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Water quality affected by interactions with filter media in raingardens

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Acknowledgments

This thesis concludes my master’s degree in Environment and Natural Resources at the Norwegian University of Life Sciences (NMBU). Where I have chosen the profile Soil and Environment.

First, I would like to express my gratitude to my advisor Helen French at MINA/NMBU. For having me as one of her master students and letting me take on this subject.
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Dagny Vannebo
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Abstract

It has been expressed a need for stormwater management practices that mitigate the negative effects of urbanization on water quality and the hydrological cycle. Solutions which are sustainable, decentralized, perform well in winter conditions, and which add a restorative natural green space to the urban landscape have been encouraged by the Norwegian Water Association. Raingardens, also referred to as bioretention or biofilters are useful tools that can provide many of these services. Untreated surface runoff may contain several contaminants and can have serious implications for freshwater ecosystems.

The objective of this thesis is to investigate how the filter media in raingardens can affect the water quality. This will be done by comparing water quality of the water entering the raingarden with the quality of the water exiting the raingarden. Water sampling and flow measurements will be done in the research raingarden and a mesocosm experiment at NMBU Campus Ås and the Bolstadhagen raingarden and along Bjørnstjerne Bjørnsonsgate in Drammen. The water will be tested for nutrients, metals, and salts as well as PCBs, PAHs and oil in the raingardens in Drammen.

Due to the composition of the raingardens with both an organic rich mixed soil layer and a sand layer it should be able to both adsorb dissolved components and remove particulate bound contaminants. To study these effects, soil samples will be tested for cation exchange capacity and organic matter and compared with samples from before the raingarden was planted.

The analysis in the research rain garden showed low levels of pollutants but an increase in colour. The mesocosm experiment showed leaking of nutrients as well as an increase in colour. The increase in colour can also be seen in increased turbidity and total carbon measurements. The analysis conducted in the Bolstadhagen raingardens showed no PCBs, PAHs or oil in the water entering, but some PAHs in the water in the outlet. There was a decrease in chloride and sulphide between the inlet and the outlet. Infiltration tests conducted in Bolstadhagen showed an increased infiltration compared with previous infiltration test.

Sammendrag

Det har blitt uttrykt et behov for overvannshåndtering som kan minske de negative effektene ved urbanisering på vannkvalitet og den hydrologiske syklusen. Løsninger som er bærekraftige, desentraliserte, velfungerende gjennom vinter forhold og som tilfører et oppbyggende grønt areal i urbane områder har vært anbefalt av Norsk Vann. Regnbed, også referert til som biofiltere eller bioretensjon er nyttige verktøy som kan tjene mange av disse behovene. Ubehandlet overflateavrenning kan inneholde en rekke forurensninger og kan ha seriøse påvirkninger på ferskvannsøkosystemer.

Målet med oppgaven er å utforske hvordan filtermedia i regnbed kan påvirke vannkvalitet. Det vil bli gjort ved å sammenligne vannkvaliteten på vannet i innløpet til regnbedet med kvaliteten på vannet i utløpet. Vannprøver vill bli tatt i et regnbed og et mesocosm forsøksbed ved Norges Miljø og Biovitenskapelige Universitet (NMBU) Campus Ås, og ved Bolstadhagen regnbed og langs Bjørstjerne Bjørnsonsgate i Drammen. Vannet vill bli testet for næringsstoffer, metaller og salt, regnbedene i Drammen vil også testes for PCB, PAH og olje.

Ettersom regnebedene ofte er bygd opp av et organisk rikt blandet jordlag og et sandlag skal de kunne både adsorbere løste komponenter og filtrere ut partikulere forurensninger. For å studere disse effektene vil jordprøver taes og testes for kationbyttekapasitet, ledningsevne, pH og innhold av organisk materiale.

Vannanalysene fra NMBU regnbedet og mesocosm bedene viste utlekking av næringstoffer og en økning i farge. Også økt turbiditet og total organisk karbon. Analysene utført i Bolstadhagen viste ingen PCB, PAH eller olje i innløpet, men noe PAH i utløpet. Det var en nedgang i klorid og sulfid gjennom sysemet. Infiltrajsons tester i Bolstadhagen viste en økt hydraulisk ledningsevne sammenlignet med tidligere infiltrasjonstester.

Contents

Chapter 1 Introduction

1.1 Background

Urbanization has led to more impermeable surfaces, in addition to more people gathered in a smaller area. This increases the risk of flooding damages to human infrastructure and human life. The water can no longer move freely or percolate into the ground and groundwater. This has negative consequences both on the surface, as there could be more pooling of water and more erosion, but also in the ground as ground water is no longer replenished, and the ground water level could subside. Soil erosion, water pooling and lowering of ground water level may all have serious consequences.

Climate change is resulting in both more frequent and more heavy rain events. The stormwater drains are already under dimensioned in many areas and cannot be deemed adequate to transport rainfall under further intensification of rain events. This is especially a problem where stormwater and sewage are transported together in combined wastewater systems. Heavy rain events could then cause untreated or insufficiently treated sewage to be released into natural waterbodies.

Another issue with stormwater from urban areas are pollutants collected by the water as it flows towards natural waterbodies. Particles, heavy metals, oil compounds, pesticides, nutrients, road salts among others could harm the natural aquatic ecosystems of nearby streams, rivers, lakes, and the ocean. This is especially a problem with the first flush of a rainfall event. In order to mitigate these issues, it has been expressed a need for stormwater management practices that mitigate the negative effects of urbanization on water quality and the hydrological cycle, which are sustainable, decentralized, perform well in winter conditions, and which add a restorative natural green space to the urban landscape by the Norwegian Water Association (Lindholm et al., 2008).

The retention period of the water is important for the filter properties of the soil. For instance, if the water passes through very fast, with little retention the water and soil have little opportunity to interact, and the raingarden will not be an efficient filter. The “fordrøyd volum” and “flomtop-reduksjon” in figure 1.1 shows the water that are delayed and can interact with the soil in the raingarden.

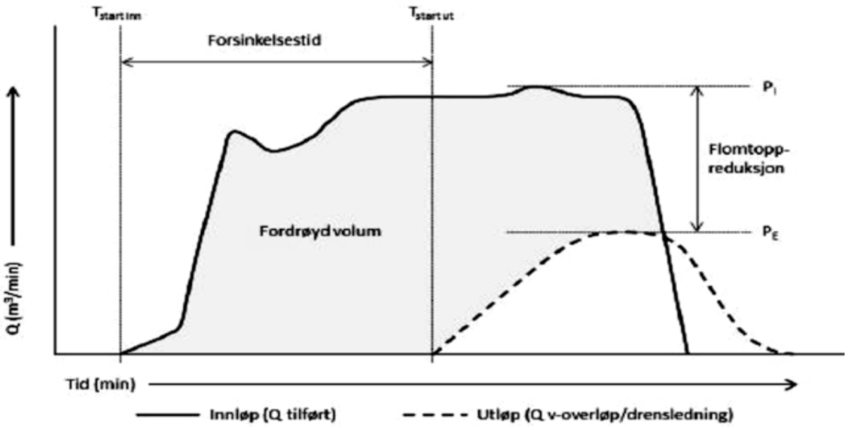


Figure 1.1 Graphic description of delayal time and flood peak reduction in a raingarden system(Braskerud et al. 2012) Bent C. Braskerud, Kjetil Strand Kihlgren, Vegard Saksæther og Jarle T. Bjerkholt VANN04 2012 p. 497. via vannforeningen.no

1.2 Problem statement

Raingardens, also referred to as bioretention or biofilters, have been installed in many urban areas as a measure to reduce stormwater flooding. The way these are constructed with a soil filter often consisting of sandy material and organic compost in addition to native soils could provide good filtering of the water in addition to delaying stormwater.

The main aim of this thesis is to investigate this effect with the use of a raingarden at NMBU campus and two in Drammen where I can compare water quality before and after the raingarden. A mesocosm raingarden study site was also included to investigate the potential difference between different soil and plant combinations on a small scale. In addition to looking into the possible cleaning effect of raingardens, I will investigate potential nutrient loss from the organic rich soils used in the raingardens. I have chosen this approach as I see this as an interesting and useful effect. In addition, there have not been many studies on this subject in Norway or in northern climate and I hope to contribute into the field.

1.3 Study area

The study areas are located in Ås and Drammen in Norway (figure 1.2). They are located at a similar latitude. The raingardens in Drammen are however closer to sea level, than those in Ås. I have included the four different raingarden systems to be able to compare different catchments.

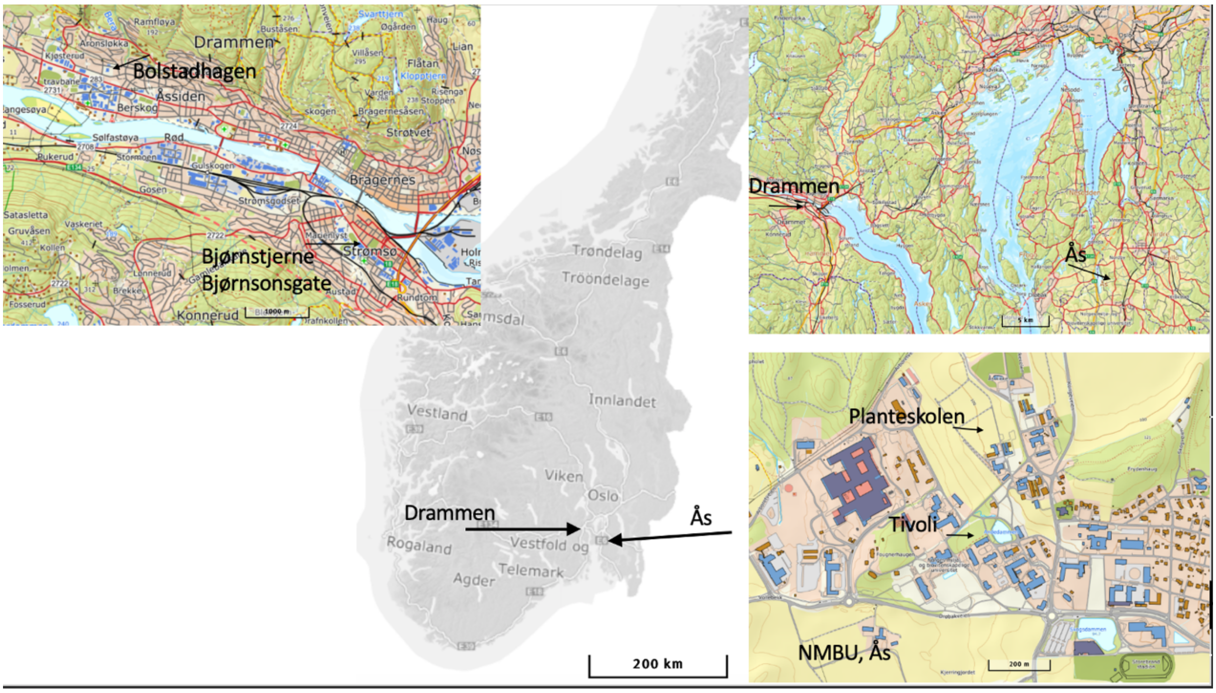


Figure 1.2 Maps modified from Norwegian Kartverket, displaying Ås and Drammen and the various locations of the raingardens.

NMBU Campus Ås

The NMBU raingarden see figure 1.2, figure 1.3 and figure 1.4was built in 2014 as a research raingarden in a collaboration between several institutes, Environmental Sciences, Plant Sciences, Mathematical Sciences and Technology, Landscape Architecture and Spatial Planning as well as the technical section managing the campus of the Norwegian University of Life Sciences (NMBU). The raingarden collects water from the roof of the building Tivoli and the area between the building and the rain garden, together approximately 285m^2. Rainwater is transported from the roof through open grass-covered drains. The raingarden is 35m^2 which is about 5% of the catchment area as suggested by several guidelines (Minnesota Stormwater Steering Committee, 2008).

Both underneath the raingarden itself and the drains is there in this case placed an impermeable membrane. This is special here because it is a research raingarden, and it ensures that no water is lost to deeper percolation as the main research objectives are concerned with the interactions within the raingarden. In a raingarden installed as a mean of delaying and infiltrating rainwater it could be beneficial to allow the rainwater to percolate into the native soils surrounding the raingarden. There are drainage pipes along the bottom of the NMBU raingarden to prevent water saturation of the system. The drains are connected to a manhole, measuring the discharge from the raingarden, and then connected to a stormwater drain. The raingarden is equipped with two sensors measuring soil moisture and soil temperature at three depths, figure 1.4. Sensors measures at approximately depths 5cm, 15cm and 45 cm. Sensor one has all measurements in the mixed soil layer, while sensor two has the deepest measurement in the sandy soil. Another peculiarity with the design of the NMBU raingarden is that is has a bottom layer of sand. This is to enhance the hydraulic conductivity especially in the winter to help the raingarden function year-round.

Above the sand layer at the bottom, there is a mix of native soils, sand, and compost/organic material. At the very top there is planted various plants based on the special requirements of the raingarden. The plants chosen should be able to handle both very dry and very wet conditions. In addition, because of this raingarden's location on the NMBU campus it must also meet special requirements as it is historical garden. In this case they chose to use native plants with a historical use. These included some flowers, some ferns, and some grasses; *Athyrium filix-femina, Caltha palustris, Dryopteris filix-mas, Filipendula ulmaria, Geranium sylvaticum "Amy Doucastes", Iris pseudacorus, Luzula sylvatica, Lysimadria vulgaris, Molinia caerulea, Smilacina racemose, Polygonatum multiflorum,* and *Succisa pratensis.*

Figure 1.3 The NMBU research raingarden with the building Tivoli in the background, spring 2020.

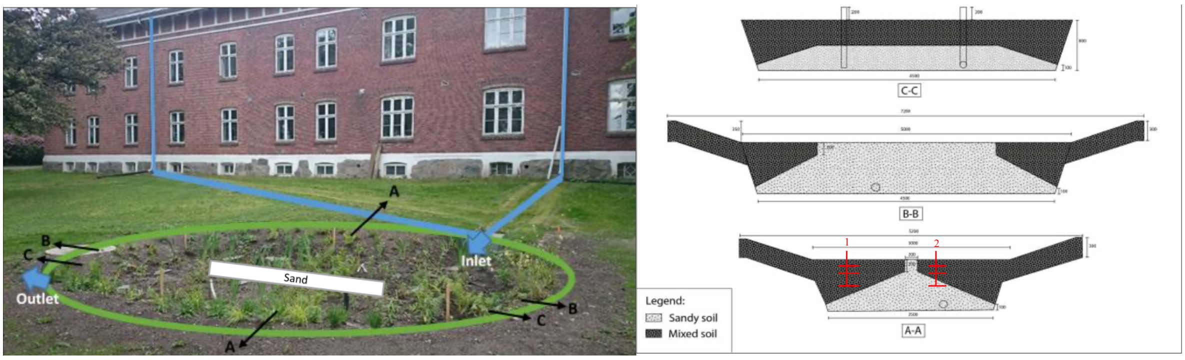


Figure 1.4 NMBU Raingarden Design: Area, roof drainage pipes and water inlet & outlet. Raingarden dimensions and type of media (Mixed soil and sandy soil). Cross sections: A-A, B-B and C-C (Jaramillo, 2016) Red lines indicate location and depth of soil moisture and soil temperature measurements (pers.med. H. French).

Bolstadhagen Drammen

Bolstadhagen raingarden in Drammen was built in 2017 on initiative by Drammen municipality as a pilot project. It is located by Kjøsterud ungdomsskole, see figure 1.2 and figure 1.5. The experiences from Bolstadhagen will be useful as the city is looking to enhance their stormwater management and hope to use raingardens as a tool. Their experiences could also be of value to other municipalities looking to build raingardens (Viker, 2019). The raingarden is constructed as four raingardens which are connected in a sequence, figure 1.6, with the inlet at the top of raingarden1 and an q-bic magazine under, with outlets both from the fourt raingarden and from the q-bic magazine.

The total area of raingarden is 75m^2 and is receiving water from a 26000m^2 urban catchment see figure 1.7. In addition to the urban catchment water from nearby ski lift and nature are is also to be expected to drain into the raingarden,especially during snowmalt. The Q-bic magazine which increases the volume allowing the actual raingarden to be as small as it is. The catchment was originally 17740m^2, but due to the high capacity of this raingarden with the storage magazine it was expanded to 26000m^2 in April 2018. (French H. et al, 2018).

Figure 1.5 Bolstadhagen raingarden 13. December 2019. Raingarden 1 is in the front and raingarden four is furthest away. Kjøsterud ungdomsskole can be seen in the background.

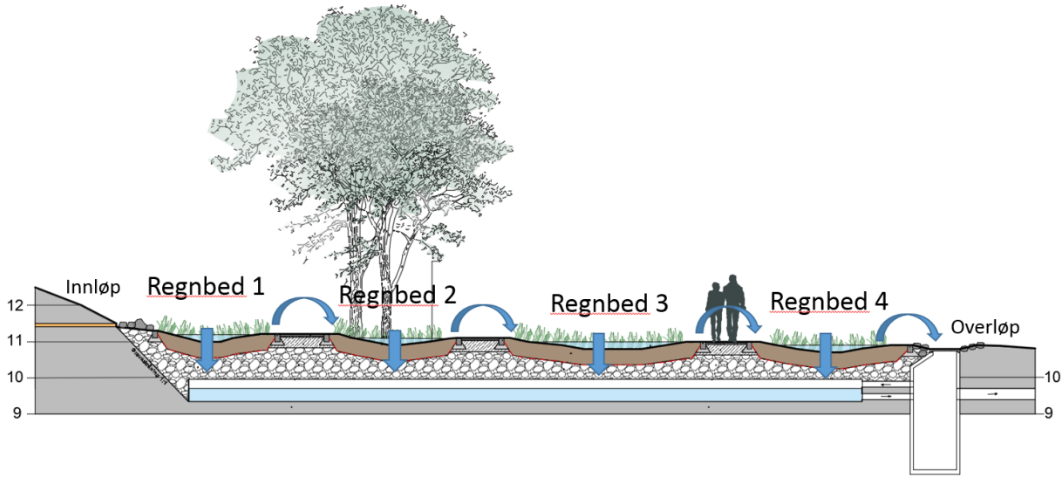


Figure 1.6 Concept sketch of Bolstadhagen raingarden. Connection between Inlet, raingarden1, raingarden 2, raingarden 3, raingarden 4, outlet and Q-bic storage. Depth of raingarden is shown in m.a.s.l. (Stener Sørensen, MINA fagrapport 68).

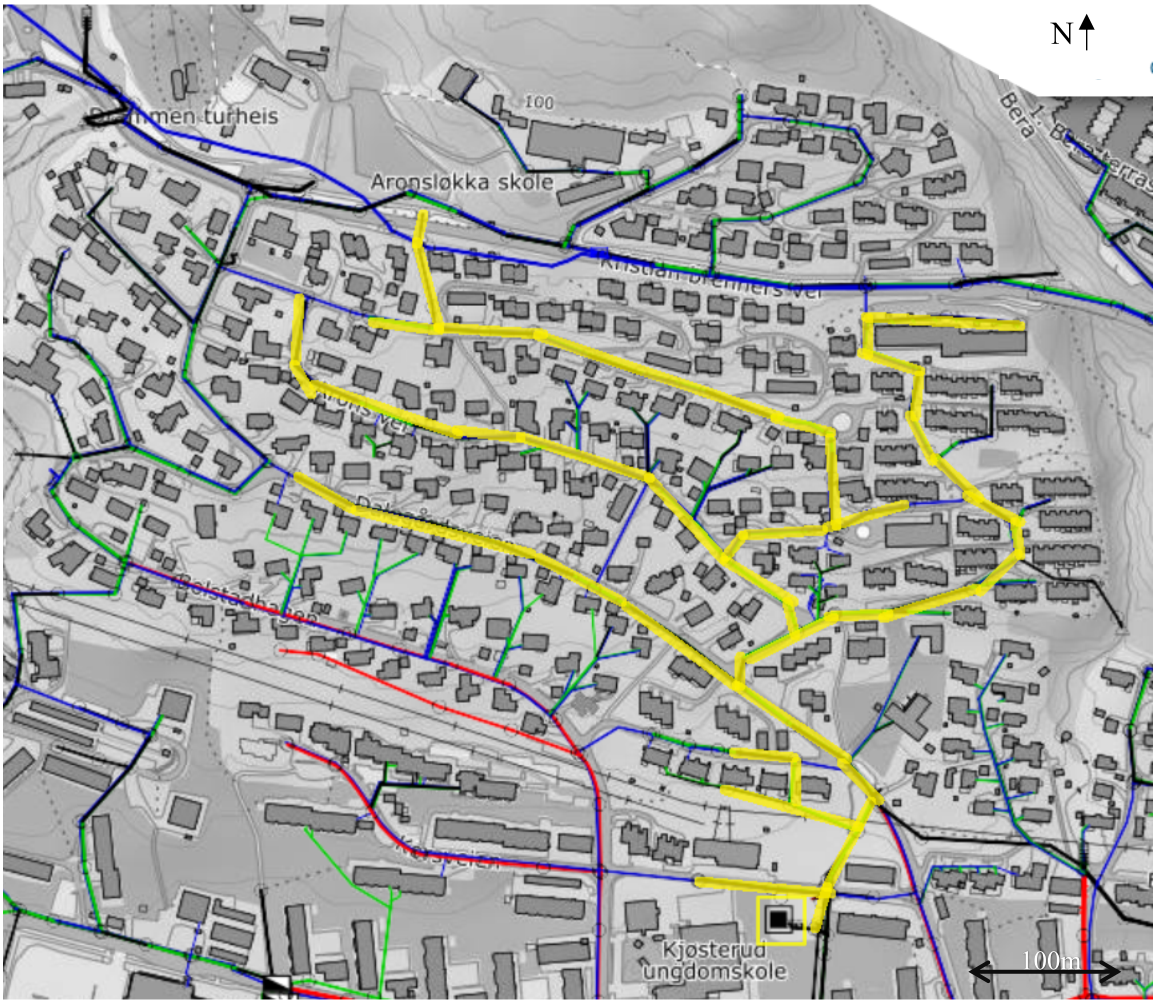


Figure 1.7 Map of catchment for Bolstadhagen raingarden. The raingarden is marked with a yellow square. The yellow lines show pipes connected to the raingarden. Map received from Drammen Kommune.

Raingardens Bjørnstjerne Bjørnsonsgate, Drammen

An additional raingarden used in this thesis is one of the raingardens along the newly renovated street Bjørnstjerne Bjørnsonsgate in Drammen (figure 1.2). This raingarden was included as it is situated next to a heavily trafficked road and is potentially polluted with road contaminants. The raingardens along the street are owned by the Norwegian road authorities and were implemented during the road renovations in 2017-18. Along the 750m of road are nine raingardens with 30 different plants, and two different soil types. (Statens Vegvesen 2019) Samples taken for this thesis were taken from a manhole in raingarden 5(figure1.8), in the intersection between Bjørnstjerne Bjørnsonsgate and Knoffs gate in front of Drammenshallen. These raingardens infiltrate the rainwater into the ground and consequently do not have an outlet. Samples were thus only taken of water entering the raingarden. It would have been interesting to have samples from water that have been through the raingarden as well for comparison, but this was not accessible. The raingarden was included anyway as it is more prone to pollutants than the other raingardens in this study.

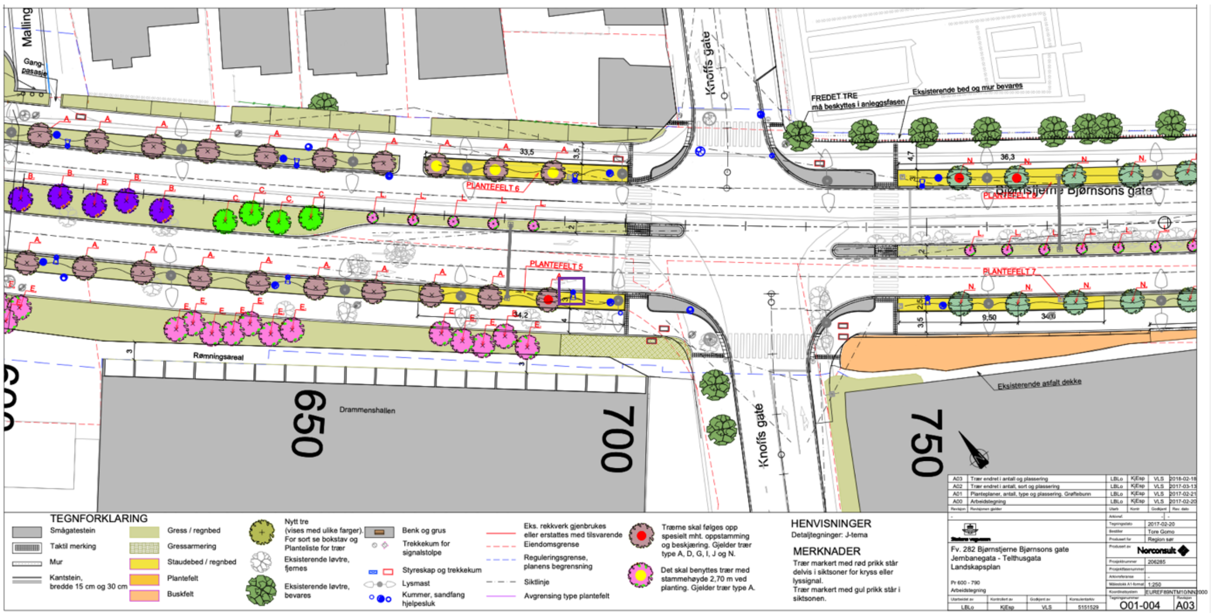


Figure 1.8 Sketch of part of the renovated Bjørnstjerne Bjørnsonsgate. The samples were taken from the manhole(kum) in raingarden 5, indicated with a purple square. (Pers. Med. Kristine Laukli)

Mesocosm Raingarden boxes at NMBU

Box experiment of PhD candidates Marina Bakthina and Joris Stuurop at Planteskolen NMBU (figure 1.2 & 1.10). 24 boxes with two different soil types and four different plant combinations, i.e. eight treatments with three replications (table 1.1 and figure 1.9). The setup has collection of drainage and surface runoff. For the purposes of this thesis only drainage water was collected and analysed and compared with rainwater. The water quality of the drainage water can in this experiment be linked with the different soil types and plants in the boxes. Each box is 0,077m^3 and has a drain system and a runoff collecting system as well as a sensor on the top for measuring temperature. The two soils used are Soil 1: Lindum raingarden soil, Soil 2: Lindum raingarden soil 70% + sand 30%

Table 1.1 Research setup of plant boxes, adapted from MINA fagrapport 68.

#	**Soil type**	**Vegetation, (Norwegian name)** ***latin name in kursiv***	**Root depth**	**Code (No. Ref. to soil type)**	**# replicates**
1	Soil 1 and 2	No vegetation (controll)		B1 and B2	3 + 3
2	Soil 1 and 2	Grass (Østfoldgress (med blant annet Engrapp og Rødsvingel))	shallow	G1 and G2	3 + 3
3	Soil 1 and 2	Evergreen, (Storfrytle (vintergrønn)), *Luzula sylvatica*	medium	L1 and L2	3 + 3
4	Soil 1 and 2	Blue Candale (Aksveronika) *Veromica spicata,* Yarrow (Ryllik) *Achilea millifolia,* Feather reed grass (Hagerørkvein), *Calamagrostis arundinacea* Bloody geranium(Blodstorknebb) *Geranium sanguineum*	deep	M1 and M2	3 + 3
		Total number of boxes with different treatment			24

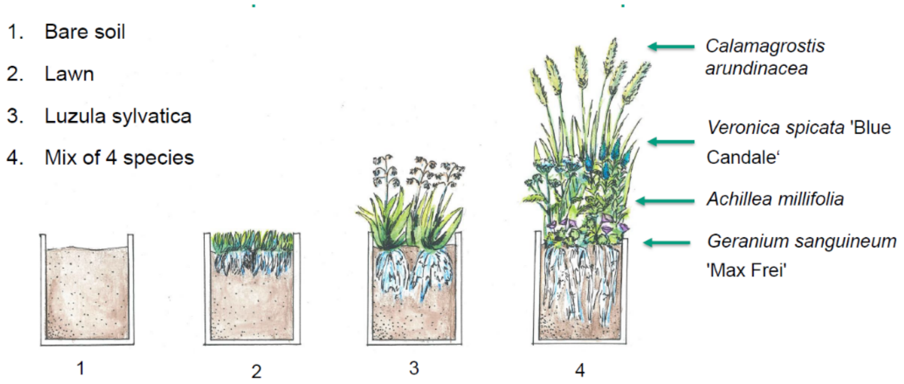


Figure 1.9 Principal sketch of plant boxes with the different plant set up, as listed in table1.1. (Drawing Marina Bakhtina)

Figure 1.10 Mesocosm set up at Planteskolen, NMBU. Right picture show top of plant boxes and surface runoff system left picture shows system for collection of drained water. (right pic. Marina Bakhtina 5. Nov 19)

What has already been researched/what do we know about the NMBU and Bolstadhagen raingardens.

Previous investigations, mostly done when the raingarden was installed and shortly after were focused towards the hydraulic potential, infiltration rates, and plant suitability. Results from this can be found in the master thesis of Juan Jaramillo for the NMBU raingarden. For the Bolstadhagen there is not yet been published any results, but while working with this thesis I had access to the unpublished work of H. French, L. Rosef, L. Jakobsen and I. Schmidt (*Lokal overvannshåndtering-regnbed Bolstadhagen, delprosjekt; oppfølging av funksjonalitet 2018*). These and other student reports gave information about the structure and soil properties, the infiltration, plant choice, permeability, and nutrient content of the raingarden soil at the NMBU raingarden.

For the raingardens along Bjørnstjerne Bjørnsonsgate in Drammen I received information about the project from Kristine Laukli, Statens Vegvesen. And taken water samples myself.

1.4 Theory of chemical processes and water quality

Common stormwater pollutants,
-Suspended Solids
-Nitrogen and Phosphorous
-Heavy Metals
-Oil and Grease
-Salts
-Pathogenic Bacteria

Table 1.2 Raingarden processes. (The Prince George's County. (2007). Bioretention manual.)

Process	Description
Settling/ Sedimentation	As the runoff slows down and forms ponds within the raingarden area, particles and suspended solids settle. This process occurs on the surface of the raingarden and serves as a pretreatment before entering the filter medium.
Filtration	Particles are filtered from runoff as it moves through mulch and soil. In raingardens, filtration removes most particulates from runoff.
Assimilation	Plants taking up nutrients used for growth and other biological processes. Plants used in raingardens can be selected for their ability to assimilate certain kinds of pollutants.
Adsorption	The ionic attraction holding a liquid, gaseous, or dissolved substance to a solid's surface. Humus, which can be found in raingardens with the breakdown of mulch and plant matter, adsorbs metals and nitrates.
Nitrification	Bacteria oxidize ammonia and ammonium ions to form nitrate (NO_3) a highly soluble form of nitrogen that is readily used by plants.
Denitrification	When soil oxygen is low, temperatures are high, and organic matter is plentiful, microorganisms reduce nitrate (NO_3) to volatile forms such as nitrous oxide (N_2O) and Nitrogen gas (N_2), which return to the atmosphere.
Degradation	The breaking down of chemical compounds by microorganisms in the soil medium
Decomposition	The breakdown of organic compounds by the soil fauna and fungi.

Possible negative effects/challenges:

- Nutrient leaching from the compost material used in the raingarden
- Will the soil become saturated with pollutants? How to deal with this possibly heavily polluted soil?

Chapter 2 Methods

For all raingardens except soil samples at NMBU raingarden I have taken the samples myself. For NMBU raingarden results from previous investigations are presented. I have also analyzed the samples taken, with help from the Jordfag laboratory. Except for PCB, PAH and oil in water analysis as they were sent to external laboratory, Eurofins.

2.1 Field methods

Soil and water Sampling

Samples have been taken fall of 2019 and winter 2020 from the raingardens at NMBU, at Bolstadhagen, Drammen, and along Bjørnstjerne Bjørnsonsgate in Drammen, as well as from the planting boxes from Marina Bakhtina at NMBU. Both soil and water samples have been taken in all locations. After sampling different tests and analysis have been conducted. Mostly at the lab at NMBU but water samples from Drammen, both locations, were also sent to Eurofins laboratory for further analysis.

Saturated Hydraulic conductivity

Modified Philip Dunne´s method. Saturated hydraulic conductivity measured with 30 to 40 cm long plastic tubes placed 5cm into the ground. Filled with water in this case up to 20cm above ground. Infiltration is found by making use of a measuring stick inside the tube and a stopwatch. The stable infiltration is used to calculate the infiltration rate (Nestingen, R.S., 2007) Here was the simplified method described by Elisabeth Blom Solheim (2017) used.

2.2 Laboratory methods

-Soil samples:

Pre-treatment.

Soil from NMBU and Bolstadhagen raingardens. Drying, sieving, and crushing.
Samples were dried at room temperature over the weekend and then placed in a drying cabinet at 60 degrees Celsius for 48 hours. They were then sieved through 2mm steel sieves with manual shaking and use of a porcelain pistil. The fractions larger than 2mm were thrown out. The sieved fraction got put back into the paper boxes to be stored until further analysis. Between sieving different samples, the sieve, pistil, and collecting pan were cleaned with pressure air.
A small part, three teaspoons of each sieved sample was taken and crushed with a mechanical agatpistil.
The soil used in the other analyses is the dried and sieved through 2mm, unless otherwise stated.

pH, soil

pH- meter with a glass electrode. MeterLab PHM210 Standard pH meter was used in the laboratory. Measured in suspension liquid with deionized water. The suspension liquid was made by mixing 10ml soil with 25ml water. As described in *Laboratoriemetoder til emnet JORD212. Jordanalyse* by Tore Krogstad.

Electric conductivity, soil.

Electric conductivity meter was used on suspension liquid made by mixing 10ml soil with 25ml water. Metrohm 712 Conductometer was used in the laboratory. The samples used for measuring electric conductivity was also used for soil pH. With electric conductivity being measured first to ensure no salt contamination from the pH probe. (Øien & Krogstad, 1989)

Cation Exchange Capacity

3.00 g of soil transfers to a 100 ml Erlenmeyer flask. For samples high in organic matter 1-1.5 g of soil is used. 50 ml of 1 M NH4OAc added and allowed to stand overnight. The suspension filtered through blue ribbon paper filter into a 250 mL volumetric flask. Then made sure all the soil from the Erlenmeyer flask is washed into the filter by using 1 M NH4OAc from a wash bottle. The soil in the funnel washes with small portions extraction solution. It is important that everything has passed the filter before new portion adds. The washing continues until the flask is filled to about 230 ml and make up to volume (250 ml) with 1 M NH4OAc.

The base cations are measured by ICP using standard procedure.

Exchangeable H^+ is determined by titrating 20 ml percolate by 0.05 M NaOH back to pH 7.00. (JORD200 field and laboratory methods, T. Krogstad and T. Børresen)

Organic Content, DM/LOI.

Between 3 and 5 grams from each sample were transferred to separate crucibles. They were weighed and set to dry at 105 +/- 5 degrees Celsius for three days. After drying they were weighed again. The difference is used to calculate the dry matter fraction. Then the crucibles were placed in a furnace burning at 550 +/- 25 degrees Celsius overnight. After the crucibles had cooled, they were weighed again, and the difference was used to calculate loss on ignition and the organic matter fraction of the soil.

To find the dry matter content and the organic matter content the following formulas were used (Krogstad 2009, p.10).

$$\%\text{dry matter} = \frac{m3-m1}{m2} * 100$$

$$\%\text{Loss on Ignition} = \frac{m3-m4}{m3-m1} * 100$$

where

m1 = weight of crucible

m2 = weight of soil sample before drying

m3 = weight of crucible and soil sample after drying

m4 = weight of crucible and soil sample after burning

-Water quality:

Blanks were made of deionised water from the Jordfag laboratory, taken directly from the basement to prevent possible contamination from the pipes.

Some of the water analyses requires filtrated water. The required 50 ml of the samples and blanks were filtrated through 0,45 μm filters with the use of syringes. Both filters and syringes were cleaned with deionised water before and between samples went through.

Electric conductivity, water

Water sampled from NMBU and Bolstadhagen raingardens and measured with an EC meter in the laboratory. Metrohm 712 Conductometer was used. Measured in filtrated (0,45 μm filters) samples.

pH, water

Water sampled from NMBU and Bolstadhagen raingardens and measured with pH meter in the laboratory. MeterLab PHM210 Standard pH meter was used. Measured in filtrated (0,45 μm filters) samples.

Cations

K^+, Mg^{2+}, Ca^{2+}, Na^+, Al^{3+}, Fe^{3+}, Cd^{2+}, Cu^{2+}, Zn^{2+}, Pb^{2+}, P

Samples were filtered through 0,45μm filters and added acid before they were analysed with the ICP -MS. Also, blank samples made from deionized water and otherwise filtrated and treated the same as the samples were analysed.

P- PO43- and N-NH4

Samples were filtered through 0,45μm filters.

For N-NH_4 3ml filtrate was transferred to a new test tube. Then 0,50ml hypochlorite was added and stirred before 0,50ml salicylate was added. The tubes were stirred again and set aside in a dark cabinet for at least one hour while the colour developed before the absorbance was measured with a spectrophotometer at 655nm. Two sets of standards at 0,05mg/l, 0,1mg/l, 0,5mg/l and 1mg/l as well as three blanks were measured to create a standard curve to determine the concentration in the samples based on their absorbance.

To measure P- $PO4^{3-}$ 5ml of the filtrate was transferred to new test tubes then added 0,25ml ascorbic acid, stirred and then added 0,25ml molybdate and stirred again. The tubes with the samples were then left to develop colour for ten minutes before measured with the spectrophotometer at 880nm. Two sets of standards at 0,05mg/l, 0,1mg/l, 0,5mg/l and 1mg/l as well as three blanks and a bought QC standard were measured to create a standard curve to determine the concentration in the samples based on their absorbance. The samples were mixed and measured in two rounds as the colouring is only good for about 45 min. In order to measure samples with concentrations of P- $PO4^{3-}$ higher than 1mg/l they had to be diluted. Based on the results of the Ion chromatographer samples 23, 26, 27, 30, 35, 36, 37, 40 and 42 were diluted 2x. In addition, sample 39 had to be diluted 2x and 35 was diluted 5x after the initial measurement on the spectrophotometer. Methods described by Ivan Digernes (2004).

Anions

Anions Cl^-, F^-, SO_4^{2-} were measured through ion chromatography as described by Digernes (2004).

N-NO_3

Measured in filtrated samples with an Ion-sensitive electrode, ORION- ion selective electrode was used in the laboratory.

External laboratory, Eurofins

Oil in water:
Reference: NS-EN ISO 9377-2 Water quality - Determination of hydrocarbon oil index - Part 2: Method using solvent extraction and gas chromatography (ISO 9377-2:2000) (https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=145780)
Uncertainty: 20-35%
LOQ: 0.5mg/l

PAH(16) EPA:
Internal methods. Uncertainty: 30-40% LOQ: 0.002 µg/l to 0.01µg/l.

PCB 7:
Internal methods. Uncertianty: 25-40% LOQ: 0.01µg/l.

Chapter 3 Results and Discussion

I will start by presenting the soil parameters from the Bolstadhagen and the Mesocosm experiments from my analysis as well as soil parameters from the NMBU raingarden and Bjørnstjerne Bjørnsons gate provided from previous studies, Eva Vike and Juan Jaramillo at NMBU raingarden and Statens Vegvesen at Bjørnstjerne Bjørnsons gate. Then I will present water quality parameters with climate data in the NMBU and Bolstadhagen raingardens. Next, I will present nutrients and trace elements found in the water in the NMBU, Bolstadhagen and Bjørnstjerne Bjørnsonsgate raingardens. Then the water parameters from the mesocosm experiment at NMBU. Finally I present the organic contaminates PAHs and PCBs from Bolstadhagen and Bjørnstjerne Bjørnsonsgate as these are most likely to be affected by these contaminates

The results will be presented groupwise and discussed both individually and comparatively.

3.1 Mineral contents and contaminants in the raingarden soils

Er det noen grenseverdier som finnes for forurensningene? Hvis noen målte konsentrasjoner er over grensen kunne du ev. gi cellen de står i en annen farge.

Hva skiller seg ut her? Ser at EC er høyere enn de andre i bed 1, og pH og CEC er litt lavere. Vurder (for hele kapitlet om du vil diskutere resultatene forløpende (da mener jeg f.eks. her: skriv om hva som vises I tabell 3.2 og 3.3) etter disse to tabellene diskuterer du forskjeller og likheter mellom Bolstadhagen, nmellom bed og Mesocosm jorda. Forsøk og forklare hvorfor det er forskjeller/likheter. Er dette typiske verdier målt I andre regnbed? I landbruksjord? Finn noen referanser på dette. Tilsvarende gjør du for de neste to tabllene som viser PAH. Er nivåene høyere/lavere/ enn forventet (litt referanser på dette fra regnbed eller annen jord-vegnær jord f.eks.)

Table 3.1 Soilanalysis NMBU raingarden in bottom zone and rind zone(Vike pers.med)

	Mold %	*pH mg/100g*	*P-AL mg/100g*	*K-AL mg/100g*	*Mg-AL Mg/100g*	*Ca-AL Mg/100g*	*Na-AL Mg/100g*	*Glødetap % TS*
Bottom zone	*6.8*	*7.8*	*65*	*29*	*33*	*430*	*<5*	*7.8*
Rind zone	*7.7*	*7.6*	*71*	*25*	*32*	*440*	*5*	*8.7*

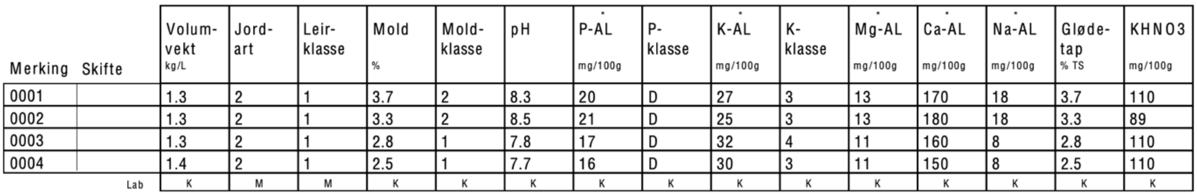
Table 3.2 Soilanalysis Bolstadhagen,one sample from each raingarden.

Soil sample	**Garden1**	**Garden2**	**Garden3**	**Garden4**
Ca (cmol(1/2Ca+)/kg)	8,3	10	10	11
K (cmol(k+)/kg)	0,096	0,13	0,094	0,16
Mg (cmol(1/2Mg+)/kg)	0,44	0,49	0,42	0,4
Na (cmol(Na+)/kg)	0,15	0,13	0,11	0,094
H+ (cmol(H+)/kg)	11	13	10	9,8
CEC (cmol(c+)/kg)	19,9	23,7	20,6	21,4
Drymatter (%)	99,5	99,4	99,5	99,5
LOI (%)	4,0	4,7	3,4	3,5
Conductivity (µs/cm)	465,5	255,5	176,5	210,8
pH	6,91	7,23	7,52	7,25

Table 3.3 Soil analysis Mesocosm, samples from the same soil as used in the boxes.

Soil sample	**Raingarden soil**	**Mixed raingarden soil**
Ca (cmol(1/2Ca+)/kg)	7,1	5
K (cmol(k+)/kg)	0,34	0,21
Mg (cmol(1/2Mg+)/kg)	0,64	0,49
Na (cmol(Na+)/kg)	0,046	0,041
H+ (cmol(H+)/kg)	16	16
CEC (cmol(c+)/kg)	24,1	21,7
Drymatter (%)	99,6	99,8
LOI (%)	2,6	1,7
Conductivity (ms/cm)	243,4	200,9
pH	7,29	7,25

Table 3.4 Soil analysis of Lindum soil used in the Raingardens along Bjørnstjerne Bjørnsonsgate (pers.med Kristine Laukli)



Merking	Skifte	Volum-vekt kg/L	Jord-art	Leir-klasse	Mold %	Mold-klasse	pH	P-AL mg/100g	P-klasse	K-AL mg/100g	K-klasse	Mg-AL mg/100g	Ca-AL mg/100g	Na-AL mg/100g	Gløde-tap % TS	KHNO3 mg/100g
0001		1.3	2	1	3.7	2	8.3	20	D	27	3	13	170	18	3.7	110
0002		1.3	2	1	3.3	2	8.5	21	D	25	3	13	180	18	3.3	89
0003		1.3	2	1	2.8	1	7.8	17	D	32	4	11	160	8	2.8	110
0004		1.4	2	1	2.5	1	7.7	16	D	30	3	11	150	8	2.5	110
	Lab	K	M	M	K	K	K	K	K	K	K	K	K	K	K	K

3.2 Water quality

NMBU raingarden

The water quality of the NMBU raingarden sampled four times during fall 2019 and winter 2020 is presented in the following figures.

To give some background information about the weather conditions during and before the sampling times I have included Figure 3.1 which shows climate data throughout the sampling period of the winter 19-20. Additionally, figure 3.1 shows soil moisture and soil temperature measured in the NMBU raingarden, measured at two locations at three depths (figure 1.4). From Figure 3.1 it is possible to see fluctuations in the soil moisture contents in the raingarden that corresponds to rain events.

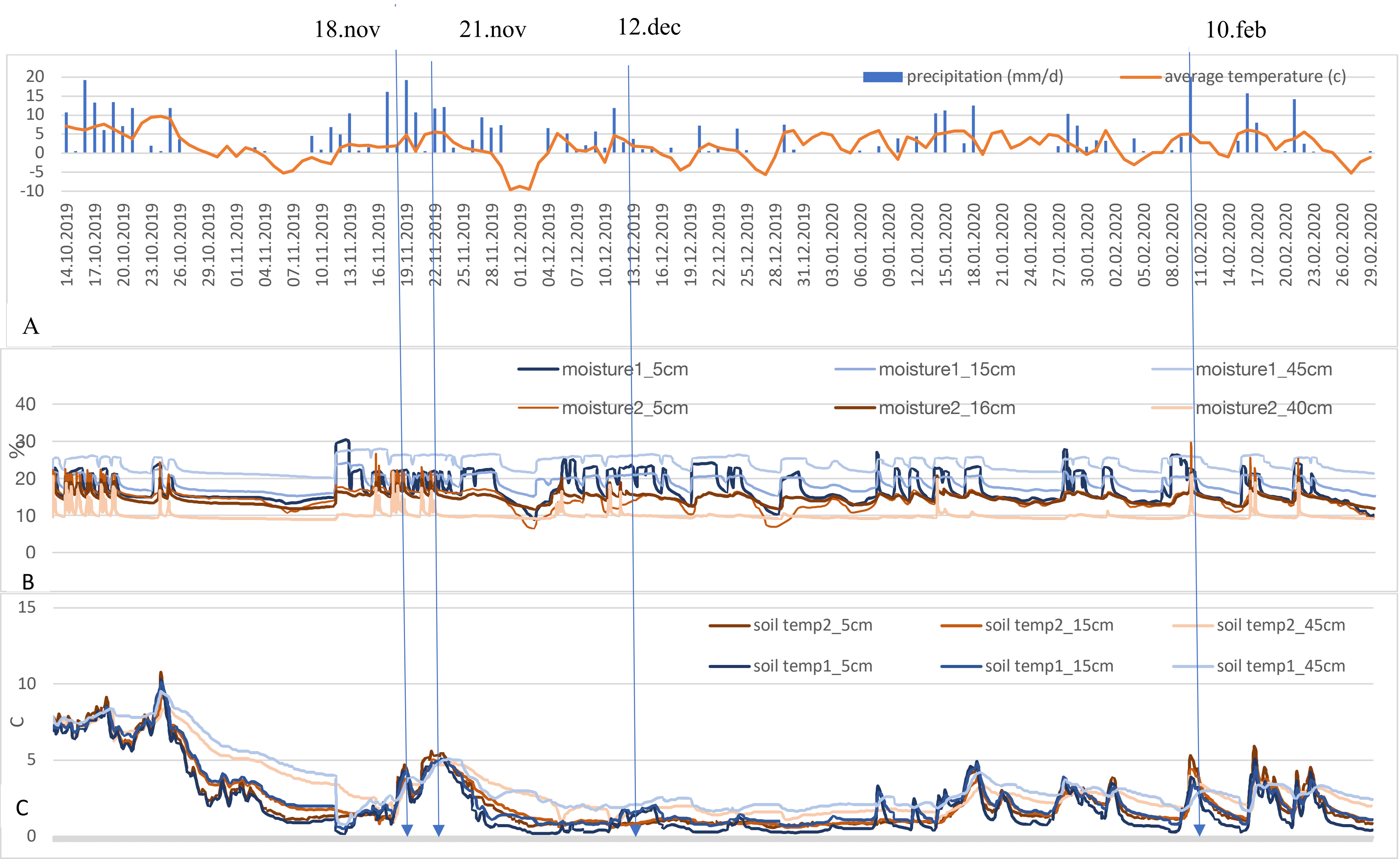


Figure 3.1. Climate conditions in Ås during winter 19-20. Sampling times are indicated on the top. A shows precipitation and temperature from measuring MET station Ås. B and C shows soil moisture and soil temperature both with measurements at 5cm, 15cm and 45cm depths in the Tivoli raingarden at NMBU.

In figure 3.2, 3.3, 3.4 and 3.5 climate data is shown in the background, to give a context to the sampling times. Figure 3.2 show conductivity at the inlet and outlet of the NMBU raingarden. The conductivity at the outlet is higher than at the inlet at all sampling times.

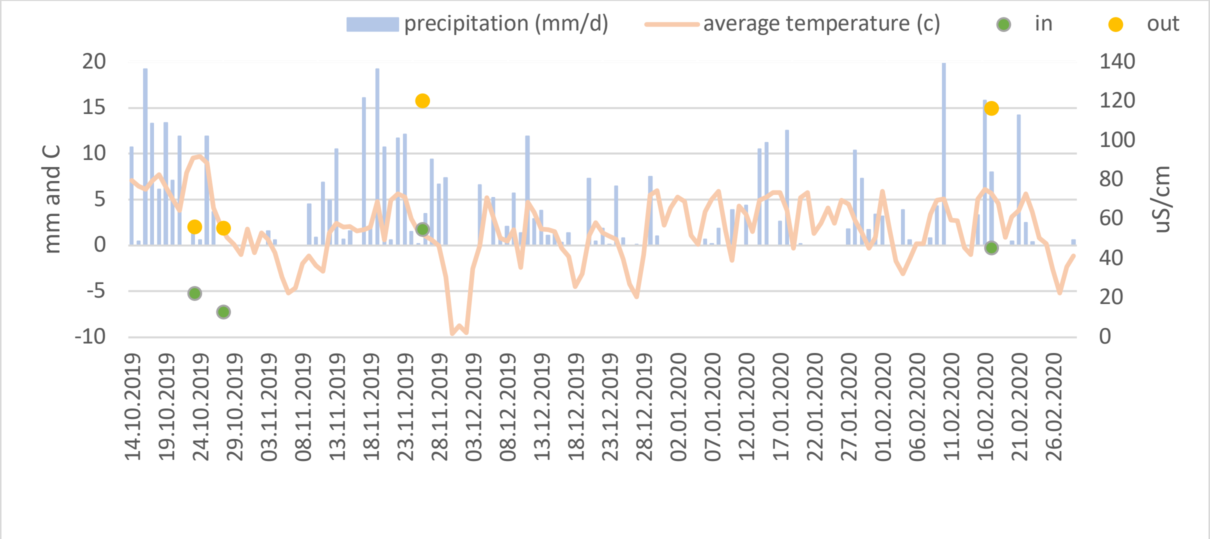


Figure 3.2. Electric conductivity at inlet and outlet of the NMBU raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.x1

The water entering the NMBU raingarden is very clean, compared with most other raingardens, due to the catchment being the roof of building Tivoli. It is therefore as expected that water in the inlet has low conductivity. The water in the outlet has a higher conductivity indicating that there are some reactions/processes within the raingarden that is resulting in leaching from the raingarden.

Figure 3.3 display pH at inlet and outlet of the NMBU raingarden, the pH at the first two sampling times is higher at the outlet than the inlet, but at the two later samplings the pH is higher at the inlet than the outlet. The pH has also increased throughout the sampling period, in the inlet from 6,7 to 7,6 and in the outlet from 7,1 to 7,4.

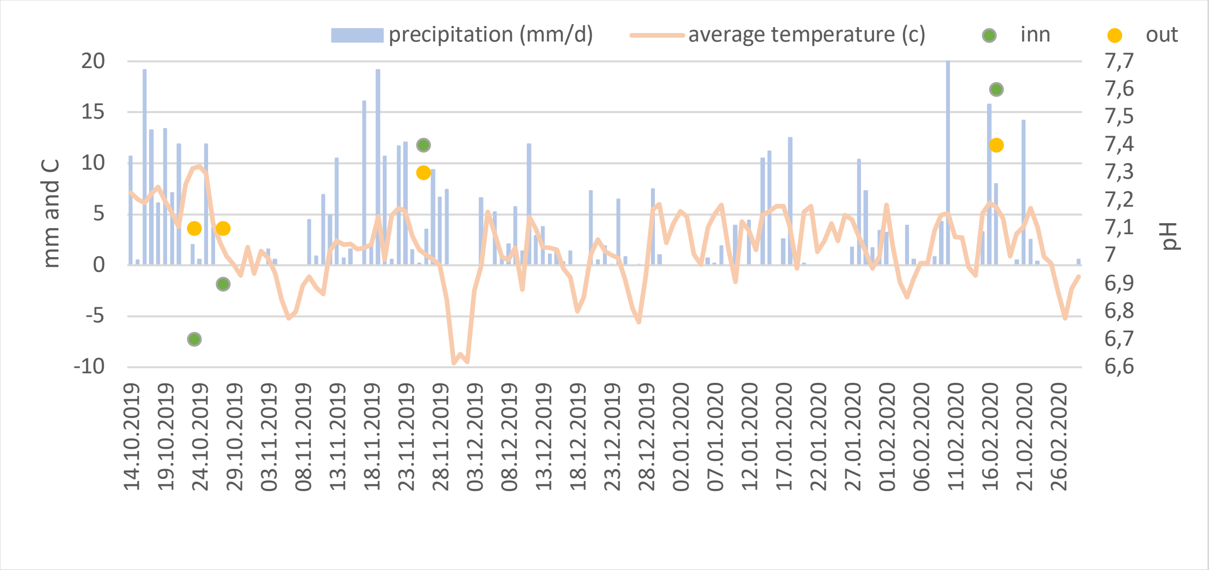


Figure 3.3. pH at inlet and outlet of the NMBU raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.x1

All water samples in NMBU raingarden have close to neutral (7) pH, the change between inlet having lower pH than outlet to inlet having higher pH could be connected to atmospheric differences. Outlet more buffered due to interaction with soil.

Figure 3.4 display colour at the NMBU raingarden. The samples from the outlet have a higher colour number than those of the inlet. The colour of the inlet are low throughout the whole period, but in the outlet samples there is an increase in colour.

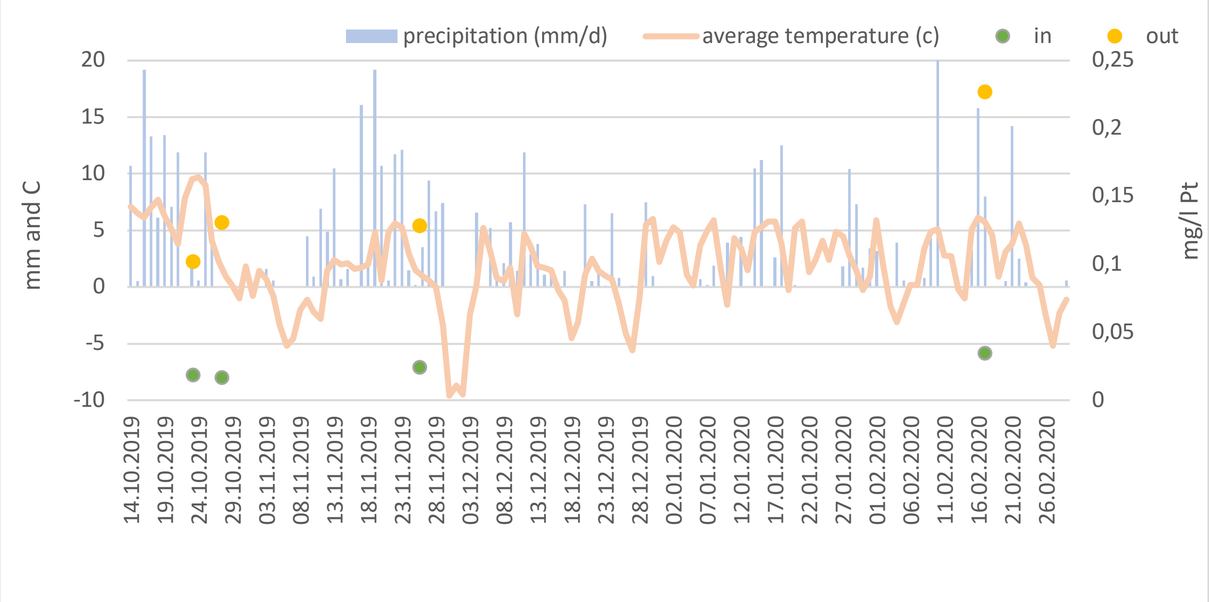


Figure 3.4. Colour at inlet and outlet of the NMBU raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.x1

Colour is as expected higher in the outlet than the inlet. The water in the inlet has had little contact with organic soil particles, such as hummus, which is measured as colour in the water. The catchment is also small and with low risk of pollution. The water in the outlet has a higher, but still quite low colour number. As a reference drinking water must be under 20 mg/l Pt, which all samples are way under (Norwegian Drinking water regulations).

Turbidity at the NMBU raingarden is portrayed in figure 3.5. Turbidity varied during the sampling period, it is lower in the inlet than the outlet at the first two samplings, at the third sampling turbidity is higher in the inlet than the outlet, and at the last sampling inlet and outlet had very similar turbidity.
The first sampling in the inlet is higher than the rest, which are more similar.

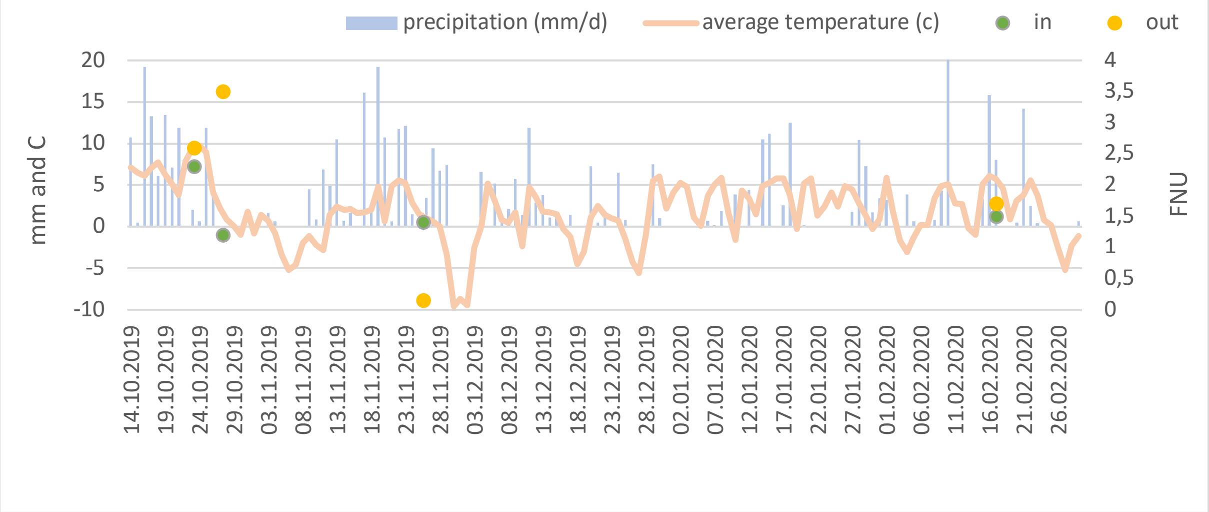


Figure 3.5. Turbidity at inlet and outlet of the NMBU raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.x1

Turbidity says something about the particles in the water sample. In the NMBU raingarden there are both samples where inlet and outlet have similar turbidity and samples with different turbidity. The sample at 12.12.19 have a higher turbidity in inlet than outlet, this could be due to the rain event in the time before, with particles accumulating in the catchment and then being collected at the inlet. In the outlet, due to such a large rain event we could get a dilution effect.

Bolstadhagen

Figure 3.6 portray climate data from the nearest meteorological station to the Bolstadhagen raingarden, Sletta in Drammen. Located about 6 km east of the raingarden. The temperature fluctuations can be seen reflected in the soil, but the soil moisture is stable, except for one dip in November 2019. Figure 3.7, 3.8, 3.9 and 3.10 all include these climate data in the background with the different water quality parameters from Bolstadhagen raingarden.

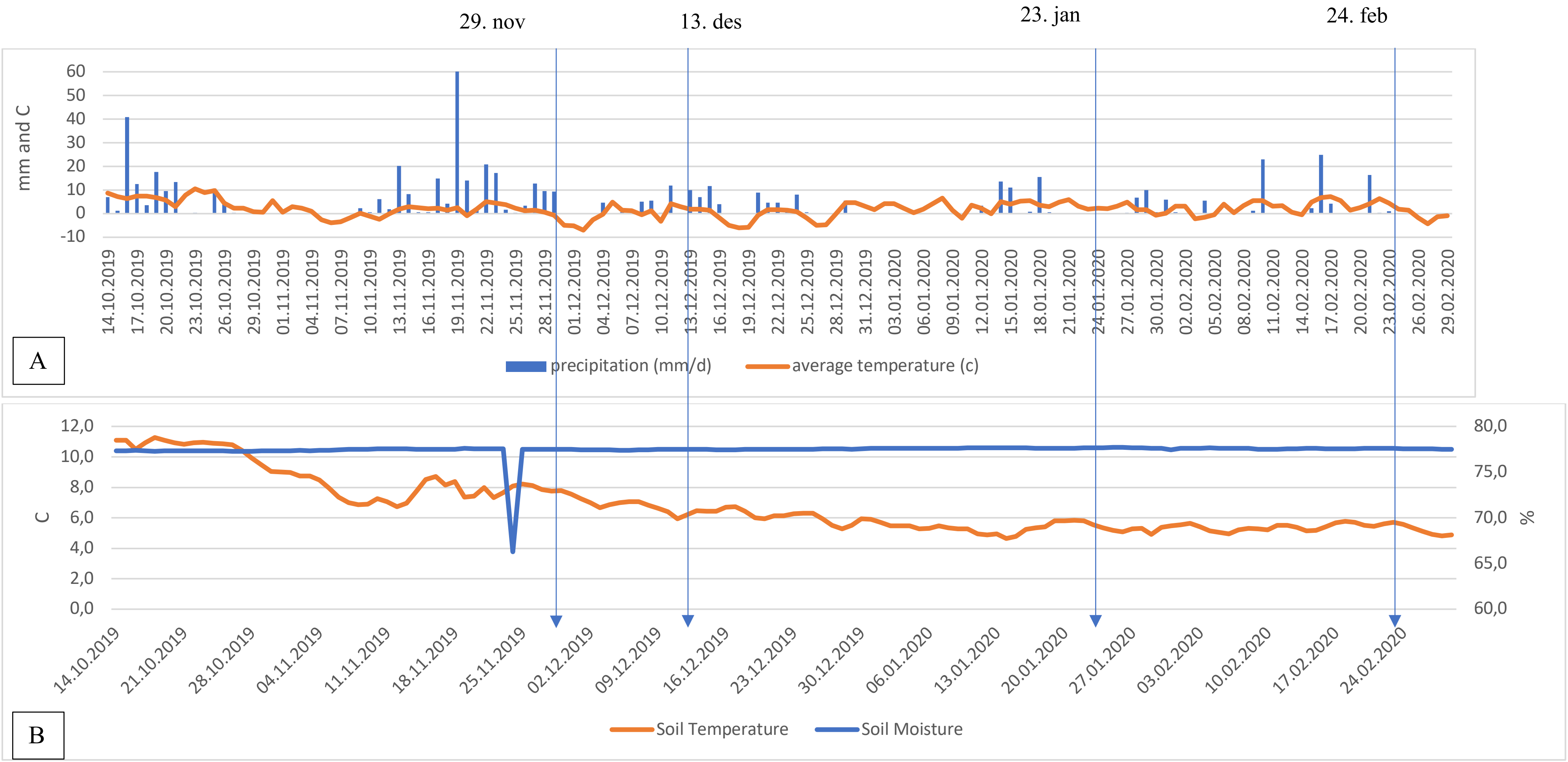


Figure 3.6. Climate conditions in Drammen, during winter 19-20. Sampling times are indicated on the top. A shows precipitation and temperature from Sletta MET station. B shows soil moisture and soil temperature with measurements at 22 cm and 15 cm depths in the Bolstadhagen raingarden in Drammen.

Figure 3.7 show conductivity Bolstadhagen raingarden with climate data in the background. Inlet is more stable and higher than outlet. The outlet decreases.

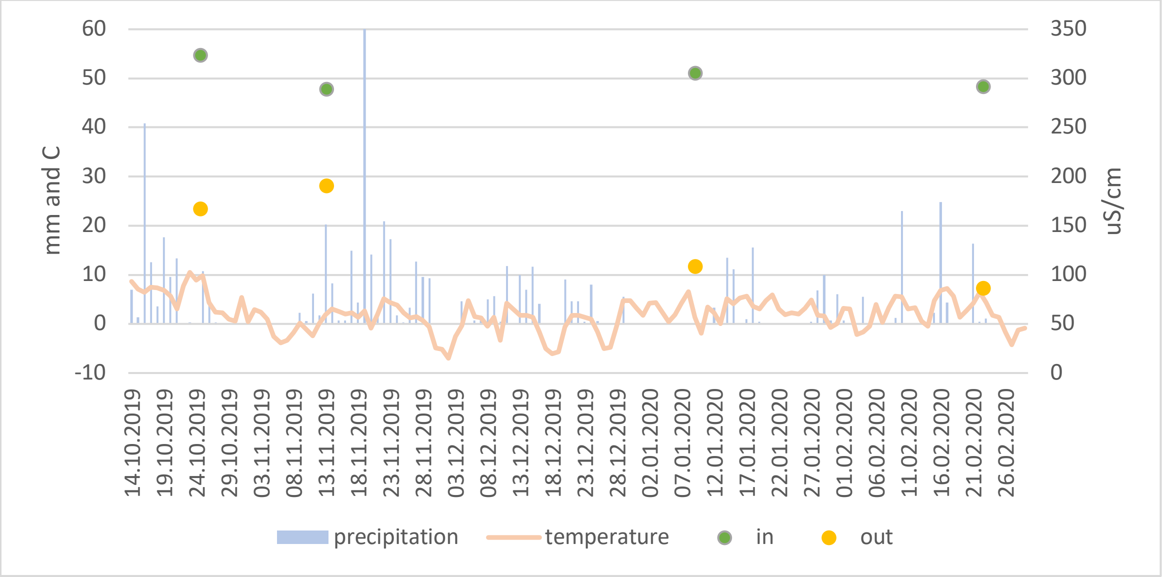


Figure 3.7. Electric conductivity at inlet and outlet of the Bolstadhagen raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.3.6

Electric conductivity is higher in the inlet than outlet, this could be caused by salts used for deicing the streets in the catchment.

pH is portrayed in figure 3.8, where pH is higher in the inlet than the outlet, except 13.12.19 where pH of the inlet and outlet is the same. The difference between inlet and outlet is greater in the two last measurements than the first.

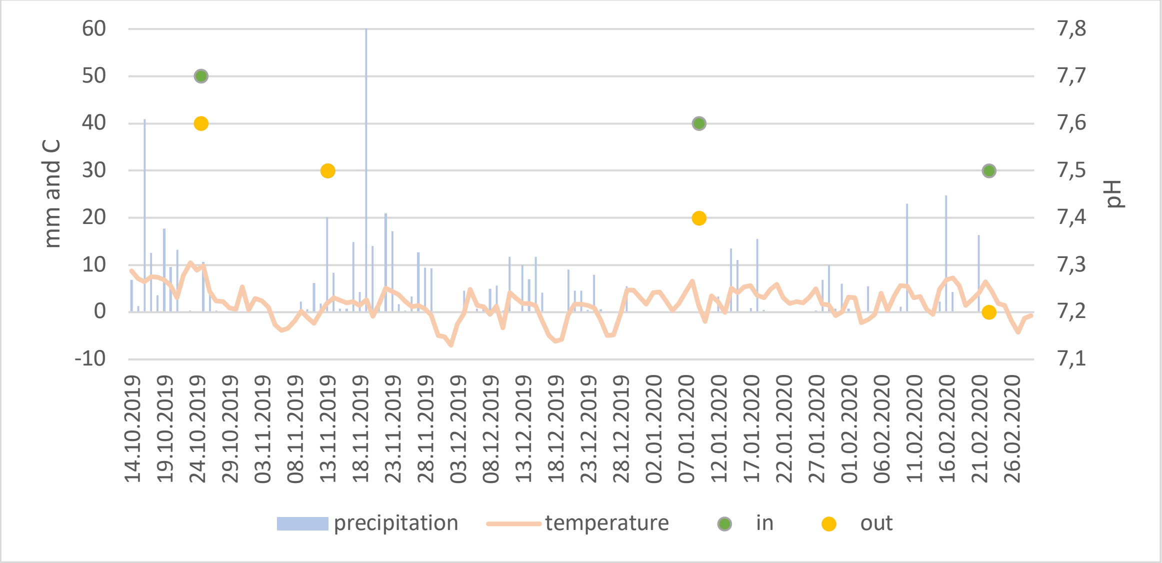


Figure 3.8. pH at inlet and outlet of the Bolstadhagen raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.3.6

All pH measurements were in the neutral range. Outlet being a little lower could be due to buffer effects in the raingarden.

Colour is shown in figure 3.9. Inlet is higher than outlet at all measurements, and both are decreasing throughout the period. Note that the values are very low at all measurements.

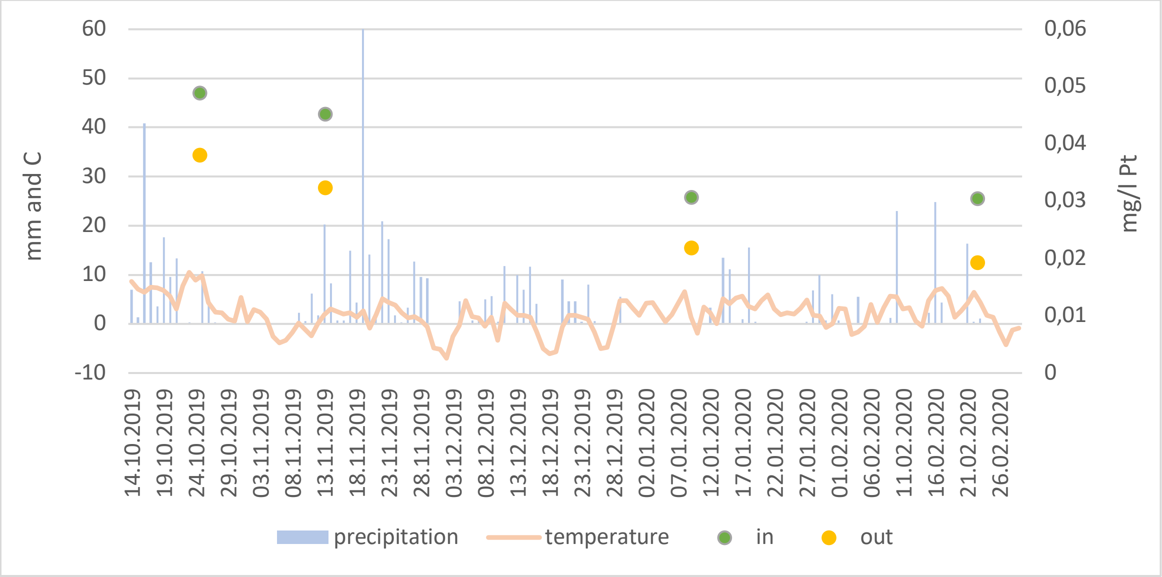


Figure 3.9. Colour at inlet and outlet of the Bolstadhagen raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig 3.6

Both inlet and outlet have low colour values. The inlet being a little higher could be caused by runoff of organic material from forest area, which is then settled in the raingarden.

Turbidity is showed in figure 3.10, the outlet is higher than the inlet. At the first sample time they are very similar, but at the rest outlet is notably higher than inlet.

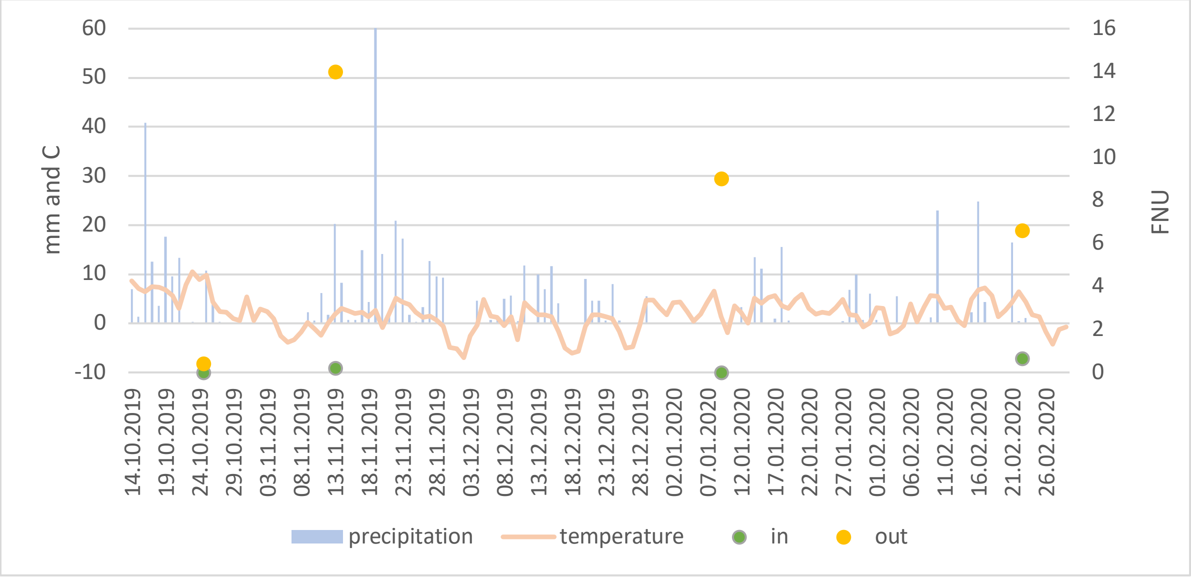


Figure 3.10. Turbidity (FNU) at inlet and outlet of the Bolstadhagen raingarden, with climate data. Measuring points are the same as those indicated with vertical lines in Fig.3.6

Turbidity being higher in the outlet than the inlet could be loss of particular matter from the raingarden. Inlet water has very low turbidity

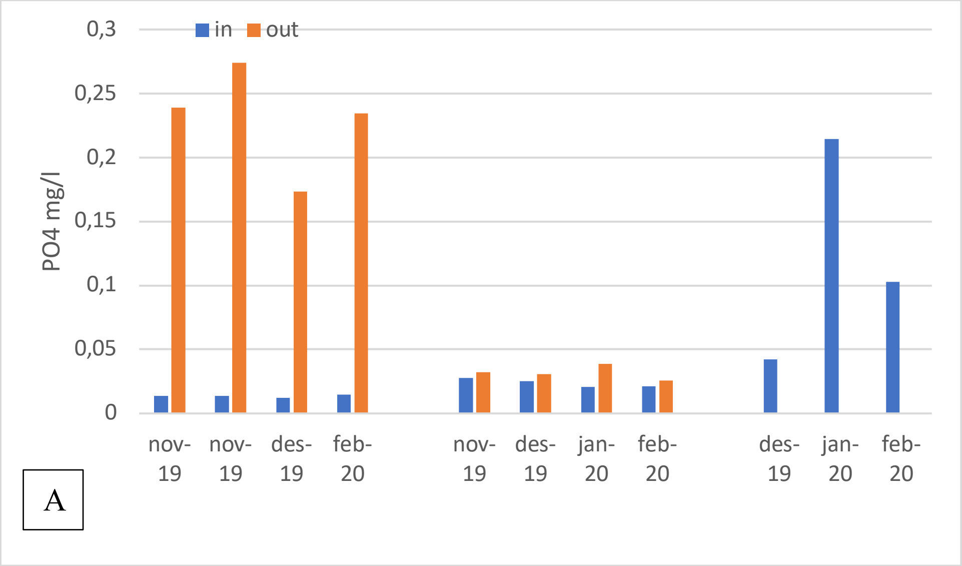
EC: Inlet at Bolstadhagen much higher than NMBU, Bolstadhagen sable and inlet always higher than outlet. NMBUmore variations and switch between outlet higher than inlet to inelt higher than outlet. Road salts in catchment of Bolstadhagen most lilkely reason for this.

pH: Similar values,more variations at NMBU
Colour: Very low at both locations, would have expected Bolstadhagen to be higher as water comes from larger catchment with more contact with soil. But Bolstdhagen could be more diluted and the organic compounds can have settled elsewhere in the catchment.
Turbidity: Bolstadhagen higher than NMBU, more variations at NMBU.

Water quality in different raingardens

Figure 3.11 shows phosphate(A) and ammonia(B) at inlet and outlet of NMBU and Bolstadhagen raingardens and water entering the Bjørnstjerne Bjørnsonsgate raingarden. The phosphate in the NMBU raingarden inlet is much lower than outlet. In Bolstadhagen inlet is lower than outlet, but the difference is little. Ammonia in the NMBU raingarden is higher in the inlet on the first three sampling times then higher in the outlet on the last sampling time, but values are overall low, with a small difference between inlet and outlet. In Bolstadhagen the inlet and outlet are almost the same at the two first sampling times, with the inlet being a little higher than the outlet. On the two last sampling times the inlet was similar to the first two, but the outlet was considerably higher. In Bjørnstjerne Bjørnsonsgate the concentration of both phosphate and ammonia varies more and are higher than in both the NMBU and Bolstadhagen raingardens. In all raingardens the concentration of phosphate was higher than the ammonia concentration at all sampling times.

NMBU Bolstadhagen BBG



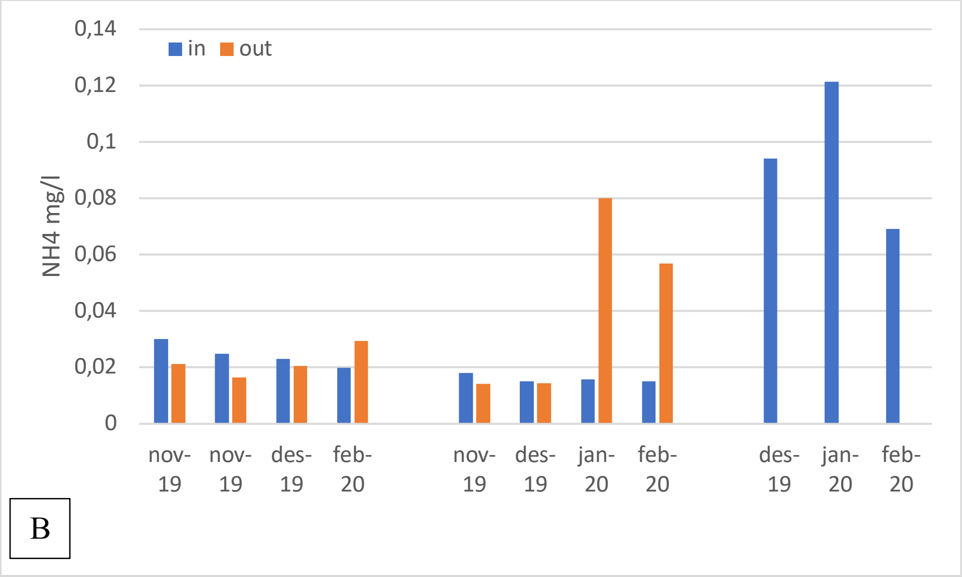


Figure 3.11. Major nutrients at inlet and outlet of NMBU, Bolstadhagen and Bjørnstjerne Bjørnsonsgate (BBG) raingardens. A shows phosphate and B shows ammonium.

Sodium concentrations in the raingardens are shown in Figure 3.12. NMBU raingarden has very low concentrations both in and out, little higher concentrations in inlet in December and February. Bolstadhagen has almost ten times as much as NMBU at inlet, and lower concentrations in outlet at all measuring times. Bjørnstjerne Bjørnsonsgate has higher and increasing concentrations throughout the sampling period.

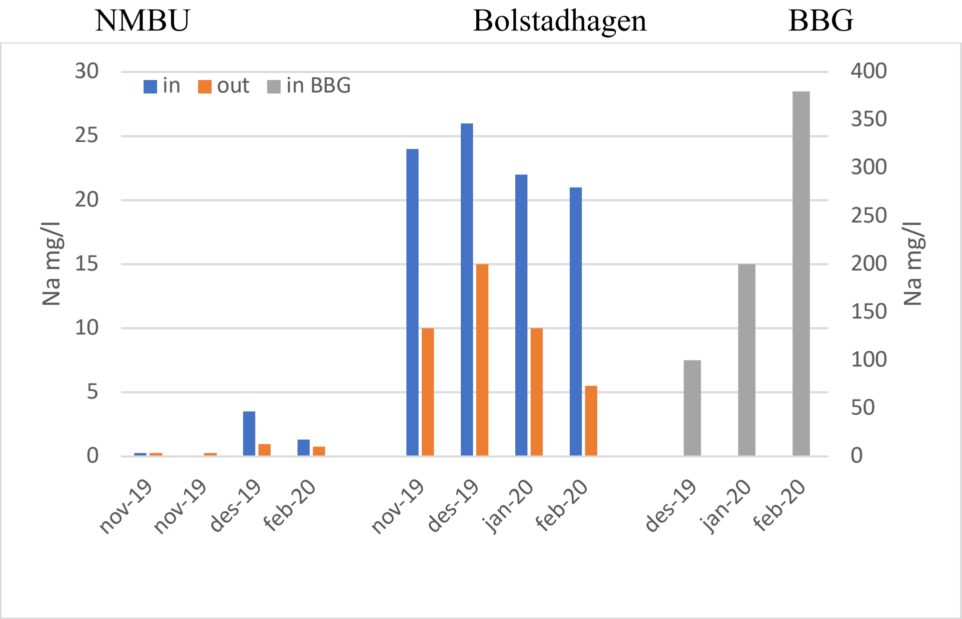


Figure 3.12. Sodium in the inlet and outlet of NMBU and Bolstadhagen raingardens on the left y-axis, and the inlet of Bjørnstjerne Bjørnsonsgate (BBG) on the right y-axis.

Chloride concentrations are shown in Figure 3.13. Concentrations are low in the NMBU raingarden, higher in Bolstadhagen with inlet concentrations higher than outlet. The Bjørnstjerne Bjørnsonsgate raingarden has high and growing concentrations.

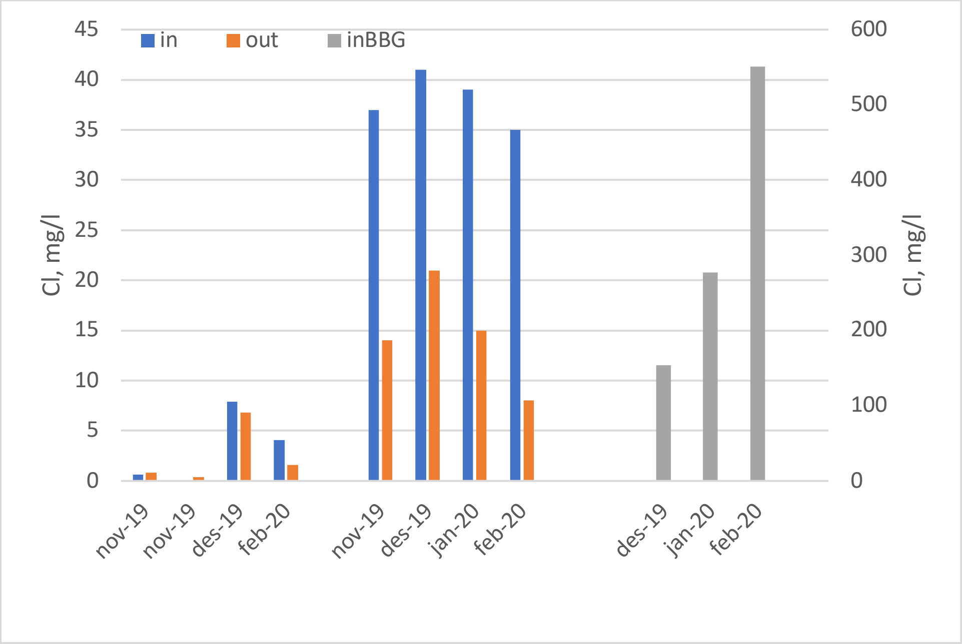


Figure 3.13. Chloride in the inlet and outlet of NMBU and Bolstadhagen raingardens on the left y-axis, and the inlet of Bjørnstjerne Bjørnsonsgate (BBG) on the right y-axis.

Magnesium concentrations are displayed in figure 3.14. NMBU raingarden has higher outlet concentrations than inlet, outlet concentrations are higher at the last two sampling times than the two earliest ones. Bolstadhagen has higher inlet concentrations than outlet concentrations. Bjørnstjerne Bjørnsonsgate has concentrations between those of NMBU and Bolstadhagen, with all raingardens having low concentrations of magnesium.

NMBU Bolstadhagen BBG

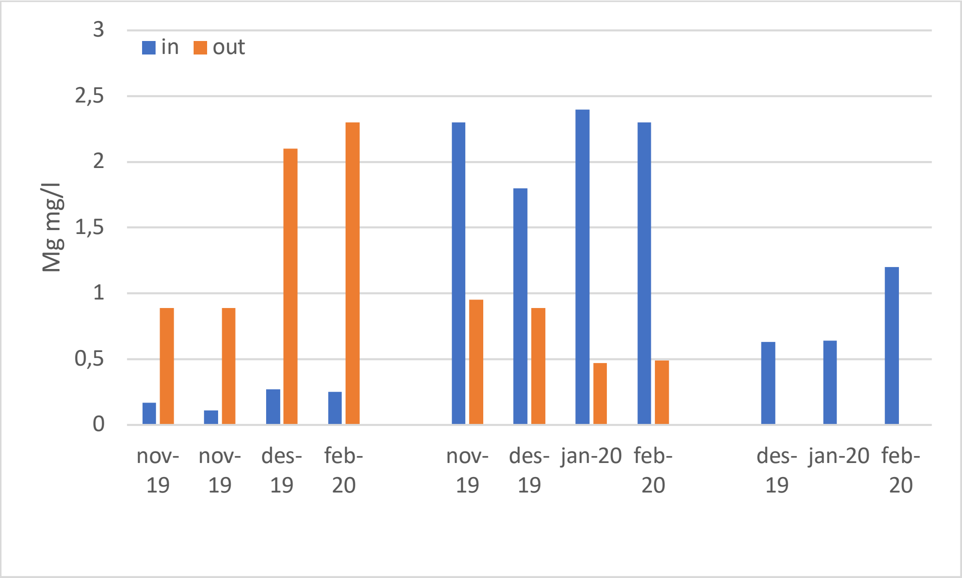


Figure 3.14. Magnesium in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG).

Calcium concentrations are presented in figure 3.15. Show similar trends as magnesium, but with higher concentrations.

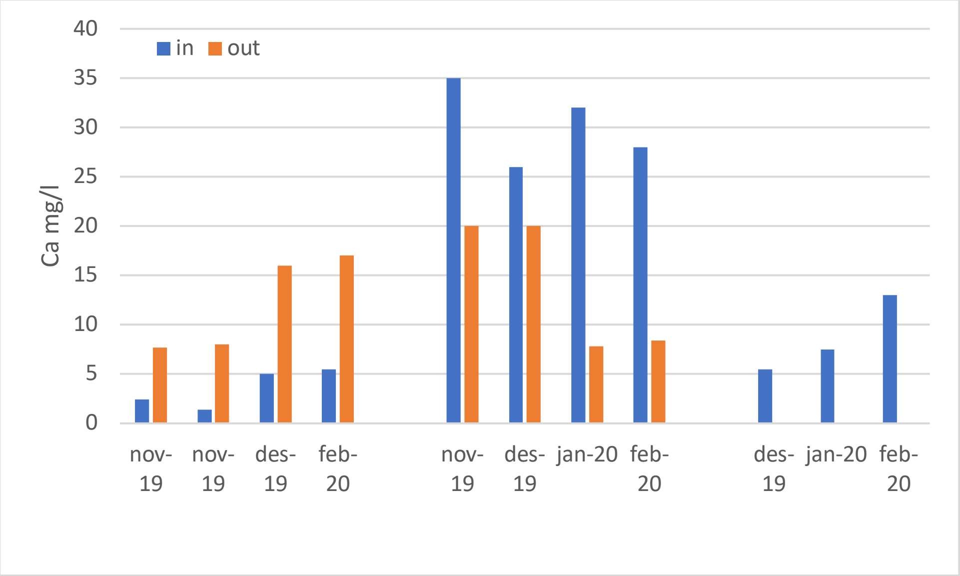


Figure 3.15. Calcium in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG).

Potassium concentrations are presented in figure 3.16. NMBU raingarden has higher outlet concentrations than inlet concentrations, with an increasing trend throughout the sampling period. Bolstadhagen has higher outlet concentrations than inlet concentrations in the first two sampling times and higher inlet- than outlet concentrations at the last two sampling times all samples from Bolstadhagen have similar concentrations. The Potassium concentrations in Bjørnstjerne Bjørnsonsgate are increasing throughout the sampling period.

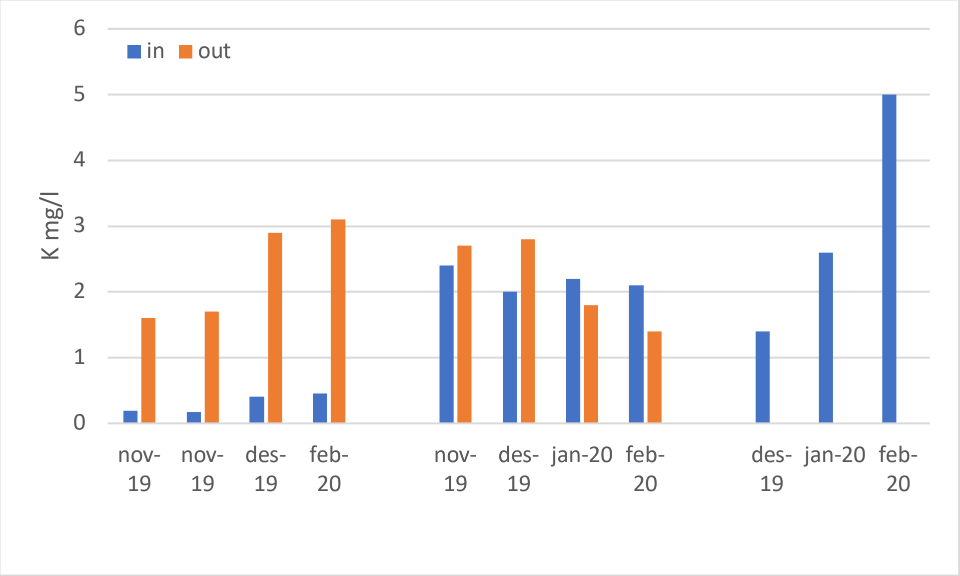


Figure 3.16. Potassium in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG).

Aluminum concentrations in both NMBU and Bolstadhagen raingardens have higher concentrations in inlet than outlet. In the NMBU raingarden and in Bjørnstjerne Bjørnsonsgate there is an increase in concentration while in Bolstadhagen it is more stable (figure 3.17).

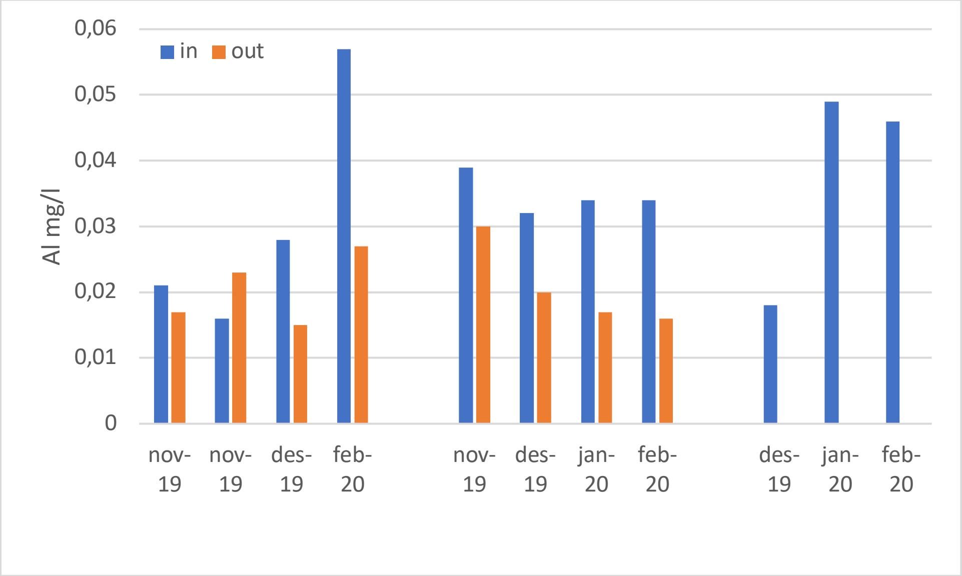


Figure 3.17. Aluminum in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG).

Iron concentration in NMBU raingarden is higher out than in, with an increasing concentration in both inlet and outlet. Bolstadhagen has similar inlet and outlet concentration with little change during the period. In Bjørnstjerne Bjørnsonsgate the January sampling was higher than the other two (figure 3.18).

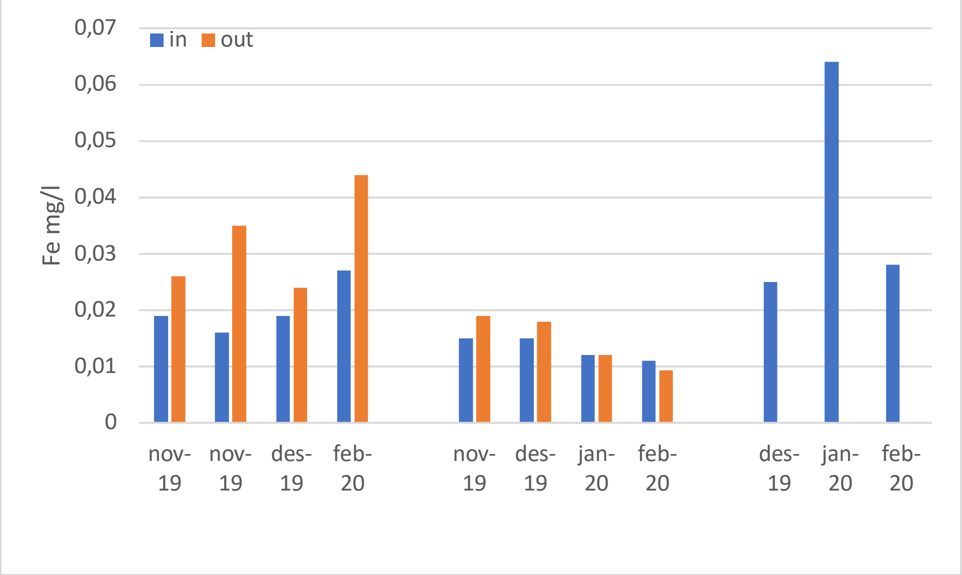


Figure 3.18. Iron in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG).

Zink concentrations in the inlet at NMBU raingarden were very high but reduced by one order of magnitude in the outlet (fig.3.19 A). Outlet at NMBU still had values over limit, 11µg/l. Bolstadhagen raingarden had more similar concentrations in inlet and outlet, with one sample being higher than limit value. It varied between inlet having the highest concentrations to outlet having the highest concentrations. In Bjørnstjerne Bjørnsonsgate the two first samplings were higher than limit value, while the last being lower (fig.3.19 B).

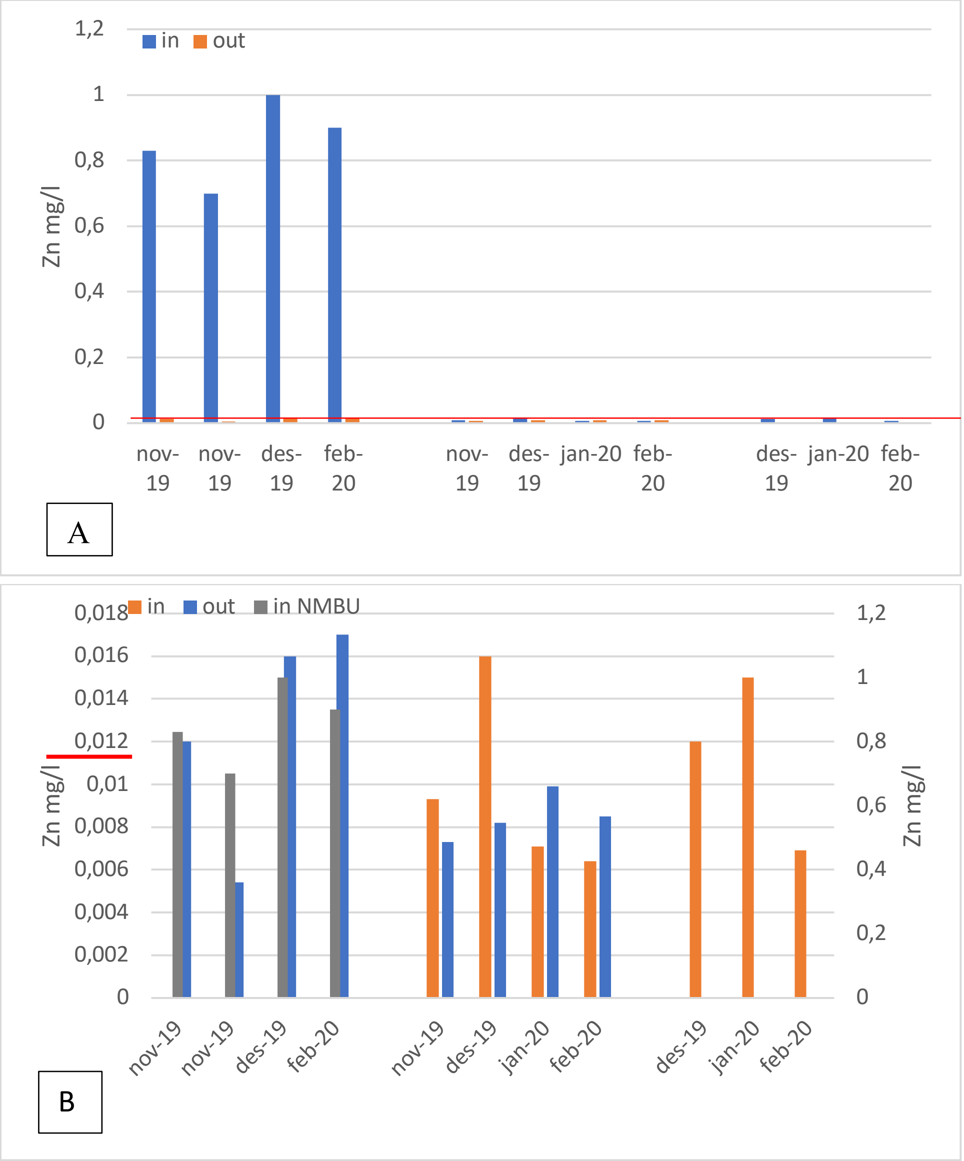


Figure 3.19. Zink in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate(BBG). A shows all on the same axis, B shows inlet at NMBU(grey) on the left y-axis and the rest on the right-axis. The red line indicates the limit value/ environmental quality standard proposed by the Norwegian directorate group for implementation of the water directive(11ug/l).

Lead concentrations in NMBU raingarden are decreasing between inlet and outlet except one high outlier. Concentrations decrease during the sampling period. In Bolstadhagen raingarden there is also a decrease between inlet and outlet and during the sampling period. Bjørnstjerne Bjørnsonsgate have similar concentrations as the two other raingardens (Figure 3.20).

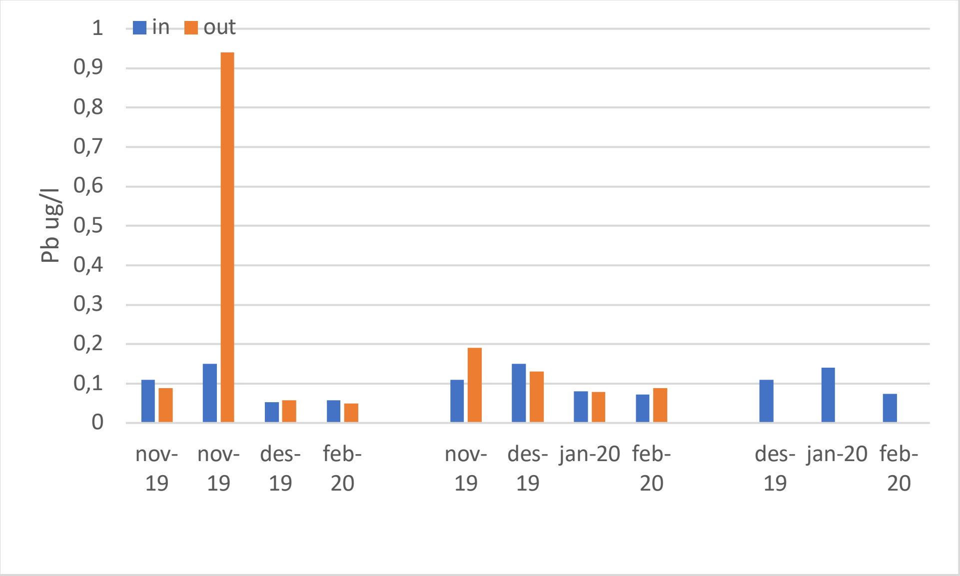


Figure 3.20. Lead in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate (BBG).

Cadmium concentrations in NMBU raingarden varies between higher inlet than outlet and higher outlet than inlet, and overall increase during sampling period. The Cadmium concentrations in Bolstadhagen raingarden decrease from inlet to outlet. In Bjørnstjerne Bjørnsonsgate concentrations decrease during the period (figure3.21).

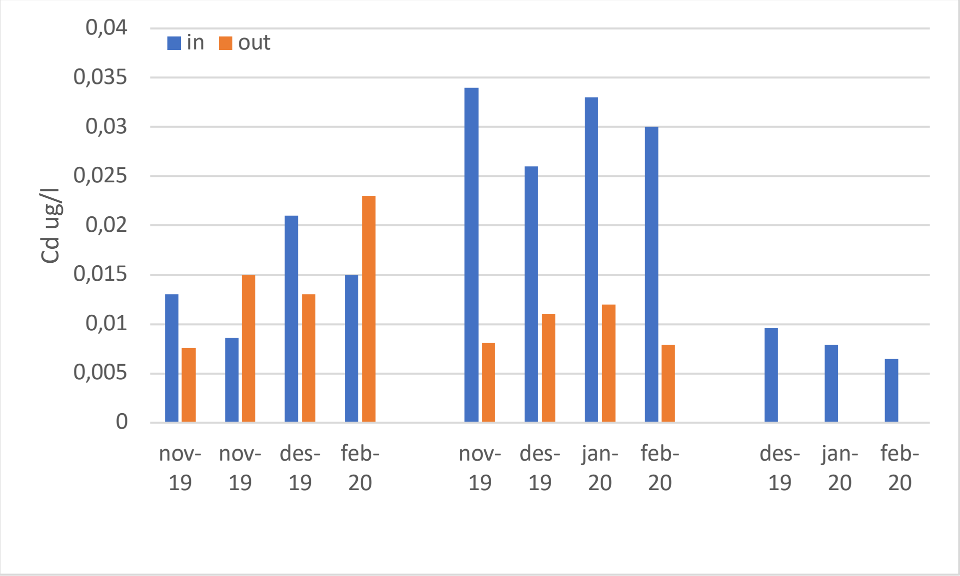


Figure 3.21. Cadmium in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate (BBG).

Copper concentrations in NMBU raingarden increase between inlet and outlet. There is a slight increase in inlet concentrations, all samples well under limit value. Bolstadhagen raingarden have one sample higher than limit value, the others are very similar, with a slight decrease in the two latest sampling times. Bjørnstjerne Bjørnsonsgate have one sample with copper concentration higher than limit value (figure 3.22).

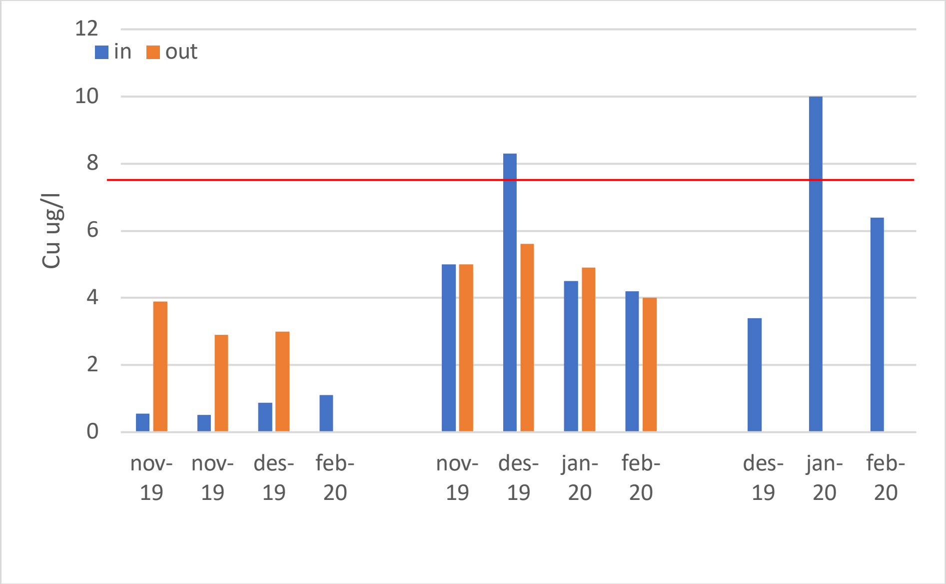


Figure 3.22. Copper in the inlet and outlet of NMBU and Bolstadhagen raingardens and the inlet of Bjørnstjerne Bjørnsonsgate (BBG). The red line indicates the limit value/ environmental quality standard proposed by the Norwegian directorate group for implementation of the water directive(7,8ug/l).

Water analysis Mesocosm/Plantekasser

Soil 1 is the raingarden soil from Lindum, soil 2 is a mixed raingarden soil (70% raingarden soil from Lindum and 30% coarse sand). B is bare soil, G is lawn, L is Lysula and M is mix of species (table 1.1 and figure 1.9). The values are average between three replicas. Little difference in pH the two soil types. Type 2 has the higher values except for plant type B, where soil type 1 has the highest pH (figure 3.23).

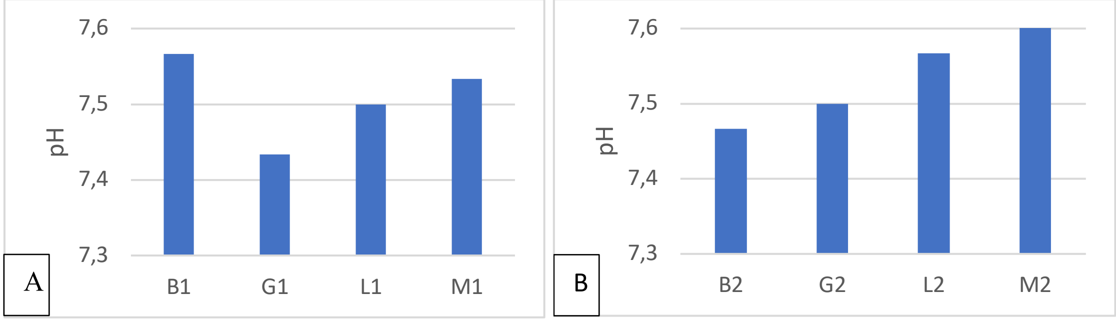


Figure 3.23. pH in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2, letters refer to vegetation mixture

Soil type 1 has higher conductivity than soil type 2 (figure 3.24). Plant type L, lysula, has the lowest conductivity in both soil types.

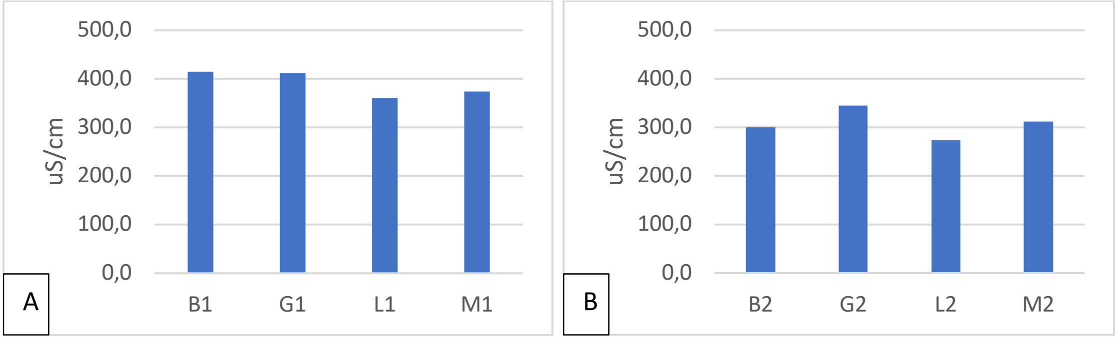


Figure 3.24. Electrical conductivity in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Soil type 1 has slightly higher colour than soil type two. Plant type G, lawn has the lowest colour in both soil types(figure 3.25).

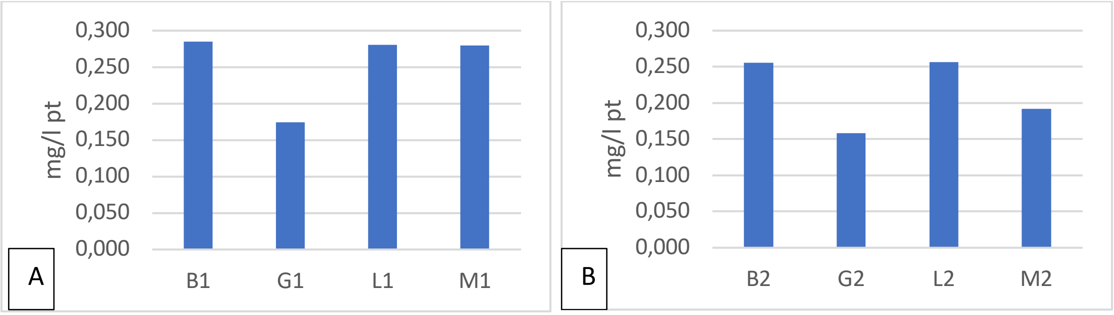


Figure 3.25. Colour in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Turbidity is higher in soil type 2 than soil type 1, except for plant type B, bare soil. Plant type B also has the biggest difference in turbidity between the two soil types (figure 3.26).

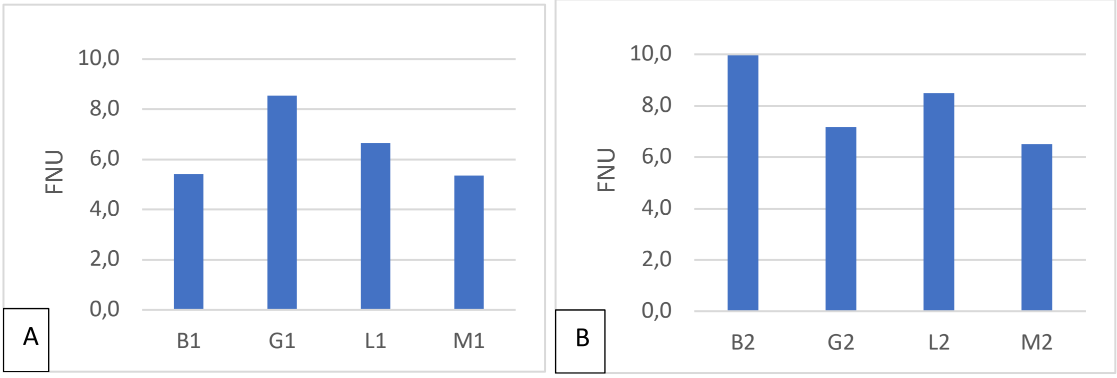


Figure 3.26. Turbidity (FNU) in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Total organic carbon is higher in soil 1 (figure 3.27) This is as expected as it has a higher organic content than soil 2.

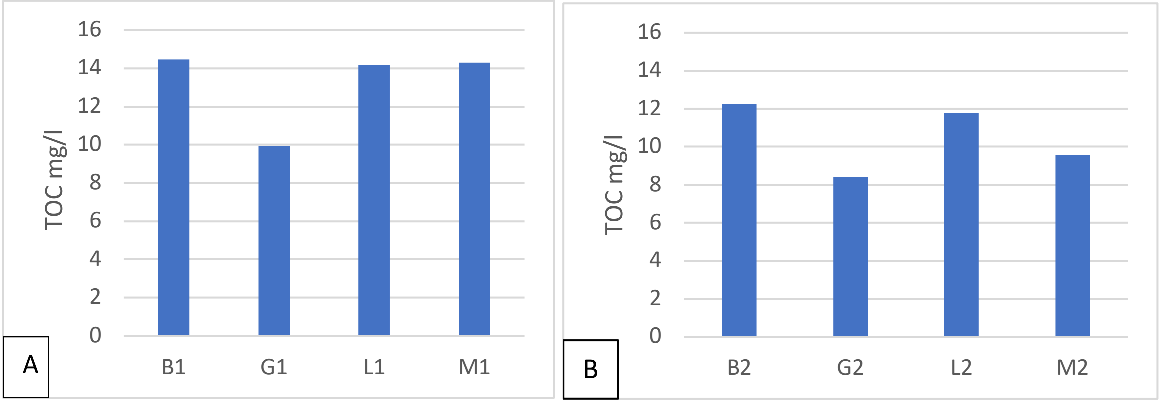


Figure 3.27. Total organic carbon in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Soil 1 has a higher loss of nutrients, especially phosphate, than soil 2 (figure 3.28). As expected, due to higher content of organic matter. Bare soil has a higher loss of nitrate than the planted boxes.

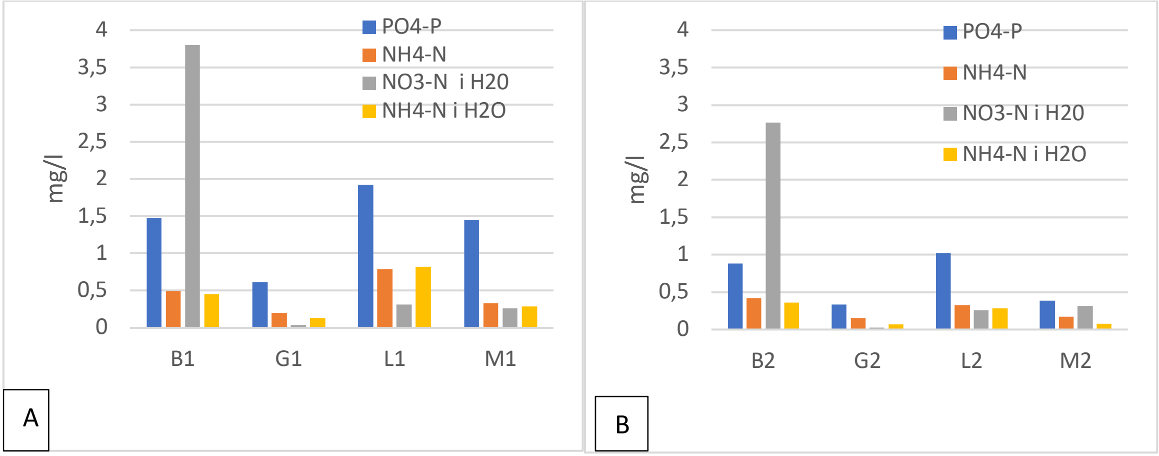


Figure 3.28. Major nutrients in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Copper is much higher than cadmium and lead (figure 3.29) but stil under the limit value of 7,8 µg/l (the Norwegian directorate group for implementation of the water directive). Copper is a more naturally occurring mineral than cadmium and lead.

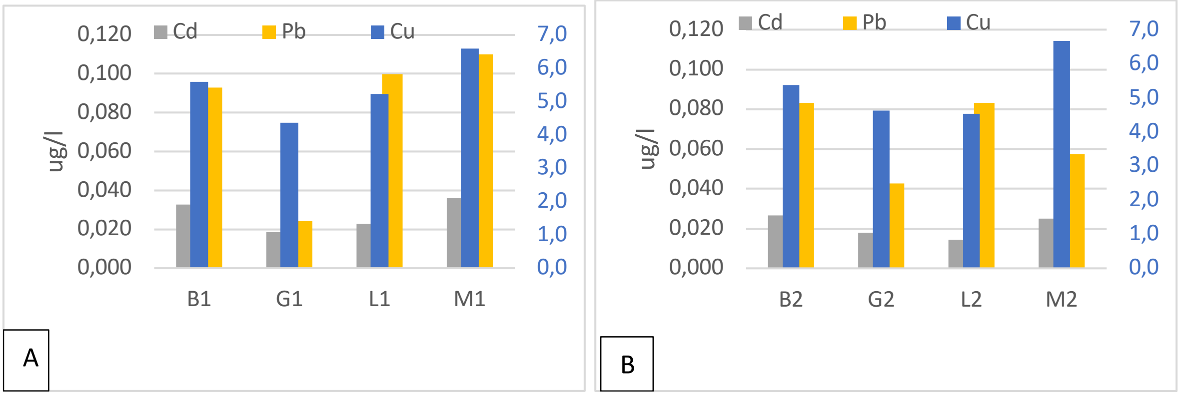


Figure 3.29. Cadmium, Lead and Copper in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2. Cu(blue) is on the right y-axis(ug/l), Cd and Pb on the left y-axis(ug/l).

Iron is higher in the organic rich soil (figure 3.30) than the more sandy soil. Iron is also more naturally occurring than aluminum and zinc. Not much difference between the two soils in regards of aluminum and zinc concentrations in the drainage water.

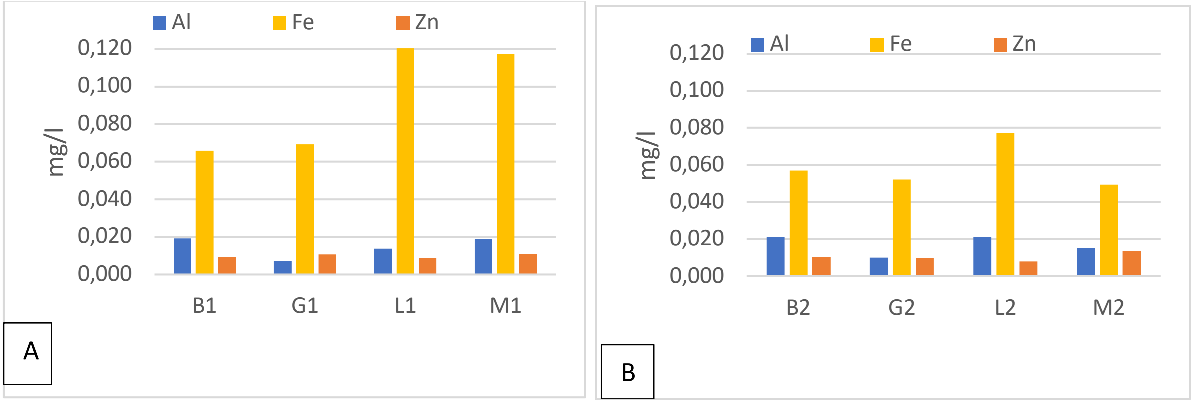


Figure 3.30. Aluminum, Iron and Zink in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Calcium and potassium are higher in soil one than soil 2(figure 3.31). Not much difference between the different plant treatments.

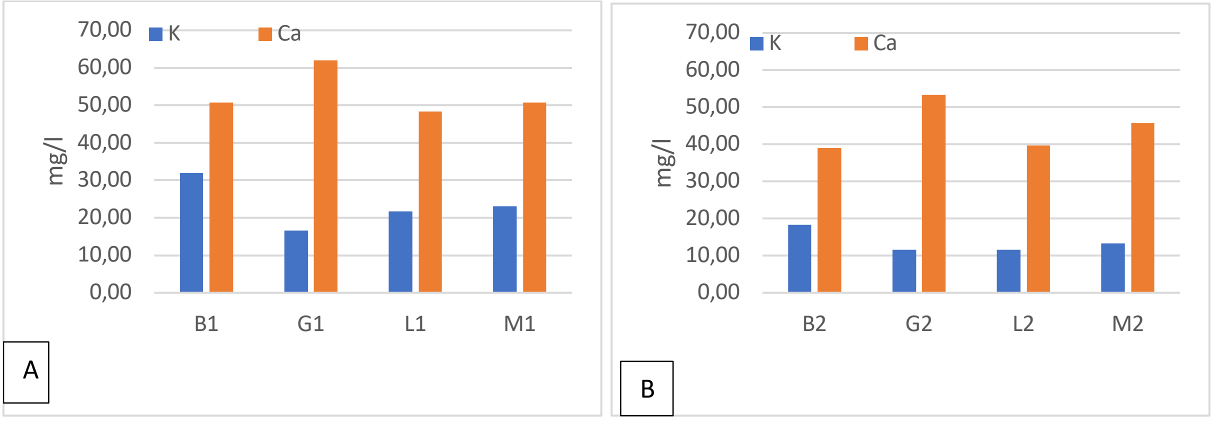


Figure 3.31. Potassium and Calcium in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Magnesium and chloride are higher in soil two while sodium and sulphate are more similar between the two soils (figure 3.32).

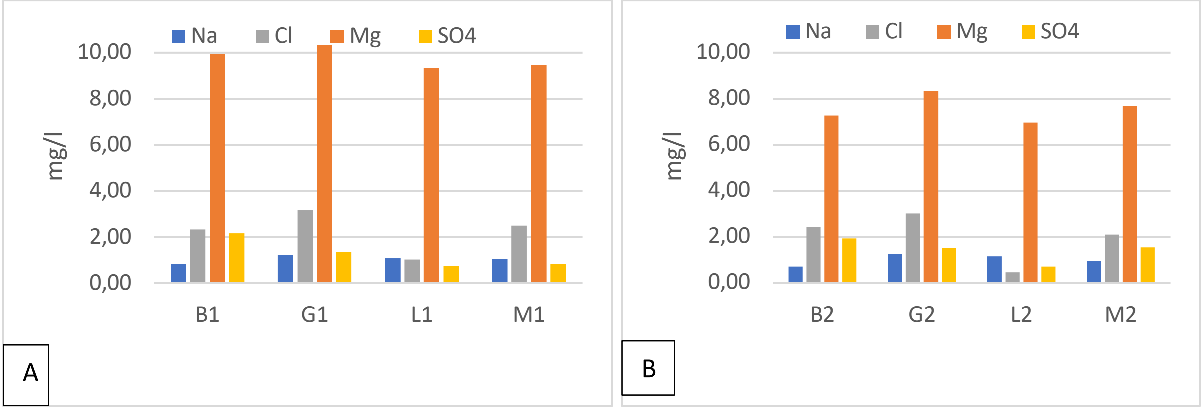


Figure 3.32. Sodium, Chloride, Magnesium and Sulphate in the drained water from the mesocosm experiment. A soil type 1 and B soil type 2.

Organic polutants PAH were found in outlet water in Bolstadhagen (table 3.5) and Bjørnstjerne Bjørnsonsgate (table 3.6) The PAHs found in Bjørnstjerne Bjørnsonsgate and Bolstadhagen exceeded the acceptable levels (Direktoratsguppen vanndirektivet, 2018). There was not found any PAH in the inlet water at Bolstadhagen. This could be that PAH was washed through the raingarden and accumulated in the outlet, or possibly from the Q-bic magasine consisting of plastic crates. PCB and oil were not found in any of the location at the measuring times.

Table 3.5 PAHs in outlet water from Bolstadhagen

	13.12.19	**23.01.20**	**24.02.20**
Phenanthrene (µg/l)	0,016	0,022	0,015
Fluoranthene (µg/l)	0,012	0,012	-
Pyrene (µg/l)	0,015	0,015	-
Indenol(1,2,3-cd)pyrene (µg/l)	-	0,0033	-
Benzo(ghi)perylene (µg/l)	0,0044	0,0038	-
Sum PAH(16)EPA (µg/l)	0,047	0,055	0,015

Table 3.6 PAHs in water from Bjørnstjerne Bjørnsonsgate

	13.12.19	**23.01.20**	**24.02.20**
Naphthalene (µg/l)	0,025	0,016	-
Acenaphthylene (µg/l)	0,011	-	-
Phenanthrene (µg/l)	0,062	0,032	0,013
Fluoranthene (µg/l)	0,050	0,020	0,013
Pyrene (µg/l)	0,090	0,037	0,020
Benzo(a)anthracene (µg/l)	0,010	-	-
Chrysene/Triphenylene (µg/l)	0,056	0,019	0,011
Benzo(b)fluoranthene (µg/l)	0,037	0,014	-
Benzo(a)pyrene (µg/l)	0,015	-	-
Indenol(1,2,3-cd)pyrene (µg/l)	0,013	0,0067	0,0035
Benzo(ghi)perylene (µg/l)	0,034	0,013	0,0067
Sum PAH(16)EPA (µg/l)	0,40	0,16	0,068

Bolstadhagen Raingarden Infiltration

Infiltration test, modified Philip Dunns.
The infiltration tests from Bolstadhagen raingarden were conducted 30.04.20. At this time raingarden 1 and 2 were flooded so infiltration test were only conducted in raingarden 3 and 4. MPD1 and MPD2 are from raingarden 3, and MPD3 and MPD4 are from raingarden 4.

MPD2 and MPD4 were made on the west side of the raingardens while MPD1 and MPD3 were made on the east side of the raingardens.

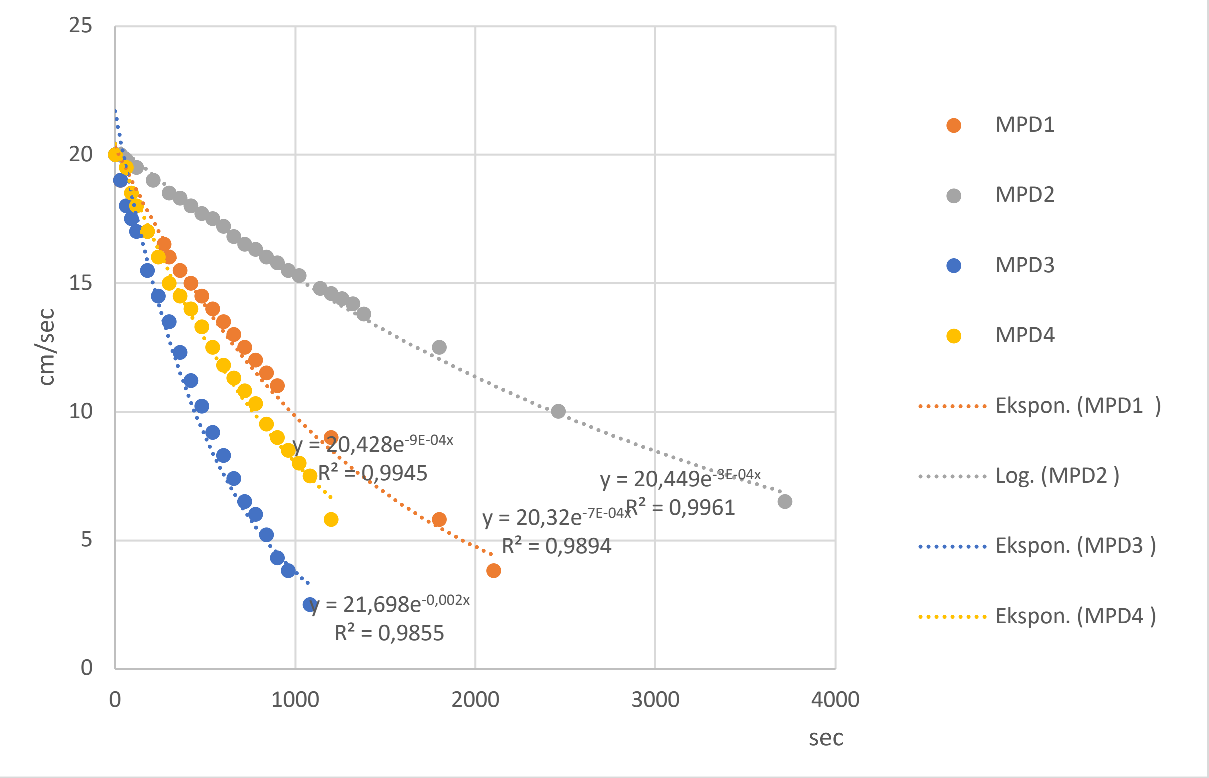


Figure 3.33 Modified Philip Dunns infiltration test. MPD1 and MPD2 are from raingarden 3, and MPD3 and MPD4 are from raingarden 4.

Chapter 4 Conclusions

Higher organic matter content in the soil seam to lead to greater loss of nutrients, based on the results from the mesocosm raingardens.

The pollutants found in the catchment and what you can allow to drain from the raingarden should influence what soil type is used when constructing raingardens.

Using Direktoratsguppen vanndirektivet (2018) Chapter 11.10 *Tilstandsklasser for Prioriterte- og vannregionspesifikke stoffer i ferskvann, kystvann og sediment* Table 11.10.1 *Tilstandsklasser for ferskvann (µg/l)* as a guide to classify whether the water is polluted or not most samples taken from the four raingarden systems included in this thesis were in good condition, class I or class II. This means that no measurers need to be taken. However, the water entering the NMBU raingarden had very high concentrations of zinc, class V(highest). The water in the outlet still had high concentrations of zinc, but it was lowered to a class IV. This should still be lower further to obtain good water quality. Also samples from Bjørnstjerne Bjørnsonsgate have concentration of zinc that were in class IV.

The nutrients found in the raingardens are lower than the recommended values by Drikkevannsforskriften, so even if it is undesirable that some of them leak nutrients it is not something that needs immediate measures. The same applies to the colour.

The soil analysis showed high cation exchange capacity (table 3.2 and 3.3) and loss on ignition (tables 3.1, 3.2, 3.3 and 3.4) (Krogstad T. & Børresen T. 2015). This should mean good conditions for binding cations.

To sum up, raingardens can both leak and bind pollutants. The NMBU raingarden and mesocosm gardens leaked nutrients while the Bolstadhagen garden bound them.

It would be interesting to look more into the linkage between the differences in soil and how that potentially can give different conditions in handling different pollutants. Also having more data from around the year would be interesting, does the raingardens behave differently in the spring and summer seasons when plant growth and uptake plays a bigger role, perhaps nutrient leakage is not an issue then. How long these effects last would additionally be interesting to investigate, does the raingardens become clogged?

In Bolstadhagen I would recommend the municipality to continue monitoring, possibly with new master thesis to investigate the processes further and to look into the water transport. The first raingarden after the inlet appears to be clogged with fine particles as every time I have observed it it always water filled, also in periods longer than 48 after rain events. The sensor data (figure 3.6B) indicate continuous water saturation.

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