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Seasonal Variations in Infiltration in Cold Climate Raingardens

A Case Study from Norway

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Civil and Environmental Engineering
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Description of Master Thesis spring 2017

Candidate name: Sondre Nytrø Balstad

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Title: Seasonal Variations in Infiltration in Cold Climate Raingardens – a Case Study from Norway

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Background

Raingardens are shallow planted depressions, which facilitate a local management of stormwater. A raingarden is constructed using a filter media of, silt, sand and leaf compost, and a small fraction of clay. The top surface is vegetated with a mix of local relatively hardy plants. A well-functioning raingarden will drain completely between each rainfall event, typically set at 24 hours. Winter infiltration in raingardens is a key function for proper year round function. At Åsveien School in Trondheim, a new raingarden has been built as part of the stormwater system.

This thesis will investigate the winter infiltration capacity in this raingarden. The conducted work of this research are field tests using Modified Phillip-Dunne Infiltrometers (MPD) and assisted laboratory work, and model simulations of continuous measured water flows in Åsveien School raingarden. The saturated hydraulic conductivity (K_{sat}) will function as a measurement of infiltration capacity in the raingarden.

Comparisons between the raingarden at Risvollan will also constitute a part of the performance assessment. The RECARGA model will be used to simulate the movement of water through the raingarden for different infiltration capacities.

Objectives

The main objectives of the project are:

1) How does winter conditions influences the infiltration capacity in the raingarden?
2) What modifications to the MPD-method are necessary for measuring the K_{sat} of frozen winter soils?
3) What are the design implications of seasonal variations in infiltration capacity?

Collaboration partners: Klima2050, Trondheim Kommune

Location: The Master thesis will be conducted at the Department of Civil and Environmental Engineering. The candidate should have regular meetings with advisors(s). The laboratory work will be conducted at the laboratories at the Department of Civil and Environmental Engineering.

Advisors: Edvard Sivertsen and Tone Merete Muthanna

Preface

The Master thesis is carried out in connection with the course TVM4905 (Vannforsynings- og avløpsteknikk). The course TVM4905 is a 30 credit Master course for students studying civil and environmental engineering at Norwegian University of Science and Technology (NTNU), Trondheim. The Master thesis has been carried out in the spring of 2017 at the Department of Civil and Environmental Engineering, with Associate Professor Tone Merete Muthanna as main supervisor and senior research scientist Edvard Sivertsen from Klima 2050 as co-supervisor. The Department of Civil and Environmental Engineering and Klima 2050 funded the work. Klima 2050 is a centre for research-based innovations financed by the Research Council of Norway and the consortium partners. The thesis consist of field measurements of infiltration capacity in the Åsveien raingarden, winter modification of the MPD-method and simulations of a typical raingarden located in Trondheim.

I started the fieldwork for this Master in October 2017 and my project thesis "VA-normens og fysiske areal planers påvirkning på valg av overvannsløsninger" was a preliminary work for this Master thesis.

I would like to thank my supervisor Associate Professor Tone Merete Muthanna for giving me help, support and guidance. Thank you for motivating me to write my Master thesis in this format. Secondly, I will thank dr. art Jardar Lohne for helping me write the research article. You have taught me a lot about the art of writing research articles. Last but not least, I will like to thank my co-supervisor and discussion partner senior research scientist Edvard Sivertsen. Thank you for your comments and the discussions we have had.

Finally, I will thank my family and friends. You have been a wonderful support for me through my years at school.

Trondheim, 11.06.2017

Sondre Nytrø Balstad

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Publication schedule

This thesis was written as a manuscript for a research article for the Norwegian research Journal Vann. The article will be submitted for review before July 1st 2017. The format of this Master thesis is a new and unconventional format for water and wastewater part of the Department of Civil and Environmental Engineering. The format focuses on the manuscript for the research article and depends on a more precis language than the traditional Master thesis format. The choice of format was done early in the 2017 spring semester in collaboration with my main supervisor.

In correlation with the Master thesis, I have been accepted to present my research in an oral presentation in conjunction with the 14th IWA/IAHR International Conference on Urban Drainage. The conference will be held 10th to 15th of September 2017 in Prague.

The thesis’s Norwegian summary is also intended as a summary of the presented research in the popular science magazine Byggeindustrien under the column Nytt fra NTNU. The article will most likely be published in around August 31st 2017.

Sammendrag

Sesongvariasjoner i infiltrasjon i regnbed i kaldt klima – en case studie fra Norge

Åpne overflateløsninger som regnbed avhenger av at vann infiltrer i bakken. Mer nedbør og mer våt vinternedbør gjør infiltrasjon stadig viktigere også i vinterhalvåret. En fersk masteroppgave fra NTNU har funnet stor endring i regnbeds infiltrasjonsevne fra høst til vinter.

Regnbed er vegeterte forsenkninger, bygget for å redusere volumet av overvann gjennom infiltrasjon i bakken og/eller holde det tilbake. Det er ofte usikkert hvilken infiltrasjon man kan regne med i åpne overvannsløsninger som regnbed på vinters tid. Målet med masteroppgaven har vært å undersøke hvordan infiltrasjonsevnen endrer seg fra høst til vinter. Arbeidet har vært utført i tett samarbeid med Klima 2050.

Hvorfor er det viktig med infiltrasjon om vinteren?

Med klimaendringer er det forventet mer regn og varmere temperaturer vinterstid. Vinteren er ikke lenger en tid hvor snøen ligger og venter på at bakken skal tine. I stedet avløser frost og smelteforhold hverandre stadig hyppigere, noe som utfordrer bruken av regnbed. Lite forskning er imidlertid utført på infiltrasjonsevnen til regnbed vinterstid.

Fremgangsmåte

Det undersøkte regnbedet er en del av Åsveien skole i Trondheim. Fokuset for undersøkelsen har vært såkalt mettet hydraulisk konduktivitet (K_{sat}). K_{sat} er et vanlig mål på jordens evne til infiltrasjon. Det har blitt fokusert på at metoden skal være enkel og rimelig. Derfor ble det valgt å bruke den modifiserte Phillip-Dunne infiltrometer-metoden (MPD). Dette gjør målingene lettere etterprøvbare. Metoden går ut på å montere plastsylindere i regnbed. Sylindrene fylles så med vann og det registreres hvordan vannstanden endrer seg som grunnlag for beregning av K_{sat}. Slike målinger er gjort med jevne mellomrom i regnbedet gjennom vinteren 2016/2017.

Tidligere har MPD-metoden primært blitt brukt på forhold som ligner norsk vår og sommer. I februar 2017 var det ikke mulig å presse plastsylindrene langt nok ned i jorden for å gjøre målinger (krav om 5 cm). Vi har derfor ingen måleresultater i februar. Løsning for mars ble en metallsylinder montert i enden av plastsylinderen. Metallsylinderen kan slås ned i frosset jord med hardere kraft enn plastsylinderen.

Stor forandringer i infiltrasjon

Målingene viser en markant nedgang i K_{sat} fra 1 cm/time (oktober) til rundt 0,05 cm/time (november, januar, mars og april). I mai ble K_{sat} målt til 3 cm/time. Dette er mye lavere enn hva som er anbefalt (K_{sat} >10 cm/time). Simuleringer av et typisk regnbed viser at andelen av vinter avrenningen som infiltreres/dreneres i regnbedet synker fra ca. 75 % til ca. 25 % når K_{sat} går fra 1 cm/t til 0,05 cm/t.

Betydning av forandring i vanninnhold

Infiltrasjon raten i bakken synker etter en tilnærmet eksponensiel kurve ned til K_{sat}, som er infiltrasjonshastigheten i jord som er vannmettet. Under feltmålingene ble derfor vanninnholdet i jorden målt, dette brukes til å korrigere for hvor langt unna mettet vanninnhold jorden er under forsøkene. I analysen av prøveresultatene ble det oppdaget at ved målinger med K_{sat} <0,1 cm/time hadde forandring i vanninnhold i bakken lite å si på verdien av K_{sat}. For høyere verdier hadde den derimot betydelig påvirkning. De fleste av målingene ble avsluttet etter en time. I datanalysen av prøveresultatene ble det observert en stor forskjell mellom målinger hvor vannstanden hadde gått til null og hvor den hadde blitt avsluttet før. Hvor av målinger hvor vannstanden hadde gått til null ga mest realistiske verdier. For å gi mest mulig realistiske verdier ble det lagt til verdier som fulgte trenden til målingene av vannstand. Dette ga en mye mer realistisk sammenheng mellom økning i vanninnhold og K_{sat}.

Anbefaling

Undersøkelsen viser at man kan forvente stor nedgang i infiltrasjonsevne fra høst til vinter. Dette viser viktigheten av å ta hensyn til begrenset mulighet for infiltrasjon om vinteren. Forholdene i vinterhalvåret vil for mange steder være kapasitetsbestemmende. Vi anbefaler derfor å velge jordmasser i regnbed som gir større infiltrasjonsevne sommerstid enn nødvendig, slik at man tar hensyn til senkning i infiltrasjonsevne vinterstid.

To my grandfather, Anders Erik Nytrø

Thank you for introducing me to natural science

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Seasonal Variations in Infiltration in Cold Climate Raingardens – a Case Study from Norway

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Keywords: Cold climate, Field studies, Infiltration, Raingarden, Urban stormwater management.

Sammendrag

Sesongvariasjoner i infiltrasjon i regnbed i kaldt klima – en case studie fra Norge

Infiltrasjonsbaserte overvannsløsninger som regnbed er avhengige av tilstrekkelig infiltrasjonskapasitet. Høy infiltrasjonskapasitet er spesielt viktig for regnbed i kaldt klima, da vinterforhold byr på særlige utfordringer for deres funksjon. Denne studien har undersøkt variasjonen i et regnbeds vinterinfiltrasjon og dens påvirkning på design av regnbed i kaldt klima. Mettet hydraulisk konduktivitet (K_{sat}) er brukt som mål på infiltrasjonskapasitet og er anbefalt å være høyere enn 10 cm/t for regnbed i kaldt klima. Resultatene viser en sesong variasjon i K_{sat}, fra 1 cm/t (oktober) til ca. 0.05 cm/t (November-April). Simuleringer viser at andelen av vinter avrenningen som infiltreres/dreneres i et regnbed i Trondheim synker fra 75 % til 25 % når K_{sat} synker fra 1 cm/t til 0.05 cm/t. Det er i forbindelse med studien utviklet en vinter modifisert versjon av MPD-metoden. Få tilsvarende studier er funnet internasjonalt og enda færre har hatt hovedfokus på vinterinfiltrasjon.

Abstract

Winter infiltration in cold climate raingardens is a key function for proper year round function. The Modified Phillip-Dunne Infiltrometers (MPD) procedure was used for measuring winter variation in infiltration capacity in a raingarden. The research was based on a case study approach, combining field measurements and simulations. The results were compared to publicized results from the raingarden at Risvollan and literature values addressing cold climate. Saturated hydraulic conductivity (K_{sat}) provides a measure of infiltration capacity and is recommended to be above 10 cm/h in cold climate raingardens. The results show a seasonal variation in K_{sat}, from 1 cm/h (October) too close to 0.05 cm/h (November-April). Simulation of a raingarden in Trondheim, show a change from 75 % to 25 % in the amount of winter inflow the raingarden infiltrate or drain when K_{sat} goes from 1 cm/h to 0.05 cm/h. This paper presents a winter adaptation of the MPD-method. Few similar studies have been carried out in cold climates. Of these, few investigated the seasonal variations in infiltration capacity.

1. Introduction

The use of raingardens for handling stormwater has been limited in Norway, though it is slowly growing. A lack of knowledge around design of raingardens among consultants, architects and developers and practical experience might explain this. A main concern for the performance of raingardens is their winter infiltration capacity, where only limited experimental data exists. Previous work leading up to the research presented in this paper has shown that the municipality of Trondheim have concerns on the use of raingardens. The raingarden in question belongs to the municipality of Trondheim. It forms part of Åsveien School. The School was constructed in collaboration with the Norwegian national project *Fremtidens byer* ("Cities of the future") (Om Framtidens byer, 2014). For pictures of the raingarden see Appendix D and for illustrations see Appendix E.

Several research projects on raingardens located in Norway has been carried out (Dalen, 2012; Paus, 2016; Blom, 2017). Paus et al. (2015) evaluated the hydrological performance of the three raingardens in Norway using K_{sat}. Dalen (2012) carried out a similar research. The raingarden used by Dalen (2012) and Paus et al. (2015) is located in at Risvollan, Trondheim.

The objective of this research was to document a raingardens infiltration capacity in the winter months. The expectation is that these results on winter infiltration can help develop better standards for designing cold climate raingardens.

The research questions:

1) How does the winter conditions influence the infiltration capacity in the raingarden?

2) What modifications to the MPD-method are necessary for measuring the K_{sat} of frozen winter soils?

3) What are the design implications of seasonal variations in infiltration capacity?

2. Theoretical framework – state of the art

2.1. Infiltration

The Three-step-strategy described by Lindholm et al. (2008), is a stepwise approach for handling stormwater on the surface. As the name indicates, it consist of three steps. The first one being infiltrating and retaining the water from small rain events. The next step being retaining and delaying water from medium to larger rain events. The last step being securing safe floodways for the excess water under rain events larger than design rain events. Raingardens are typically designed for functioning as part of step 1 and 2.

The main difference between infiltration based stormwater solutions and subsurface storage stormwater solutions, is the ability to infiltrate and filter water (Paus, 2016). Pitt et al. (2008) found with field and laboratory test, that compaction of the soil greatly reduced the steady-state infiltration rate. They found that the infiltration rate depends on the soil type, ponded water depth, initial soil saturation and soil compaction. The K_{sat} value can be seen as a conservative minimum measure of the actual infiltration rate (Dingman, 2002; Paus, 2016). According to Hillel (1971) the infiltration rate in vertical direction is expected to settle down to a steady state driven by the earth's gravity and this is practically equal to the K_{sat}. Archer et al. (2002) found that the K_{sat} decrease with increase in silt concentration. Since bulk density's positive correlation with the silt concentration and negative correlation with the K_{sat}. This is in line with Hillel (1971), which says that K_{sat} depends on the soil pore size. Braga et al. (2007) in the US observed a seasonal variation in the infiltration rate and based their study on a calibrated model and field measurements of an infiltration basin. They observed that the infiltration rate decreased with decreasing temperature.

2.2. Raingardens

Raingardens are vegetated depressions in the soil, to which stormwater is lead during rainfalls. They are also called bioretention, rain gardens or biofilters. Raingardens typically consist of plants that tolerate high water levels for up to 48 hours. Ødegaard et al. (2012) recommended not constructing raingardens where ponding last for longer than 48 hours. Typically, raingardens are designed to infiltrate and retain water before gradually releasing it into the stormwater network or receiving recipients. The capacity of raingardens depends mainly on their infiltration capacity and storage area (Medina, D. & Pomeroy C., 2012). In urban area – where there often is limited surface area – the storage area can be the limiting factor for raingardens' capacity.

In situations similar to this, raingardens typically form a part of a local stormwater system. In such situations, raingardens are generally designed to retain and infiltrate moderate rainfall event. What is considered moderate vary significantly from place to place (Lindholm et al., 2008).

Paus and Braskerud (2013) suggest using Equation 1 for sizing of the raingarden cell. The equation presents the relationship between the surface stored and infiltrated water in the raingarden.

$$A_{raingarden} = \frac{A \times c \times P}{h_{max} + (K_{sat} \times t_r)} \tag{1}$$

Where: $A_{raingarden}$ [m^2] stands for the surface area of the raingarden. P [m] is the design precipitation of the raingarden. A [m^2] is the area of the catchment, c [-] is the runoff coefficient of the catchment, h_{max} [m] is the maximum ponding depth and t_r [h] is the duration of the stormwater flow into the raingarden. K_{sat} uses the [m/h] as denomination. Paus et al. (2015) recommended a K_{sat} value of at last 10 cm/hour in cold climate raingardens.

2.3. Raingardens in cold climate

Measurements in the last years (1985-2014) has shown an increase in annual rain (4 %), autumn runoff (3%), winter runoff (6 %) and spring runoff (6 %) in Norway (Hanssen-Bauer et al., 2015). In some regions the summer, winter and spring has experienced a 10 % increase in rain. The temperature during winter has increased with 0.4 ˚C. The report *Climate in Norway 2100 – a knowledge base for climate adaptation* recommend that developers base there assumptions for the climate in the next decades on observation from the last years (1984-2014). Peel et al., (2007) has developed an updated world map of Köppen-Greiger climate classification. There they classify the climate in Trondheim as a cold climate without dry season and with cold summer.

During winter the soil media in cold climate raingardens will normally freeze. There are mainly two types of soil frost: concrete frost and porous/granular frost. Concrete frost occurs if the soil was fully saturated before freezing. Whereas granular frost occurs if the soil was unsaturated before freezing and with low moisture. The main difference between these two is the ability to infiltrate water. Whereas concrete frozen soil has low and granular frozen soil can have high infiltration capacity (Muthanna, 2007).

2.4. Measuring infiltration with Modified Philip-Dunne Infiltrometers

The Modified Philip-Dunne Infiltrometers (MPD) was developed at the University of Minnesota, as a low water need simplified method for measuring infiltration capacity (Ahmed et al., 2014). It is a modified version of the Philip-Dunne borehole permeameter. The MPD-method is among other things designed more affordable and easier to operate in the field. The MPD-method carries out measurements of K_{sat} based on surface infiltration. Whereas the Philip-Dunne method is based on measurements of K_{sat} in a borehole underground. Both the MPD-method and the Philip-Dunne method is based on assumptions of the Green-Ampt model (Philip, 1993; Ahmed et al., 2014). Ahmed et al. (2014) presented both the MPD-method and procedures for calculating K_{sat}. Paus (2016) rewrote the procedure presented in Ahmed et al. (2014) in the form of a computer code. The computer code was written in the computer program Matlab R2016b. This uses Matlab and Microsoft Excel. The method presented by Paus (2016) automatically calculates K_{sat}. The code uses water level at specified time, column distance below ground, initial and final soil water content, inside column radius and initial water level as inputs. For example, the code is used in Paus et al. (2013), Paus et al. (2014), Paus et al. (2015) and Dalen (2012). Blom (2017) assessed different in-situ methods for measuring infiltration rate. The methods in question was Double ring infiltrometer (DR), Mariotte-infiltrometer, Pit-infiltration and MPD. Blom (2017) found out that the MPD-method had the highest infiltration and was the easiest method to operate. Blom (2017) pointed out the importance of measuring the natural infiltration capacity when planning local infiltration based stormwater solutions. Dalen (2012) concluded that the geometric mean gives the most accurate presentation of K_{sat} from MPD measurements.

2.5. Simulations of raingardens using the RECARGA model

The RECARGA model was developed to simulate raingardens by the University of Wisconsin-Madison (Dussaillant et al., 2005). The inputs needed for simulating a raingarden are precipitation data (mm per hour), the soils K_{sat}, raingarden design parameters and catchment data. It can simulate everything from a single storm event up to several years of precipitation. It can only simulate raingardens and can not simulate combinations of raingardens and other stormwater solutions. Dalen et al. (2012a) used RECARGA to investigate the importance of a raingardens area percentage of the impervious catchment area on the amount of annual rain infiltrated and hours with ponding in a year. Dussaillant et al. (2005) presented a similar study as Dalen et al. (2012a). In addition to presenting the

RECARGA model Dussaillant et al. (2005) simulated the impact of the ratio between raingarden and the impervious catchment area on groundwater recharge.

3. Materials and Methods

3.1. Field measurements of infiltration capacity

The examined raingarden is located in a cold climate zone (Peel et al., 2007). The research on the raingardens performance was based on a case study approach (Yin, 2003), combining technical (field measurements), experimental (simulations) and qualitative approaches. A scoping literature review on cold climates infiltration based stormwater systems was carried out (Arksey & O`Malley, 2005), alongside a content analysis of drawings and technical specifications (Weber et al., 1990) (Appendix E).

K_{sat} was measured with MPDs through the winter and spring 2016-17, (October- May). The Åsveien raingarden consist of nine connected sections (see illustrations in Appendix E). The MPDs were constructed of a plastic column of 50 cm length and approximately 5 cm inner radius. The columns were put 5 cm down in the soil and filled with water. The water level in the column was measured with regular intervals. The water level and time were registered. The tests were limited to approximately one hour, since the low infiltration capacity rendered infiltrating all of the water impractical. The soil mass water content [gram water/gram undried soil] before and after test, were obtained with soil samples taken during field test. The samples were analyzed for mass water content (ϴ) [%] in lab and stored in a refrigerator. Where the samples weight was measured before and after drying. The samples were dried in a stove for at least 48 hours at 105 ˚C. The K_{sat} values calculated with the Matlab code from Paus (2016) were compared with results from similar studies. The cold condition of the test site made measuring the change in ϴ further difficult than anticipated. Analyzing change in ϴ was challenging due to the ice content in the frozen ground. When the increase in ϴ was calculated to be negative, the increase was set to 1 %.

3.2. Winter Modifications on the MPD-method

The in-situ conditions of the research necessitated some modifications to the original methodological approach. Modifications on the MPDs rendered measurements on frozen ground possible. A cast iron pipe (inner radius 5 cm) was hammered down in the frozen soil. The cast iron pipe and the original MPD plastic column was connected with the help of an internal muff. The muff have a smaller internal radius then the iron pipe and PVC column. This modification of the MPD-method was developed with experimental testing through

February and March 2017. The winter modified MPDs are further called Balstad Modified Philip-Dunne Infiltrometers (BMPD). For supplementary information about the MPD- and BMPD-method, see Appendix A.

3.3. Simulations of seasonal variation in K_{sat}

To investigate the design implications of seasonal variations in infiltration capacity, simulations of a typical raingarden located in Trondheim was carried out in RECARGA. In the simulations, it was distinguished between winter and summer season. This to investigate the design implications of the seasons. The winter season was defined as lasting from October 1st to April 31st. This definition was chosen because it corresponded with this study's period of field measurements. The summer season was defined as the rest of the year (May 1st – September 30th). The needed precipitation data was imported from Eklima. Eklima is a database of hydrological data from Norway. In the periods of interest, no available data on evaporation or runoff from snowmelt from the measurement stations in Trondheim existed. This led to that the inflow input data into RECARGA only were precipitation data. The precipitation data were mm per hour, from Voll measurement station in Trondheim. The data were from the period October 1st 2012 to April 31st 2015. The data were manually divided into the following winter and summer periods: Winter 2012/2013, Summer 2013, Winter 2013/2014, Summer 2014 and Winter 2014/2015. The Åsveien raingarden was defined as a typical raingarden located in Trondheim, with a depression zone of 18 cm depth, a root layer of 60 cm loamy sand, a storage layer of 20 cm sand and a native soil layer of clay. The model of the raingarden included an underdrain pipe with diameter of 100 mm. The size of the catchment was set 10 000 m^2 and with a 100 % imperviousness. The size of the raingarden and the K_{sat} value of both the root layer and storage layer varied throughout the simulations. The K_{sat} value of the native soil layer was set fixed to the programs standard for clay (0.18 cm/h). For supplementary information about the input data to RECARGA, see Appendix C.

The size of the catchment and the raingarden is irrelevant for the simulations. The vital factor is the ratio between the raingarden and the catchment area. The imperviousness of the catchment was set to 100 %, because it then is equal to the impervious catchment. This renders the results of the simulations independent of a catchments imperviousness and renders the results usable for similar raingardens with different catchment imperviousness.

The ratio between a raingardens area and the impervious catchment area, are further called the RIC ratio. The RIC ratio was simulated for the following values: 0.5 %, 1%, 2%, 4%, 6% and 10%. The K_{sat} value of the root layer and storage layer were always set to the same value. The value of K_{sat} (in root and storage layer) was simulated for the following values: 0.05cm/h, 0.1 cm/h, 0.5 cm/h, 1.4 cm/h, 2.5 cm/h, 5 cm/h and 10 cm/h (not 0.05 cm/h in summer). The results presented in this study are percentage of seasonal inflow that infiltrated or drained.

Typically, it is necessary to underdrain a raingarden located in Trondheim. The native soil layer was set to clay because it is often the native soil in Trondheim and it provides a conservative assumption of the infiltration capacity in the native soil.

Dalen (2012) inspired the procedure described above. Dalen (2012) investigated the percentage of the annual precipitation that the raingarden infiltrated, while the presented study in this paper distinguished between summer and winter season. Dalen also used inflow data (precipitation and snowmelt) from Trondheim (Risvollan measurement station), but from the years 1998, 2000 and 2002. The presented study in this paper chose to simulate lower K_{sat} values than Dalen (2012). This to show K_{sat} values that corresponds with the presented field measurements of K_{sat} in this study when simulating winter conditions.

4. Results and Discussions

4.1. Field measurements of infiltration capacity

The mean K_{sat} value from the results of Paus et al. (2015), through the whole period of testing (36 months) was 5.0 ± 5.7 cm/h. Paus et al. (2015) also analyzed K_{sat} of two raingardens in Oslo, 52.5 ± 23.7 cm/h (36 months) and 31.5 ± 26.7 cm/h (23 months). The large standard deviation clearly indicate seasonal variations. The results presented in this paper indicates large seasonal variations in infiltration capacity (Figure 1). The variations are larger than what were presented in previous studies (Figure 2) (Dalen, 2012; Paus et al., 2015). The results presented in this paper clearly show that the winter conditions (low temperature) negatively influences the saturated hydraulic conductivity (K_{sat}) by decreasing it (Figure 1). Therefore also negatively influences the infiltration capacity in the raingarden, this is in line with Braga et al. (2007). The reason the presented values in October and May is low could be because of compaction, but the degree of compaction (bulk density) was not tested. However, it is not believed this could have affected the variation in K_{sat}. The geometric mean were chosen to most accurately present infiltration capacity in the raingarden from the field measurements of K_{sat}. The K_{sat} value was close to 0.05 cm/h from November to April, but sometimes it were 0 cm/h.

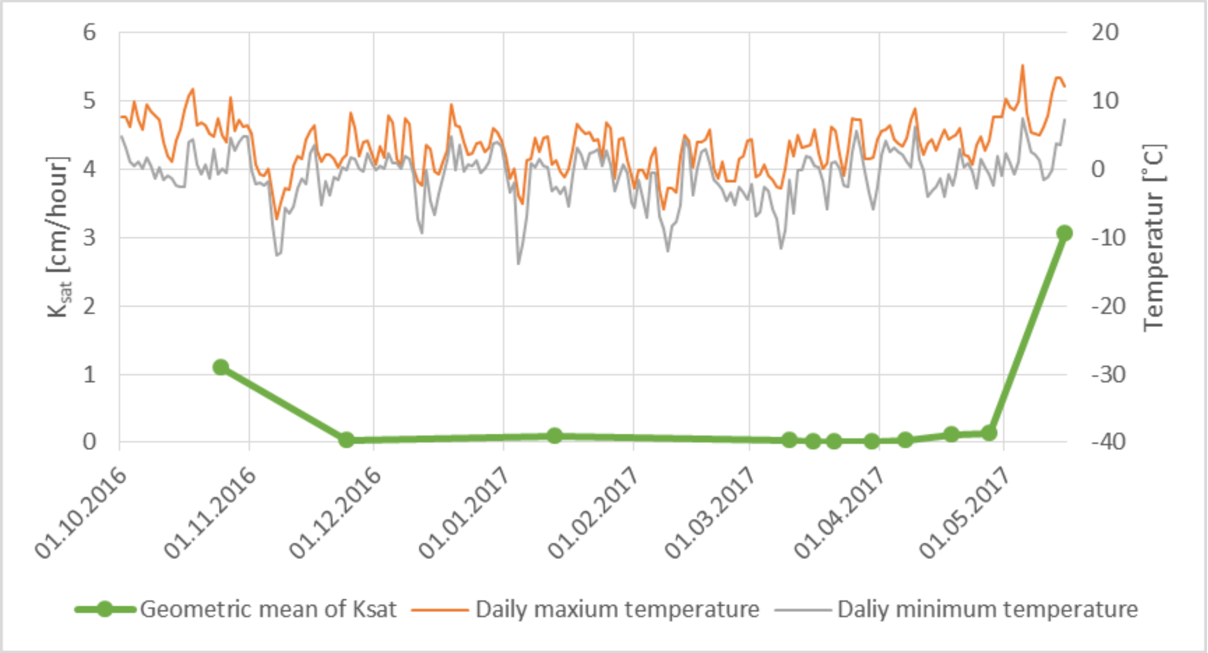

Figure 1 The variation in the geometric mean of the K_{sat} field measurements and temperature in the period of field measurements. The markers on “the geometric mean of K_{sat}” represents the geometric mean of every usable field measurement of K_{sat} on that specified day.

The results from field measurements of K_{sat} is lower than the reported values from Dalen (2012) and Paus et al (2015) (except for in May) (Figure 2). Paus et al (2015) presented values of K_{sat} estimated from observed infiltration rate (OIR) including the months of November, March and April. As previous reported Paus et al (2015) conducted this part of his study on the raingarden at Risvollan, and according to the comparisons in Appendix F the Risvollan and Åsveien raingarden are similar in many ways. The reason for the difference in K_{sat} values in the mentioned months could be dissimilarities in the raingardens not shown in Appendix F (degree of compaction, organic matter in the soil & etc.) or that the OIR method measures larger values than the MPD-method. However, this is in conflict with the fact that Paus et al (2015) concluded that the MPD-method measured larger values than the OIR method. Another reason can be that the effect shown in Figure 1 had enlarged impact on the K_{sat} when this study conducted the MPD measurements, than when Paus et al (2015) conducted the OIR and MPD measurements.

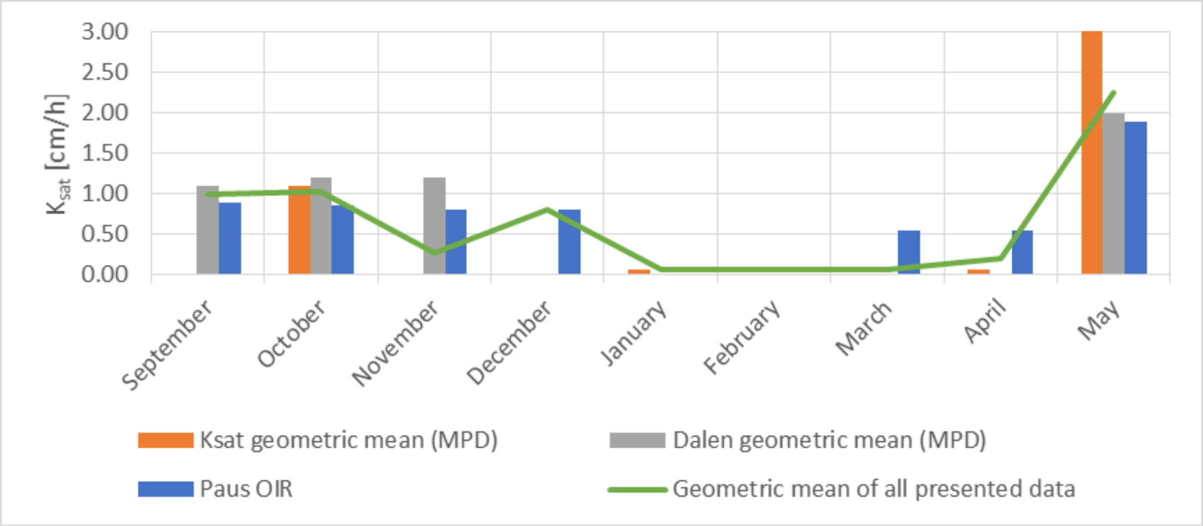

Figure 2 Comparison of this study's geometric mean K_{sat} field measurements with MPD against the geometric mean K_{sat} field measurements with MPD from Dalen (2012) and the mean K_{sat} values estimated by Paus et al. (2015) from observed infiltration rate (OIR).

It is believed that the value of K_{sat} will decrease with increasing change in ϴ (Paus, 2016). During analyzing the results from field measurements of K_{sat}, it was discovered that this relationship was often illogical and seemingly random (see Figure 3). To investigate the reason for this, it was created a Matlab code that looped the code presented by Paus (2016) with increasing change in ϴ (see Appendix B). The investigation revealed that the value of K_{sat} was dependent on the last recorded value of water level. In measurements with last water level above zero, then K_{sat} as function of change in ϴ was illogical. However, in measurements with last water level equal to zero, then the K_{sat} as function of change in ϴ was logical and in line with the theory. In measurements were the last recorded water level was above zero, it were created artificial measurement data of water level and time. This were completed by linearly increasing the expected values of water level and time too where the water level were expected to equal zero. This were based on the measured data of water level and time, and their linear trend line formula.

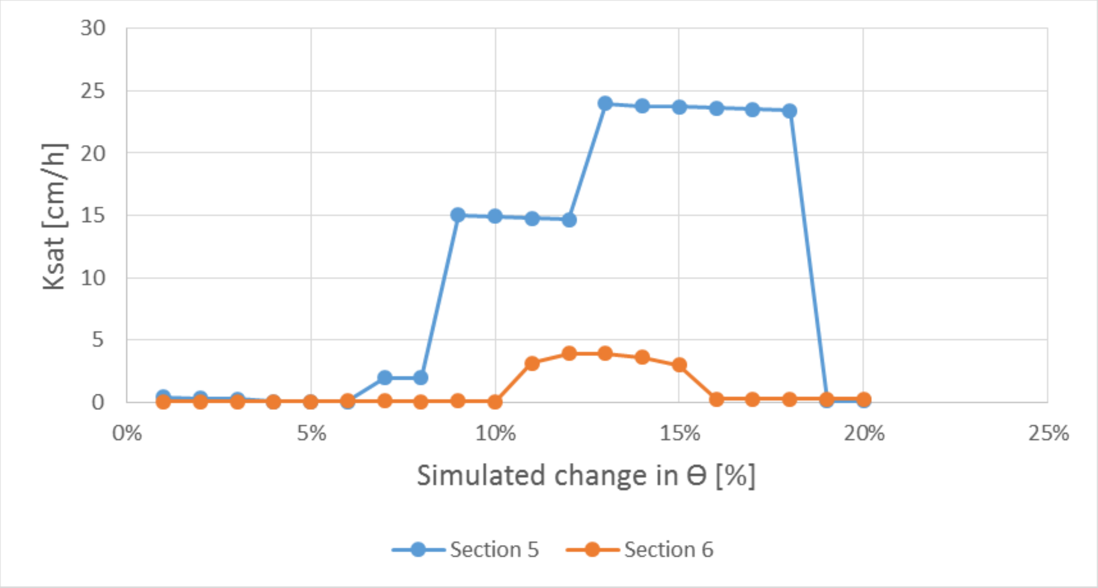

Figure 3 Example of illogical results from simulating change in ϴ, used field measurements from 21st of March 2017

In addition to show logical results from simulating change in ϴ, Figure 4 shows that the K_{sat} value only depends on the change in ϴ if its maximum value independent of change in ϴ is above 0.1 cm/hour. Below 0.1 cm/hour the change in ϴ have no real implication on the K_{sat}. This could be because the K_{sat} values in these situations is close to zero. This removes the need for measurements of change in ϴ, when the maximum achievable value of K_{sat} is below 0.1 cm/h.

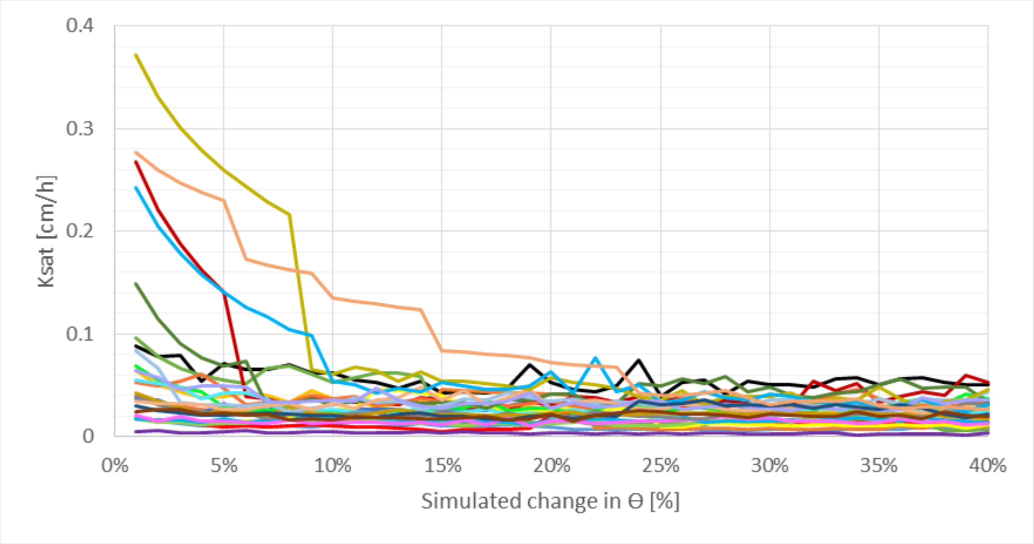

Figure 4 Logical results on simulated effect of increased change in mass water content (ϴ) during testing on field measurements of K_{sat} with theoretical highest K_{sat} above and below 0.1 cm/h.

The graphs in Figure 3 and Figure 4 were calculated by running the Matlab code in a loop, where the change in Θ were increased from 1% to 40% (the simulation in Figure 3 had error values from 20% to 40%). As previous stated, analyzing change in Θ was challenging due to the ice content in the frozen ground. This result also removes these uncertainties. Not needing to analyzing soil samples also renders the MPD-method easier to operate and less time consuming.

4.2. Experience from winter modifying the MPD-method

During measurement of infiltration capacity in the field, the study revealed that the MPD-method sometimes did not manage to get infiltration measurements when the soil was frozen. The study experienced that the soil was soft enough for measurements in January. However, in February the soil was too hard for measurements. The problem was that when the soil was too hard –because of frost – it was not possible to place the end of the measurement column 5 cm below ground. In these conditions, it would have taken a lot of force to press the column below ground. Since the material of the column is Polyvinyl chloride (PVC), it was presumed that the column would break in the procedure. When realizing this in February we tried to come up with a modification that made measurements in cold conditions possible. One of the objective was to come up with an easy and low cost solution. After several attempts, the optimum solution was the solution described in "Winter Modifications to the MPD-method". The solution is easy to make and have a low cost. It was used in field measurements in March and it has not been observed any faults with it. The choice of muff ended on an interval muff, because the external muff could not properly seal the joint between PVC column and cast iron pipe. However, by definition the internal muff have a smaller internal radius (4.5 cm) than the PVC column and the cast iron pipe. This was assumed insignificant on the result. However, this could have resulted in slightly lower values of K_{sat} then presented in this paper.

4.3. Simulations on the design implications of seasonal variations in K_{sat}

Figure 5 and 6 shows the results from RECARGA simulations of the raingarden. This shows the effect of the raingarden infiltration capacity (K_{sat}) and RIC ratio on the percentage of winter or summer inflow infiltrated or drained. The percentage of winter inflow infiltrated or drained is the mean value from simulating three winters (Winter 2012/2013, Winter 2013/2014 & Winter 2014/2015) is shown in Figure 5. The percentage of summer inflow infiltrated or drained is the mean value from simulating two summers (Summer 2013 & Summer 2014) is shown in Figure 6. On average the values in Figure 5 is approximately 10 % higher than the values in Figure 6 for the same value of K_{sat} and RIC ratio.

Data on evaporation and runoff from snowmelt were not used in the simulations. Data on evaporation would probably not have affected the results in Figure 5. The reason for this that evaporation does not occur when the temperature is around zero Celsius. In the period of field measurements, the temperature were often around zero Celsius (Figure 1). However, the lack of data on evaporation could have affected the results in Figure 6. This could have resulted in higher values of percentage inflow infiltrated or drained. However, you can see the values in Figure 6 as conservative percentage values of inflow infiltrated or drained by the raingarden in summer season.

Data on runoff from snowmelt would have resulted in higher volume of inflow to the raingarden in the end of winter season and in the beginning of summer season (spring). It is unclear to what extent this would have reduce the values of percentage inflow infiltrated or drained.

The design implications of results shown in Figure 5 and Figure 6, are that a reduction in infiltration capacity (K_{sat}) will result in a reduction in a typical raingardens performance to infiltrate or drain inflow. This means an increase in the volume of runoff that goes in overflow from the raingarden. This emphasizes the importance of having stormwater solutions downstream the raingarden, which can handle the overflow from the raingarden. The simulation shows that a raingarden similar to the Åsveien raingarden (2.8 % RIC ratio) might experience a change in its performance to handle winter inflow from 75 % to 25 %, when the K_{sat} value goes from 1 cm/h to 0.05 cm/h.

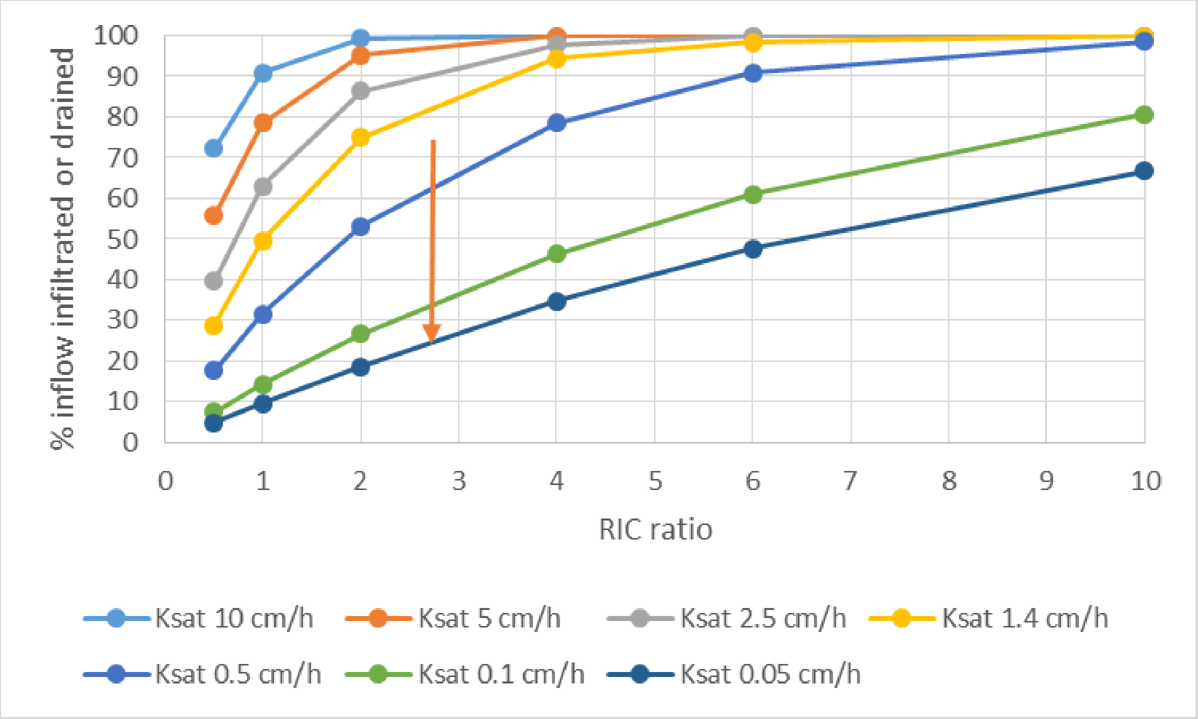

Figure 5 The effect of the raingardens infiltration capacity (Ksat) and the raingarden area impervious catchment area (RIC) ratio on the percentage of winter season inflow infiltrated or drained. The arrow shows change in percentage of winter season inflow infiltrated or drained, when Ksat changes from 1 cm/h to 0.05 cm/h.

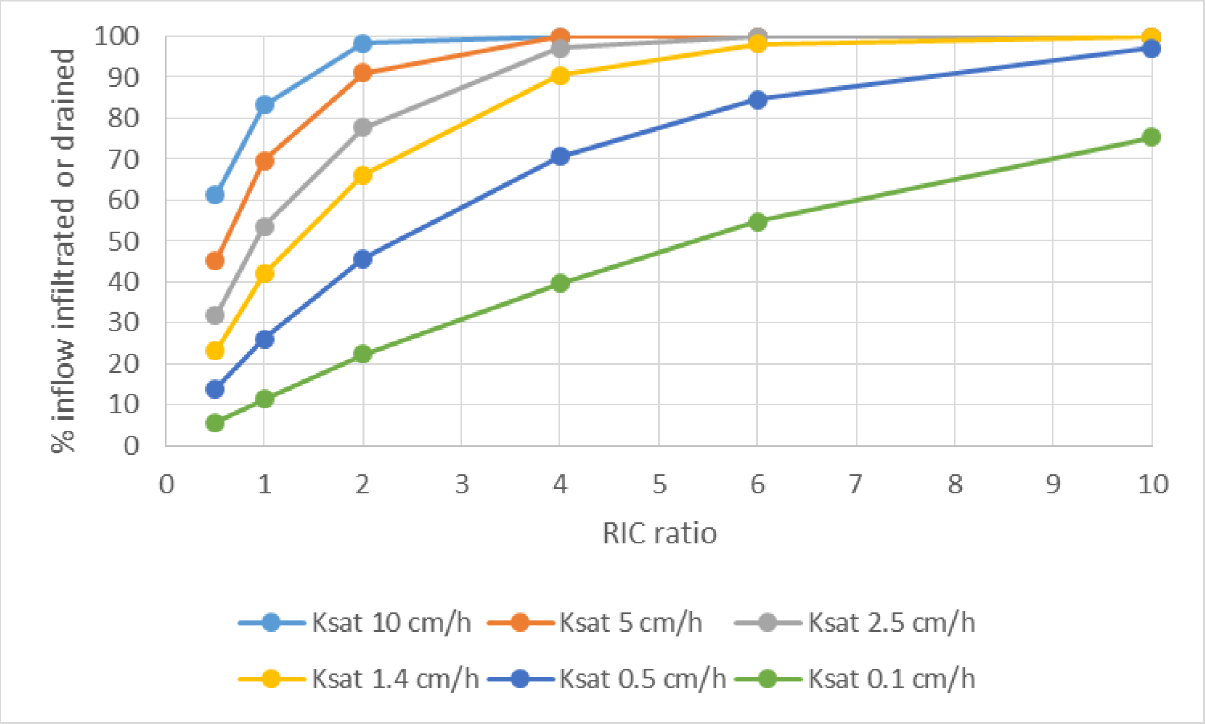

Figure 6 The effect of the raingardens infiltration capacity (Ksat) and the raingarden area impervious catchment area (RIC) ratio on the percentage of summer season inflow infiltrated or drained.

5. Conclusions

Few studies on raingardens in cold climates have been carried out. Of these, few have included full-scale tests on seasonal variations in infiltration capacity.

The results presented in this study clearly show that the low temperature during winter decreases the infiltration capacity (K_{sat}) in the raingarden. The infiltration capacity changed from 1 cm/h in October too close to 0.05 cm/h in November-April and up to 3 cm/h in May. This shows reduced infiltration during winter, with values much lower than the recommended level of 10 cm/h (Paus et al., (2015)).

To achieve field measurements of K_{sat} during mid-winter it was necessary to winter modify the MPD column. It was necessary to connect the MPD-column with a cast iron pipe for measuring the K_{sat} of frozen winter soils. This new modification of the method is called Balstad modified Phillip-Dunne (BMPD).

Simulations in RECARGA shows that the design implications of seasonal variations in infiltration capacity for a typical raingarden in Trondheim, is that its performance to handle the winter inflow (infiltrate or drain) will decrease with decreasing infiltration capacity (K_{sat}). For a raingarden with a RIC ratio of 2.8 %, the performance will decrease from 75 % to 25 % of winter inflow when the K_{sat} decrease from 1 cm/h to 0.05 cm/h.

Additional research on the infiltration capacity of cold climate raingardens in winter months could deepen the understanding of this picture. Additional field measurements from different raingardens in the similar climate – as on the Åsveien raingarden – are needed for a deeper understanding of the seasonal variation in infiltration capacity. The simulation of different K_{sat} values will improve with data on snowmelt and evaporation. Laboratory analysis of the BMPD-method and MPD-method could extend the understanding of the possible differences between the methods.

6. Acknowledgments

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Appendices

A Supplementary method

The following text is intended as supplementary information about the MPD- and BMPD-method used in the presented manuscript. This also functions as a more detailed description of the method used for measuring saturated hydraulic conductivity (K_{sat}) in this thesis. The information in this text is based on experience obtained through field measurements associated with this thesis and advice from supervisor Associate Professor Tone Merete Muthanna.

The following equipment are needed for the measuring K_{sat} with the MPD-method:

- Needed number of transparent PVC column (MPD column) (Length 50 cm, internal radius approximately 5 cm)
- Measuring tape on every MPD column
- Two airtight plastic bags for every measurement with MPD columns
- Notepad and pen
- Small garden shovel
- Hammer and piece of wood (minimum 2 x 10 x 10 cm)
- Stopwatch or smart phone
- 10L water can per third MPD column

Additional equipment for BMPD-method:

- Cast iron pipe (minimum length 15 cm, internal radius 5 cm)
- Muff (need to go inside the PVC and iron pipe) (exterior radius 5 cm)
- Sledgehammer
- Large piece of wood (minimum 5 x 10 x 10 cm)
- Metal measuring tape

The number of needed MPD columns depend on how many measurements of K_{sat} is needed at the same time. Several MPD columns will reduce the total needed time for field measurement and can result in more measurements per hour. However, a large number of MPD columns will render the measurement of water level and time more difficult.

From experience, it is recommended that the you use at least three MPD columns, since some the field measurements can be disturbed by members of the public. During the work related to this thesis it has been experienced that one man can handle up to six MPD columns.

The field measurements start by selecting a spot for each measurement of K_{sat}. From experience, it is recommended to place the columns at least 1.5 meter from each other to isolate the measurements. Press the columns 5 cm into the ground, utilize the hammer and piece of wood if needed. Try to install the columns as vertically as possible. Sample a soil sample (at least 100 gram) of surface soil with the small garden shovel and place it in the airtight bag. Sample the soil in the proximity of the MPD column, around 20 cm to 50 cm from the column. Label the airtight bag for improved control over the samples. Dalen (2012) filled the columns with 40 cm water column, this is not necessary for the analysis of field measurements. When the soil have high infiltration capacity (> 10 cm/h) 40 cm of water column could be beneficial for easier registration of water level. This because of that the water level will drain faster with increased infiltration capacity. When the soil has low infiltration capacity (< 1 cm/h), it can be adequate with initial water level of 20 cm.

Begin to write down the water level and time when the water inside the column is at desired initial water level. The water level is by Ahmed et al. (2014) defined as the distance between water surface in the column and the ground surface. The time step between registration of water level and time needs to be adapted to the rate of change in water level. The optimal analysis of field measurements require the water level in the MPD columns to reach zero (see “Field measurements of infiltration capacity” in the manuscript). When the water level has reached zero or the field measurement is determined to be terminated, remove the MPD column from the ground and sample the soil where the column was.

Repeat the same procedure as described above for additional MPD columns.

The procedure for the BMPD-method is similar to the MPD procedure, apart from that the cast iron pipe is hammered 5 cm down in the soil. When the cast iron pipe is in position, the muff connects the cast iron pipe with the original MPD column. The muff have a 0.5 cm smaller internal radius then the cast iron pipe and MPD column, the effect of this temporary change in radius is assumed insignificant on the result. The research presented in this thesis has used a metal measuring tape inside the BMPD column for the registration of water level, this because the BMPD column is not completely transparent as the MPD column.

The analysis of field measurements is independent of the chosen method (MPD or BMPD). The computer code written by Paus (2016) uses a excel sheet with the field measurements and equipment specification as input. For more information about the Matlab script and the input excel sheet see Paus (2016) or Appendix B. For more information about the MPD-method, see Ahmed et al. (2014) or Dalen (2012).

B Looped Matlab script

The following text is a Matlab script modified for this thesis. The Matlab script is based on the Matlab script presented in Paus (2016) for analyzing field measurements of MPD columns. Most of the code is a direct copy of the script presented in Paus (2016). The difference between this script and the script presented in Paus (2016) is that this one goes in a loop 40 times and increases the change in water content by 1 % for each loop. In other words, this is the script from Paus (2016) that goes in a loop 40 times and do not have a fixed change in water content. The codes highlighted with yellow is codes written in conjunction with this Master thesis and is not copied from Paus (2016).

```
data = xlsread('name excel file', 'Input');              % Reads input
matrix
n = size(data);                                        % Finds the size of
the input matrix
n = n(1);                                              % Finds the number of
rows (n)
t = data(1:n,3)*60*60*24;                             % Finds time time
matrix and convert values from days to seconds
h = data(1:n,2);                                       % Finds head matrix

Ksattabel = zeros([40 3]);

for p= 1:40

dteta= (p/100);                                         % Finds differences
in volumetric water content (dteta)


Lmax = data(3,1);                                       % Finds length of
device below surface
rd = data(4,1);                                         % Finds radius of
device
H = data(5,1);                                          % Finds phase one
initial height
K = 0.001;
C = -1000;

tt(1,1)=0;                                             % Sets first
intermediate time value to zero
i=2:n;                                                 % Prepare integers for
the remaining intermediate time values
tt(i,1)= (t(i,1)-t(i-1,1))*0.5+t(i-1,1);               % Finds intermediate
time values (tt)
hh = spline(t,h,tt);                                   % Cubic spline
interpolation to find intermediate h values (hh)

q(1,1)=0;                                              % Sets first
difference value to zero
qt(1,1)=0;                                             % Sets first time
difference value to zero
qh(1,1)=0;                                             % Sets first head
difference value to zero
```

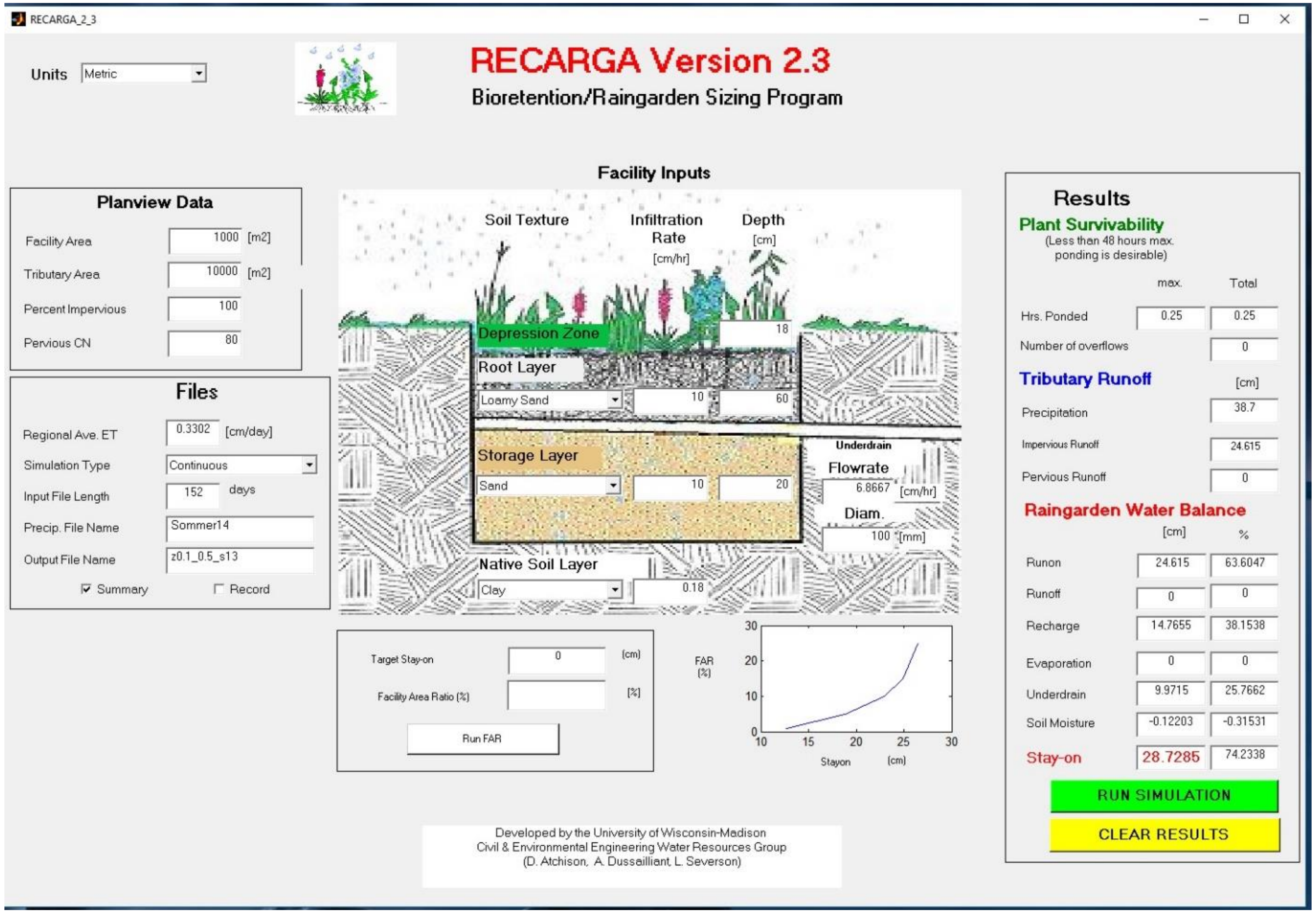
```
i = 2:n;                                             % Prepare integers for
the remaining intermediate time values
qt(i,1) = tt(i,1)-tt(i-1,1);                         % Fills in remaining
time difference values (qt)
qh(i,1) = hh(i,1)-hh(i-1,1);                         % Fills in remaining
head difference values (qh)



for i=2:n,                                         % Calculate difference
values (q)

    q(i,1)=qh(i,1)/qt(i,1);

end

i=1;
while(i<n+1)                                         % Using Newton-Rhapson
to find R values
    x = 1;
    ii = 1;

    while(ii<100000)

    f1=2*x^3+Lmax*3*x^2-Lmax^3-2*(rd/2)^3-3*rd^2*(H-hh(i,1))/(dteta);
    ff = 6*x^2+Lmax*6*x;
    x = x-f1/ff;
    ii =ii +1;
    R(i,1)=x;

    end
i=i+1;
end


for i=2:n,                                           % Calculate difference
values (q)

    q(i,1)=qh(i,1)/qt(i,1);

end

i = 1;
while(i<n+1)
    if R(i,1)<(Lmax^2+rd^2)^0.5, R(i,1)=0;           % Calculate R values
(R)
    end
    i=i+1;
end



i = 2:n;                                             % Prepare integers for
the remaining intermediate time values
dt1(i,1)=tt(i,1)-tt(i-1,1);                          % Fills in remaining
time difference values (qt)
```

```
for i=1:n,
    if R(i,1)<10^-10, ss=i;            % Calculate R values (R)
    end
end



KC0 = [0.01,-100];
f = @(KC)optt(KC,n,Lmax,dteta,R,rd,hh,dt1,ss);
[KC,f] = fminsearch(f,KC0);

Results(1,1)=KC(1);
Results(1,2)=KC(1)*60^2;
Results(1,3)=KC(2);
Results(1,4)=f;
Results(1,5)=n-ss-1;
Results(1,6)=sqrt(f/(n-ss-1));


i = 2:n;                                                  % Prepare integers for
the remaining intermediate time values
dh1(i,1)=-hh(i,1)+hh(i-1,1);                              % Fills in remaining
time difference values (qt)

KC0 = [0.01,-100];
f = @(KC)opth(KC,n,Lmax,dteta,R,rd,hh,tt,dh1,ss);
[KC,f] = fminsearch(f,KC0);

Results(2,1)=KC(1);
Results(2,2)=KC(1)*60^2;
Results(2,3)=KC(2);
Results(2,4)=f;
Results(2,5)=n-ss-1;
Results(2,6)=sqrt(f/(n-ss-1));


'Estimated parameters:';

format shortG

ForExcelSheet(1,1)=Results(1,1);
ForExcelSheet(2,1)=Results(1,2);
ForExcelSheet(3,1)=Results(1,3);
ForExcelSheet(4,1)=Results(1,4);
ForExcelSheet(5,1)=Results(1,5);
ForExcelSheet(6,1)=Results(1,6);
ForExcelSheet(7,1)=Results(2,1);
ForExcelSheet(8,1)=Results(2,2);
ForExcelSheet(9,1)=Results(2,3);
ForExcelSheet(10,1)=Results(2,4);
ForExcelSheet(11,1)=Results(2,5);
ForExcelSheet(12,1)=Results(2,6);

ForExcelSheet;
```

```
if Results(1,4)<Results(2,4), 'Delta T optimization gives smallest error:';
else 'Delta H optimization gives smallest error: ';
end

 if Results(1,4)<Results(2,4),Ksat=Results(1,2);
 else Ksat=Results(2,2);
 end

if Results(1,4)<Results(2,4), C=Results(1,3);
else C=Results(2,3);
end


Ksattabel(p,1)= (dteta*100);
Ksattabel(p,2) = Ksat;
Ksattabel(p,3)=C;




end


disp('    Ksat [cm/h]')
disp(Ksattabel(1:40,2))


clear all
```

C Input window in RECARGA

This is a Print screen of the window where you simulate precipitation events in RECARGA. This the only window in the RECARGA model. Precipitation, evaporation and runoff data from snowmelt is inputted in the model by writing the inputfile's name in the space next to "Precip. File name", in this example its name is Sommer14. The results can be seen on the right side and in an output file, in this example named z0.1_0.5_s13. The raingardens and the catchments area are called Facility area and Tributary area. For more information about the RECARGA model see Dussaillant et al. (2005)



Units: Metric

Planview Data

Facility Area: 1000 [m2]
Tributary Area: 10000 [m2]
Percent Impervious: 100
Pervious CN: 80

Files

Regional Ave. ET: 0.3302 [cm/day]
Simulation Type: Continuous
Input File Length: 152 days
Precip. File Name: Sommer14
Output File Name: z0.1_0.5_s13
☑ Summary ☐ Record

Depression Zone: Depth 18
Root Layer: Loamy Sand, Infiltration Rate 10, Depth 60
Storage Layer: Sand, Infiltration Rate 10, Depth 20
Native Soil Layer: Clay, 0.18
Underdrain Flowrate: 6.8667 [cm/hr]
Diam.: 100 [mm]

Target Stay-on: 0 (cm)
Facility Area Ratio (%): [%]

Results

Plant Survivability
(Less than 48 hours max. ponding is desirable)

	max.	Total
Hrs. Ponded	0.25	0.25
Number of overflows		0

Tributary Runoff [cm]

	[cm]
Precipitation	38.7
Impervious Runoff	24.615
Pervious Runoff	0

Raingarden Water Balance

	[cm]	%
Runon	24.615	63.6047
Runoff	0	0
Recharge	14.7655	38.1538
Evaporation	0	0
Underdrain	9.9715	25.7662
Soil Moisture	-0.12203	-0.31531
Stay-on	28.7285	74.2338

Developed by the University of Wisconsin-Madison
Civil & Environmental Engineering Water Resources Group
(D. Atchison, A. Dussailliant, L. Severson)

Figure 7 Print screen of the input window in the RECARGA model

D Pictures of Åsveien raingarden

The following pictures have been captured in conjunction with this Master thesis.

Figure 8 Picture of the Åsveien Raingarden during field measurements in October 2016.

Figure 9 Picture of the Åsveien raingarden during field measurements in January 2017.

Figure 10 Picture of the Åsveien raingarden in March 2017

Figure 11 Picture of the Åsveien raingarden in April 2017

E Illustrations of the Åsveien school and raingarden

The following illustration have been received from Løvetanna Arkitekter (“*Dandelion Architects*”). Higher quality version of the illustrations are available as electronic appendix. The illustrations are not “as-build drawings” of the School, but are illustrations of the raingarden and its surroundings.

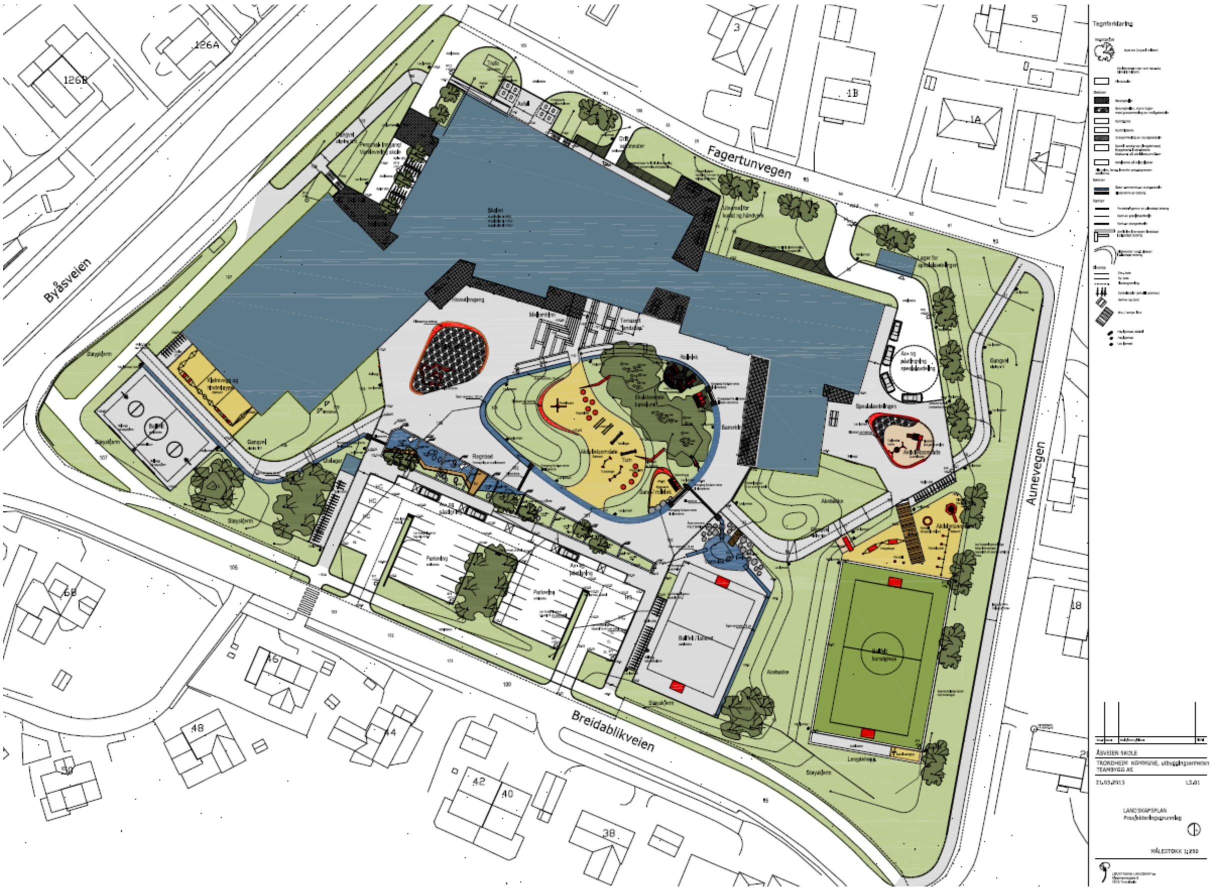


Figure 12 Illustration of the Åsveien School, The raingarden is located next to the parking lot

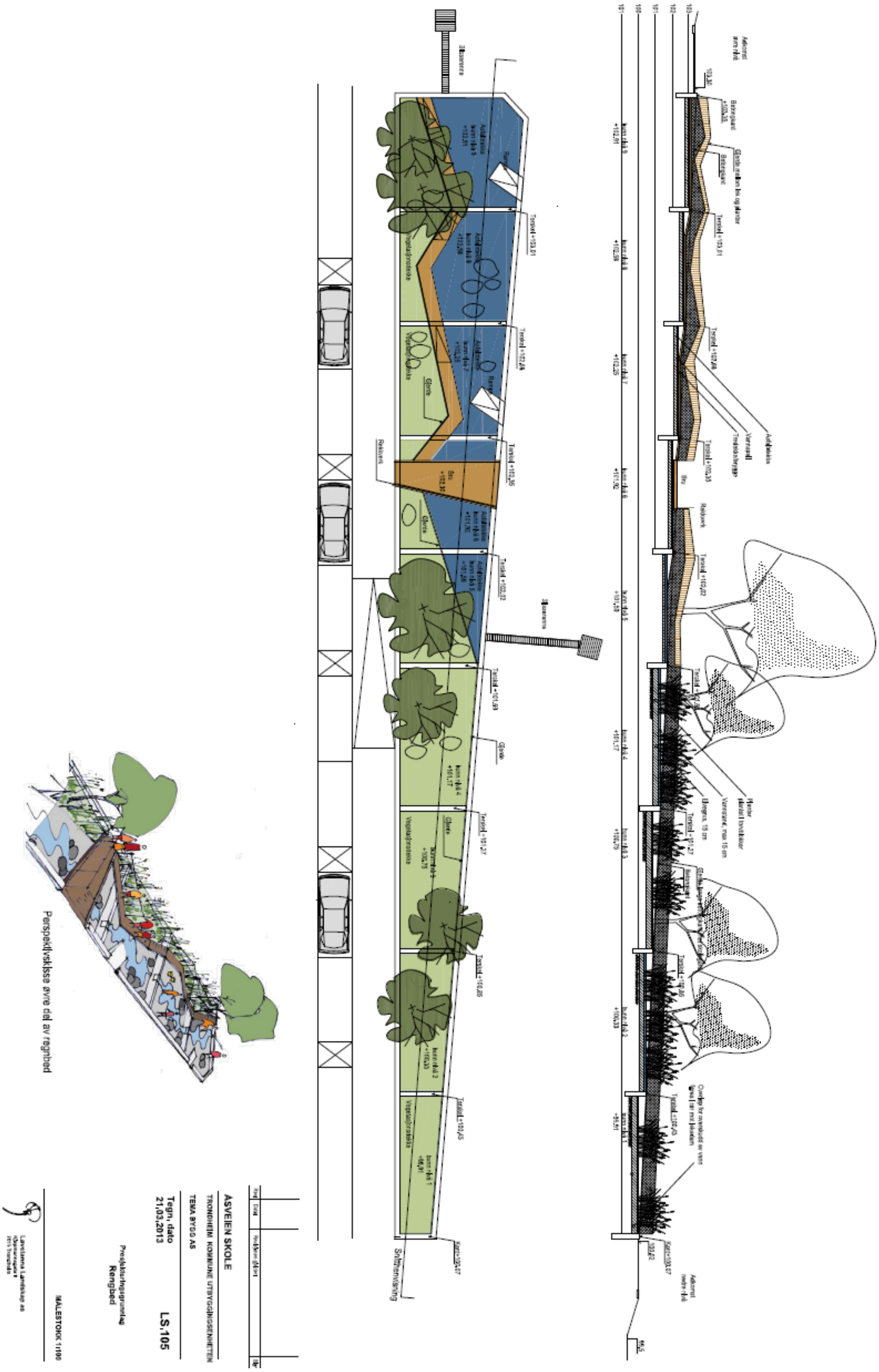


Figure 13 Illustration of the Åsveien raingarden. The green areas in the raingarden are vegetated surfaces and the blue areas are impervious surfaces. The vegetated surfaces in the raingarden are divided into 9 sections. With number one starting from the bottom of the sheet.

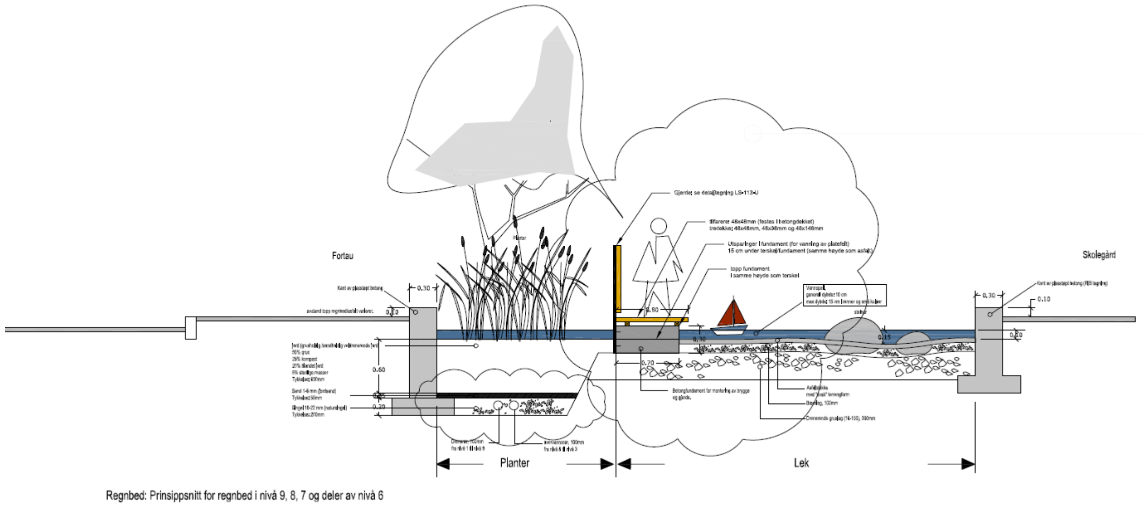


Figure 14 Cross section illustration of the Åsveien raingarden section 7, 8, 9 & part of 6.

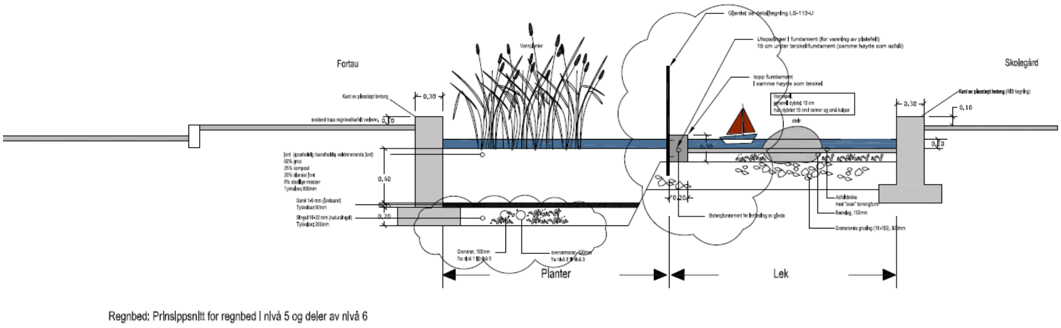


Figure 15 Cross section illustration of the Åsveien raingarden section 5 & part of 6.

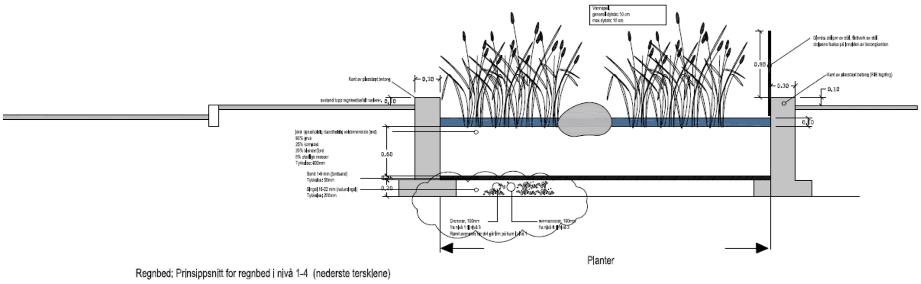


Figure 16 Cross section illustration of the Åsveien raingarden section 1, 2, 3 & 4.

F Comparison of Risvollan and Åsveien raingarden

The following tables is assembled using information about the Risvollan raingarden from Paus et al. (2015) and information about the Åsveien raingarden from illustrations, field observations and from measuring the grain size distribution.

Table 1 Results from analyzing the grain size distribution of soil samples from section 4, 5, 8 and 9 in the Åsveien raingarden. Section 4 & 5 are the largest sections in the raingarden and 8 & 9 are some of the smallest sections in the raingarden. See Appendix E for more information.

	Section 4	Section 5	Section 8	Section 9	Average
Sand	84.4%	84.5%	84.8%	84.42%	84.5%
Loam	11.6%	11.54%	11.84%	11.58%	11.64%
Clay	4%	3%	3%	4%	3.5%

Table 2 Comparison of different properties in Risvollan raingarden and Åsveien raingarden. The information about Risvollan raingarden is from Paus et al. (2015).

Property	Risvollan	Åsveien
Constructed	2010	2015
Raingarden area [m^2]	40	147[a]
Catchment area [m^2]	8300	6938[b]
Imperviousness	40 %	76 %[c]
Impervious catchment area [m^2]	3320	5272
Raingarden impervious catchment ratio	1.2 %	2.8 %
Clay	3 %	3.5 %
Loam	21 %	11.64 %
Sand	75 %	84.5 %
Media texture	Loamy Sand	Loamy Sand
Drain pipes	2 x 100 mm	1 x 100 mm
h_{max} [cm]	16	18[d]
Media bed depth [cm]	75	80

[a] Estimated using Google Earth Pro, impervious surface areas in the raingarden is not included. This because they do not contribute to infiltration.

[b] Estimated with field observations and using Google Earth Pro

[c] Estimated with field observations of the catchment, area of different surfaces estimated in Google Earth Pro and runoff coefficients from table 14.4 (page 363) in Ødegaard et al. (2012).

[d] The physical h_{max} in the raingarden is 10-15 cm, but is estimated to 18 cm to include storage volumes on impervious areas.

G Data on K_{sat} used in calculating Geometric mean K_{sat}

The following table is the basis for the geometric mean K_{sat} values presented in Figure 1. The table show every data on K_{sat} from the Åsveien raingarden that have been used in the presented manuscript.

*Table 3 Data used in calculating Geometric mean K_{sat}. The data from 24st of November 2016 and 27nd of April 2017 which are labeled with * are all measured in section 4.*

Date	25.10.2016	24.11.2016	13.01.2017	10.03.2017	16.03.2017	21.03.2017	30.03.2017	07.04.2017	18.04.2017	27.04.2017	15.05.2017
Section	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]	K_{sat} [cm/h]
1								0.0172	0.0281	3.55*	5.54
2			0.0570						4.81	0.276*	5.72
3	2.19		0.0389		0					0.140*	15.02
4	0.098	0.0100*	0.0719	0.0157	0	0.0150	0	0.0320	0.0897	0.0698*	1.61
5	6.17	0.0433*	0.337			0.0169		0.0270	0.0379	0.0297*	5.38
6						0.00474			0.0311	0.0199*	
7					0.019						0.194
8								0.0201			
9			0.0552		1.19						
Geometric mean	1.10	0.02	0.09	0.02	0.00	0.01	0.00	0.02	0.11	0.13	3.05