg, 2015).

Figure 24 Salex viminalis (plantes.ch 2015)

Pulford (2002) did a study on metal uptake in 20 different kinds of willows during two consecutive years. The result was that around half of the species were suitable for phytoremediation whereas the other half showed very slow growth rate or survival in the contaminated soil. This shows that not all species within a family (Salix) have the same capacity to take up metals so when plants are being considered to be used for phytoremediation it is important to choose the specific species with proven results.

In the study of Pulford the willow plants could be divided into two groups with similar uptake patterns of the metals. Group 1 had low Ni and Cu in the bark but high content of Zn in the wood. Group two had relatively high Ni and Cu in the bark but low Zn in the wood during the first year. When comparing the total biomass it can be seen that Group 1 has the overall highest content of Zn but Group 2 have higher levels of Cu and Ni, see Table 24 . Also not the difference between the two years, the second year has almost always lower uptake (Pulford 2002). Studies for several years will need to be done to estimate the long term removal of metals from contaminated sites.

The Groups contained the following types of willow:

- Group 1: Rosewarne White (S. aurita x cinerea x viminalis), Delamare (S. aurita x cinerea x viminalis), Othery Moor (S. cinerea x viminalis x cinerea), Spaethii (S. spaethii), Dasyclados (S. dasyclados), Candida (S. candida), Germany (S. burjatica), Calodendron (S. caprea x viminalis x cinerea), and Bjorn (S. viminalis x .schwerin ii).
- Group 2: Coles (S. caprea x viminalis), Jorunn (S. viminalis), Jorr (S. viminalis), Ulv (S. viminalis), Q83 (S. triandra x viminalis), Tora (S. viminalis x .schwerinii), Gigantea (S. aquatica), Mawdesley (S. eriocephala), 699 (S. viminalis), Orm (S. viminalis), and Black Maul (S. triandra). (Pulford 2002)

Table 24 Concentration of metals (mg/kg) in willow biomass.

	Group 1 year 1	Group 1 year 2	Group 2 year 1	Group 2 year 2
Cu	13.4	8.0	15.3	12.6
Zn	253	120	134	98
Ni	5.5	5.2	22.2	6.5

The species Paulford (2002) found overall best for removal of metals was: Rosewarne White, Germany and Spaethii.

The highest uptake was 37.2 g/ha of Ni, 822 g/ha of Zn and 58.6 g/ha of Cu which is very low and Paulford states that the treatment method is not economic by itself for heavily contaminated soil but it can be used if the soil is not very contaminated or if other economic value can be gained from harvesting the trees (Paulford 2002).

Brachythecium populeum (Hedw.) B.S.G

Brachythecium populeum is a moss that can take up Fe, Zn, Pb, Cu, Ni, Cr, and Mn. A study done in India showed that the moss near heavily trafficked roads had high concentrations of heavy metals from the vehicle exhausts, see Table 25. (Sharma, 2009). The high levels of metals did however reduce sugar content and chlorophyll degradation in the moss. This plant does not exist in Sweden (Anderberg, 2015).

Figure 25 Brachythecium populeum (Biopix 2015)

Table 25 Metal concentration in brachythecium populeum (mg/kg dry weight)

	Summer	Monsoon	Winter
Cu	20.3+-74.94	70.30+-7.49	21.60+-0.56
Zn	640.03+-20.56	375.50+-36.0	239.00+-12.16
Ni	70.10+-1.32	104.80+-68.87	30.50+-3.25

Winter rye *(Secale cereale L.)*

Rye is an annual grass that can reach 1.5 m tall. Rye is cultivated in Sweden but can also survive in the wild. (Anderberg, 2015)

Winter rye have been found to reduce oil contamination with rhizodegradation. In a study by Muratova (2011) the soil was contaminated with 11.54 g/kg of oil spill of which 16% was polycyclic aromatic hydrocarbons (PAHs). In 120 days the levels of oil contamination had been reduced by 58%, but no specific number is given for how much PAH remains (Muratova 2011).

Figure 26 Winter rye (Floradecanarias 2015)

Alfalfa *(Medicago sativa)*

Alfalfa is a shrub with yellow white or purple flowers. It is originally from south west Asia but was brought to Sweden already 4000 years ago. It has been used for fodder production but it is also edible. It is a leguminous plant meaning that it can bind nitrogen from the air (most plants need nitrogen available in the soil). (Anderberg, 2015).


Figure 27 Alfalfa

Since alfalfa binds more nitrogen to the soil its present can increase the phytoremediation of oil as nutrients is often a limiting factor (Muratova, 2011). In Muratovas study 2011 the removal efficiency went from 58% with just winter rye to 70% when it was combined with alfalfa and fertilizer.

Tall fescue *(Festuca arundinacea)*

Is a thick grass that can reach 1-1.5m tall. It is common on the east coast of Sweden but is less likely to find on the west coast even if it exists there as well. (Anderberg, 2015).

Tall fescue was found to remove of 55% of the 16 priority PAHs in a soil with 2g/kg of cresot (Huang 2003). When phytoremediation was combined with other techniques like landfarming, bacteria and plant growth promoting rhizobacteria, the efficiency rose to 78%. (Huang 2004). In a 1 year study by Parrish (2004) tall fescue reduced the PAH concentrations with 23.9% so there is a variety depending on the place, soil conditions initial contamination level.

Ryegrass *(Lolium multiflorum)*

Ryegrass can be up to 8 dm tall and is quite common but only stays temporally Sweden (Anderberg, 2015). In a study by Parrish (2004) it removed 15.3 % of the PAH from contaminated soil.


Figure 28 Ryegrass (Floradecanarias 2015)

Yellow sweet clover *(Melilotus officinalis)*

Yellow sweet clover can reach 1 m tall and has yellow flower between july and September. It is common in south and middle Sweden but can also be found further north. (Anderberg, 2015).

Yellow sweet clover has been found to remove 9.1% of PAH in contaminated soil (Parrish 2004).

Figure 29 Yellow sweet clover

Appendix III Interview questions

The interviews were started with some general questions to get a better understanding of the problem:

1. What do you know about the issues of flooding problems and high pressure on the wastewater treatment plant?
2. How are the activities of your department or organization affected by flooding and high pressure on WWTP?
3. How can you prevent, mitigate and handle it?
4. What has been done until now? What ideas or plans do you have for short and long term?
5. What processes are in place?
6. What are the main challenges you face (or expect to) when implementing these changes?

After showing a presentation about our idea of a bioretention planter the following questions were asked:

1. What do you think about the idea of a bioretention planter?
2. What improvements would you like to make for the planter to better fit your organization and you personally?
3. How do you see the possibility of your organization implementing bioretention planters?

Appendix IV Stakeholders

Table 27 show the stakeholders that were interviewed.

Table 26 Selected stakeholders for research

Organization	Contact person
Chalmers	Ulrika Palme
Gryaab	David Ions
Park & Nature	Ylva Offerman
Kretslopp & Vatten	Glen Nivert
Kretslopp & Vatten	Helen Ander
Traffic Office	Karin Lundskog

Appendix V Calculation for the bioretention planter for Gothenburg

The calculation are done according to the heading Sizing procedure on chapter Bioretention planter design3.3. Bioretention planter design. The motivation of the choices are stated in the Analysis.

Step 1: Selection of type of bioretention planter

Flow – through bioretention planter

Step 2: Considerations prior sizing

Drainage area: 200 m^2

Step 3: Sizing

a. Selecting layer thickness

A bioretention planter in Gothenburg would have the composition seen in Table 27

Table 27 Layer thickness selection

Layer	Gothenburg
Ponding depth	15 cm
Mulch	5 cm
Bioretention soil/ planting soil bed/ filter media	100 cm
Gravel	30 cm
Sum	150 cm

b. Equivalent Storage depth De

Using Equation 1 Bioretention Equivalent Storage Depth and the porosities values from Table 9 the result is the following.

$$D_e = (1 * 0.15m) + (0.40 * 1.0\ m) + (0.40 * 0.30m) = 0.67m$$

c. Runoff coefficient Rv

Using the Equation 2 Runoff coefficient (simple) (Rvs), and 100% impervious area the result is the following.

$$R_{vs} = 0.05 + 0.009\ (100) = 0.95$$

d. Treatment Volume Tv

Using equation 4 and the precipitation as the one in a ten year 24 hour rainfall event for Gothenburg the result is:

$$T_v\ = (0.05m)(0.95)(200) = 9.5\ m^3$$

The treatment volume is 9.5 m^3

e. Sizing area

The sizing formula can be found in equation 6 and with the calculated storage depth and treatment volume the needed area of the bioretention planter is 14.2 m^2.

$$SA = \frac{9.5m^3}{0.67m} = 14.2\ m^2$$