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Characterisation of the stormwater in The Bryggen catchment

A thorough study of Norwegian urban pollutants and its impact on decomposition of archaeological remains

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Geotechnology
Submission date: June 2013
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Abstract

Increased urbanization leads to more impermeable surfaces. Togther with climate changs with more intensive precipitation, more frequent urban floodings should be expected in the near future. As undreground convey systems have proven to be inadeqate, leading to several combined sewage overflows each year, new innovative stormwater management devices are relevant and also getting more recongnition.

Raingardens, a planted depression, work as local stormwater management and allows water to infiltrate into the ground. A raingarden is planned on The Bryggen in Bergen, Norway. The Bryggen has struggled with lowering of the groundwater table, causing settling of overlaying buildings and increased decomposion of underlayning protected archaeological remains. The raingarden will be fed with stormwater from the catchment above The Bryggen. Microorganisms in the ground are responsible for decay of the archaeological remains, it was therefore importante to characterize the stormwater and indetify potential treaths to the archaological remains.

It was found that stromwater from the impervious surfaces at The Bryggen catchment varies with location, surface use and within rain events. Different roofing material and traffic volume have different effects on pollutant distribution and concentration. The road Øvregaten with the most traffic (5001-10 000 vehicles pr day) had the highest pollution levels for 8 parameters (TSS, Conductivity, total P, PO_4, Cu, Ni Zn and Cu), while the smaller road Koren Wibergsplass had the highest pollution level on one parameter (Pb). The roof surfaces had signigicantly lower pollutant levels, but does not achieve insignificant pollution level for recieving waters according the The Climate and Pollution Directorate in Norway. An estimated value for monthly TSS was 654 kg. The catchment had a minimum volume percent of particles with diameter below 1.2 µm at 70% for S2, 10% for S6, while S3 and S4 had a maximum at 15% and 30% respectivley.

Comparing filtrated and unfiltrated heavy metal samples for Øvergaten it was shown that mimimum 65% of the metals was particle bound, while a value of 75% particle bound metals were more common. Through litterature review of pollutant retension in raingardens, it is estimated that the planned raingarden, with its high content of organic material will be able to retain heavy metals concentrations from 55% to 99%.

It is suggested that the stormwater from the large road is not utilized in feeding the groundwater, due to the high pollutant level. No clear answer regarding sulfates and dissolved oxygen level in the effluent of the raingarden was found.

Sammendrag

Økt urbanisering fører til flere tette overflater. Sammen med klima forandringer med mer intens nedbør, er flere urbane flommmer er ventet i fremtiden. Tradisjonelle kloakksystem har vist seg å være utilstrekkelige og fører hvert år til utslipp av kloakk blandet med overvann. Nye innovative lokale overvannsmetoder er i relevante for disse problemene og får stading større tiltro.

Regnbed, en planted depresjon, håndterer lokalt overvann og tilltater overvann å infiltrere ned i grunnen. Ett regnbed er planlagt på Bryggen i Bergen. Bryggen har problemer med senkning av grunnvannsspeilet som fører til settninger i overliggenede bygninger og nedbrytning av arkeologisk viktig materiale. Regnbeddet vil bli matet med overvann fra nedbørsfeltet over Bryggen. Mikroorganismene er ansvarlig for nedbrytnining av organisk materiale og kan bruke forurensningene i overvannet som energi kilde, det var derfor viktig å karakterisere overvannet med tanke på potensielle trussler mot de arkeologiske lagene i grunnen.

Resultatene viser at overvann fra nedbøresfeltet bak Bryggen varierer med lokasjon, overflate bruk og gjennom nedørshendelser. Forskjellig takmateriale, og trafikk mengde har forskjellig effekt på overvannets areal- og tidsfordeling og konsentrasjon. Øvregaten, den veien med høyest trafikk mengde (5001-10 000ÅDT) har høyest forunensningsnivå for 8 parametere (TSS, konduktivitet, total P, PO_4, Cu, Ni Zn and Cu), mens den mindre veien, Koren Wibergsplass, har det høyste forurensningsnivået for en parameter (Pb). Avrenning fra takene hadde betydelig mindre forurensning, men og oppnår ikke "‘ubetydelig forurensningsnivå for utslipp til vann"’ ifølge Klima og Forurensnings Direktoratet. Ett estimert verdi for TSS var 654 kg for en gjennomsnittlig måned. Nedbørsfeltet hadde en minimums verdi for partikkler med diameter under 1.2 µm på 70% for S2, 10% for S6 mens S3 of S4 hadde maksimums verdier på henholdsvis 15% og 30%.

Minimumsverdien av partikel bundet metall var 65%, mens 75% partikkel bundet metaller var det mest hyppigest observert i resultatene. Gjennom litteraturstudie av retensjon av metaller i regnbed er det estimert at regnbeddet på Bryggen vil være i stand til å redusere tungmetall innholdet fra 55% til 99%.

Det ble gitt forslag om å ikke bruke overvann fra Øvregaten, da denne har det desidert høØyeste forurensningsnivået. Ett klart svar på hva som vil skje med sulfater og oppløst oksygen gjennom regnbeddet ble ikke besvart i oppgaven.

Preface

This master thesis (TGB 4935) counting 30 studypoints, is written in the spring of 2013 at the Institute for Water and Environment at The Norwegian University of Sience and Technology(NTNU), Trondheim.

This thesis investigate the stormwater quality through field and lab work at The Pier catchment.

NIVA has in a cooperation together with NIBR, NGU, NIKU, The National museum in Copenhagen and The Technical University of Delft in The Netherlands the project Urban WATCH -Cultural Heritage and Water Management in Urban Planning. Work Pacage 3 in URBAN WATCH has an objective to ”‘ Create Solutions that preserve sustainable water management to protect cultural heritage”’ It is in cooperation with the project Urban WATCH that this master has been enabled. In this project Bryggen in Bergen is an excellent study site as it is build on archaeological remains, and the overlaying buildings are dated back to 1700 century.

Urban WATCH has supported this master with both knowledge and economy. Through Urban WATCH it is decided to build a raingarden at the back of The Pier in Bergen. The results from this master thesis will be used to estimate treatment efficiency of the raingarden and characterize pollutants that should be foucused on in the treatment process.

A special gratitude goes to Doctor Tone M. Muthanna for excellent guidance and procjet management. Muthanna has broad insight of the objectives of the procjet and has with this guided and put me in contact with a number of resourceful people, given me the opportunity to present my work for the URBAN WATCH group and participate on useful seminars on the topic of conservation of archeological remains. All in all, this master has been very exciting to work on, and I hope it will be useful for others. I would also like to thank the URBAN WATCH group for useful information and feedback on the thieses, Ole Kristian Hess Erga and Åse Åtland at NIVA for lending and guiding me through their laboratory, Syverin Lierhagen for identifying the metal samples, taking the time to answer questions and sharing excellent Excel skills, Trine Ness He̱rg and Gøril Thorvaldsen for guidance in lab and sample examination and a special tank to Trine for stand by call in the sampling period, Bergen Municipality, by Joyce Wakker and Endre Leivestad, for providing me with maps and information of Bergen city. A thank to people answering mails, Kevin Tuttle and Torstein Dalen at Norconsult, Floris Boogard, Hans De Beer and Rolf Tore Ottesen.

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Abbreviation	Description
NGU	Norwegian Geological Survey
NIBR	Norwegian Institut for Urban and Regional Research
NIKU	The Norwegian Institut for Cultural Heritage Research
NIVA	Norwegian Institut for Water research

1 Introduction

The climatic changes excpected for Norway gives us increased temperature by 2-3 degrees and more intensive precipitation. It is predicted that there will be about 20% more precipitation, which will have to be conveyed in safe ways out of the cities. This spring one of the main throughfares between Norways larges cities were closed, numbers of homes were ruind and large areas destroyed due to flooding of the valley Gudbransdalen. Another excample of this intense precipitation was shown in Oslo city, Sunday the 2nd of June, 2013. Local roads were flooded and prevented traffic.

It has been a tradition in Norway to use underground structure to convey sewage and stormwater in a combined system. These structures are old and has proven to be insufficient, each year leading to multiple combined sewage overflows, flooding of cellars and urban floods. Urban surfaces accounts for a relatvley small portion surfaces generating stormwater that reaches rivers and oceans. As urban surfaces contribute significantly to the overall pollution load to recieving waters, cleaning this portion of stormwater will contribute to cleaner and healthier rivers and marine environment.

At the same time the cities expand making urbanization the fastest growing area type in the world. Impermable surfaces will decrease evapotranspiration and infiltration to the ground leading to yet more incidents of flooding. A classical illustration of this can be seen in Figure 1.1. Expanded residential areas, roads, commercial properties and industries all give more impermable surfaces which gives a more rapid response to precipitation and a higher peak flow. As urbanization leads to a sealing of the ground, storm and rainwater cannot feed the groundwater reservoar. On top of this underground infrastructure, tunnels and ditches with fill materials often drains groundwater as it creates a path with less resistanse than the insitu masses.

All of this causes the groundwater to sink significantly, causing problems as settling of buildings. In Bergen the situation is more crutial. The Pier in Bergen is on the preservation list of UNESCO World Herritage Sites. The Bryggen is build on old cultural deposits, also called medieval layers, beeing organic material containg intersting information about mode of living thousand of years ago. Waterlodged sites conserve materials better than dry sites and lowering of the groundwater at The Bryggen exposes the medieval layers to oxygen. With this the microbiological degradation process increases.

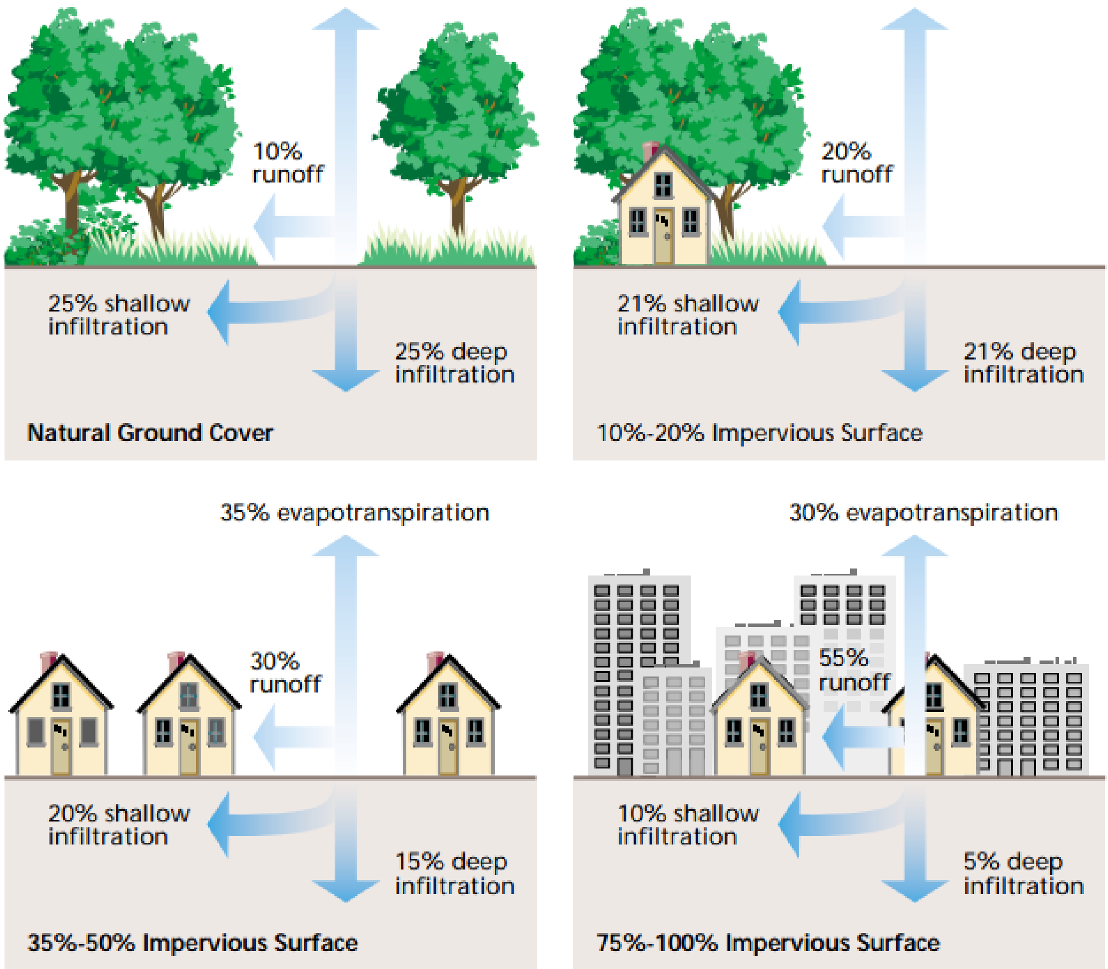


Figure 1.1: The realtionship betwwen impervious cover and surface runoff (F.I.D.S.R.WGroup, 1998)

Through an incentive by the EU, The Valletta Treaty, it is decided that European archaeological heritage should be protected from degradation. This includes all remains, objects and any other traces of humankind from past times. The Directorate of Cultural Herritage in Norway has decided that preserving the cultural deposits insitu, untill there exsist technology to unearth the cultural herritage, is the most suitable solution. Up untill now extensive survailance of the groundwater table and groundwater flow has been conduncted, as well as classification of the preservation conditions and in the medieval layers.

The municipality of Bergen has set goals to use stormwater devices that does not harm the environment, buildings and constructions. They state that Low Impact Development devices(LID, norsk: lokale overevannshåndtering) (or Best Mangagement Practises, BMP's), beeing raingardens (or bioretention), swales, wet and dry ponds and wetlands, should be utilized where possible (BergenKommune, 2005). As one of many actions to stabilize and hopefully increase the groundwater table there has been decided, by the procjet URBAN WATCH, to bulid a raingarden at the back of The Bryggen.

The importance of urban green-spaces, and particularly the ecosystem services they provide, is gaining increasing recognition as contributors to environmental sustainability and the well being of urban dwellers (Edmondson et al., 2011). A challange is to get muncipalities and careholders to see the benefits of LID. That said, the planned raingarden will both add a recreational factor to The Bryggen environment as well as beeing a bold and modern effort to convey stormwater and increase the groundwater table. This raingarden will be a pioneer example of a raingarden, due to the location and the attention around The Bryggen, and it will be most important for LID supporters that this raingarden function optimaly.

This thieses will look at the possibility to recharge the groundwater at The Bryggen with stormwater infiltrated from The Bryggen catchment. Field observations and desctop methods is used to find the area of the watershed and for estimating runoff volume. Different sample points with different area use are pointed out to quantify the stormwater characteristics. The stormwater quality will be important to quantify due to microbial prosesses in the medieval layers.

1.1 Objectives

This thieses is in the interface between urbanization and stormwater management, climate changes and the in situ preservation of medieval layers.

The main obcjetive for this master is:

1. Reweiv relevant literature on stormwater quality and find expected values
2. Identify potential harmful pollutants for the medieval layers
3. Through field and laboratory work characterize stormwater from different pollutant sources at The Bryggen
4. Use desctop methods to estimate runoff volume in The Bryggen catchment
5. Use desctop methods to evaluate the difference betwwen stormwater and groundwater quality
6. Evaluate treatment efficiency of the raingarden

Figure 1.2: Left:Raingarden(Photo:regjeringen.no), Right:excavation pit exposing medieval layers((Christensson et al., 2008)), Bottom:Flooding in the city centre of Oslo on the 2nd of June 2013 (Eriksen, 2013)

1.2 Previous Published Knowledge

As this thieses is in the interface between several siences , important sources of information comes from different disciplines. Chemistry data from the groundwater below Bryggen is gatherd from dip wells, and is used for comparison with the stormwater, to identify potential differences. This data comes from Matthiesen (2008a,b,c, 2011).

Numberous of studies has characterized the compostition of stormwater, and it is in general found that traffic voulme and closness to high trafficed roads give higher pollution loads (Van Metre and Mahler, 2003; Melidis et al., 2007; Priggemeyer, 1999; Egodawatta et al., 2009; Lindholm, 2004; Zafra et al., 2011). Espesially Lindholm (2004) has gatherd stormwater data from Norway, making standard vaules for stormwater runoff according to surface area and surface use.

1.3 Sturcture of Master Thieses

This thieses is devided into Introduction, Background, Methods, Study Area, Shortcomings, Results and Disscusion, Application of Results and Conclusion. The Background chapter will go through history, geology, groundwater quality and the climatic conditions in Bergen. Then different pollutant sources will be assesed, and excpected values for pollutants based on litterature study. Last presented in the background material is the decay and metabolism of bacterias.

The chapter Methods describes field sampling and analysis. It presents the statistical program R and which statistical tests that are conducted and why.

The chapter Study Area describes The Bryggen catchment and goes through different matematical method for estimating runoff volume and Event Mean Consentration (EMC) for the catchment area.

The chapter Shortcomings gives a decription of what went wrong in the thieses, what could have been done different, and the influence of these choices.

The Disscusion and Results chapter presents the results, wheras the disscusion mainly focus on the pollutants that is belived to have the greatest infulence on the microbiological prosess in the ground, and decay of the medieval layers.

Application of Results will compare some previous studies of raingardens in cold climate to the planned raingarden at the Bryggen. A small section of types of filtermedia, and which polluntant they remove will be assesed. Then a estimate of pollutant removal of the stormwater in the raingarden, and which problems might be encounterd.

Finaly a conclusion of the thieses.

2 Background

In this chapter background material for the study will be reviwed. The chapter starts with a presentation of terms that will be assessed throughout the master. The history of Bergen explains why there are medieval layers in the ground. The history of Bergen, the geology and climate conditions are all factors helping us understand the complicated problem at The Pier today. Several studies have been conducted on the water quality at The Pier, and it is important to have these parameters in mind when deciding whether or not the ranigarden will be sufficient as a treatment device. At the end of this chapter the existing quality of the medieval layers will be presented. As the medieval layers are a heterogeneous mass, it is hard to generalize the conditions.

2.1 Terms

In this pre chapter some terms and their significance and meaning to this procjet will be shortly presented.

- Alkalinity [mg/l $CaCO_3$], or carbon alkalinity is the buffering capacity of a water body and measures the waters ability to resist change in pH. Alkalinity and pH are closely connected and will both change with time and temperature. Regarding stormwater alkalinity decrease if the rain is acidic.
- Dissolved Oxygen [mg/l] is the amount of O_2 molecules in the water. Fully saturated dissolved oxygen is 10 mg/l. Any value above this under standard conditions will be oversaturated water.
- Electric Conductivity [µS/cm] is a measure for a substance ability to lead electornes. In stormwater conductivity is the measure of free ions in the water. Regarding the use of stormwater for infiltration to the groundwater, high conductivity measurements can reduce the ability for mulch to adsorb metal.
- Medieval layer is a layer of earth on sites of human habitation containing traces or remains of manâĂŹs activities. Can also be called cultural deposits or archaeological remains.
- Redox reaction is a chemical reaction involving both reduction and oxidation, which results in changes in the oxidation numbers of atoms that are included in the reaction.
- Sorption consist of two concepts, adsorption and absorption. Adsorption is the phenomenon where a chemical substance in a liquid or gaseous phase will adhere to a solid interface. Absorption is when a substance passes through an interface and penetrate into another phase (HvitvedJakobsen et al., 2010)

2.2 History of Bergen

Bergen 60 ° North, 5° East, the second largest city in Norway is located at the West coast of Norway. The study area is the Bryggen in Bergen which is a UNESCO World Heritage Site. Bergen was founded in 1030, has about 260 000 inhabitants (Statistisk-Sentralbyrå, 2013). The Bryggen area has burned down several times, and the new city has been build on top of the city deposits. As a consequence of this, archaeological interesting deposits remain the ground foundation of The Bryggen today. After another fire in 1955 a hotel was build on The Bryggen. In retrospect it is proven that the foundation of the hotel drains groundwater and thereby contribute to lowering of the groundwater table (Norconsult, 2011; De Beer, 2008).

Effort from Hordaland County, The City Antiquarian of Bergen (norwegian: Byantikvaren), The Pier Private Farm Owner Forum (norwegian:Bryggen Private Gårdeierforum) and The Pier Foundation (norwegian:Stiftelsen Bryggen) is put into save The Pier in Bergen from settling and decomposition of the archaeological remains.

2.3 Geology

The surrounding geology has created the in situ sediments and has influence on groundwater flow and groundwater composition. With this, the geology influence the medieval layers and is an important factor when initiative to save the layers are taken.

Bergen is situated on The Caladonian mountain range, which mostly consist of hard, metamorphic rocks as gneiss, anorthosite, green schist and gabbro. The underlying sediments consists of alluvial deposits on top of moraine material which again is on top of the bedrock. The alluvial deposits most likely being sea deposits consists of sand, silt and humus. These has proven to have good hydraulic conductivity. The Bryggen the bedrock, green schist, is reached from approximately 2 to 10 meters from the surface. As the city expanded seawards The Pier was gradually build on fill materials. The hydraulic properties of fill material differs from the hydraulic properties of the city sediments.

The medieval layers (Figure 2.1) in Bergen have been monitored in several projects. The term "‘ state of preservation"’ is used to quantify the preservation conditions, and does not explain what condition the medieval layers themselves. The term "‘state of conservation"’ is used to quantify the state of the medieval layers. The knowledge about soil and water quality is important when considering which actions should be prioritized to prevent decomposition of the medieval layers and the surrounding organic material.

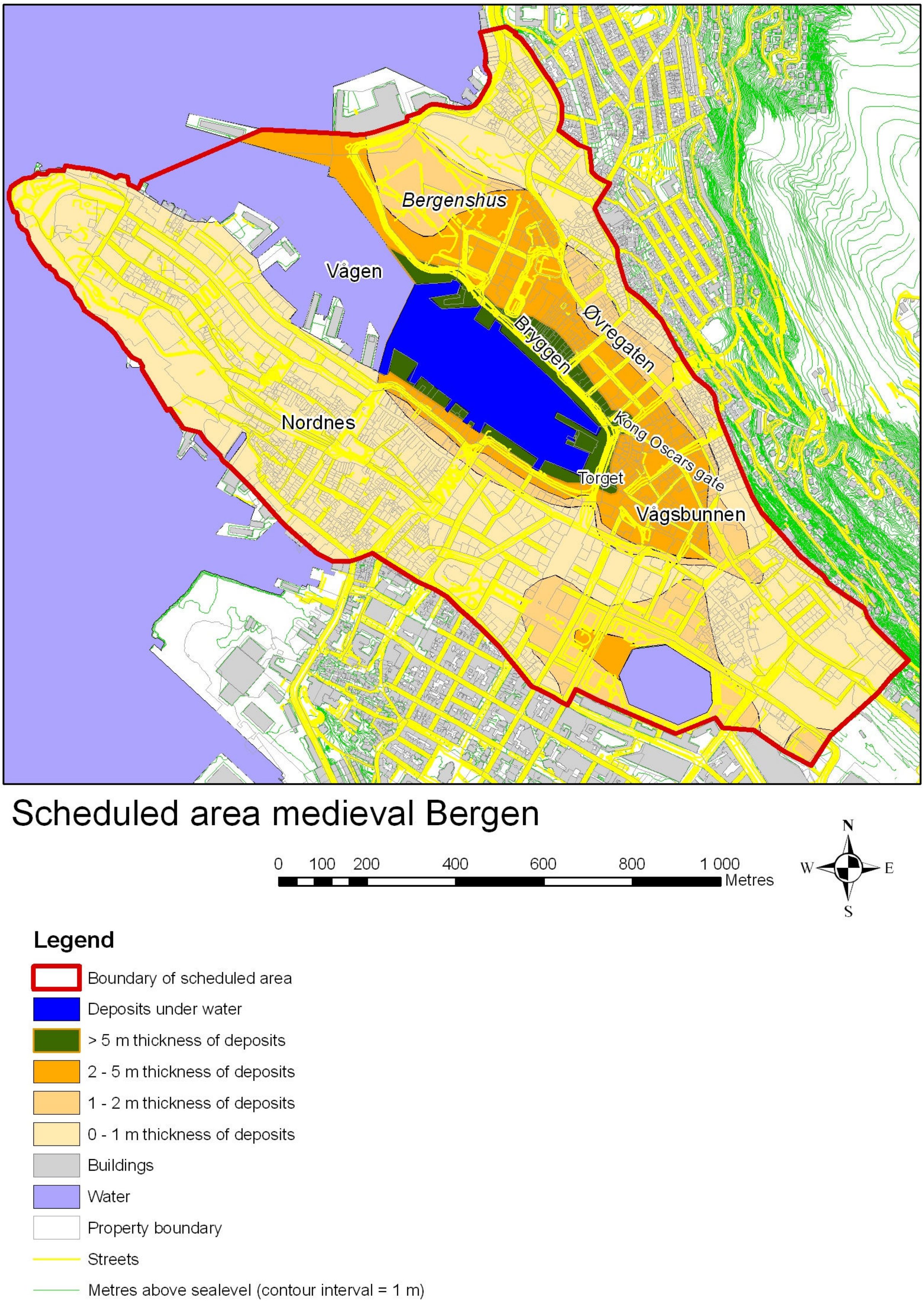


Figure 2.1: The medieval layers in Bergen (Christensson et al., 2008)

As a wide generalization the strata of the dip wells have 1 meter of modern materials which are likely to be back fill materials, which have poor a state of preservation. The unsaturated sone in Bryggen mostly contain sandy soil with a low organic content, meaning the oxygen will not influence the material by decay. Then post medieval and medieval deposits are found. Deeper in the strata there are higher concentration of organic material, as well as more compact material. With this the state of preservation also increases. Some dip wells have a fire layer below this. At the bottom sandy soil, where low organic content is found.

The state of preservation also changes with location. Dip wells by the harbor front have poor to medium preservation conditions because of seawater intrusion. Preservation state also varies significantly according to groundwater table and where in the strata the conditions are measured (Walpersdorf, 2013; Dunlop, 2008). Figure 2.2 shows a graphical section of the strata under The Pier.

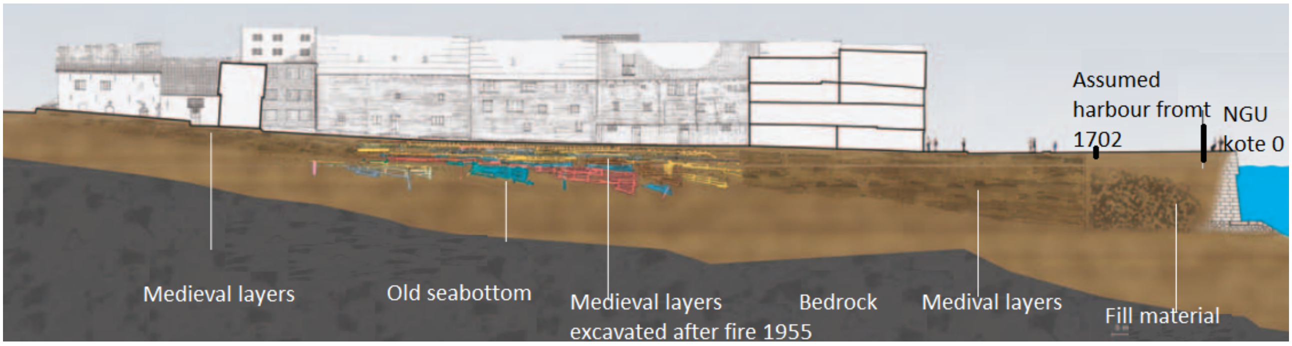


Figure 2.2: Medieval layers under The Pier(HordalandFylkeskommune, 2004)CAD Quality by Arild SÃętre

2.4 Quality of the Groundwater

Matthiesen (2011), has studied the water content and preservation conditions of dip wells (norwegian: Miljøbrønn, MB) (Figure 2.3) situated at The Pier. Identifying the quality and origin of the groundwater is important. With this information it is possible to estimate the correlation between preservation of the medieval layers and the groundwater quality. It can also give information about the groundwater flow. At some point it was suggested to let seawater infiltrate into the medieval layers. This would probably have increased the decay of the medieval layers due to the seawater composition. The study of groundwater and its coherence with preservation state of the medieval layers ended this plans. The groundwater pressure is influenced by topography, geology, permeability in the bedrock and in situ masses, precipitation, sea level, and physical interventions through trenches (De Beer, 2008). It has been proven throughout several studies that decay of cultural layers will decrease significantly when a high groundwater table is established (De Beer and Matthiesen, 2011).

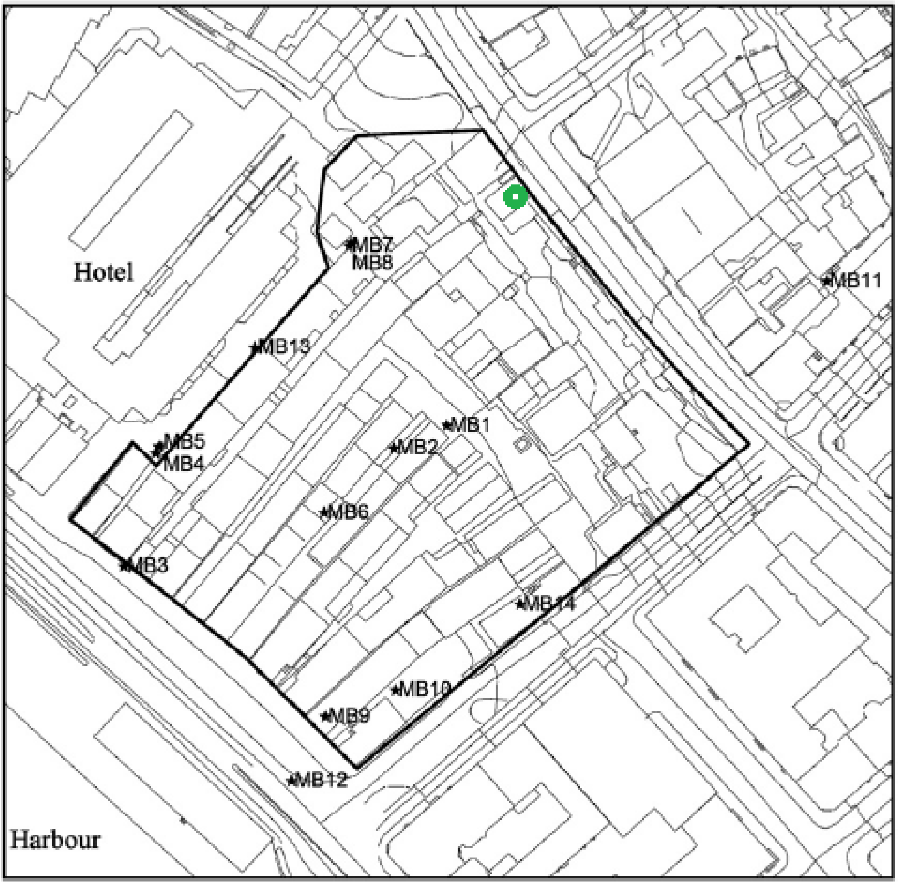


Figure 2.3: Location of dip wells at The Bryggen, the planned raingarden is marked in green(Matthiesen, 2008a)

The groundwater at The Pier has three different origins, seawater, rainwater and stagnant water. Seawater (Figure 2.4) is found to be dominant at the harbor front. The groundwater at the harbor front is characterized as highly varying because of the tidewater. These dip wells may have poor preservation conditions because of the effect sulphate reduction has on medieval layers. Rainwater influence on the backside of The Pier. Rainwater will dilute stagnant water, and possibly add oxygen and NO_3- which can oxidize organic material in the soil. Stagnant water has reduced conditions, and are characterized by Ca^{2+}, HCO^{3-}, NH^{4+} and CH_4. Preservation in these conditions are good. Natural deposits has a similar composition as stagnant water, however it is to some extend diluted. The dilution in the natural deposits comes from downwards flow from the archaeological remains and low ion content flow from the bedrock behind the Bryggen (Figure 2.5).

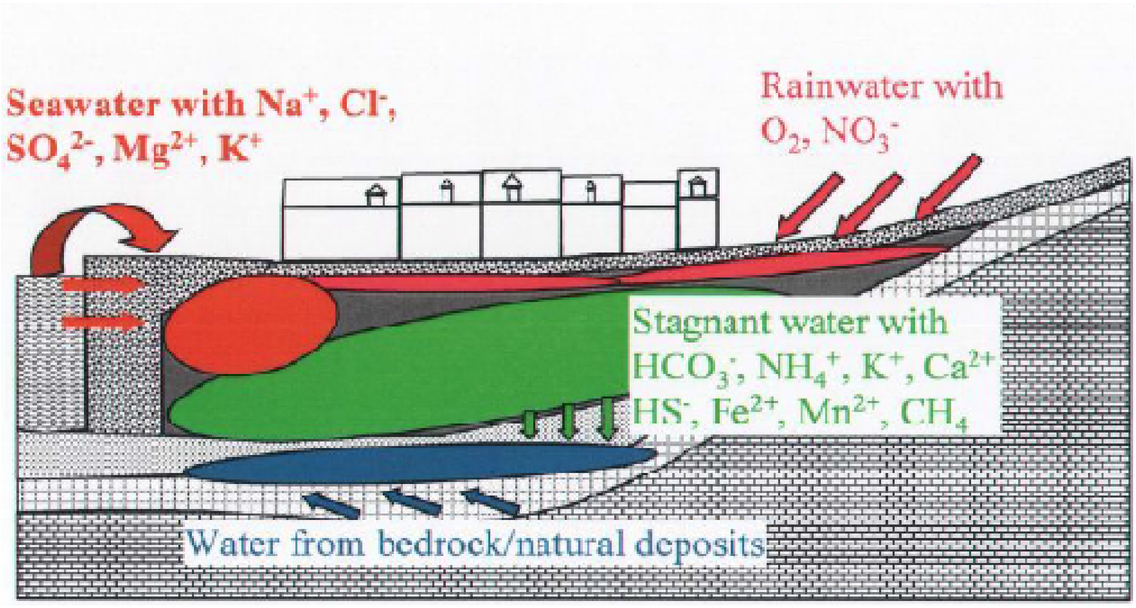


Figure 2.4: Conceptual groundwater model of The Pier based on a small number of dipwells at Bryggen (Matthiesen, 2008a)

There is a correlation between depth and the composition of the groundwater (Matthiesen, 2008c). At a deeper water intake, more stagnant water is found and it is less diluted with rainwater. There is indication that groundwater flows from the archaeological remains and downwards. In this case the archaeological remains are not influenced by underlying water quality. The groundwater flow in the region is in a southwest going direction, through cracks and permeable fractionsones in the mountain bedrock. Groundwater pressure shows that the groundwater surface is greatest at the back and in the middle of The Pier, and decreases towards the harbor front.

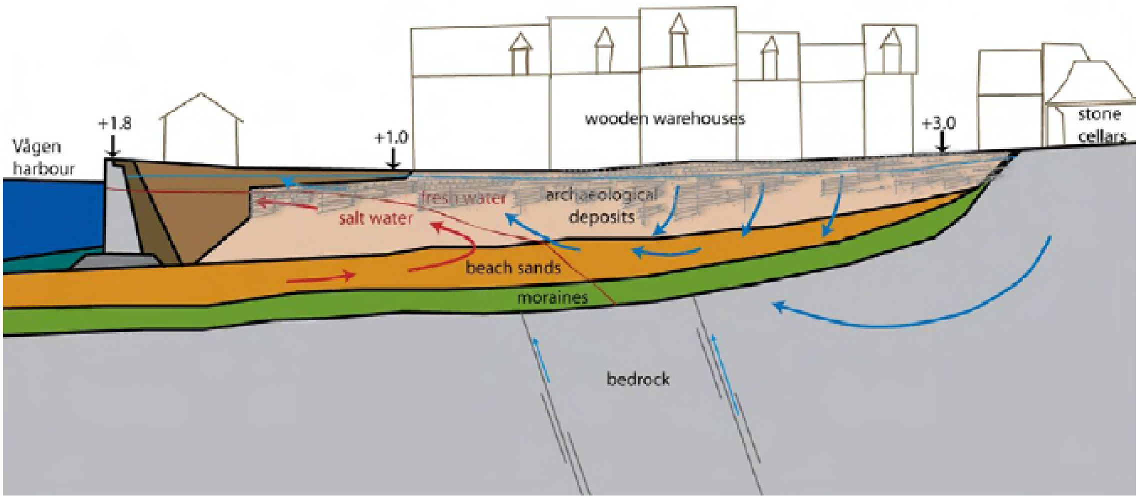


Figure 2.5: Groundwater flow below The Bryggen (De Beer, 2008)

2.5 The Meteorological Conditions

Type and amount of precipitation is a major factor to know if it is possible to increase the groundwater table with precipitation. Temperature decide the form of precipitation. Within cities the precipitation can vary significantly for the same rain event. Weather data in this report is gathered from The Meteorological institute Station Florida(50540), Sandsli(50480) and Bryggen meteorological station.

The climate in Bergen is classified as temperate oceanic conditions, relatively warm winters and moderate summers. The surrounding mountains in Bergen causes the north Atlantic moist air to undergo oreograpic lift, and become precipitation. The mean average yearly precipitation from Florida is 2315 mm. Most precipitation falls as rain, as temperatures rarely goes beneath 0° C.

Both monthly (Figure 2.6) and daily precipitation (Figure 2.7) varies, and there has been several periods with little to no precipitation in Bergen the last year. This is of main concern regarding recharge of the groundwater. Dry periods can decease the groundwater table and without artificial recharge this can effect the medieval layers negatively

The average temperature from 1960 to 1991 which is the latest normal period. The average yearly temperature is 7.6°C (Figure 2.9).

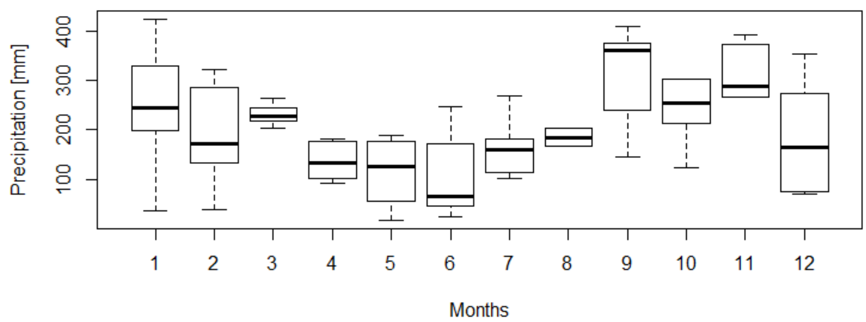


Figure 2.6: Monthly precipitation at Florida weaterstation the last 6 years

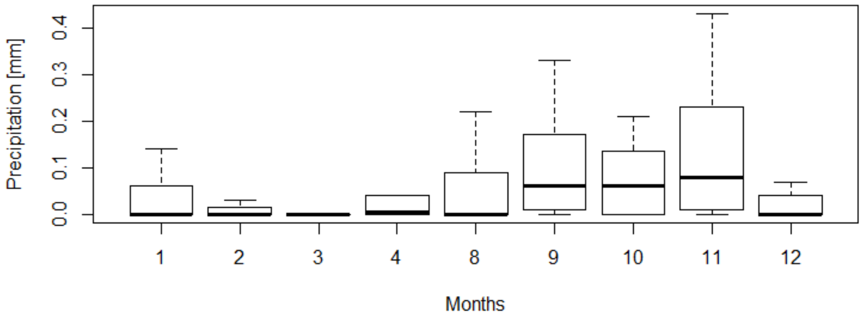


Figure 2.7: Average daily precipitation from the weatherstation at The Bryggen from August 2012 to April 2013. Note that May, June and July is not represented

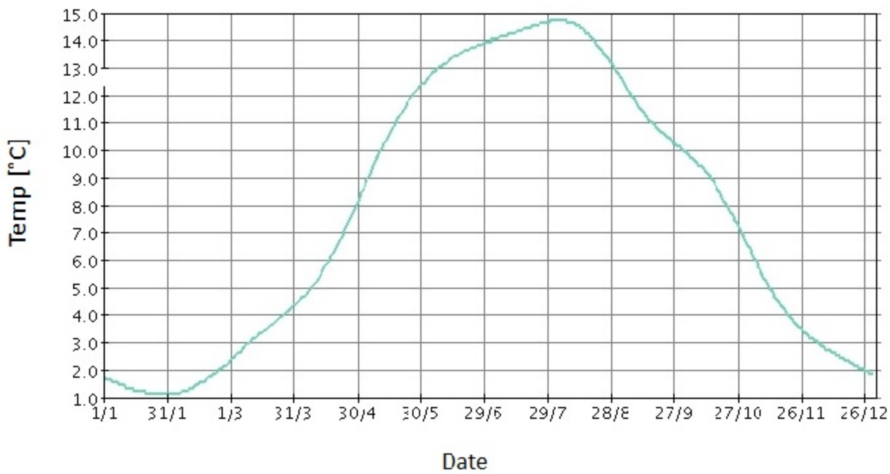


Figure 2.8: Florida, temperature in the period of 1960-1991 (eklima, 2013)

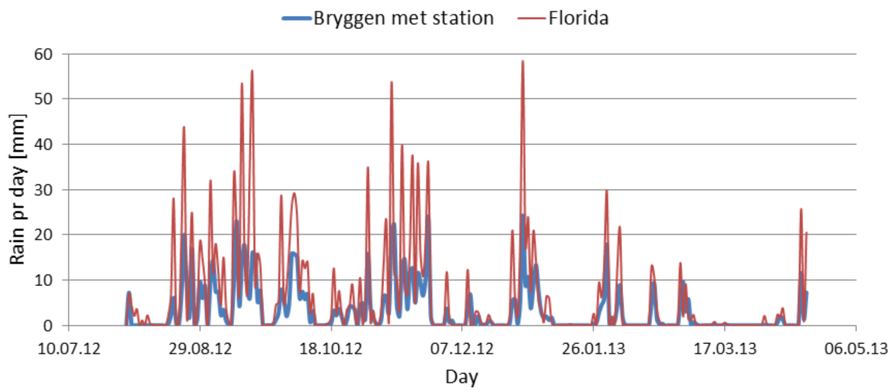


Figure 2.9: Comparison between Florida meteorological station and The Bryggen meteorological station in the preiode between 01.08.2012 and 18.04.2013

The wind is in a south-east direction (Figure 2.10). In wintertime heavy cold air together with the surrounding mountains prevents an air-exchange and causes an air lid with extremely poor air quality conditions. Danmarksplass in Bergen has the poorest air quality conditions in Norway because of morning traffic combined with the air lid.

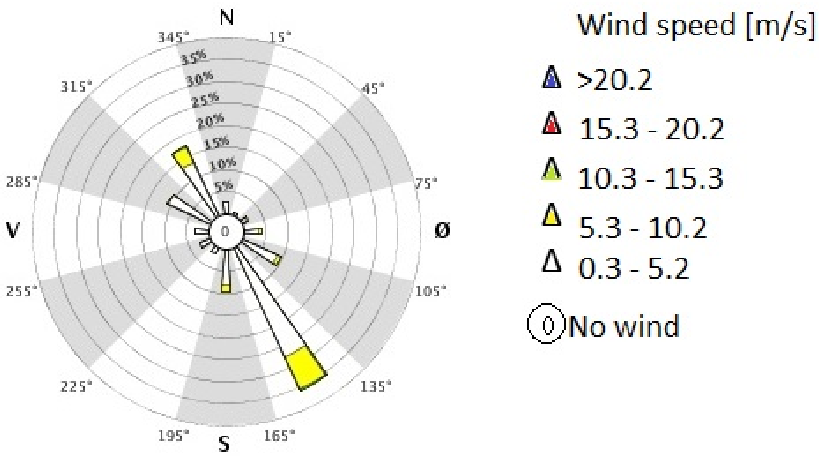


Figure 2.10: Wind Rose Bergen 2012. Frequency distribution of wind where wind direction is divided into sectors of 30 °C (eklima, 2013)

2.6 Pollutant Sources

This chapter is a review of pollution from different urban sources and an examination of the pollutants of main concern for the medieval layers at The Pier. At the end of this chapter an estimation of pollutant amounts created from the catchment will be presented, this will later on be compared to the pollutant concentrations in The Pier catchment.

2.6.1 Roof surfaces

Runoff from roofs can contain pollutants originating from atmospheric deposition and degradation of roofing materials or bio material. Rainwater itself is considered to be non polluted, or at least not significantly polluted, but often acidic and contain traces of pesticides and other atmospheric pollutants, depending on the surrounding environment. Deposition rate of pollutants is due to surrounding land use, land activities, traffic and climatic conditions (Van Metre and Mahler, 2003; Melidis et al., 2007; Priggemeyer, 1999). Degradation of roofing material depends on composition of material, age, weather-ability, roughness and acidity in the precipitation.

Microbiological pollutants primary has origins from birds, leaves from overhanging trees and small mammals. Several studies show that microbial pollutants are smaller on metal roofs, which might be due to the heat that metal roofs gain in the summer season (Meera and Ahammed, 2006). A decrease in ${SO_4}^{-2}$ leads to increase in pH and the heavy metal corrosion decrease significantly. The appearance of organic macro pollution as bird excrement, leaves, pollen is site and season specific and hard to quantify (Gobel et al., 2007)

Studies by Egodawatta et al. (2009) on roof-bild up show that around 80% of the buildup occur during the first 7 days of dry weather. The build-up on a 3 m^2 corrugated steel and build-up on concrete roofs were not statistically different, only varying from 1.8 g/m^2 to 2.0 g/m^2 after 21 antecedent dry days. Van Metre and Mahler (2003) has similar results studying a 4 m^2 roof close to a highway that had build-up 0.16 to 2.1 g/m^2. It is suggested that both deposition and re-suspension is independent of particle size. A particle count in the study of Egodawatta et al. (2009) showed that 70 % of the particles were under 200 μm, and the fraction larger than 400 μm was less than 13 %. New roofs are often galvanized and are covered in metals as Zn, Cu and Pb. Conveyance systems (drains and down pipes) can be made of Al and Pb containing materials. These all create corrosion products contain metals. Studies conducted in Germany confirm that due to low pH, Cu containing roof emit 1.0 g/m^2 and Zn containing roof emit 3.0 g/m^2 (Priggemeyer, 1999).

Is is implied by several studies that the distance from highly trafficked roads are an important factor for pollution loads. Van Metre and Mahler (2003) conducted a study in humid conditions in Austin, Texas. It was fond that from a highway with 134 000 vehicles pr day there is a significant difference in pollution loads whether the roof was situated 12 m or 102 m away from the highway. They found no difference between roof types of galvanized metal roofs and asphalt shingle roofs.

Pointed out by a number of researchers the highest particulate matter concentration is found in the initial part of the roof run off also called ”‘first flush”’ (Egodawatta et al., 2009; Van Metre and Mahler, 2003; Meera and Ahammed, 2006). This ”‘first flush ”‘effect is due to a number of reasons. Pollutants deposited in dry days will run off, weathering- and corrosion products and washed off and pollution concentration in the rain itself will decrease due to scavenging of aerosols, gasses and particles by rain droplets (Meera and Ahammed, 2006).

Egodawatta et al. (2009) found that the roof particles wash off depending on the rain intensity, the larger intensity, the more particles will be removed.

(a) Typical red brick roof **(b)** White metal roof

(c) Typical grey roof **(d)** Typical black brick roof

Figure 2.11: Roof types, catchment Bryggen(Photo: C. Gremmertsen)

2.6.2 Ground level

Pollutant sources from the road and traffic include road surface abrasion, tire abrasion, brake pad abrasion, drip loss (fuel, gear oil, grease, brake fluid, antifreeze, etc.), corrosion products and road salts. Pollutants have different origins. Rubber and heavy metal oxides with Zn, Pb, Cr, Cu and Ni originates from tire abrasion. Break pad abrasion determines Ni, Cr, Cu and Pb (Lindholm, 2004; Zafra et al., 2011; Opher and Friedler, 2010). Salt is the main ingredient of de icing agents consist mainly of

Sodium chloride (NaCl), but also up to 10 % of calcium chloride ($CaCl_2$), calcium sulphate ($CaSO_4$ x $2H_2O$), magnesium chloride ($MgCl_2$ x $6H_2O$) and magnesium sulphate ($MgSO_4$). The quantity of salt used in Germany is between 10 g/m^2 and 40 g/m^2 of road surface (Gobel et al., 2007). In Norway a road salt manufacturer produce road salts from the Oslo-fjord. According to the manufacturer the calcium and sulphate content is 0.5% and 1.5% (Kjensmo, 1997). Testing of the road salt in Trondheim gave 4.04g/l Na, 5.75g/l Cl, 348 µg/l Mg and 5385 µg/l Ca (Bue, 2013). The trend is an increased use of salt as de icing agent in Norway (Strø m, 2012).

The runoff created from grass surfaces in urban areas does not seem to be significantly less than from previous areas. Compaction of soil due to public use, as walking and car parking will occur. This leads to a higher bulk density and decreased pore volume that results in reduced infiltration capacity (Yang and Zhang, 2011; Pitt et al., 2008).

2.6.3 Urban Pollution Studies

Within 700 meters of The Pier area lies The Bergen Square. A study conducted at The Square (Norwegian: Torgalmenningen) in 2008 -2009 measured the TSS through a year. The results are shown in Table 1.

Table 1: Total Suspended Solids at The Square in Bergen city center (Band Bogen, 2010)

Sample time	Inorganic SS[mg/l]	Organic SS[mg/l]	TSS[mg/l]
APR 2008	40.6	16.8	57.4
MAY 2008	0.0	3.1	3.1
JUN 2008	22.2	9.4	31.6
JUL 2008	5.2	6.1	11.3
AUG 2008	8.5	2.0	10.5
SEP 2008	1.0	3.1	4.1
OCT 2008	2.5	4.6	7.1
NOV 2009	20.3	12.0	32.3
DES 2009	10.7	6.6	17.6

StormTac

Based on values from StormTac (StormTac, 2013), and urban pollution studies (Lindholm, 2004) an estimation of pollution load from The Bryggen catchment had been assessed. Area, precipitation,land use and traffic volume was the main parameters put into the model.

Table 2: Estimated pollutant load with values from Lindholm (2004) for The Pier catchment(16671 m^2) and Øvregaten(18495 m^2) with values from StormTac (2013) where yearly precipitation is 2315 mm

Sample area	Øvregaten	Catchment without Øvregaten
Cd [**kg/yr**]	0.01	0.02
Cr [**kg/yr**]	0.14	0.19
Cu[**kg/yr**]	2.84	1.14
Pb [**kg/yr**]	0.98	0.76
Zn [**kg/yr**]	5.77	5.32
Ni [**kg/yr**]	0.12	0.38
PAH [**kg/yr**]	0.06	0.02
N [**kg/yr**]	0.09	
P [**kg/yr**]	0.01	
TSS [**kg/yr**]	4.26	

2.7 Decay of Medieval Layers

The cultural layer consists of organic material which is decomposed at a certain rate. This rate depends on the reaction rate of the organic material, water content, microorganisms in the ground, temperature and supply of oxidizing material, where the oxygen supply is the foremost important factor. Decay of organic material can be inhibited by the presents of toxic material. Acid and high ion concentrations will expedite the corrosion of metals and deterioration of bone. Decay of organic material and corrosion of metals will occur parallel with the reduction of other compounds (Bergersen et al., 2009). The metabolism of bacteria is extremely complicated, and will not fully explained in this master thieses. This said, it is necessary to asses the basic of bacterias metabolism to understand which pollutants that should have the main attention when designing the raingarden.

2.7.1 Calculation Methods for Bacterias Metabolism

Regarding recharge of the groundwater at The Pier, the objectives should be to infiltrate water with a better water quality than the groundwater. The pollutants of most concern are identified by their availability to function as substrate for microorganisms. Microorganisms can be classified in terms of evolutionary origin and genetic differences, in terms of carbon source used for development of new cells, in terms of energy source for growth and survival and in terms of specific redox characteristics (HvitvedJakobsen et al., 2010).

2.7.2 Gibbss‘s Free Energy

In energy transformation related to the redox process it is the thermodynamic energy that rules. The thermodynamics related to Gibbss free energy defines the state and the potential for change in the redox process.

$$\Delta G = \Delta H - T\Delta S \tag{2.1}$$

G = Gibbss‘s free energy (kJ mole^{-1})

H = enthalpy (kJ mole^{-1})

T = temperature (K)

S = entropy (kJ mole^{-1})

The Gibbs‘s free energy equals the work potential that is lost by transfer of the electrons from the oxidation to the reduction step. The difference in electron potential between these two half-reactions is related to ΔG for the redox process:

$$\Delta G_{\circ}‘ = -nF\Delta E_{\circ}‘ = -nF(E‘_{o,red} - E‘_{o,ox}) \tag{2.2}$$

G°‘ = Gibbs‘s free energy at standard conditions(25 *circ* C , pH 7 and 1 atm (kJ mole$^-$1)

n = number of electrons transferred according to the reaction scheme

F = Faraday‘s constant equal to 96.48(kJ mole^{-1}V^{-1})

E $_{\circ}$ = redox potential of electron acceptor E‘$_{o}, ox$ minus redox potential of electron donor E‘$_{o}, red$ (V)

The redox potential is relevant for biochemical reactions, as the energy lost by the redox process is energy gained for microorganisms. The energy gained by the redox reaction is dependent on temperature and pH, and will therefore vary significantly with the in situ conditions.

2.7.3 Process Conditions and Kinetics

Process conditions refers to the availability of oxygen. A system can have aerobic, anoxic or anaerobic conditions. The different oxygen conditions will have a large influence on the ability of a specific electron acceptor and thereby the redox potential. Process kinetics are related to the rate of reactions. It is the basics of any quantitative description of transformations that takes place in a system. Processes with living organisms include a number of different reactions with chemical substances, as transformation and transportation, where the organisms will gain energy. In urban drainage the Monod kinetics is used to explain the transformation of substrate and growth rate of microbial biomass(HvitvedJakobsen et al., 2010)

$$r = \frac{\delta X}{\delta t} = \mu_{max} \times \frac{S}{K + S} \times X \tag{2.3}$$

r = the rate of change in concentration

X = microbiological biomass

S = substrate

μ_{max} = maximum specific growth rate

K = constant for process

2.7.4 Microbiological Processes

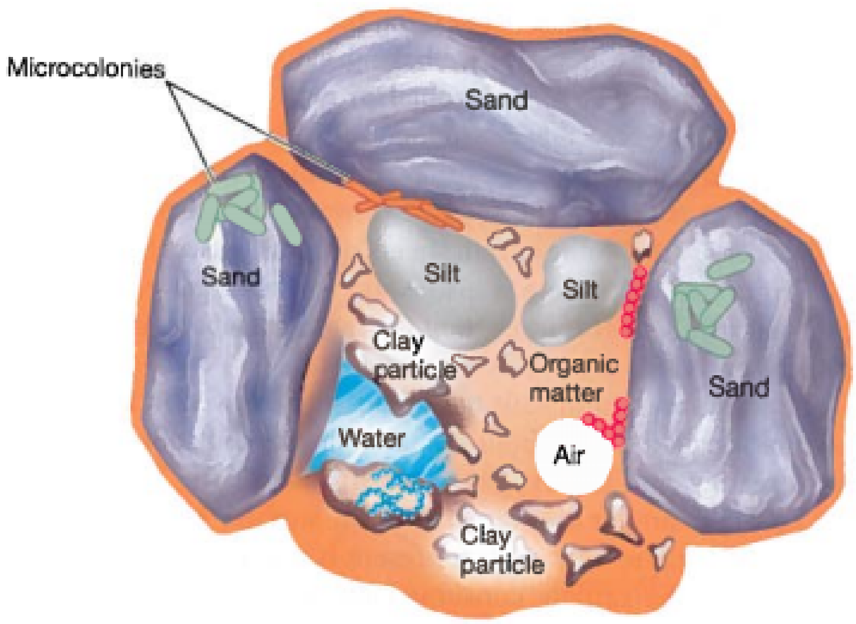


Figure 2.12: Microcolonies in soil (Michael Medigan, 2012)

The temperature and pH have an influence on the dissociation reaction of chemical substanses and will affect the microbiological metabolic processes. The microbiological reastions vary with the in situ conditions.

Microbiological processes are especially important for the transformation of pollutants regarding their biodegradability. Dissovled Oxygen (DO) is related to the activity of microorganisms in terms of degradation of organic material. The energy microorganisms get from redox reactions is used to enlarge their biomass. They can generate most energy from utilizing oxygen as the source to oxidize organic material. Less energy is generated when they use nitrate $NO_3{}^{-1}$, trivalent iron Fe(3), tetravalent manganese Mn(4) and sulphate $SO_4{}^{-2}$ or oxidized material.

When all material is oxidised a metanogenic condition is reached. It is under metanogenic conditions that we will find the slowest decay of organic material, and the condition we strive for in cultural layers (Bergersen et al., 2009).

The larger portion of microorganisms are located in a close distance to the plant roots because of the easy access to the organic material from plants when they die, and because plant roots make make pathways for water containing minerals and dissolved oxygen assessable and crucial fro the survival of for the microorganisms.

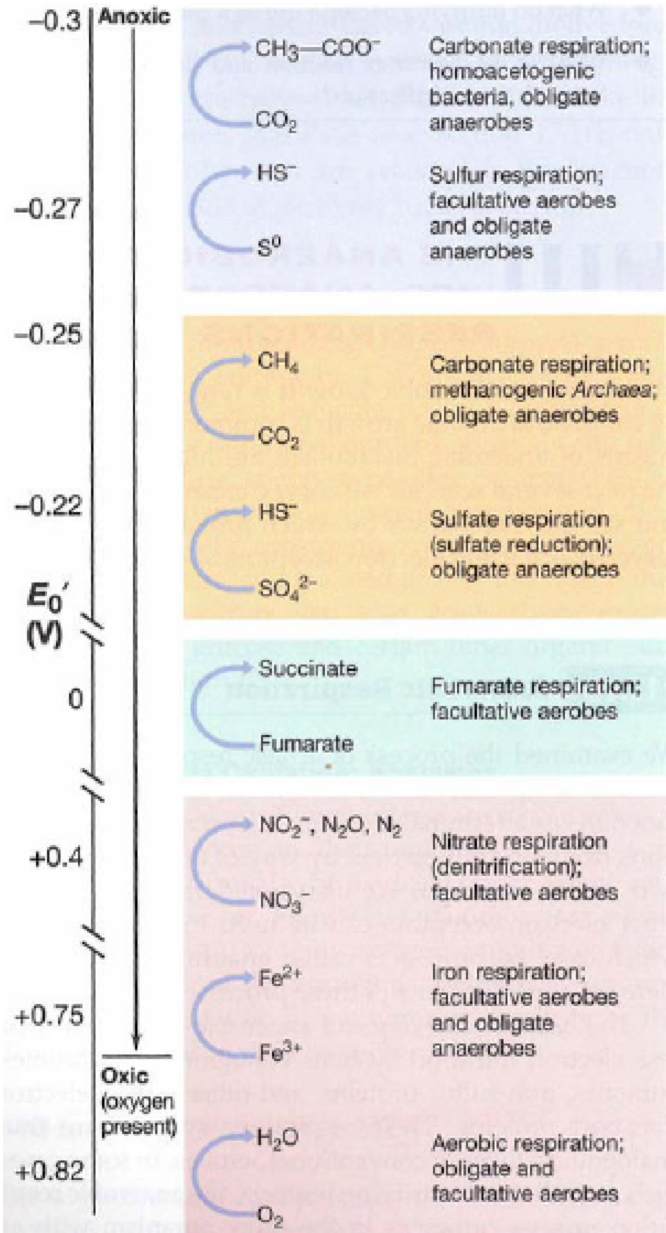


Figure 2.13: Reactions that give energy to microorganisms, (Bergersen et al., 2009)

2.7.5 Substances of Concern for the Decay of The Medieval Layers

As stated in the chapter introduction, survival and reproduction of bacterias are dependent on the substrate access. Some of the substrates of most concern is listed below.

2.7.5.1 Carbon Carbon is known to be an easy accessible energy source for humans, plants and microorganisms. Any organic material that enters a microbiological rich environment will eventualt turn into CO_2 and CH_4 by hydrolysis (Figure 2.14). For the process of breaking down carbon, there has to be a H_2 reduced environment.

The equation 2.4 is an example of energy gained from the decomposition of glucose.

$$Glucose + 4H_2O \rightarrow 2acetate^- \rightarrow 2HCO_3^- + 4H^+ + 4H_2 \rightarrow \Delta G - 207kJ/reaction \quad (2.4)$$

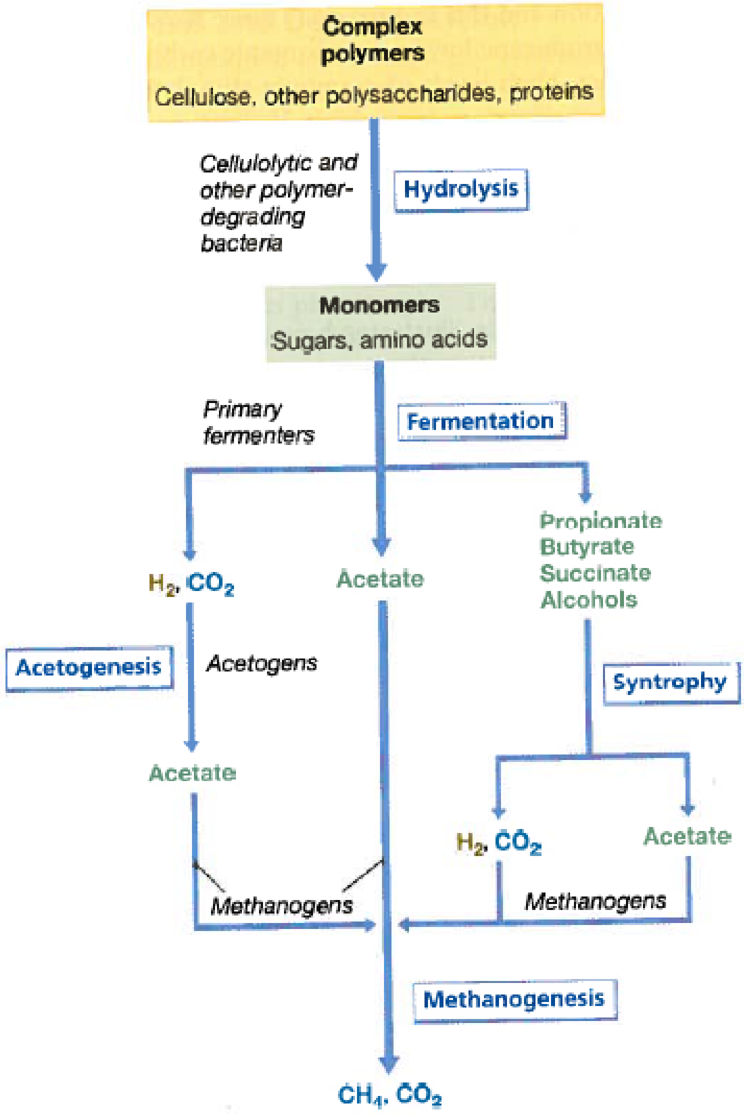


Figure 2.14: The decomposition of carbon substances (Michael Medigan, 2012)

2.7.5.2 Nitrogen The recycle of N is mostly fixed nitrogen. In this case nitrate, NO_3^-, is the most interesting. By denitrification the end products of nitrate is N_2, NO or N_2O (Figure 2.15). Nitrification is a major process in well drained oxic soils at a neutral pH, whereas denitrification takes place under anoxic conditions. Supply of NH_3 rich materials, as sewage, will increase the rate of nitrification significantly.

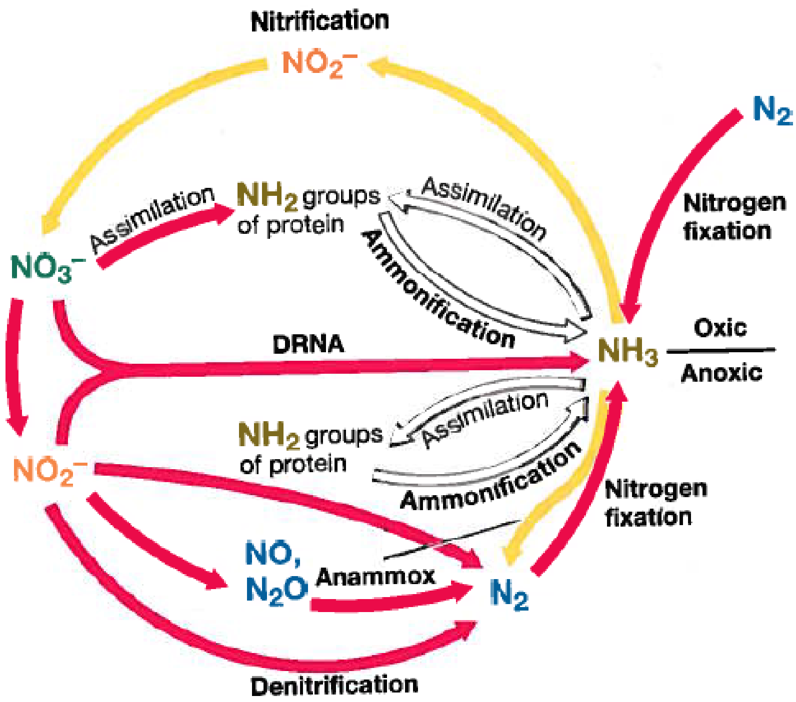


Figure 2.15: The nitrogen cycle (Michael Medigan, 2012)

Phosphorus

Phosphorus is found in nature as organic or inorganic phosphates. Inorganic phosphorus is found in phosphate-containing minerals in rock, dissolved phosphate in freshwater and seawater. Organic phosphate are found in as nucleic acids and phosphilipds in living organisms.

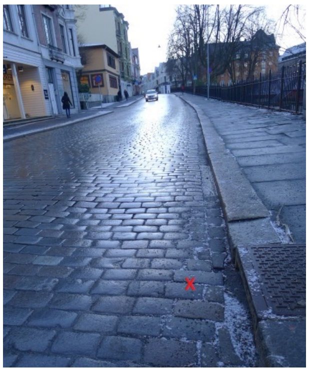
2.7.5.3 Sulfate The number one source for sulfate is the ocean. The transformation of sulpathe is highly complicated as it involved several oxidation stages. Sulfate-reducing bacteria are a large and diverse group of anoxic bacteria. They trive in habitats of high organic material as organic electron donors or H_2 is needed and has optimum temperatures between 25 -30°C (Sagemann et al., 1998). Elemental sulfur can also be reduced into sulfide. Oxidation of sulfide needs aerobic conditions and sunlight. In a marine environment carbon will be the limiting factor for sulfate reducing bacteria (Michael Medigan, 2012).

3 Methods

In this chapter the sampling points will be presented as well as the field work and analysis method.

3.1 Field sampling

The field sampling took place from February through April 2013, with aim for 3 to 4 good rain events. 7 sample was taken in February. The second sample collection was conducted on the 16.04.2013, where 6 samples where taken throughout the day. Initially four sampling points was pointed out, but S1 was not suited for sampling as the water level seldom got high enough to capture water there. A new sample point was found, S5, but this sample point proved to have very much the same composition as S3 and S4, and did thereby not represent the catchment in any new way. Another sampling point was found, S6. Therefore the sampling took place at four different sites, Øvregaten S2, Wesenbergsmauet S3, Nikolaikirkeallmenning S4 and Koren Wibergs Plass S6. The sampling points should be representative for the water quality expected from the area.



(a) Sample point S2

(b) Sample point S3

(c) Sample point S4

(d) Sample point S6

Figure 3.1: Sample points, 07.02.2013 (Photo: C. Gremmertsen and T. Muthanna)

(a) Sample S62 **(b)** Sample 45

Figure 3.2: From the sampling process 17.02.2013 (Photo: C. Gremmertsen)

3.2 Analysis

The chemical analysis was conduced at four labs. Colliform bacteria was measured at *Eurofins* i Bergen. Total suspended solids, temperature, dissolved oxygen, pH, conductivity was measured at NIVA in Bergen. Particle count, alkalinity, total and dissolved phosphor was measured at the Water Analysis lab at NTNU. Total and filtrated metals was measured by Lierhaugen at lab at NTNU. Total and filtrated metals was done with High Resolution Inductive coupled plasma (HR-ICP-MS) Element 2 from Thermo Electronics. The pH was measured at lab 2 -3 hr after the sample was taken, with Radiometer Copenhagen PHM 80 Portable pH meter. The temperature increased in the time step between sampling and pH measurement. This time step was 18 hr and 12 hr for the first and second sampling period respectively. pH dependency on temperature increase with increased pH. A buffer fluid with pH 7 at 25 °C will have a pH of 7.09 at 5°C and 6.96 at 50°C. Calibration gave a measuring error of (± 0.02).

Temperature, conductivity was measured with Metler Toledo SG3-FK2 - SevenGo^{TM} conductivity meter in the field and before analyzing the samples in the laboratory. The temperature measurement has a measuring error of (±0.01).

Dissolved Oxygen (DO) was measured with Orion 5-Star^{TM} Portable Multimeter. A measurement of DO in the effluent was done at Risvollan raingarden in Trondheim with HANNA Portable Dissolved Oxygen Meter HI 9146.

TSS was measured using Wathman GF/C 1.2 µm pore size glass microfiber filters (Norwegian Standard NS- EN 872). Event mean concentration (EMC) was calculated for field samples taken at 14.04.2013. As 6 samples for each sample point were taken throughout the day, the TSS concentration between samples were calculated with interpolation. Alkalinity was measured by titration to a pH of 4.5. Total P was measured with Norwegian Standard: NS 4725 and PO4-P was measured with Norwegian Standard: NS 4724. Sulfate and NO3 was measured with the measure method of Dr. Lange.

SO4 has measuring range of 40 -150 mg/l after filtration through GF-C filter, while NO3-N has a measuring range of 0.23 -13.5 mg/l

The particle count was done by Beckman Coulter LS230 Laser Diffraction Particle Size Analyzer. Three replications of each sample point of particle distribution was made.

3.3 R -Data Analysis

Statistical analysis is used to confirm or disprove differences and equalities in the result data.

R is a free software programming language and a software environment for statistical programming. Is was made by R Development Core Team at The University of Auckland, New Zealand (Ihaka, 2013). In addition to execute statistical test, R is also an excellent graphical fabricator.

3.3.1 The Hypothesis

The primary statistical interest in these data is to see

- Whether there are seasonal variations between the samples taken in winter months and spring
- Is there a difference in pollution levels from the sample sites
- Is there a trend in the pollution levels regarding attecent rain days or hours

To gain these data several parameters was made to divide the data set and characterize the parameters. The stormwater was divided into groups of roof (S3 and S4) and road (S2 and S6) to see whether there was a difference in water quality from these to surface types. Dates were assign a season, to be able to see whether the stormwater quality change with seasons. Also the stormwater was grouped to see whether there is a true difference between the stormwater and the groundwater.

Non-parametric statistical methods are known to be more robust, and is not depended on a population fitting and any parametrized distribution. If a parametric test would be appropriate for the sample distribution, a larger sample size would be needed to use the non-parametric method. Due to this, and that the author is familiar with parametric method, the Two Sample Welsh T-test was conducted to see whether or not there was a significance between the sample means. This test assume normal distribution of the data, which is the most common assumption in statistics. With maximum 12 samples from a single sample point it is not possible to say whether or not the data is normally distributed. But the Two Sample Welch Test does not assume that the variance in equal in the comparing groups, and is considered a non sensitive test and should give reasonable answers. The null hypothesis is that the underlying distributions are the same. The alternative hypothesis is that the populations have different underlying distributions. A small p-value will be proof that H_0 is not valid.

4 Study Area

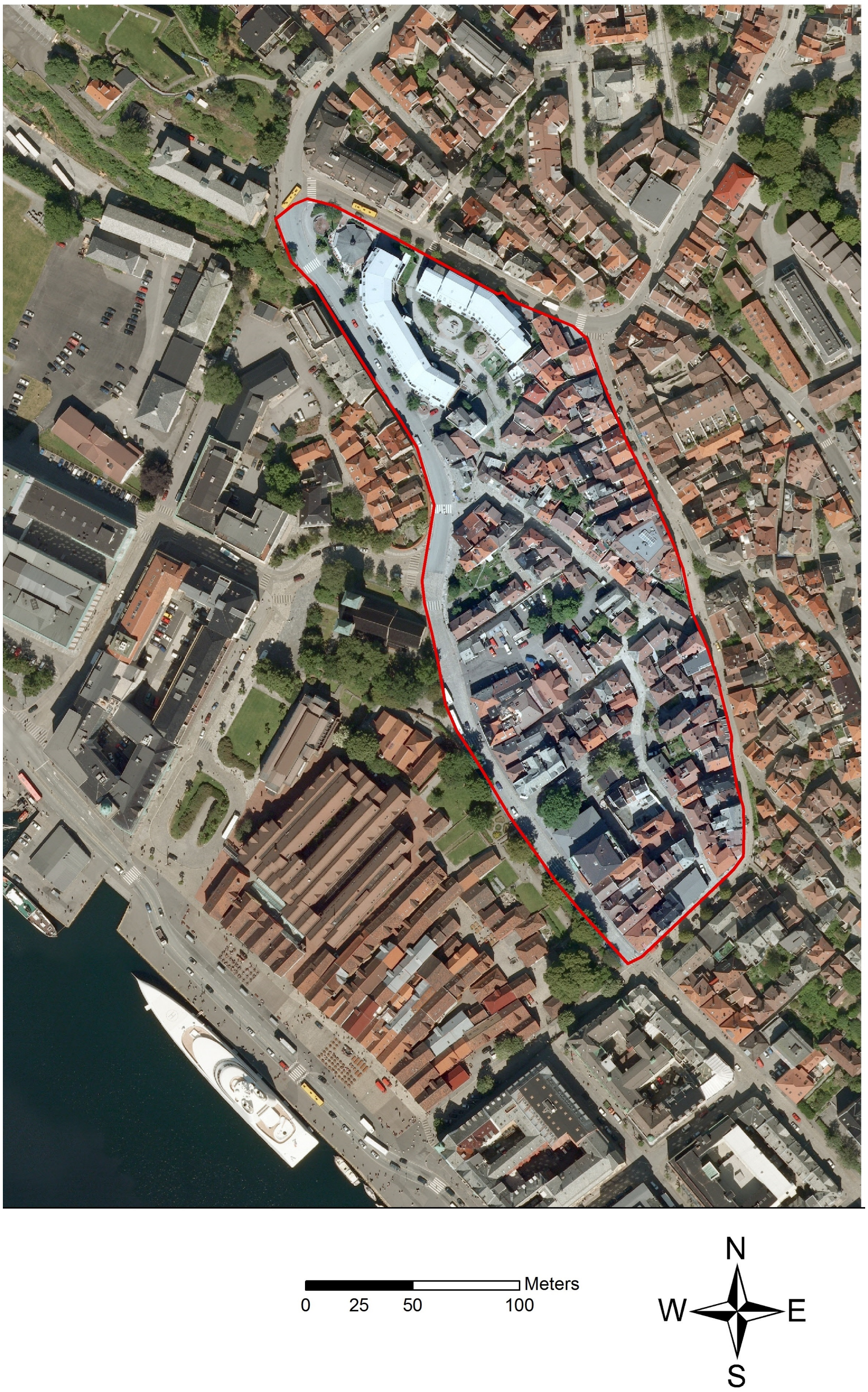


Figure 4.1: The Bryggen Catchment

The area of study is down town in Bergen city, behind the Bryggen. The catchment area was measured to be 3.516 ha as shown in Figure 4 The study areas was divided into areas of roof, road, pavement and grass. The types of roof was also divided, as different rooftops give different contaminants.

In Øvregtaten the traffic load is between 5001 -10 000 vehicle pr day. For Nikolaikirkeallmenningen and Koren Vibergsplass there exist no such data, but an estimate by field observations and comparison with street with the same size in the area gives a traffic load by 0-350 vehicle pr day. 60 -70 % of the roofs are connected directly to the sewer system, meaning that these roofs do not generate overland flow. The roofs in the city of Bergen are mostly brick, and some roofing sheets made of galvanized steel. Brick is made out of sand, cement, iron oxide and paint maid of water based acrylic enamel. In this matter there is expected that some pollutants from the roof itself. There are only two grass areas in the catchment, both heavily trampled down.

4.1 Runoff Volume

There are several ways to calculate runoff volume depending on catchment size, land-use, surface slope and precipitation type. The most popular models being Time-Area method, Summation method, Unit Hydrograph, Rational Method and SCS Method. The Bryggen catchment is realtivley small, and therefor Rational Method and SCS Method will be used to calculate runoff volume.

4.1.1 Rational Method

The municipality of Bergen recommend to use the Rational Method for catchments less than 50 ha (BergenKommune, 2005). The maximum length was calculated by ArcMap. Time of concentration was found to have a maximum value of 5.44 min after Kirplich equation. The precipitation intensity is from Sandsli meteorological station (nr. 50480) with data from 1982 -2007.

$$Q = C \times i \times A \tag{4.1}$$

Q = Runoff [l/s]

C = Runoff coefficient[$-$]

i = Precipitation intensity [l/s * ha]

A = Area [ha]

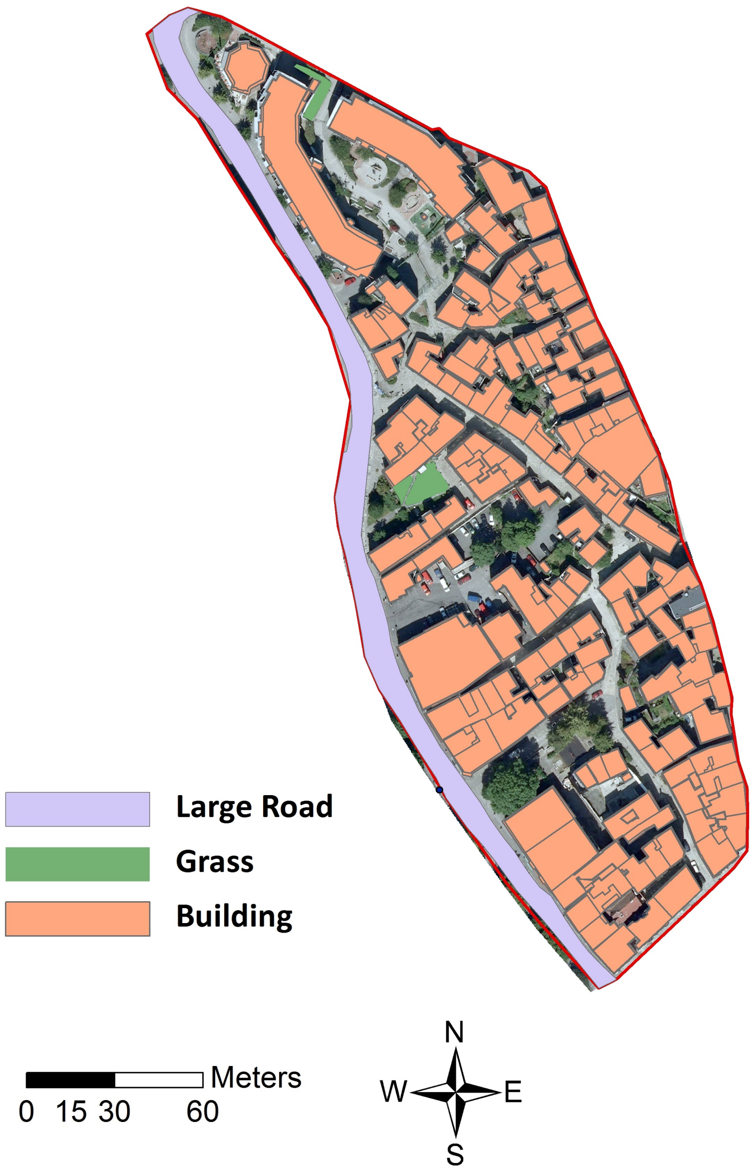


Figure 4.2: Different areas of The Bryggen catchment divided into roof, roads and grass areas.

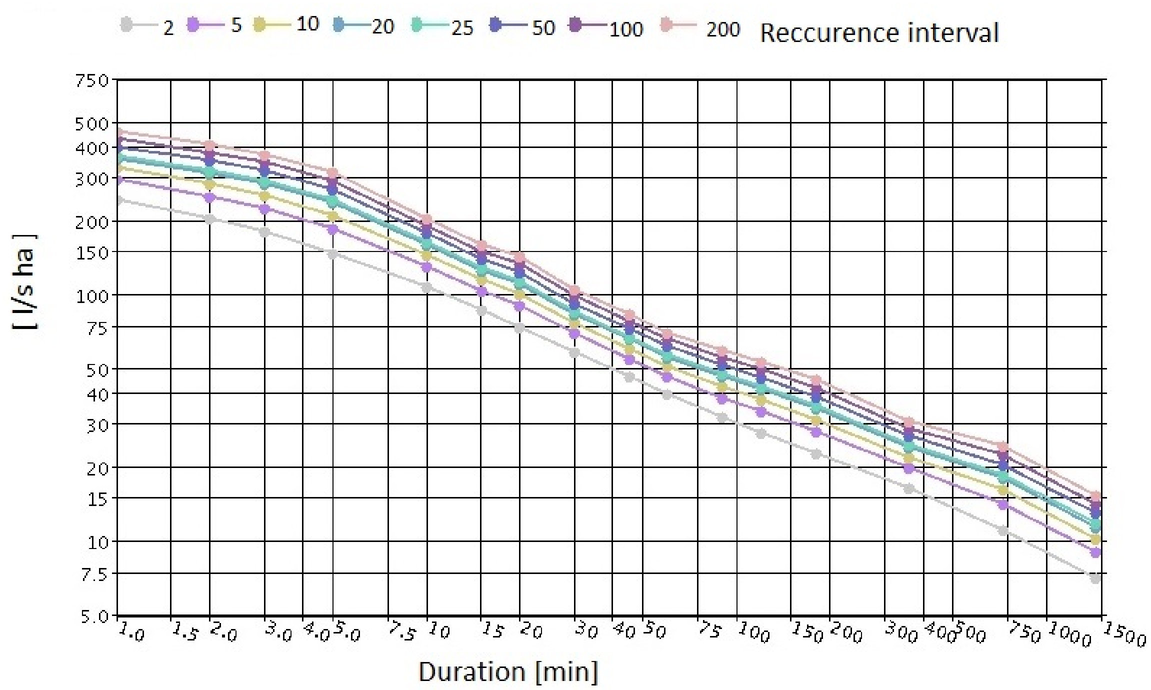


Figure 4.3: IDF curve for Sandsli meteorological station (eklima, 2013)

Table 3: Minimum and maximum design peak runoff from The Pier catchment calculated with RM

Measure Station	Sandsli 1982-2013	The whole area		Without roofs	
Return Period	Intensity l/s*ha	Q min [l/s]	Q max [l/s]	Q min [l/s]	Q max [l/s]
2 Years	155	461	545	345	386
10 Years	245	729	862	545	610
20 Years	275	818	967	612	685

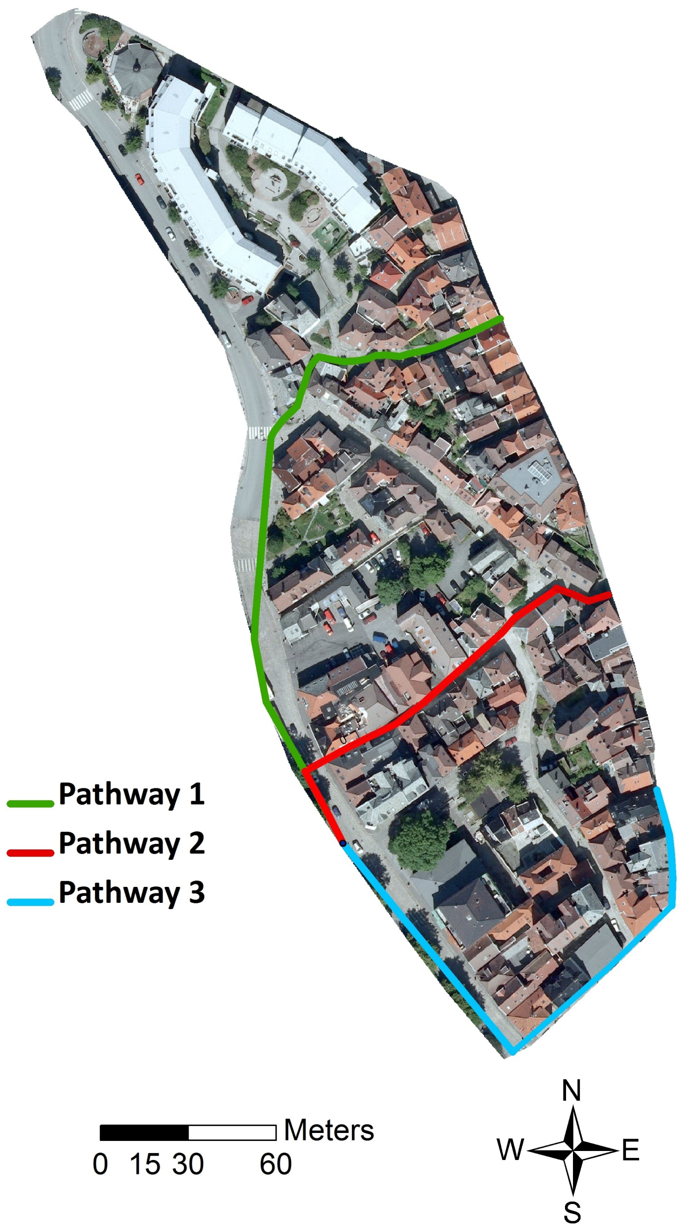


Figure 4.4: Bryggen catchment, Time of concentration calculation for three different pathways for calculation of runoff volume

4.1.2 The SCS Method

The U.S. Soil Conservation Service (SCS) has made an empirical formula to estimate the runoff volume taking rainfall abstractions into account. The potential storage capacity (S) is related to the Curve Number (CN), which is characterized by the soil type, land use and the degree of initial saturation. CN can be based on percentage of previous and impervious area and soil condition. In this calculation an area weighted CN is assessed for the calculation of the Bryggen catchment.

There are two ways to estimate the initial abstraction, first to assume that all impervious areas has an initial abstraction equal to zero and all previous has an intital abstraction of 5 mm. The second is to calculate the initial abstraction as 20% of the storage potential. In this thieses the initial abstraction is area weighted from the first alternative.

$$S = \frac{25400}{CN} - 254 \tag{4.2}$$

$$Q(t) = \frac{(P(t) - I_a)^2}{P(t)S - I_a} \tag{4.3}$$

S = Potential surface storage [mm]

CN = Curve Number (98 for impermable surfaces]

Q(t) = Effective rainfall [mm]

P = Design precipitation [mm]

I_a = Initial abstraction [mm]

Table 4: Runoff volume pr 24 hr with and without the roof area that drains directly into the sewage system

Measuring Station	Sandsli 1982-2013		
Return Period	l/s*ha	Q[m^3/day]	Q[m^3/day] without roofs
2 Years	155	23884	17841
10 Years	245	29667	22162
20 Years	275	31077	23215

4.2 Event Mean Concentration

Event mean concentration is a method used to characterize the pollutant concentration of a substance throughout a rain event. Concentration and flow is taken into account.

$$EMC = \frac{M}{V} = \frac{\int_t{}^t{}_1{}_2 Q \times C \, \mathrm{dt}}{\int_t{}^t{}_1{}_2 Q \, \mathrm{dt}} = \frac{\sum_{i=t_1}^{t_2} Q \times C \, \mathrm{dt}}{\sum_{i=t_1}^{t_2} Q \times C \, \mathrm{dt}} \tag{4.4}$$

M = Mass [mg]

V = Volume [l]

C = Concentration [mg/l]

Q = Flow [l/min]

5 Shortcomings

It would have beed desirable to have sampling in summer and autumn months to get representative characteristics throughout the whole year.

The authors unfamiliarity to field and laboratory work amounts several sources of error. Sourese of errors can appear in the sampling process and in samlning analysis.

Better preparation would have included the NO_3 and SO_4 in the characterization of stormwater at an earlier stage. That would have given more representative results on these parameters. 24 NO_3 samples was taken, but with a too high indication area. The test for measuring NO_3 had a minimum detection area of 40 mg/l, whereras the sample point had a maximum value of 23 mg/l, the test was therefore not scientific valid.

A closer investigation showed that The Bryggen catchment most likley is significantly smaller, at least by 30 %. This is due to the fact that runoff from the West side in the catchment will find its way down a road, before reaching the planned raingarden. The runoff volume is based on Intencity Duration Curves for Florida meteorological station. Florida has significantly higher precipitation level than The Bryggen metorological station, which adds another factor of uncertainty to the estimated runoff volume. With that calcultated runoff volume and TSS estimations from the whole area is over estimated.

Comparing the content of dissolved oxygen in mg/l demands that the water has the same temperature. It is possible to compare the DO level through a conversion to ppm, that takes both pressure and temperature into account. This conversion was not done in this thieses, and therefore the comparison of DO level is somewhat inaccurate.

The conductivity measurement seemed to be very high in the winter samples, and indicated some human error. Over a week after the sample were taken, new measurements were done at 25 °C, and the original data was transformed with equation for conductivity in NS 788:1933, so that the two measurements were comparable (Figure 6.19). In the statistical comparison, the new measurement was used.

6 Results and Discussion

In this chapter results will be presented and discussed. Table 9 presents mean, median concentration and Standard Deviation(SD) of pH, TSS, alkalinity, DO, conductivity, total P and PO_4 for the sample points. Table 5, 6 and 7 represent the mean and median particle size of a selection of the samples. Table 10 and 11, presents minimum, maximum, mean, median and SD for the elements and metals detected at the different sample points. For the discussion, an emphasis has been put on the results relevant for the decomposition of the medieval layers at The Bryggen, as well as compromising substances for the raingarden. This given, sulphate, oxygen, metals and suspended soilds will be the results most interesting for this master. For the metal and ions samples a total of 31 elements were detected. In the results the focus will be on Cd, Zn, Ni, Pb, Cr, Na, Cl and Fe which are the most common metals to identify in stormwater characterization. All metals and elements(P, Ce, Hg, Hf, Pr, Ag, Br, As, W, Sn, Pt, Lu, Ti, U, Mo, Li, Mg, K, S, Mn) results will be available in the electronic appendix. At the end of the chapter the results will be compared to urban stormwater internationally with an emphasis on a Dutch study and selected elements will be compared to pollution levels for receiving waters from the Norewgain Directorate for Climate and Pollution.

The statistics from R will be presented throughout the chapter. It has been interesting to see whether there is any difference between the sample sites themselves and between the sample sites and the water quality in the dip wells. Finally three dip wells was chosen to represent the groundwater quality, MB5, MB6 and MB7, due to the fact that stormwater would influence in these wells. As there was few dip wells to compare to the groundwater, The Two Sample Welch T-tests will in most cases give a high P-value compensating for the small amount of dip wells.

The Total Coliform Bacteria analysis gave 2420 MPN/100 ml for S2, 109 MPN/100 ml for S3 and 64 MPN/100 ml for S4 TCB. Since there was only conducted one test, which did not include S6, little of statistical value can be drawn form these measurements. It should be noted that S2 has a TCB level a hundred times larger than S3 and S4.

6.1 Total Suspended Solids

6.1.1 Precipitation and TSS

TSS results showed that both roads and roofs differentiate. S2 has a mean of 484 mg/l while S6 has a mean of 264 mg/l (Table 9). S3 and S4 with a mean TSS of 21 mg/l and 14 mg/l respectively, does not vary significantly (P-value= 0.629). There is a evidence that there is a difference between TSS at the road and roof (P-value= 0.000) It is proved that S2 will have the largest amount of TSS.

The EMC was calculated for the sample points on the precipitation event the 14th of April. The sample points represent different areas, according to roof type and road size, it is this area that has been used to estimate the runoff volume together with the meteorological measuring station at Bryggen.

The graphs in Figure 6.2, 6.3, 6.4 and 6.5 shows that the pollutant concentration is higher in the beginning of the rain event. The EMC for the sample points are 315 mg/l, 89 mg/l, 6 mg/l and 8 mg/l for S2, S6, S3 and S4 respectively.

Figure 6.2 shows a TSS concentration top in the middle of the event. It turned out that at this time a day, the precipitation is on its most extreme, causing a larger flow which again is able to carry with it even more sediments. In April Bergen still had leftover sand in the streets, for gritting in wintertime, and samples on 14th og April is taken after a dry period of 5 days. This indicate that the intensity of the precipitation is crucial for the amount of sediments load stormwater flow can carry.

Figure 6.6 shows precipitation from Bryggen meteorological station at the same time as TSS from the samples taken. It is interesting to see that both Figure 6.6b and Figure 6.6c has higher TSS throughout the whole than Figure 6.6a where it had been raining the previous days.

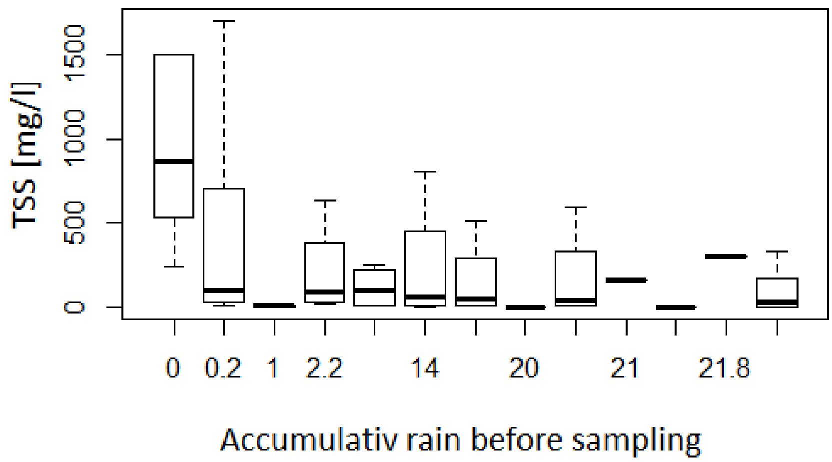


Figure 6.1: TSS vs accumulated rain before sampling. The value 0 represent sampling of the absoulte first runoff from the rainevent

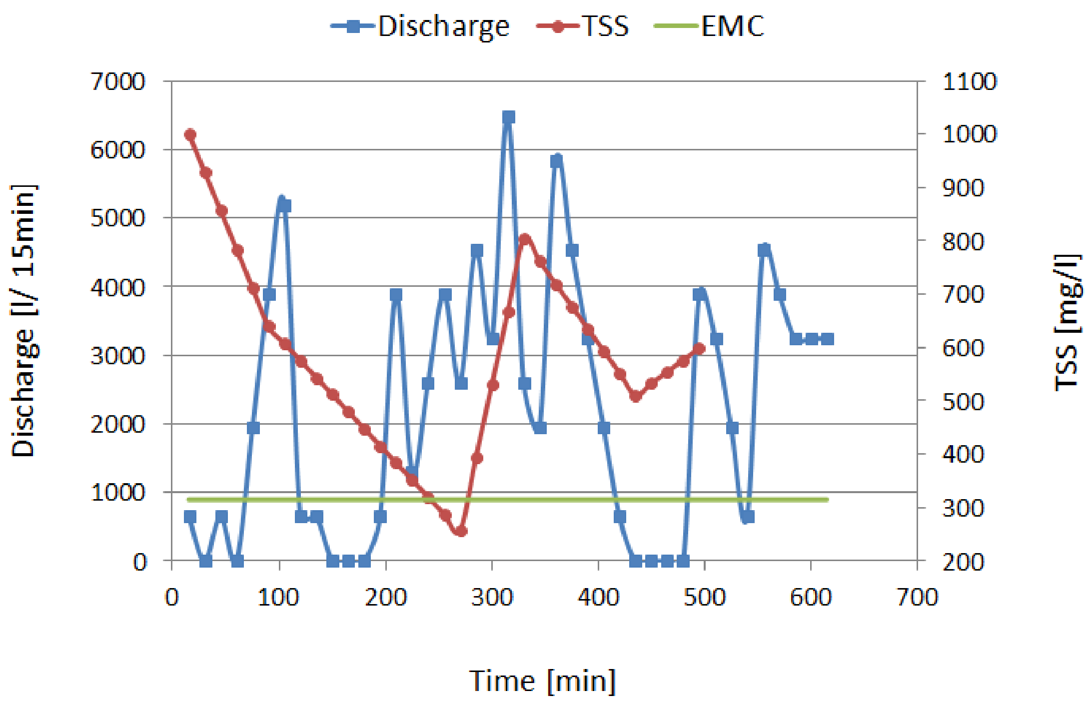


Figure 6.2: TSS and EMC vs discharge for S2

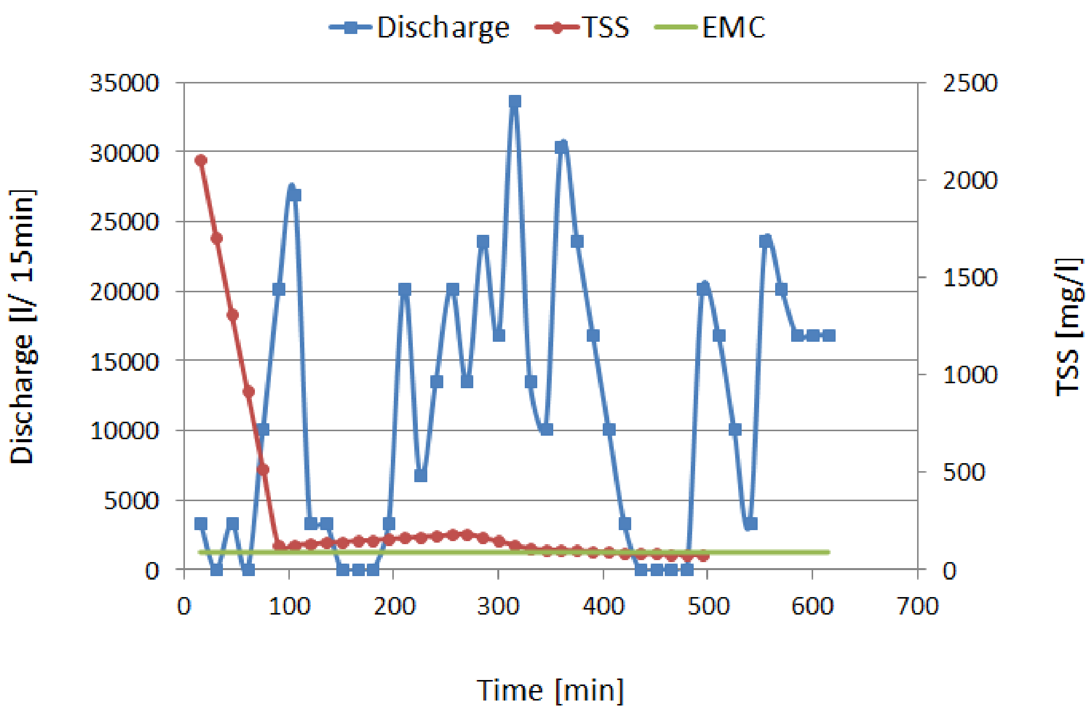


Figure 6.3: TSS and EMC vs discharge for S6

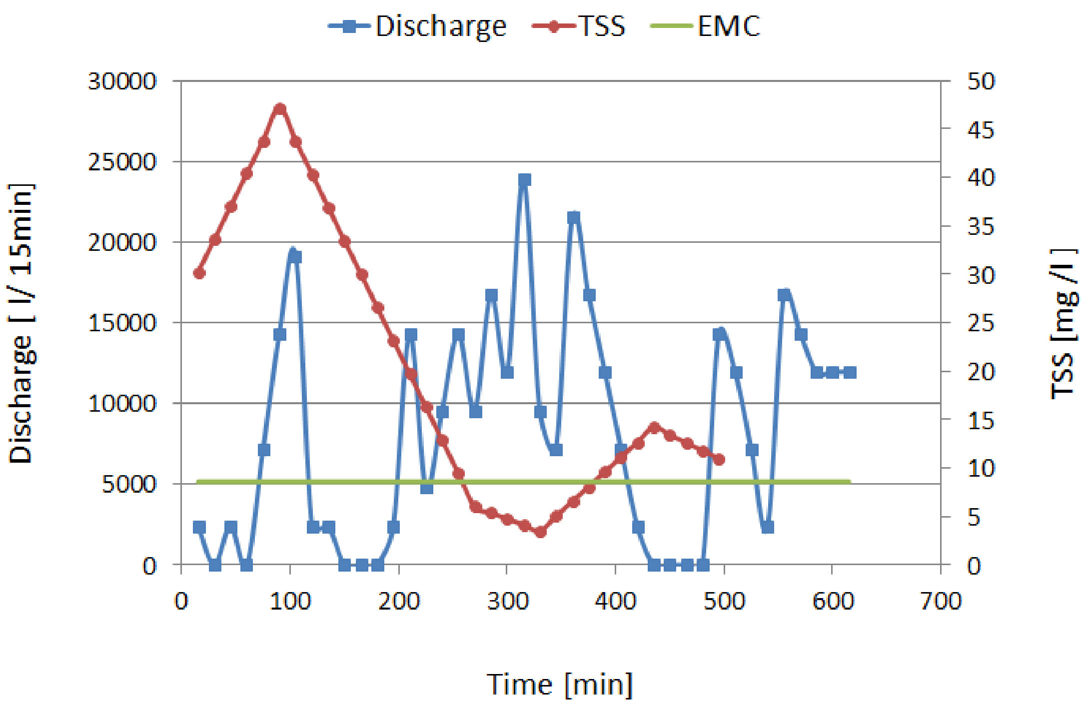


Figure 6.5: TSS and EMC vs discharge for S4

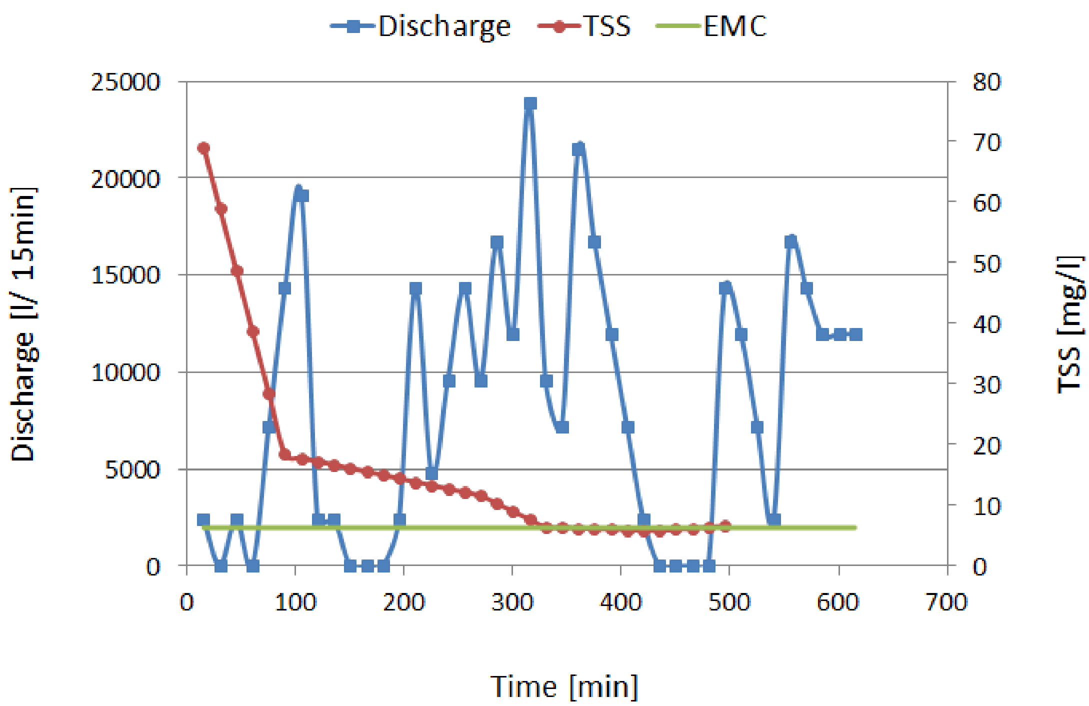
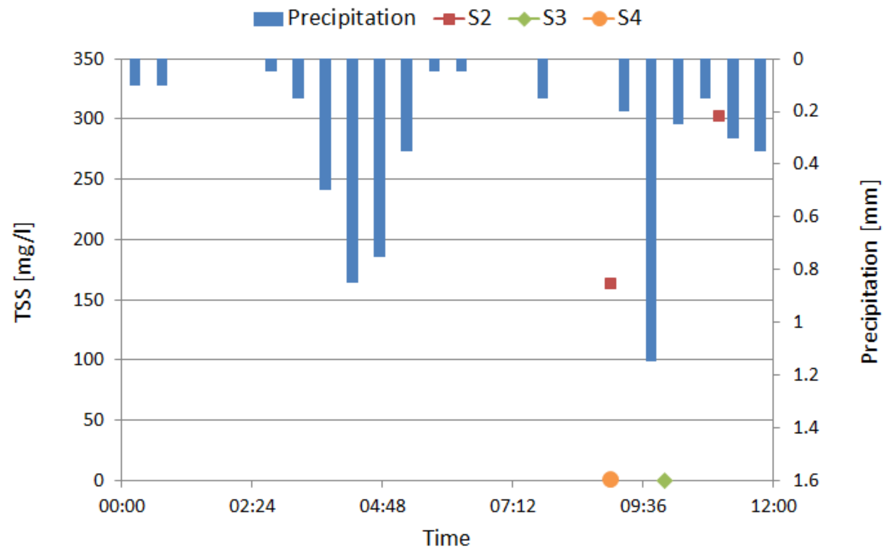
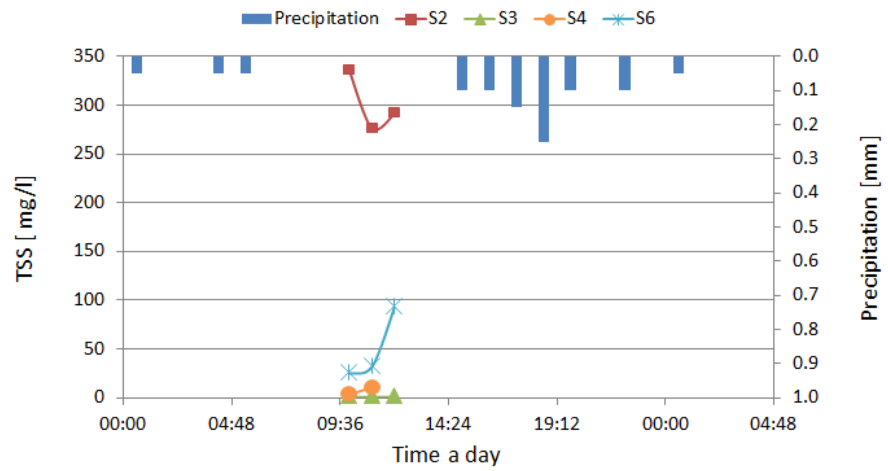


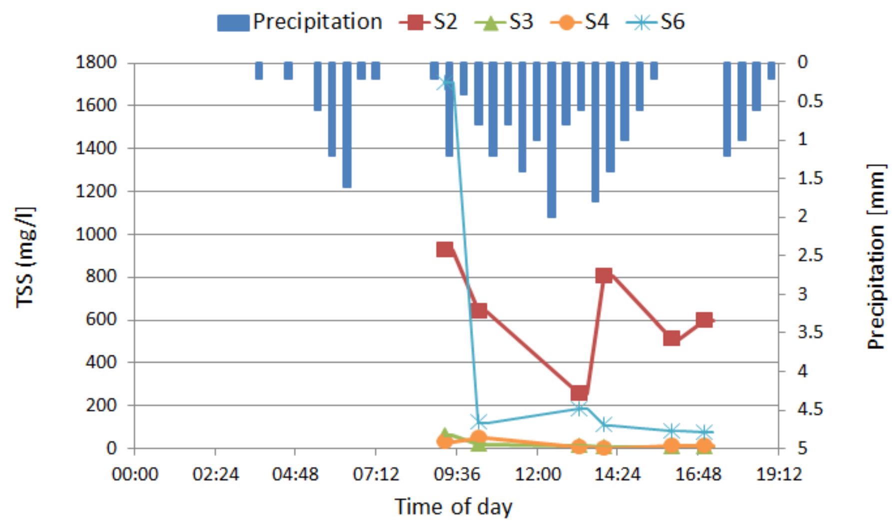
Figure 6.4: TSS and EMC vs discharge for S3



(a) Concentration of TSS vs precipitation from the 4th of February



(b) Concentration of TSS vs precipitation from the 18th of February



(c) Concentration of TSS vs Precipitation on the 14th of April

Figure 6.6: Concentration of TSS vs precipitation from the different sample days

6.1.2 Particle Size, Concentration and Distribution

Samples from the rain event on 14th of April is shown in Figure 6.7a. The first samples are taken at the very beginning of the rain event, giving a high load of sediments. As the rain continues more sediments are washed away, leaving the last sample with less sediments than the first. This is also confirmed by individual TSS measurements of the samples. The particles are distributed in the size of sand and silt. The results from the particle distribution showed that sample point S2 has the smallest median with a particle diameter of 7 µm going up to 53 µm. S3 has the largest particle diameter with a mean size of 219 µm (Tables 5, 6 and 7). The Figures 6.9, 6.8, 6.10 6.11 represent particle size distribution curves for each of the sample points. The graph in Figure 6.11 is not even because the sample contains a small amount of solids. Laser diffraction, in which the particle distribution method is based on, will not fill in where no particle size was detected.

Table 5: Particle diameter size for sample site S2. The first letter and digit S2 identifies the sample point, and the second digit is the number of sample. S21 was the first sample taken, and S213 the last. S29 to S213 was taken on the same rain event the 14th of April

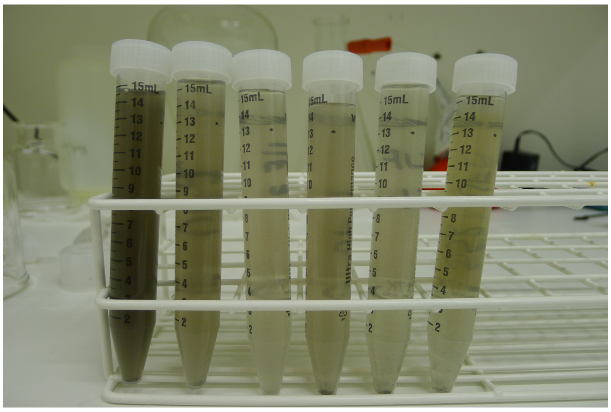
Sample id	S21	S22	S25	S27	S28	S29	S210	S211	S212	S213
Mean [μm]	8.36	7.67	21.93	13.78	38.8	53.23	34.55	41.39	41.17	47.8
Median[μm]	4.79	4.75	6.65	6.17	9.98	11.98	14.18	20.46	18.63	22.56

Table 6: Particle diameter size for sample site S3 and S4. The first letter and digit S3 and S4 identifies the sample point, and the second digit is the number of sample.

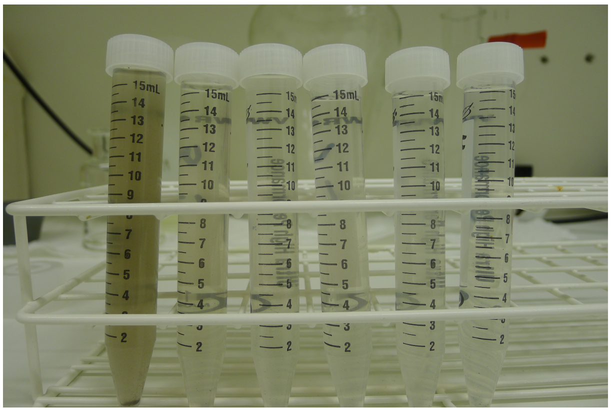
Sample id	S32	S33	S34	S37	S38	S43	S45	S46
Mean [μm]	219.99	251	93.06	201.9	266.7	189.3	212.1	220.6
Median [μm]	190.60	248.00	114.8	181.00	174.00	172.90	195.9	214.8

Table 7: Particle diameter size for sample site S6. The first letter and digit S6 identifies the sample point, and the second digit is the number of sample.

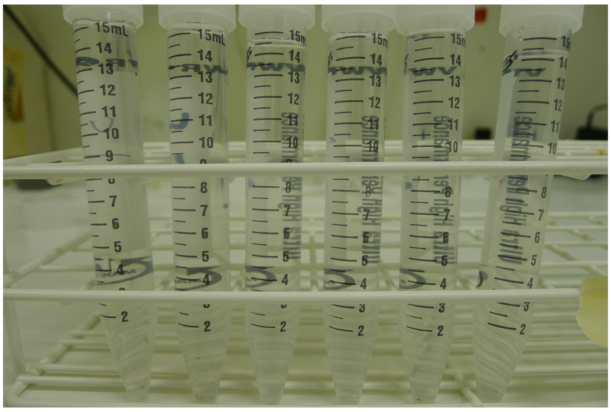
Sample id	S61	S62	S63	S64
Mean [μm]	135.2	164.2	178.7	156.3
Median [μm]	132.6	168.6	172.1	155.3



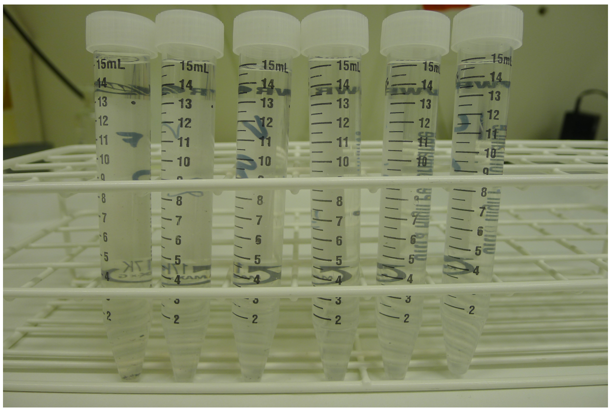
(a) Six samples from S2



(b) Six samples from S6



(c) Six samples from S3



(d) Six samples from S4

Figure 6.7: Runoff from sample points on 14th April 2013 (Photo: C. Gremmertsen)

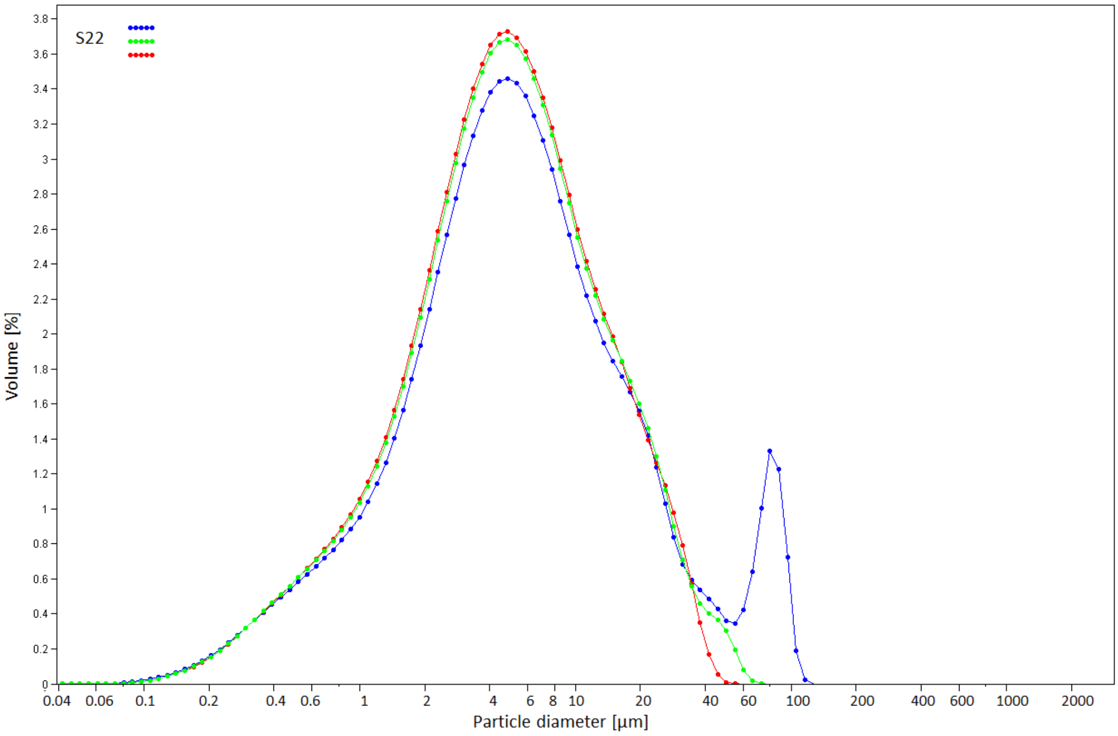


Figure 6.8: Particle distribution of sample S22 from roads at The Bryggen catchment

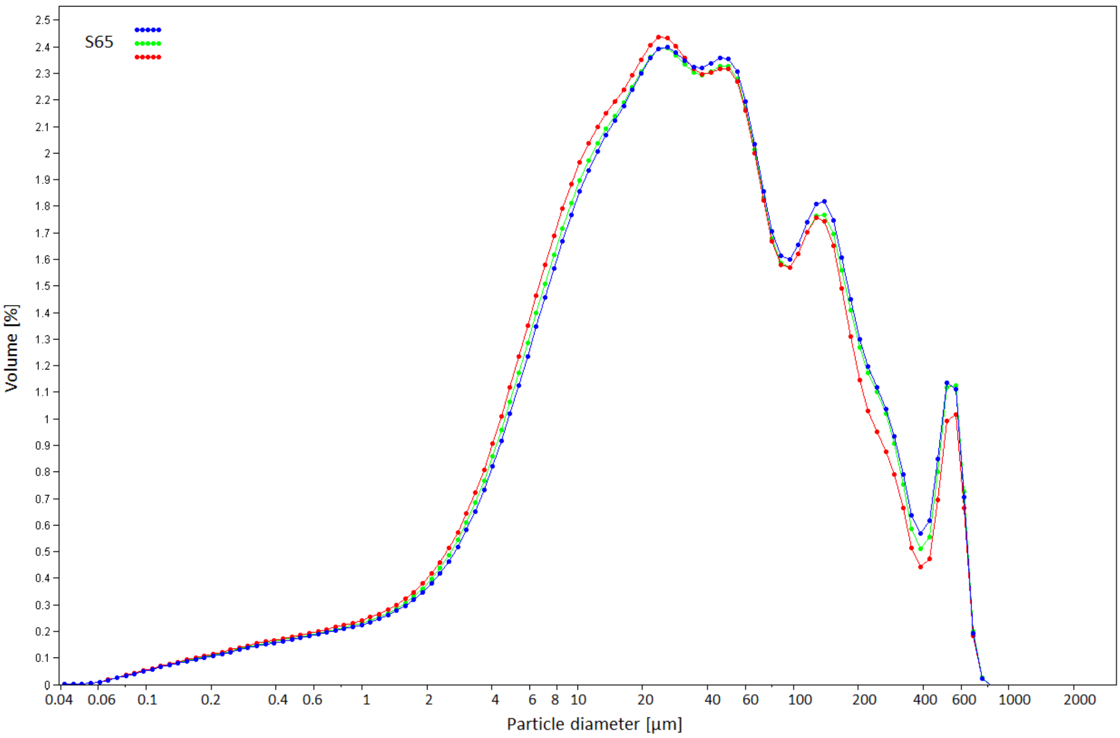


Figure 6.9: Particle distribution of sample S65 from roads at The Bryggen catchment

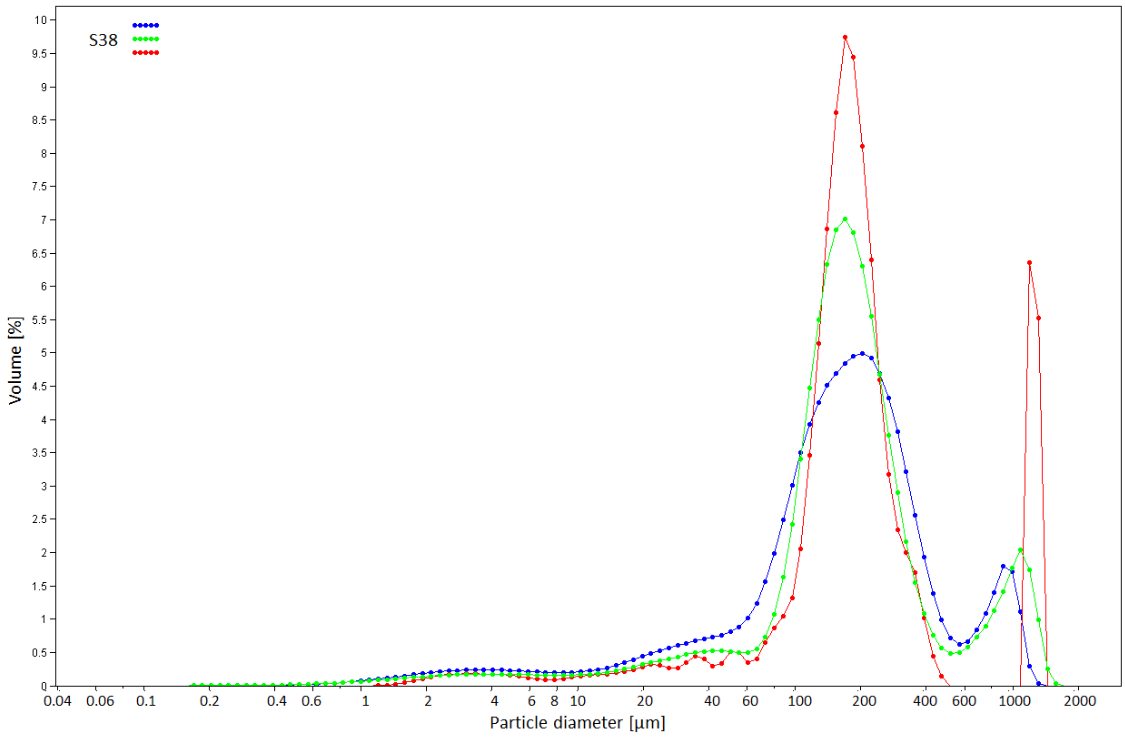


Figure 6.10: Particle distribution of sample S38 from a roofs at The Bryggen catchment

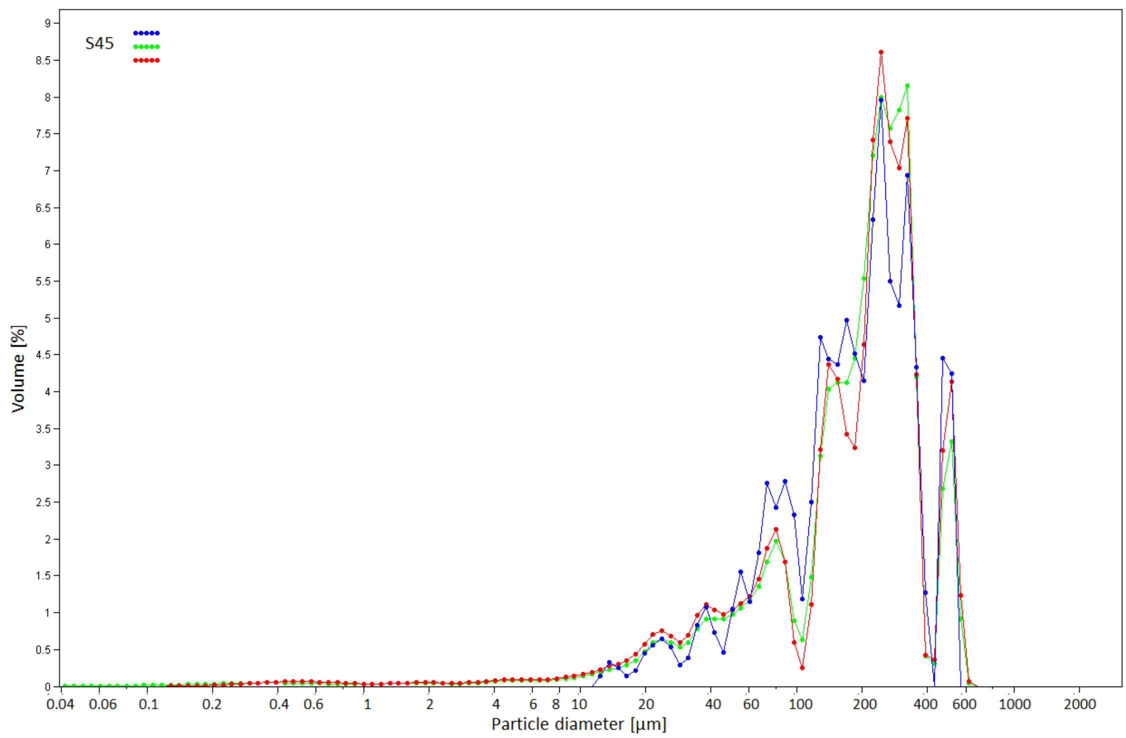


Figure 6.11: Particle distribution of sample S45 from a roof at The Bryggen catchment

The repetition of particle distribution measuring gives an indication whether or not

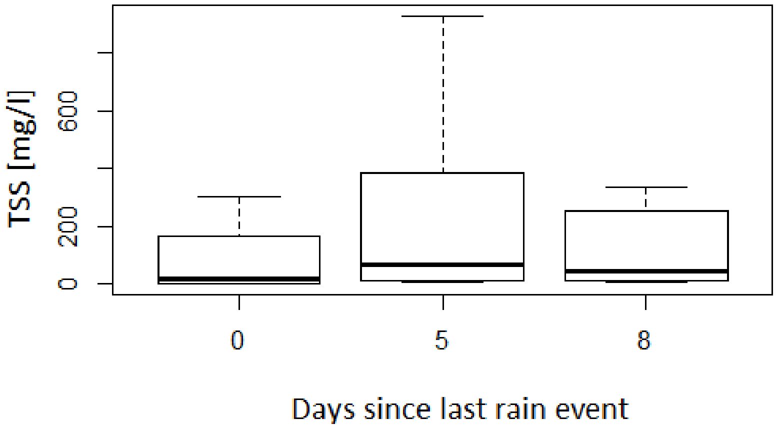


Figure 6.12: TSS vs days since it last rained when sampling. Theoreticaly 8 days should give a higher TSS load.

the particles are stable. Stable particle will have the same form and will not flocculate or split up. Samples that give the same or equal results every time indicates that the particles are stable, this is seen for S2 (Figure 6.8) and S6 (Figure 6.9). That given, S2 and S6 have a large amount of solids, and as some flocculate others may break up, giving the impression that the colloids are stable. See Appendix A for all particle diameter distribution graphs. From S3 there was expected quite large but few particles as the brick roof gave of material in intense precipitation and when raining after a long dry period (Figure 6.13). The results confirms this. The particles from S3 are classified as sand grains. These are particles that will settle in stable conditions, and which can be physically retained in the raingarden.

Figure 6.14, Figure 6.15, Figure 6.16 and Figure 6.17 shows cumulative particle distribution for a selection of samples from the sample points.

A minimum scenario for S2 gives a volume of 70% for particles with diameter below or equal to 1.2 µm, and a maximum scenario at almost 100% (Figure 6.14). It is clear that a quite high volume percent of the particles have a diameter smaller than 45 µm, going up to 95% for S24 and S26 (Figure 6.14, Figure 6.15).

Particle with a size smaller than 4 µm amount up to 10 % of the volume percent from S6, meaning that these particles would not settle in a water body unless they flocculate Particles from S6 with diameter smaller than or equal to 10 µm accounts for 25% of the particle volume. Particles with diameter smaller or equal to 1.2 µm accounts for maximum 70% and minimum 10% of the particle volume (Figure 6.15). Particle size will decide whether or not the particles will flocculate and or adsorbate and this depends on the particle size.

Figure 6.13: Rood drainage pipe for sample point S3 on 14th of April (Photo: C.Gremmertsen)

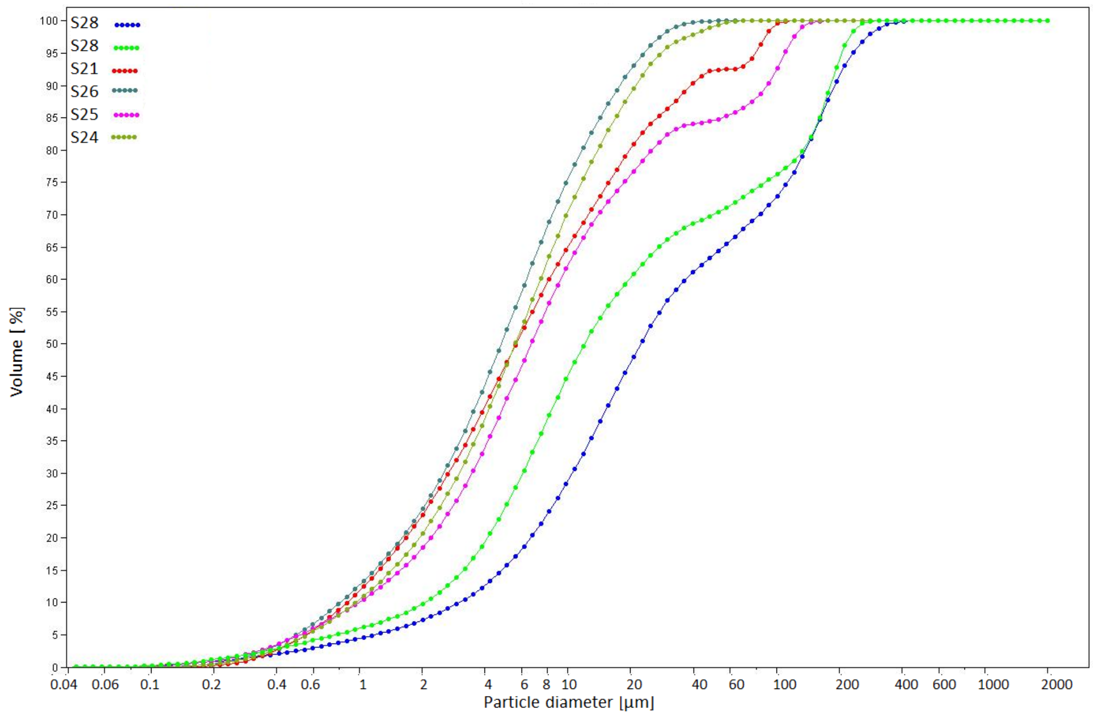


Figure 6.14: Cumulative particle distribution from S2. The particle diameter axis are given at a log scale

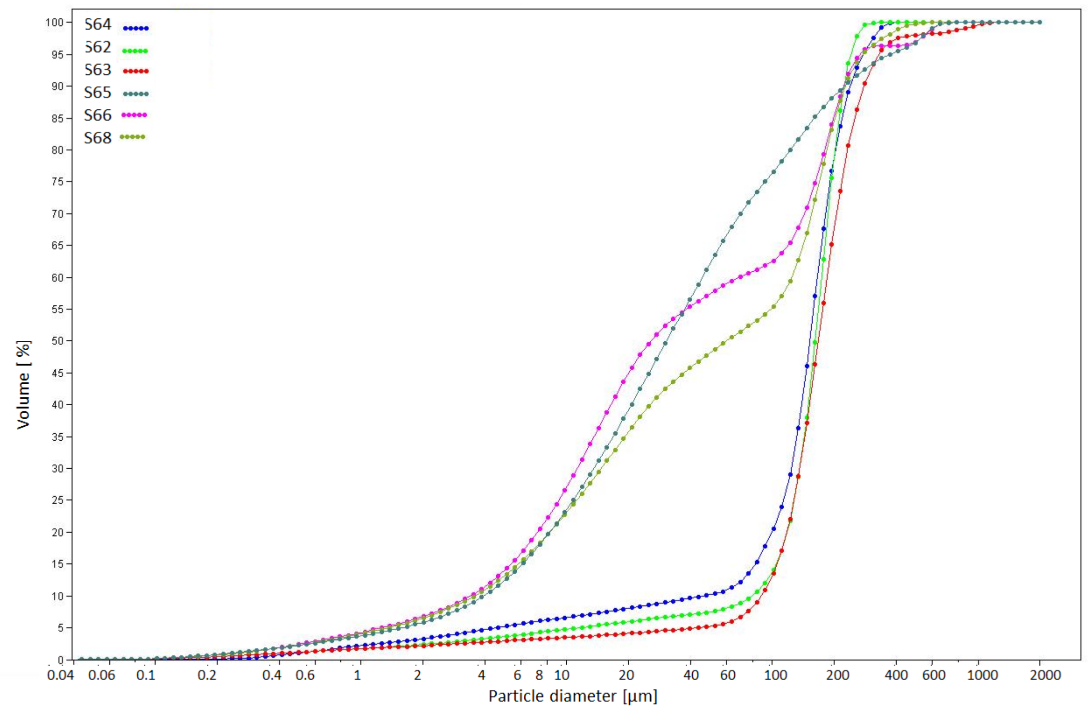


Figure 6.15: Cumulative particle distribution from S6. The particle diameter axis are given at a log scale

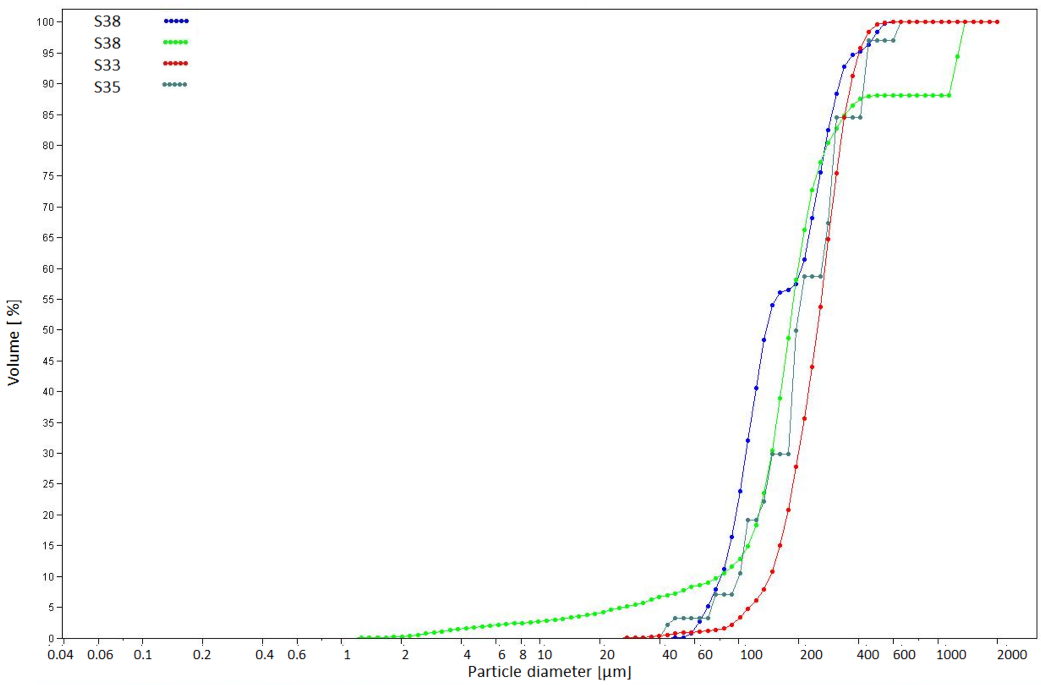


Figure 6.16: Cumulative particle distribution from S3. The particle diameter axis are given at a log scale

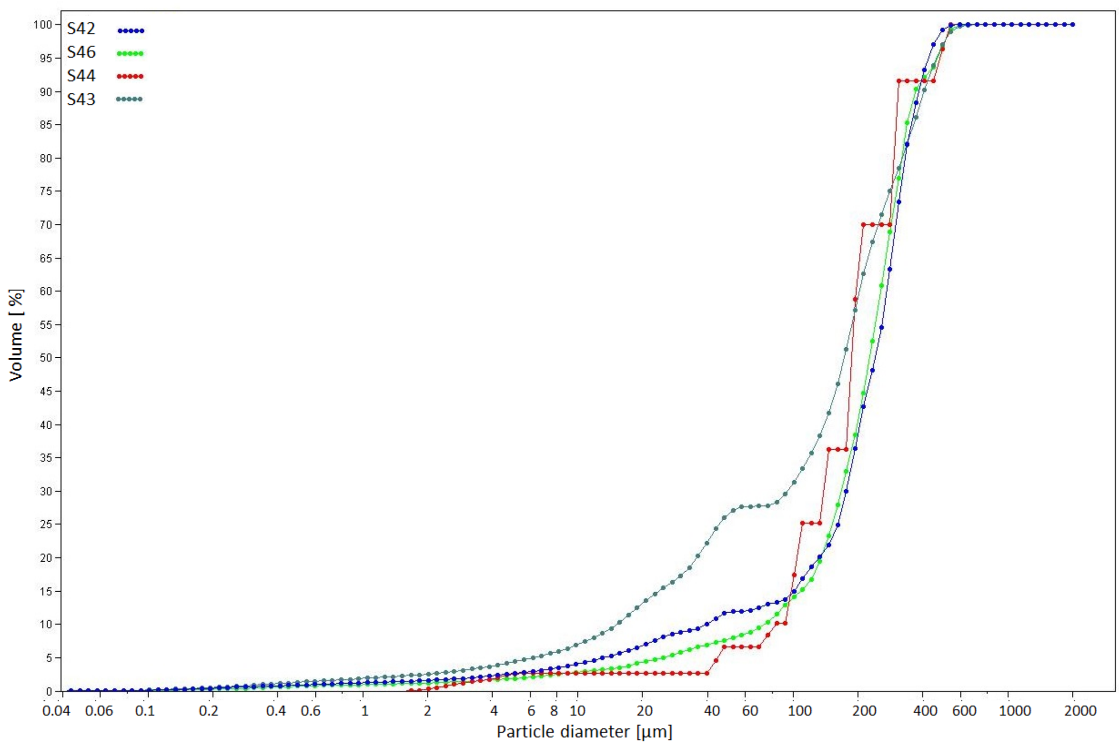


Figure 6.17: Cumulative particle distribution from S4. The particle diameter axis are given at a log scale

6.1.3 Total Amount of TSS

Before the stormwater enters the raingarden it will have time to settle in a stormwater collector tank. This will allow particles in the sand fraction to settle. Particles with size under 1 µm have the possibility, through diffusion, to form floccs in the stormwater collector tank. As the stormwater enters the raingarden it should have an filtration time of at least 24 hr, before entering a undreground infiltration system (Figure

Cold climate studies of raingardens shows that up to 95% of TSS mass will be retained (Khan et al., 2012; Davis et al., 2001), but smaller particles from 5 µm to 50 µm have shown to have larger effluent than influent. This is a common phenomenon the first period where masses from the raingarden is washed out. Studies have shown that metal ions have a larger affinity to smaller particles(Stone and Marsalek, 1996; Blecken et al., 2012; Muthanna et al., 2007)

With an area weighted TSS concentration the catchment will have an mean TSS concentration of 1282 kg/month, and a median of 654 kg/month in the winter and spring (Table 8). This is a desktop estimation, not taking into account that the stormwater from the cobblestone roads, where fewer vehicles roam are not measured but assumed to have the same TSS as sample point S6. It should be taken into consideration that when filtrating samples with a high TSS level, particles with diameter below 1.2 µm will also be retained in the filter due to clogging. In this case the estimated weight of particles with diameter above 1.2 µm is too high.

Due to high first flush concentrations of TSS the mean value is considered to high. The median value will be a more realistic value to estimate monthly TSS. It is expected that the TSS level will be at its highest in winter and Autumn due to gritting. The summer months will have a significantly lower TSS level bringing the yearly mean TSS amount down.

The TSS measurements done at The Square in Bergen (Table 1) has a maximum value of 54 mg/l. Compared to this, The Pier TSS concentrations are quite high. Traffic load can be one of the main reasons for this.

Table 8: An area weighted estimation of TSS for The Bryggen catchment. All areas are assigned a sample point and average monthly precipitation is 211 mm (Florida)

Areal use	Area[m^2]	Classification	Mean tss[kg]	Median[kg]
Black roof (S4)	1111.0	S4	3.5	1.9
White	1774.5	S3	7.7	2.5
Grey	2088.1	S4	6.5	3.6
Red Brick roof(S3)	9854.7	S3	42.9	13.7
Parking	1597.0	S6	83.2	32.0
Grass	245.7	S6	12.8	4.9
Large road(S2)	3240.9	S2	331.3	289.4
Small road(S6)	15254.4	S6	794.4	305.8
Total Area	35166.2		1282.2	653.8

6.2 Runoff Volume

The runoff volume varied from 31077 m^3/day (Table 4) to 47094 m^3/day (Table 3) for the whole area for a 2 year return period. Without the roofs that were connected to the sewage system the runoff was 17841 m^3/day (Table 4) to 29801 m^3/day (Table 3). More important is the volume of the First Flush. From the sample at the 14th of April it seems as the TSS concentration decreased after 90 min. This will account for 968 m^3 (maximum value with the Rational Method).

6.3 Conductivity, Alkalinity, pH and Dissolved Oxygen

Table 9: Results of pH, TSS, alkalinity, DO, Conductivity, total P and PO4-P form the sample points and dip wells(MB)

	pH			**TSS[mg/l]**			
Sample point	Mean	Median	SD	Mean	Median	SD	n
MB	6.7	6.5	0.4				3
S2	7.7	7.5	0.5	484.5	423.2	248.2	12
S3	7.5	7.7	0.3	20.6	6.6	38.7	13
S4	7.7	7.8	0.6	14.8	8.2	16.3	12
S6	7.8	7.6	0.5	264.8	95.0	511.4	10
	Alkalinity[mmole/l]			**DO[mg/l]**			
MB	5.05	3.88	4.29	0.43	0.32	0.18	3
S2	0.424	0.344	0.262	11.68	11.78	0.68	12
S3	0.522	0.412	0.218	11.80	12.05	1.28	13
S4	0.160	0.104	0.165	12.09	12.18	1.06	12
S6	0.263	0.264	0.096	11.70	11.92	0.69	10
	Conductivity[µS/cm]			**Total P[µg/l]**			
MB	218	220	18	4955	6813	3768	3
S2	931	500	1716	927	657	645	12
S3	210	178	191	27	9	35	13
S4	61	43	65	23.4	12	22	12
S6	777	258	1333	383	186	562	10
	NO3[mg/l]			**PO4[mg/l]**			
S2	1.20	0.88	1.2	42.4	38.6	31.1	12
S3	1.20	0.36	1.6	64.2	6.1	183.0	13
S4	0.23	0.23	(one sample)	9.1	8.1	4.8	12
S6	1.13	0.76	1.4	38.3	30.6	35.5	10

6.3.1 Conductivity

Figure 6.18: Nikolaikirkealmenningen on the 13th of April, one day before sampling

The samples were divided into groups of what time of year they had been sampled. There is no evidence that the conductivity is different in winter and spring (P-value= 0.724).

The large road (S2) had the highest conductivity with a mean of 931 mS/cm. S6 has a mean of 776 mS/cm. The metal roof (S4) gives the smallest conductivity, with a mean of 60 µS/cm. The red brick roof(S3) has a mean of 210 µS/cm. There is a difference in conductivity from the two roof types (P- value = 0.018). The conductivity from the roofs are comparable to international studies where conductivity from roofs varies from 25 to -269 µS/cm (Melidis et al., 2007; Gobel et al., 2007). The closeness to the harbor can contribute to the conductivity as aerosols that settles on the roofs can contain high seawater concentrations. Seawater has a conductivity of around 50 mS/cm. The difference between the roof types suggests that roofing material contribute to the conductivity.

The dip well conductivity does not vary significantly from the conductivity measured in the the stormwater from sample point S3 and S4. Conductivity from S2 and S6 is higher than from the dip wells (Table 9). It is assumed that most of conductivity from S2 and S6 is due to de-icing salt from the roads. It would have been normal to see a decay in this in the spring samples, but the sampling took place in early spring, and de-icing agents was observed on the roads before the last sampling campaign (Figure 6.18) . It should be noted that conductivity is temperature dependent and will increase with increased conductivity. Two samples with different temperature can therefore not be scientifically compared in relation to conductivity, as done in this thieses.

High conductivity has been believed to decrease the metal sorption in raingardens. This is a subject being under investigation by PhD candidate Kim Paus and master student Mikael Bue at NTNU. Preliminary results show that heavy metals effluent correspond to total organic carbon effluent. De-icing agents mobilized organic material where heavy metals were adsorbed (Bue, 2013).

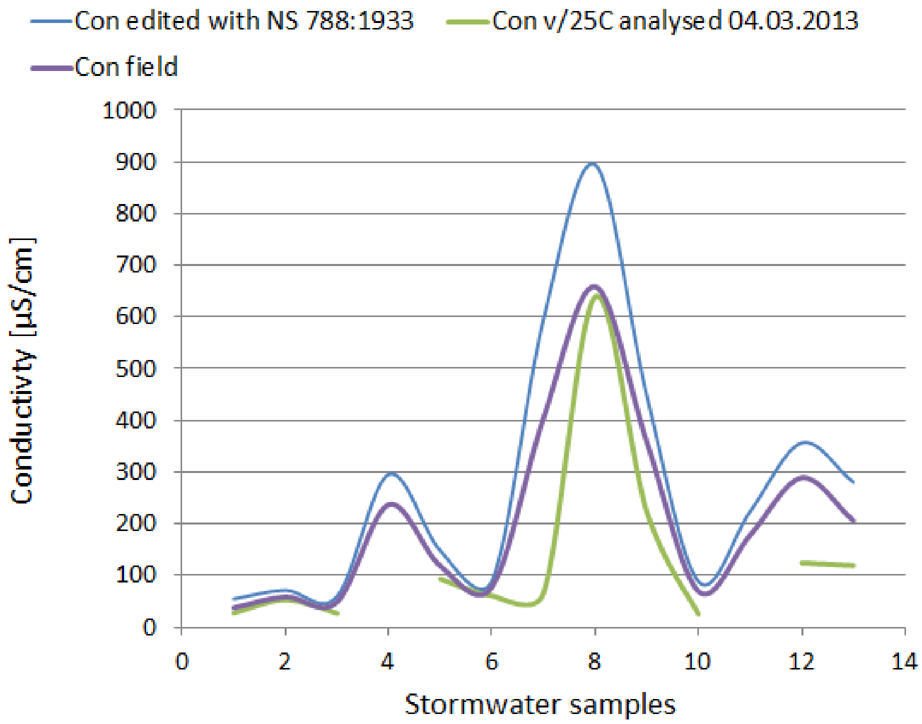


Figure 6.19: Conductivity of 14 the samples compared

6.3.2 Alkalinity

There is a difference in alkalinity content from the two roof types (P-value = 1.051e−04), with means of 0.52 mmole/l and 0.16 mmole/l for S3 and S4 respectively. There is a strong evidence that there is a difference in alkalinity from the stormwater and groundwater (P-value = 0.001), with means of 5.1 mmloe/l and 0.36 mmloe/l for groundwater in the MB and stormwater respectivley. Alkalinity is connected with pH, where a pH above 6 should give a higher buffering capacity (Figure 6.20). Igneous rock as granite should contribute to give the groundwater a low alkalinity. Other compounds that effects the buffering capacity of a water is silicates, ammonium, sulfides and organic ligands, whereas the last substance there is a major component of in the dip wells. As the groundwater in the dip wells have high concentration of phosphorous this may also affect the alkalinity.

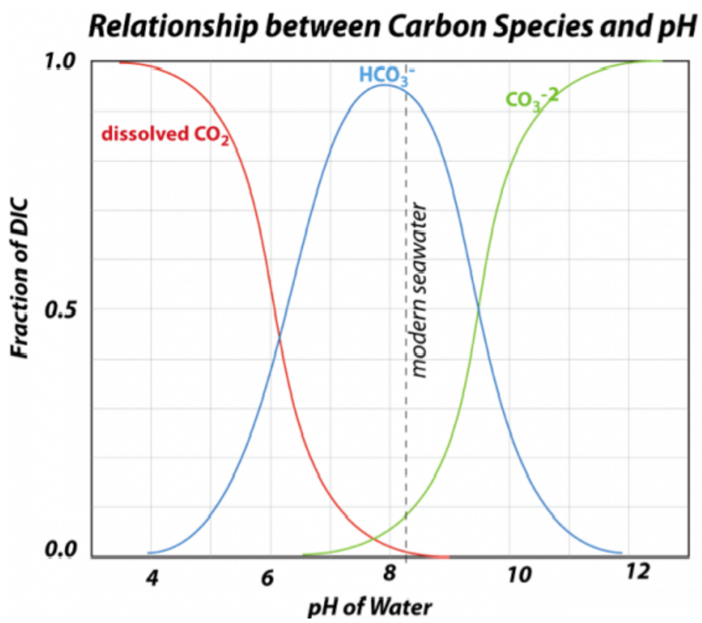


Figure 6.20: The correlation between pH and alkalinity. Adapted from (Brattli, 2011)

6.3.3 pH

pH varies from the different sample points with a median value from 7.7-7.8, all being in the alkaline area (Table 9). As pH was measured with a time delay, it gave the sample time to increase the temperature 2 to 8 °C. At a pH around 7, temperature changes in that scale should not be significant. With this pH should be considered as a stable parameter, not expecting seasonal or spatial variation. A pH of 7.5 is good for adsorption of metal ions, hench the larger pH (up to pH around 8-8.5) the better when it comes to adsorption of metals (Kan et al., 2006; Muthanna et al., 2007).

6.3.4 Dissolved Oxygen

There is a large difference in DO level in the groundwater and stormwater. The means of groundwater is 0.043 mg/l and 11.8 mg/l for stormwater.

From the nature of which stormwater occur, it is expected to have a high DO level. This means that the influent water to the raingarden has a high redox potential and as DO is a limiting factor for the bacteria in the medieval layers, external DO brought into the medieval layers will most definitely increase the decomposition of organic material.

It was therefore interesting to see what DO level that could be expected in the effluent of a raingarden. Risvollan Raingarden was chosen for its vicinity. The measurements from DO at the raingarden in Risvollan showed a mean concentration of 7.1 mg/l and SD was 0.1 and a temperature of 9.3 °C of a total of 9 samples. It is important to emphasis that even if it had been raining for two days, there was no ponding and thereby not possible to measure the inlet concentration of DO, also no water was running out from the outlet construction of the raingarden. Therefore it was impossible to say how old the water in the effluent tank was.

If assumed that Risvollan raingarden and The Bryggen raingarden has similar inlet DO concentration, a decrease of 4.7 mg/l will occur through the raingarden. It should be noted that the surrounding area of which the raingardens are situated are rather different, whereas Risvollan raingarden are situated in a grassy residential area, The Brygge raingarden is situated in the middle of commercial area. The settling tank will also be unknown factor in this estimation.

6.4 Ions, Elements and Heavy Metals

6.4.1 Sulfur and Sulphate

The results from the SO_4 measurments will be presented as an indication of the SO_4 concentration due to the uncertainties with the high indication area. (Figure 6.21).

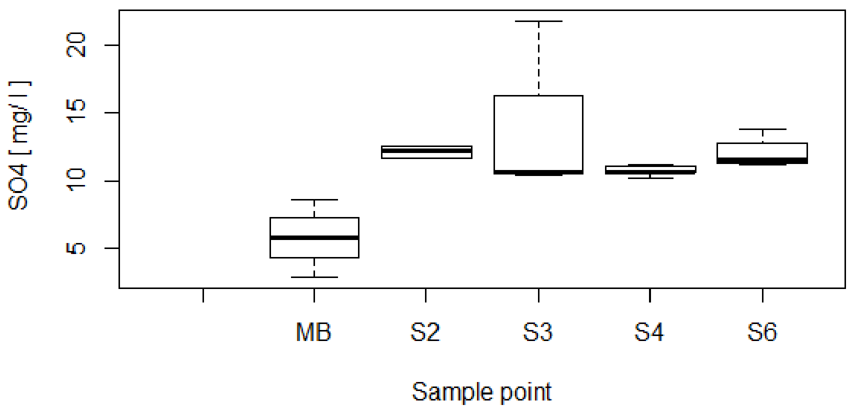


Figure 6.21: Filtrated SO_4 in the dip well(MB) and the stormwater

The elemental sulfur measurement was converted into SO_4 by assuming that all elemental S in the samples came from sulfate. From Figure 6.22 it is shown that the elemental sulfur measurement and the sulfate measurements do to some extend correspond. But as the minimum indication area for sulfate was to big, it can seem like all the sulfate measurements are exaggerated.

Most of the SO_4 in The Bryggen catchment is belived to originate from de-icing agents. As all other factors for sulphate bacteria to bloom are present, the supply of SO_4 can promote decomposition of the medieval layers. The mean value for sulfur goes from 3689 µg/l to 798 µg/l (Table 11). It should be noted that sulfur reducing conditions gives a low energy consumption, meaning that compared to other substances as carbon, the bacterias can not increase their biomass at an equal high rate when utilizing sulfate as an energy source. It is concluded that intrusion by seawater would be extremely negative for the medieval layers because of the SO_4 content in seawater.

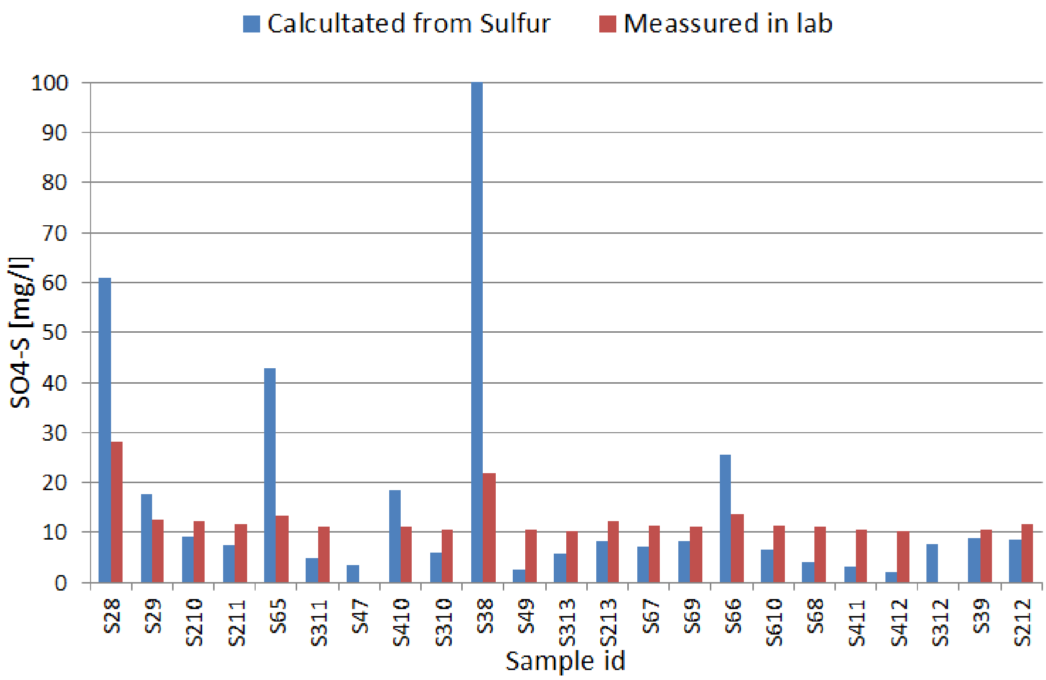


Figure 6.22: Sulfur element measurement and sulphate measurement compared. Sample S28, S65, S38 AND S66 are the first (and second for S6)sample taken on 14th April.

6.4.2 Phosphourus and Phosphate

There is no difference in PO_4 (P-value=0.299) or in total P (P-value=0.768) from the two roof types with means of 64.2 mg/l and 9.1 mg/l and 27 µg/l and 23 µg/l for S3 and S4 respectivley (Table 9).

There is a significant difference in total P from the stormwater and groundwater (P-value=1.362e-9), with means of 337 µg/l and 4955 µg/l for respectivley (Figure 6.23). The groundwater and soil in the dip wells are realtivley nutrient rich, concerning Phosphorous and Nitrogen.

There is no significant difference between PO_4 on roofs or on roads (P-value=0.924) but there is strong evidence that there is a difference in total P (P-value=$1.128e^{-}4$) and means of 679 µg/l for road and 25 µg/l for roofs.

As for the element Phosphor S2 and S6 gave the highest concentration, with means of 659 µg/l and 247 µg/l. S3 and S4 has mean of 14.3 µg/l and 13.6 µg/l (Table 11).

As the phosphorus level in the medieval layers are higher than in the stormwater, a focus should not be on P removal if the P level does increase significantly.

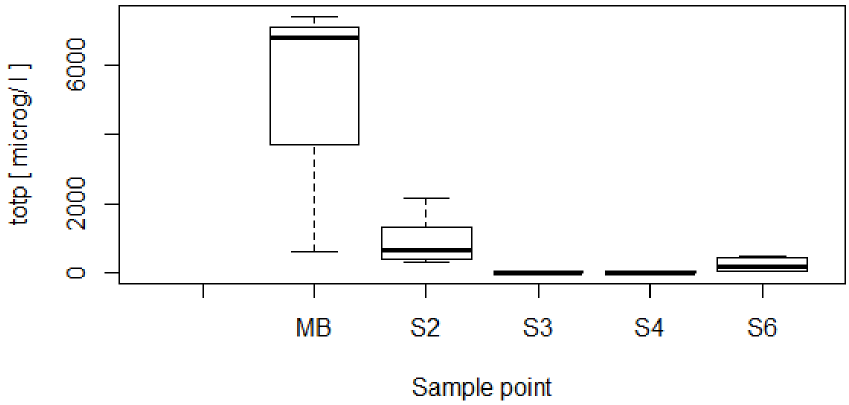


Figure 6.23: Comparison of total Phosphorous for the sample point and the dip wells (MB)

6.4.3 Nitrate

NO_3 was measured for 24 samples, whereas 10 samples had a concentration < 0.23 mg/l which is below the indication area. Counting all samples, including the ones under 0.23 mg/l T-test gives little to no evidence that there is a difference in means of NO_3 concentration between winter and spring (Figure 6.24), having means of 0.7 mg/l in spring and 1.7 mg/l in winter. A higher NO_3 concentration in the winter months may be caused by the extended use of fossil fuels in homes and due to increased NO_X-gasses from cold engines.

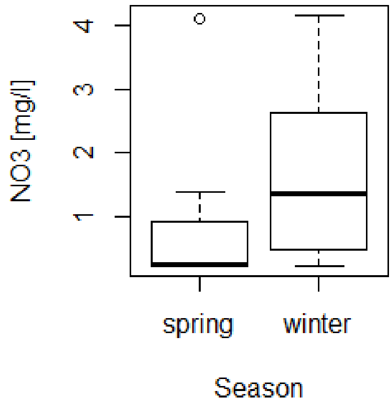


Figure 6.24: NO_3 for the different seasons

6.4.4 Ions and Metals

The level of Ca, Na, K, Mn and Fe was compared between the sample points and the dip wells, they all showed that the dip wells had a higher concentration of the metals (Appendix C).

As expected, S2 contained higher concentration of pollutants than the other sample points. A correlation chart from the filtrated samples was made to see which metals and ions that correlated (Appendix C). It was found than Na and Cl correlated quite well (R^2=0.81), but Cl also correlated with Mg (R^2=0.84) and Li(R^2=0.88) and Pt(R^2=0.82). After removing 5 outliners from the data set the relationship between Na and Cl was close to linear, indicating that Na ans Cl originates from de-icing agents (Figure 6.28). Assuming that de-icing agents in Bergen are equal to those in Trondheim, it could seem like there was external sources for Ca and Mg.

Scatter plot of the metals vs TSS gives a linear relationship between TSS and P and Ag (Figure 6.25), Fe (Figure 6.26) and Ni (Figure 6.27). Scatter plot for all other metals are given in B.

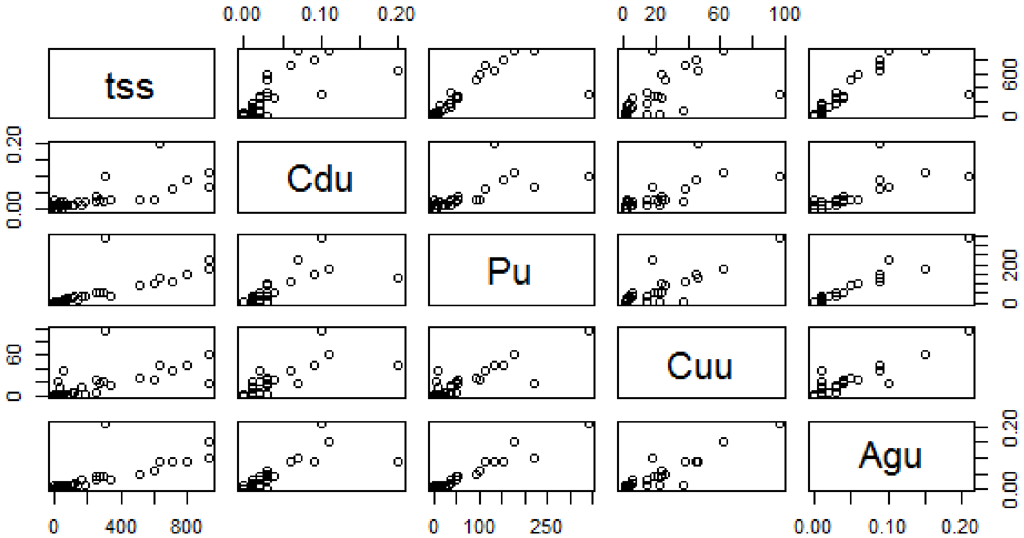


Figure 6.25: Scatter plot of TSS vs Cd, P, Cu and Ag, the u stands for unfiltered

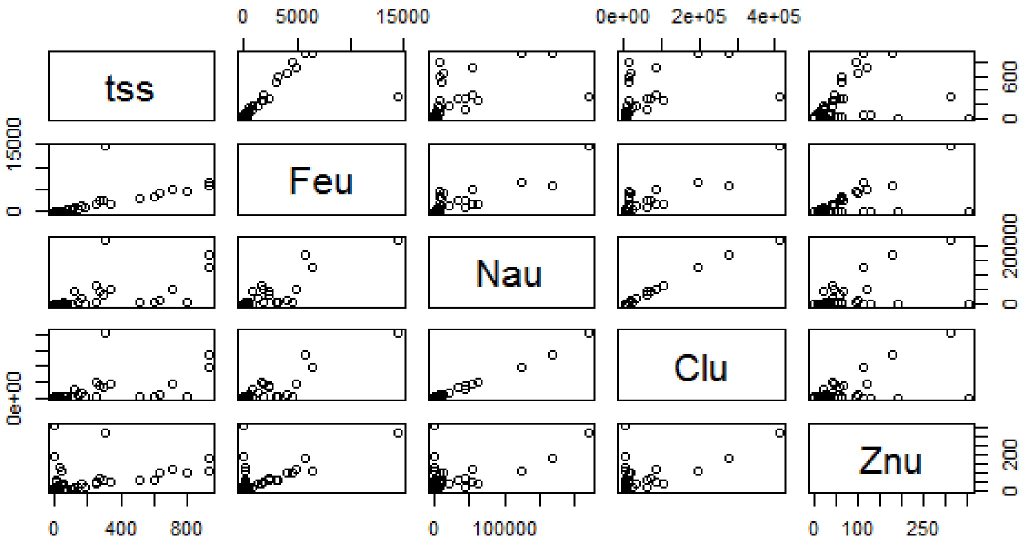


Figure 6.26: Scatter plot of TSS vs Fe, Na, Cl and Zn, the u stands for unfiltered

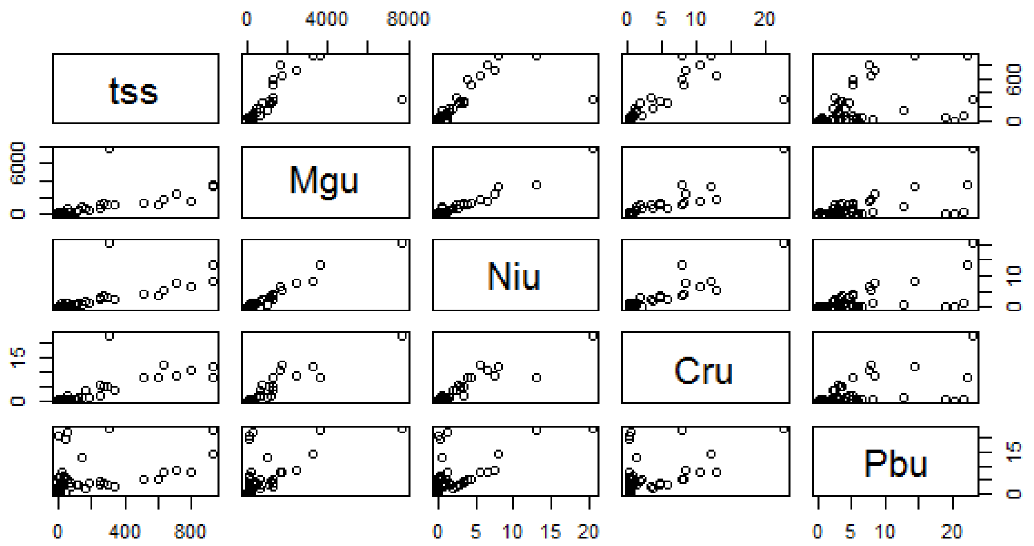


Figure 6.27: Scatter plot of TSS vs Mg, Ni, Cr and Pb, the u stands for unfiltered

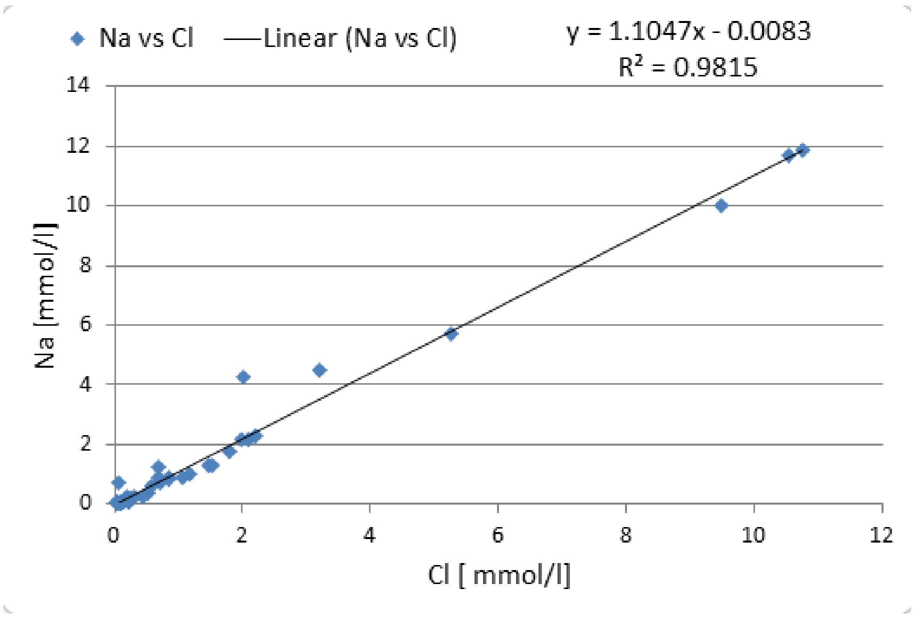


Figure 6.28: Correlation plot for Na vs Cl for the samples, without 5 outliners

The metal content for S2 and S6 had significantly different concentration for Fe (P-value=0.057) with means of 18.6 mg/l for S2 and 2.8 mg/l for S6. There was a significant difference for Cl (P-value=0.043) with means of 544 mg/l for S2 and 239 mg/l for S6, indicating that S2, the larger road, receive more de-icing agents. There was no significant difference between S2 and S6 for Cd (P-value=0.728), Pb

(P-value=0.193), Zn (P-value=0.076), Ni (P-value=0.436), S (P-value=0.209) and Cu (P-value=0.479)..

The metal concentration for S3 and S4 was significantly different for Ca (P-value=0.019) means of 14907 µg/l for S3 and 2358 µg/l for S4. This indicate that S3, the red brick roof, contain Ca in the material. There was a significant difference for Zn (P--value=0.042) with means of 40 µg/l for S3 and 492 µg/l for S4, indicating that S4, the black roof, contain Zn in the material. There was no significant difference between S3 and S4 for Cd (P-value=0.115), Pb (P-value=0.116), Ni (P-value=0.604), S (P-value=0.108), Cu (P-value=0.479), Cl (P-value=0.252) and Fe (P-value=0.423).

There was significant difference between the means of S3 and S6 for Cd (P-value=0.003), Ni (P-value=0.024), Cu (P-value=0.056), Ca (P-value=0.026). There was no significant difference between the metal concentrations between S3 and S6 for Fe (P-value=0.806), Zn (P-value=0.195), S (P-value=0.442) Pb (P-value=0.469) and Cl (P-value=0.130).

With this it is established that selected metal and ion concentrations for S2 $\neq S3 \neq S4 \neq S6$.

The difference between metal in the filtrated and unfiltered samples will give an indication of how much of the metals that are particle bound. Particle bound metals will be easier to remove in the filtration process. The two sample points S3 and S4 contained few particles and it was difficult to get samples where comparison between filtrated and unfiltered was possible. The metal samples from S2 was therefore chosen to represent expected values for particle bound metals. Note that sample S28 an onwards, comes from the same storm-event on the 14th of April.

In all metal samples the largest portion of metals were particle bound, having a small portion of solved metals (Figure 6.32). It must be taken into consideration that in some cases, with samples with large TSS, some metals might have been retained in the filter due to clogging.

Calcultation of solved metal content varied between 0.05% to 40%, while Na and Cl was found as up to 100% solved (Figure 6.29, 6.30, 6.31). The presence of Na can theoretically have an ion-exchange with adsorbed metals, giving a higher solved metal content where salt is present.

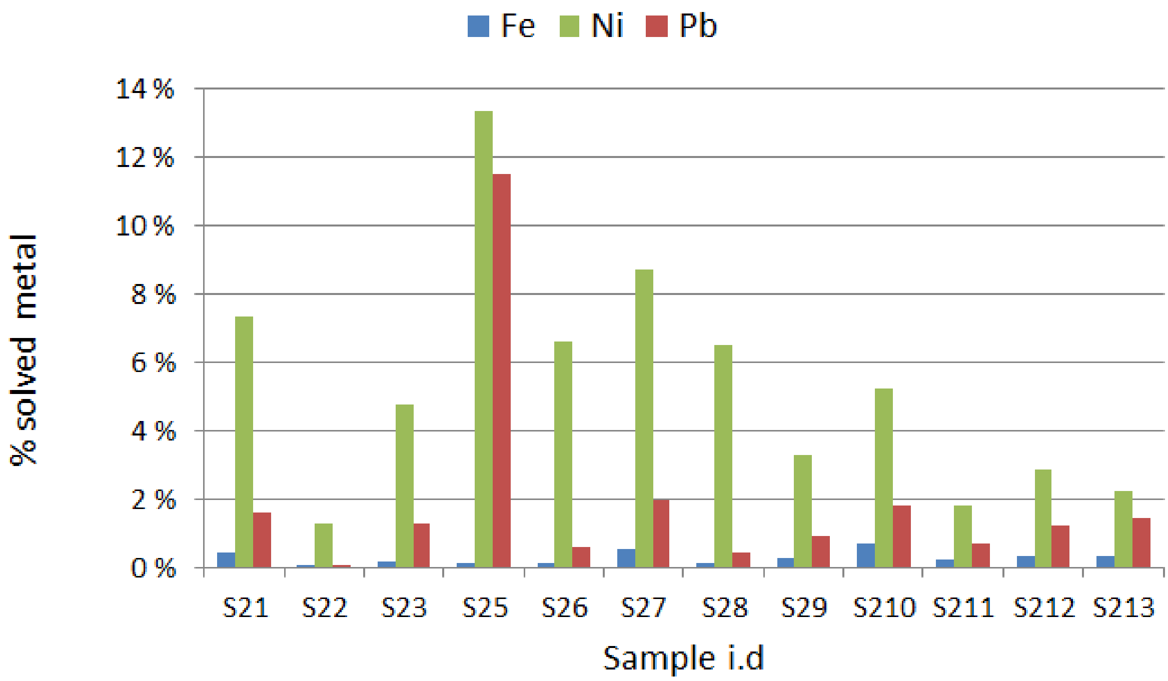


Figure 6.29: Percent solved Fe, Ni, Pb from the sample point S2

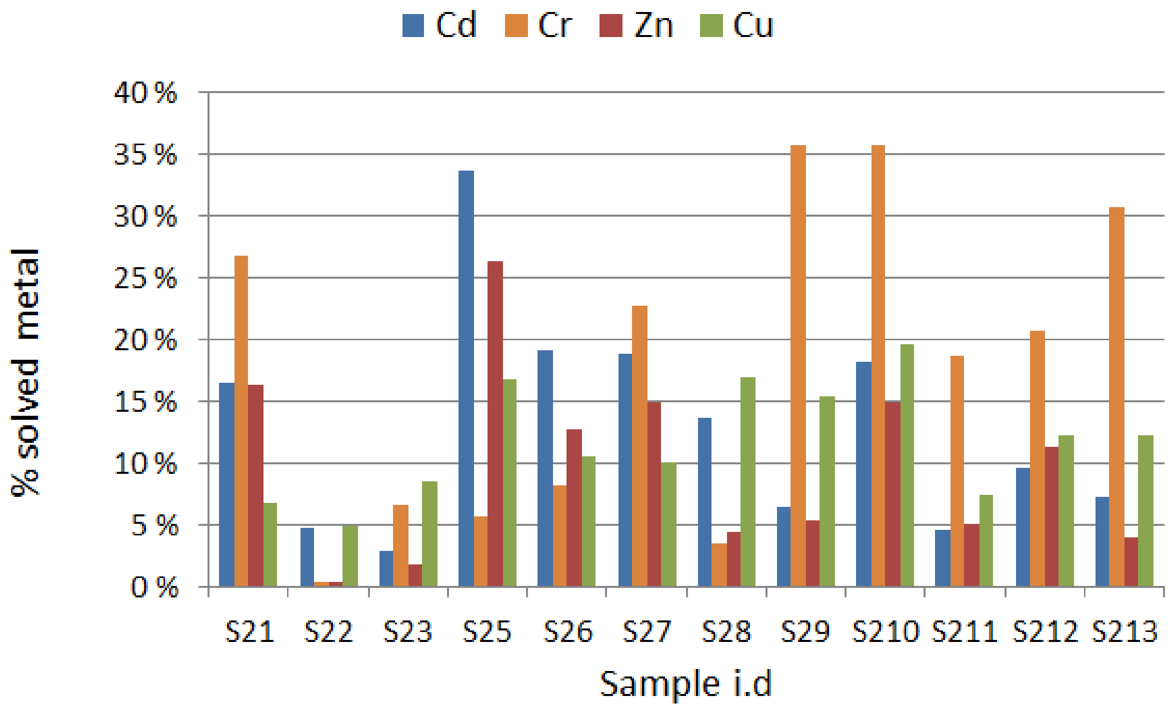


Figure 6.30: Percent solved Cd, Cr anf Zn from the sample point S2

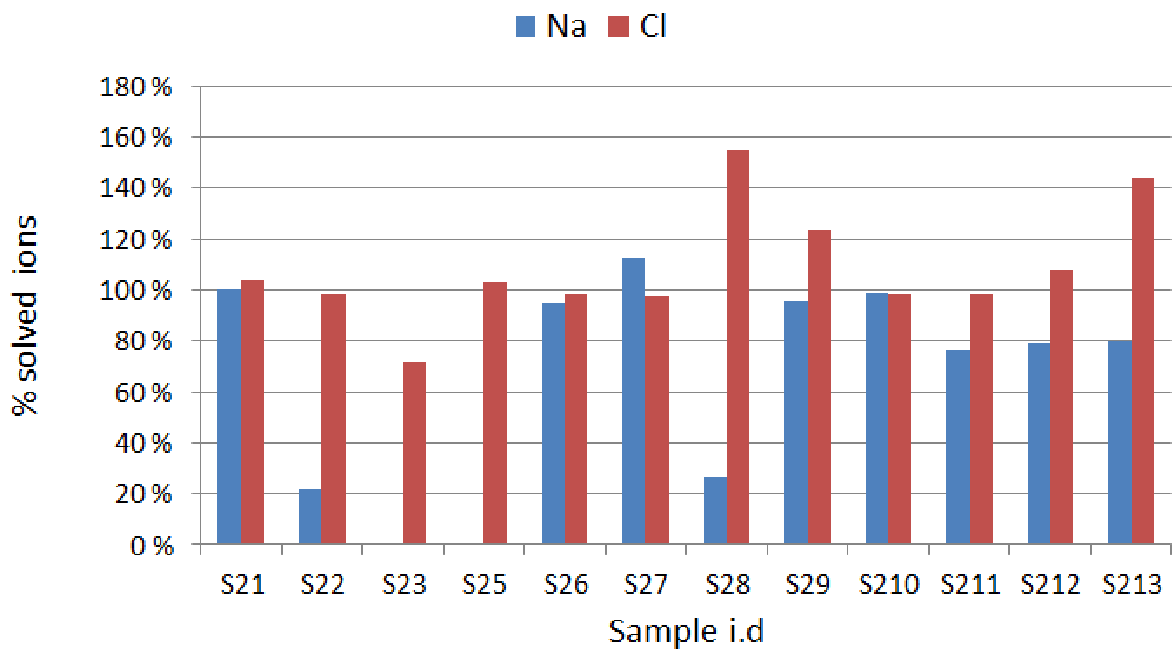


Figure 6.31: Percent solved Na and Cl from the sample point S2

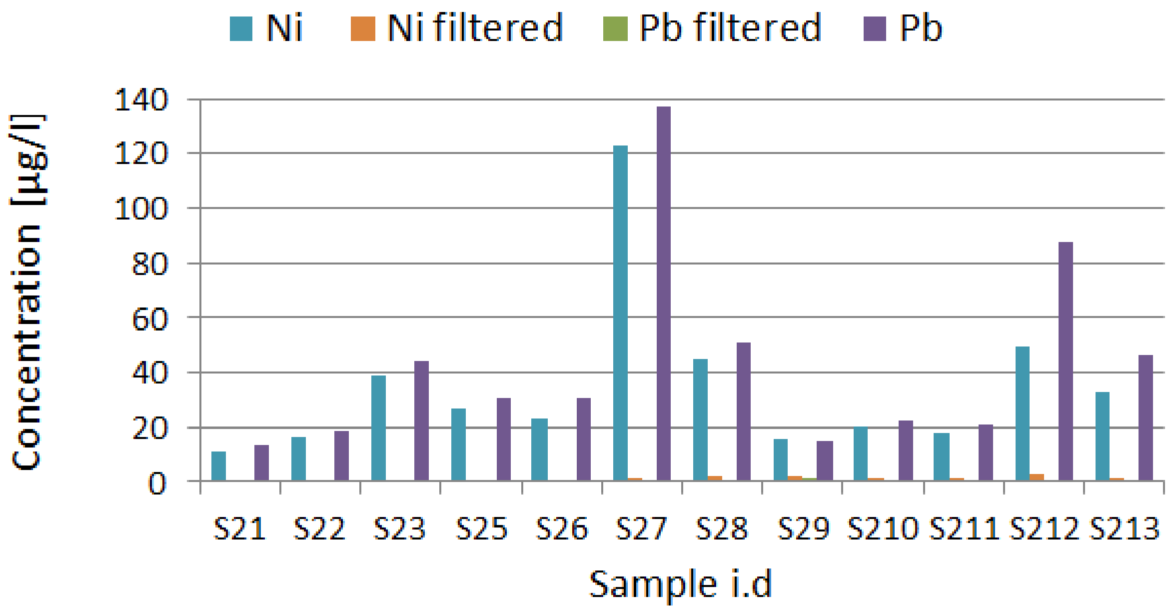


Figure 6.32: Ni and Pb filtrated and unfiltrated. The filtrated values are almost to small to be visible

The filtrated sample of S correlated with Ca (R^2=0.83), Mo(R^2=0.78) and Mg(R^2 =0.71) (Appendix C). Molybdenum and sulfur can be correlated because they are both elements in Molybdenite which is uses in steel alloys. Most likely they are correlated due to the fact that they are all elements in de-icing agents.

Table 10: Unfiltrated consentration of Cd, Cr, Pb, Zn, Ni

Cd[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	0.07	1.16	0.20	0.37	0.32	12
S3	0.01	0.11	0.02	0.03	0.03	13
S4	0.01	0.16	0.02	0.05	0.05	11
S6	0.04	0.44	0.08	0.11	0.12	10
Cr [µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	19.6	133.3	47.2	51.6	31.9	12
S3	0.4	12.2	1.0	2.6	3.5	13
S4	0.6	4.5	0.8	1.2	1.1	11
S6	1.9	46.3	3.8	8.9	13.4	10
Pb[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	13.4	137.0	30.7	43.1	36.2	12
S3	0.9	76.6	5.6	14.9	21.1	13
S4	4.4	124.7	14.2	36.5	42.5	11
S6	16.4	133.4	27.4	47.5	45.1	10
Zn[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	248.5	1863.6	384.1	596.4	464.1	12
S3	3.9	327.9	8.3	45.5	92.7	13
S4	7.7	2154.8	201.1	522.1	649.1	11
S6	78.7	673.8	127.2	193.0	177.8	10
Ni[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	11.0	122.5	24.8	34.8	30.2	12
S3	0.2	3.3	0.3	0.7	1.0	13
S4	0.2	1.4	0.4	0.5	0.4	11
S6	3.7	78.9	6.9	15.1	22.9	10

Table 11: **Unfiltrated consentration of Fe, P, Na, Al, S**

Fe[µg/l]	Min	Max	Median	Mean	SD	n
S2	7896.5	86972.2	24737.1	18614.2	21331.1	12
S3	4.2	2109.2	346.8	94.4	633.5	13
S4	21.0	600.8	159.1	87.8	189.7	11
S6	906.9	39019.0	6874.2	2817.6	11602.1	10
P[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	203.2	2025.4	569.3	659.4	514.0	12
S3	0.1	68.0	6.5	14.8	22.1	13
S4	3.6	44.3	9.5	13.6	12.4	11
S6	32.6	1319.6	121.0	247.2	386.0	10
S6	32.6	1319.6	121.0	247.2	386.0	10
Na[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	46149.5	1308377.4	157048.9	320028.0	413061.1	12
S3	1730.6	43197.1	4359.0	8445.7	11562.9	13
S4	551.2	11123.0	2971.9	3592.4	3242.0	11
S6	14674.5	745395.5	28991.9	156713.5	241744.3	10
Al[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	9226.5	103398.5	27887.7	32577.5	25750.4	12
S3	14.4	2625.7	134.8	467.0	823.4	13
S4	26.7	1074.2	118.8	222.1	312.4	11
S6	1119.9	71978.5	3966.1	11476.7	21650.7	10
S[µg/l]	**Min**	**Max**	**Median**	**Mean**	**SD**	**n**
S2	1305.9	11195.0	3011.4	3689.0	2884.6	12
S3	174.4	6685.4	564.4	1906.8	2249.9	13
S4	92.8	2434.9	415.7	797.9	768.2	11
S6	368.8	5222.2	1824.1	1910.8	1519.6	10

6.5 Urban Stormwater Comparison

To get an insight of the pollution level in The Bryggen catchment the stormwater characteristics are compared to other urban stormwater studies. A study from The Netherlads was chosen due to the cooperation with The Technical University in Delft through URBAN WATCH. The stormwater from The Bryggen catchment is compared to stormwater from commercial locations all over The Netherlands. The stormwater at Bryggen is also compared to the The Climate and Pollution Agency classification parameters for pollution concentrations in effluent water to recieving waters.

The concentrations of the contaminations in the database from The Netherlands have been compared to Dutch quality standards Maximum Acceptable Concentration (MAC). When comparing The Bryggen catchment with the study from The Netherlands (both roofs and road), it is shown that The Bryggen catchment has better stormwater quality on 6 parameters, and most parameters are below the MAC. The Bryggen has a higher median concentration of Pb and total P level, wich exceeds the MAC. The Cl concentration is significantly larger in The Bryggen catchment. As most of the Cl in The Bryggen comes from de-icing agents, and The Netherlands with its warmer climate, this difference is expected.

As with surface and roof areas (Table 12), larger cities in The Netherlands will generate higher pollution loads. In comparison of roof area, The Bryggen catchment is significantly lower on all parameters (Table 13). Comparing The Bryggen in Bergen to large cities as Amsterdam and Rotterdam, which by size should have more contaminants, means that the studies are probably not comparable, or at least does not indicate that The Bryggen catchment has a extremely low pollutant level.

Table 12: Comparison from The Netherlands(Boogaard and Lemmen, 2007) and The Bryggen from roofs and roads combined. *Roof and road are not area-weighted

Sample area	The Netherlands		The Pier	
	Median	Mean	Median	Mean
Cd [µg/l]	6.2	1.7	0.07	0.14
Cr [µg/l]	8	32.8	2.49	16.40
Pb [µg/l]	9	260	21.56	34.51
Zn [µg/l]	155	1377	150.14	335.24
Ni [µg/l]	8	38	2.93	12.68
Cl [mg/l]	10	28	78.35	365.33
Fe [mg/l]	8	679	1.00	8.08
Ptot [mg/l]	4.4e−01	5.0e−01	5.0e−02	3.0−01

Experiments with LID at The University of Delft in The Netherlands shows that most LID‘s are not capable to hold particles with size smaller than 46 µm. These

Table 13: Comparison of roof runoff from The Netherlands(Boogaard and Lemmen, 2007) and The Bryggen

Sample area	The Netherlands		The Pier	
	Median	Mean	Median	Mean
Cd [µg/l]	0.9	0.95	0.02	0.25
Cr [µg/l]	5	15	0.89	1.93
Pb [µg/l]	114	266	11.33	24.8
Zn [µg/l]	1115	1302	61.11	263.94

particles causes a large pollution load in The Bryggen catchment.

Dutch particle distribution studies of stormwater result in 50% of the particle distribution having a particle size less than 60 µm. In The Bryggen catchment the 50% particle distribution from the road areas have a mean size of approximately 10 µm. One reason might be that road salts have the ability to bind atmospheric dust, which will then deposit on the road (Aldrin et al., 2008). The road material it self can also be a source to particles, and different types of aggregates in the road material may cause a significant amount of small particles.

The Bryggen pollution loads was compared to The Climate and Pollution Agency classification parameters for pollution concentrations in water. Three elements, Pb, Ni and Zn was chosen for the comparison. The classification system goes from insignificantly polluted with condition class I to very strongly polluted, with condition class V. The mean value for the sample points was taken into consideration in the classification. For S2, S6, S3 and S4 for Pb was very strongly (V)polluted. S2 and S6 for Ni and Zn was very strongly (V)polluted. For S3 and S4 for Ni was moderately (II) polluted. In general the stormwater had poor water quality compared to The Climate and Pollution Agency classification.

6.6 Summary of Results

Regarding the particle distribution, S2 and S6 has the highest TSS load and the particle with the smallest median. For S2 up to 98% of the particles has a diameter under 45 µm (Figure 6.14), and the mean particle size is 27 µm (Table 5). S6 has a mean particle size of 158 µm (Table 7). With an average precipitation of 211 mm a month (Florida) the median TSS load is 654 kg/month for the whole catchment. First flush was observed for the samples taken on the 14th of April. Precipitation intensity was significant for the TSS load in the stormwater, being that higher intensity carries more sediment, even after the first flush event.

High conductivity from S2 and S6 is believed to come from de-icing agents, while the closeness to the harbor could explain conductivity on the roofs. pH had a mean value

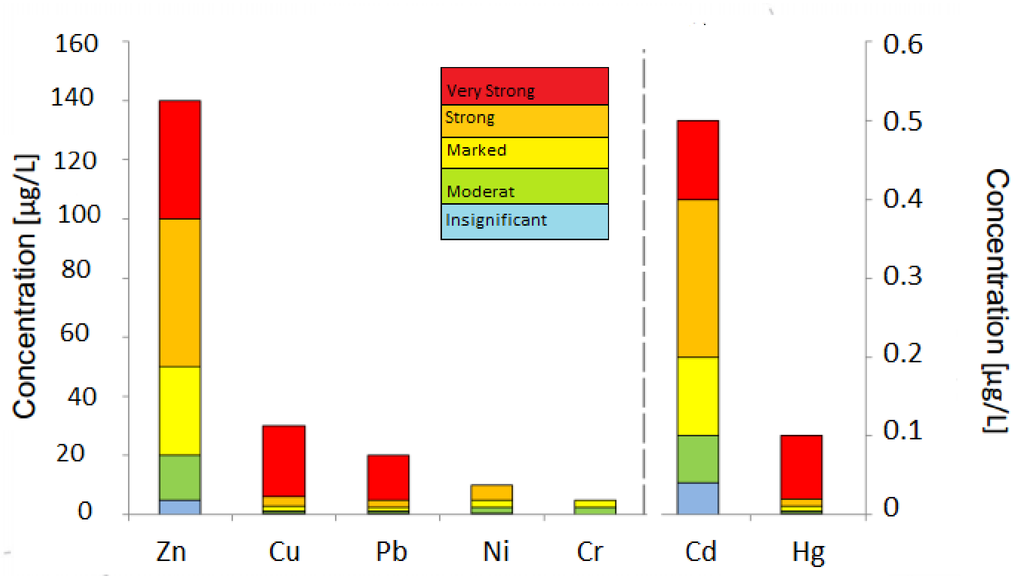


Figure 6.33: Pollution classification levels for Zn, Cu, Pb, Ni, Cr and Hg. Adapted from (Andresen et al., 1997)

of 7.5 and seemed to be a stable parameter. Sulfur and sulphate seemed to fluctuate together indicating that most of the sulfur originated from sulphate. Four samples showed significantly higher values for sulfur than for sulfate, these samples were all the first samples taken on the 14th of April (Figure 6.22). The highest phosphor level was 74 µg/l for S2, this is lower than in the dip wells(MB) (Figure 6.23). Dissolved oxygen level in the stormwater had a mean value of 11.8 mg/l. From Risvollan raingarden a DO level of 7.1 mg/l was measured in the outlet construction, which is significantly higher than the DO level in the dip wells of 0.043 mg/l (Table 9).

To reach an insignificant pollution level according to the Directorate of Climate and Pollution Agency most of the pollutants from S2 and S6 would need a high retention percentage. To lower the stormwater pollution level of Ni to insignificant (I) a retention of 96.7% to 98.6% is needed for S2 ans S6. To reach moderately (II) pollution level , 83.4% to 92.8% of the Ni in S2 and S6 would need to be retained.

S3 and S4 would need to retain 7.4% to 29.3 % to reach the insignificant level, but is below the moderately (II) pollution level for Ni. The Ni concentration is below moderatly

Zn level was high for S2, S4 and S6, and wold need a reduction from 97.4% to 99.2% to reach the insignificant pollution level, and a reduction of 96.6% to 89.6% to reach the moderately pollution level.

Pb level was high for S2, S6, S3 and S4 and would need a reduction of form 96.6% to 98.9% to reach a insignificant (I) pollution level. To reach a moderately (II) pollution level they would need a reduction of 97.5%.

7 Application of Results

In this chapter a short introduction of the structure of a raingarden will be assesed. The treatment potential of the planned raingarden and different filtermedias is compared up against previous studies of raingardens situated in equal environmental conditions. finaly the status of the raingarden and the authors opinium on the solution with the raingarden.

7.1 Raingarden

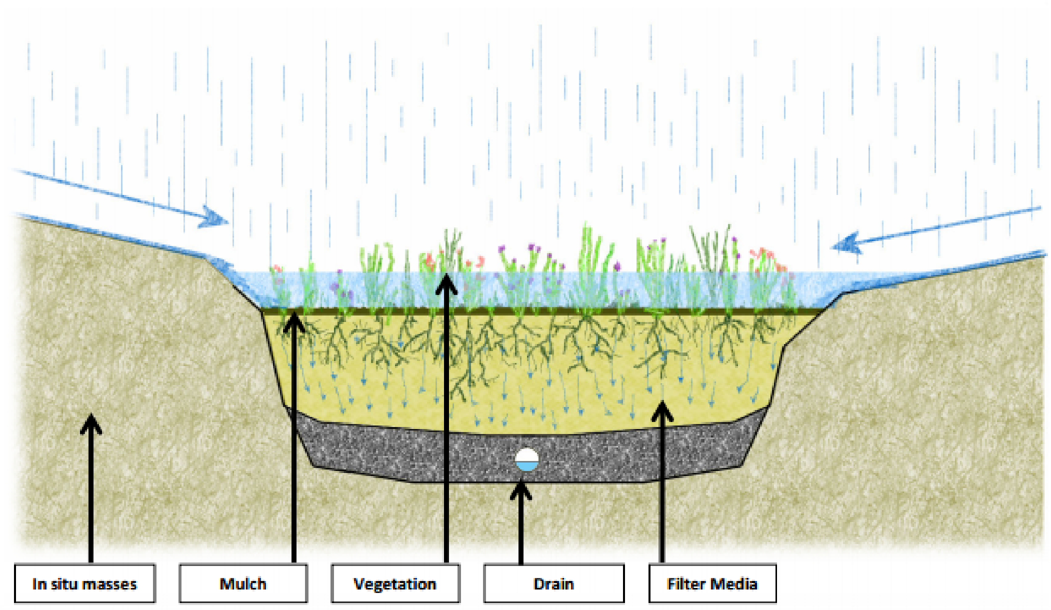


Figure 7.1: Raingarden (Paus, 2012)

Raingarden facilities consist of plants and organic material as soil and mulch. There is a certain storage capacity on top of the raingarden, which depending on design criteria could be from 10-30 cm. When this height is exceeded the water flows into an overflow device. The underlaying filter media should have an infiltration capacity so that the ponding time does not exceed 24 hours, according to the Bioretention Manual from Prince George County (2007). Depending on the underlaying soil type, the raingarden can exfiltrate into the ground, or there should be a geotextile and drainage pipe. The groundwater table should also be taken into consideration, it is not feasible to build a raingarden if the groundwater table is higher than 1.2 meters below the raingarden. This is to make sure groundwater does not infiltrate into the raingarden. Plants play a significant role regarding the hydraulic conductivity of the filtermedia.

7.1.1 Filtermedia

One important factor when choosing filter media for rain gardens is to know the objectives of the stormwater device. Different filter media has different sorption characteristics, and the filter media should therefore be customized to the pollutants of most concern.

There are several different prediction kinetics for adsorption, the most popular for metal sorption being Langmiur Isotherm and Freundlic Isotherm (Saltati and Sari, 2006). Some filter media has the ability to ion exchange. Ions with the highest electrone attraction will take up the place in the sorption medias molecule grid.

Depending on type of adsorbate, the adsorption mechanism varies, but generaly solubility of the adsorbare, size of adsorbate, pH, temperature and contact time are all crucial factors for adsorbation. For the adsorbate, lower solubility and larger particle size and higher temperature increase the adsorption capacity. As for the adsorbent lower particle size increase the rate og adsorption, as the surface area increase. Adsorbation of electrolytes are highly dependent on pH and the ionic strength. As pH decreases the adsorbation of electrolytes decreases because pH affects the dissociation.

7.1.1.1 Organic Material Sorption capacity of organic soil and bark compost is has proven to be the most efficient metal removal in raingardens (Davis et al., 2001; Muthanna et al., 2007). Metals are adsorbed by the organic soil particle, due to the soils negative charge. Organic solis has small a particle size, and thereby a large surface area that can adsorb large amounts of metals. A mulch layer is often on top of raingardens to protect the organic soil from erosion and drying (Davis et al., 2001).

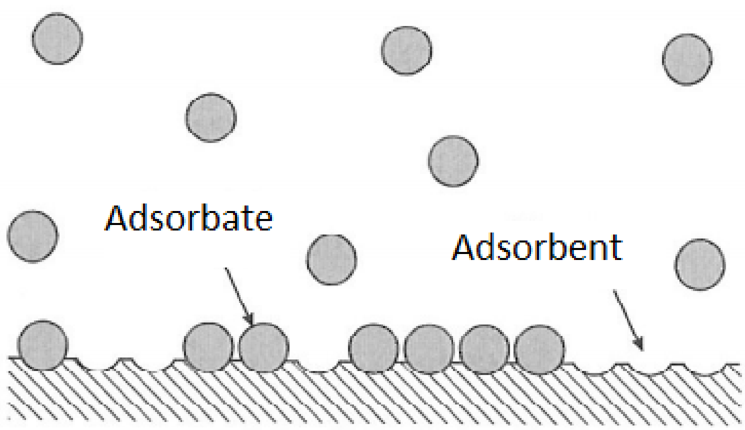


Figure 7.2: The adsorption process. Addapted from (ye, 2011)

7.1.1.2 Rocks and Minerals It is commonly known that the use of naturally occurring rock and processed rock is often used as ion-exchange media to remove cations. Plagioclase, a feldspar, can be found in natural occurring rock as gabbro, diorite, basalt, hematite and as composites in other minerals, as minerals rarely are found as clean composites in nature. Plagioclase has a high ability to exchange cat-ions with the surrounding liquid. Plagioclase can absorb heavy metals and substitute them with sodium or calcium atoms (Chardon et al., 2008; Plante et al., 2010). Smectite is a corrosion product of feldspar with the same characteristics.

Bentonite has the capacity to adsorb $NH_4{}^+$ ions and heavy metals as Zn and Cd, thus the process is pH dependent, and is most stable with pH 5 (Saltati and Sari, 2006; Mockovciakova et al., 2010). Zeolites has a porous structure that contribute to the capacity to hold cations as Mg^2+, Ca^+, Na^+ and K^+. The holding capacity of zeolites are relatively weak, meaning that with influence of other ions there could be a relatively frequent replacement of the adsorbed ion.

The ammonium exchange capacity of Zeolittic tuffes are 114 meq/100 g (Tzamos et al., 2011). That means that 1350 mg Mg^2+/100g zeolittes could be exchanged. Silt and sand from smectite has a cation exchange that ranges from 2.4 to 47.4 meq/100g (Curtin and W, 1981). Olivine based products as Brimac charcoal has proven to be efficient for removal of Pb, Cu and Sb (Mariussen et al., 2012). Pure olivine granulates, without and modification have very good sorption capacities for Pb, Zn, Cu, Cd, Ni and Ar (Wium-Andersen et al., 2012). Olivine granulates are easy to obtain, and have a low cost due to the fact that is not modified. Existing raingardens in Norway has used gravel, sandy-soil in situ soils and mulch as filter media.

7.1.2 Removal of Nutrients by Raingarden

In this study a foucus on removing dissolved oxygen, sulphates and heavy metals are adapted because bacteria easy can increase their metabolism with sulphates when the environment is anaerobic, and oxygen will make most nutrients avilable for bacterias.

Several studies have been conducted on metal removal by rain gardens. Previous studies in Trondheim, Norway, has found that even in cold temperature raingardens has a high capability to remove pollutants. The mulch layer is ecpesially important for retainting zink. Plants have shown to be less significat when it comes to metal removal, keeping in mind that some metals, as Cu, Fe, Mg, Mo, Ni, are crutial for plant survivial. Table 14 shows selection of pollutant removal by raingardens. The values are adapted from cold to temperate climate conditions, and should be comparable to the conditions in Bergen.

Table 14: Comparison of pollutant removal in bioretention where Δ C is the percentage difference between in and out flow in concentration, while % Δ M is represent mass difference (Muthanna et al., 2007; Khan et al., 2012; Davis et al., 2001; Chen et al., 2013; Blecken et al., 2011)

Pollutant	Δ C %	$\Delta M\%$
Zn	84-99	
Cu	62-92	
Pb	55-97	
Cd	86-94	
Cl	60	
COD	67-71	57
TSS	96-99	99
BOD_5	8	63-99
TP	0.6	
P	81	
NO_3^-	24	
NH_3	79	
TKN	75	
NO_3^-	33	

ARC contaminant loading model, from Auckland, New Zealand,(Version MAY6) (AucklanRegionalCouncil, 2010), is made to simplify how much sediment, zink, copper and PHC that will be generated from a site. Auckland has similar conditions as Bergen as it recievs approximatly 1200 mm of annual precipitation raining 66% of the days and has an average temperature of 8.5 ◦C (Weatherspark, 2013). Auckland is a lagrer city than Bergen, having 1.4 million people, and so the pollution level is expected to be higher. In the ARC contanminant loading model roof types, roads and grass areas seperated. The model generates contaminant load per year pr hectar, taking into account the different pollution sites. It is clear that due to gritting wintertime in Norway, The Bryggen catchmetns will have a higher TSS load (Table 8)

Table 15: Comparison of yearly outflow of selected pollutants with ARC contaminante loading model

	TSS [kg/ha]	Zn[g/ha]	Cu[g/ha]
Without raingarden	225	1836	217
With raingarden	175	1755	177
Percent reduction	22 %	4 %	18 %

7.2 Selected Solution for the Raingarden

The raingarden will consist of 50% sand and 50% with compost with a depth of 50 cm. 50% organic material will compromise the infiltration capasity, but this is done to henhance the sorption capasity. The raingarden will have a geotextile layer and a drainagepipe that will lead water to an underground infiltration complex that ensures equal even infiltration to the medieval layers (Figure 7.4).

Depending of how this drainage pipe and underground infiltration complex is put together, re-oxidatidon of the stormwater can occure.

Figure 7.3: The location of the planned raingarden (Photo: T. Muthanna)

Figure 7.4: The underground infiltration structure at Bryggen (Christenson et al., 2012)

7.3 The Authors Opinion

The groundwater below The Bryggen needs to be increased and stablized. An objective sat by The Bryggen Foundation is to infiltrate up to 10 m^3/ day, which shall compensate for the drainage by the hotel and hopefully also increase the groundwater table. Infiltration of stormwater without any type of water treatment would most likley have large consequences for the medieval layers. The concentration of metals, sulphates and oxygen would give sulphate reducing and aerobic bacteria and more energy sources to break down the medieval layers.

By using a raingarden as an infiltration device a high percentage of the metals can be adsorbed in the filtermedia, but not enough to reach insignificant pollution level. Without any obcjetives of pollution level of the stormwater infiltrated into the groundwater, it is in the authos opinion that the heavy metal effluent will be to high, and that a second treatment device is neassary before infiltrating the stormwater into the medieval layers.

A high percentage of the particles from the roads have a diameter below 45 µm which is not feasable for particle retention. We can not rely on physical retention for this part of the TSS. The largest portion of heavy meatals were particle bound which is positive for the retention of metals in the filtration media. Due to high TSS loads a stormwater collector tank can be a good solution to let large particles settle out. This tank would need regular empyting, with a special care in the winter and spring season. Based on estimation from Risvollan raingarden, the DO level would also decrease through the filtermedia.

The problem with utilizing raingarden as an infiltration device is that compared to other, more traditional water treatment devices, the treatet water quality can not be quanitfied in the same way. It is difficult to document where the effulent metals come from. Do they originate from the last influent stormwater, or is there a leach from the adsorbed metals? How much heavy metals will leach out when the salt concentration is on its greatest right after de-icing has taken place? And how much will salt influence the percentage of particle bound metals? How long will it take before the infiltration capacity is compromised? There are also no documentation of sulfate reduction in raingardens, meaning that througout winter periods in Bergen, significant amounts of sulfate could be infiltrated to the medieval layers on purpose.

If it proves that the smaller particles is big problem, a treatment train could be good solution. A treatment train is the name for multiple LID‘s in row, that conveys the same stormwater. To let stormwater run over a swale, before it enters a raingarden is a commom parctice to get rid of large parts of the sediments. Another solution could be to add flucculants to the stormwater tank, especially in the winter and spring when the TSS load is high. There is large differences between the sample areas, and high pollution related to a high traffic volume. Based on the results in would be feasable to not utilize the heavy trafficed road, this will decrease treatment requirements from the raingarden.

8 Conclusion

In this thesis a study of the stormwater quality from the impervious surfaces in The Pier catchment was conducted. The stormwater will be utilized to increase the groundwater table, and the quality of the stormwater pollutants are identified to know wheter or not they can harm the medieval layers.

A total of 46 stormwater samples was collected from four rain events, the 4th of February, 16th of February, 18th of February and on the 14th of April. One first flush event was captured on the 14th of April. Due to the time limit of this thesis a complete overview of the stormwater characteristics has not been achieved. It could be expected to get higher phosphorus and TCB concentrations in the summer months, due to animal excrement.

From litterature and data analysis it is shown that stormwater quality differ in countries, cities, locations, seasons and even within stormevents. Different roof material and traffic volume have different effects on pollutant distribution and concentration.

Concerning different traffic dencity on roads, the largest road,Øvergaten (S2) showed the highest concentration of pollutants for 8 parameters (TSS, Conductivity, total P, PO_4, Cu, Ni, Zn, Cu) while the smaller road, Koren Wibergsplass (S6), had the highest value for one parameter (Pb). For the other parameters (Alkalinity, DO, pH) there was little variation between the two sample points.

To reach a insignificant pollution level (I) for S2 and S6 the raingarden would have to retain, on a maximum influent level, 96.7% to 99.2% for Ni, Zn and Pb.

From previous cold climate studies it is shown that raingardens can retain 84-99% of Zn, 55-97% of Pb, 62-92% of Cu and 86-94% of Cd (Table 14).

The red brick roof (S3) had a high concentration of Ca. The the black roof (S4) had high concentration of Zn, being in the same range as S6. Roofs give less polluted runoff due to the fact that few pollutants will have the possibility to settle there as they often orignates from vehicles and surface abrasion. Pollution from roofs are also limited by the ability of roof surfaces to hold particles against wind.

Due to cold climate gritting is necessary, this adds significantly loads of sediments to the catchment. It was found that the precipitation intensity decide the TSS load carried by the stormwater. Higher precipitation intensity increases the stormwater velocity and volume and can thereby carry more sediments.

An estimated median value for TSS load for the catchment gives 654 kg a month. Note that TSS has the highest value in winter and spring time, and a median value throughout the year would be significantly smaller. Estimation of the runoff volume for The Bryggen catchment has a maximum value of 47094 m^3/day for a storm with a return period of 2 years. Raingardens are initially designed to capture first flush volume, the first flush on the 14th of April would account for 968 m^3 within 90 min including all surface areas in the catchment.

The medieval layers already consist of nutrients that bacterias need to increase their biomass, as phosphorus, carbon and nitrogen. The dip wells have higher concentrations of phosphorous, but a lower concentration of sulfate and oxygen. It ought to be stressed that oxygen should be considered the foremost important pollutant that will contribute to break down the medieval layers. DO measurement in the effluent device at Risvollan raingarden gave 7.1 mg/l DO, which is not an acceptable level for infiltration to the medieval layers. This measurement should not be blindly copied to The Bryggen raingarden due to large uncertainties of measurements validity, difference in filtermedia and surrounding environment.

Sulfate and element sulfur should be removed from the stormwater, or retained in the raingarden if possible. All other factors for sulfate -reducing bacteria to increace their biomass are present, and they can therefor contribute signigicantly to the decay of medieval layers. There are no publications on sulphate removal through raigardens and expected effluent concentrations of sulphate has not been estimated. Sulphates are surly the largest uncertainty factor with infiltrating stormwater into the medieval layers.

The planned raingarden will consists of a large fraction of organic material to enhance metal adsorption, it is therefore in the authors opinium that metal adsorption, to an insignificant (I) pollution level will be fulfilled. As S2 has the absoulte highest pollutant concentration it is beneficial to not utilize the stormwater from the area of S2 to feed the groundwater table. Stormwater from the roofs are considered very clean, regarding both pollutants and sediments. Therefore, if possible, recharging the groundwater with water from roofs is desirable and should only offer challenges to decrease the DO level in the stormwater prior to infiltration.

9 Further Work

1. Characterize stormwater quality in summer and autumn in The Pier catchment. That way a complete overview of the stromwater characteristics is fulfilled.

2. Quantify the increase of groundwater table due to infiltration by the raingarden.

3. Study the effect on stormwater pollutions on the medieval layers, can we observe a increase or decrease in decay of the medieval layers. Give a State of Preservation for the medieval layers affected by the stormwater.

4. Study the retention of sulphates in raingarden, by column or field experiment.

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A

Particle Diameter Distribution

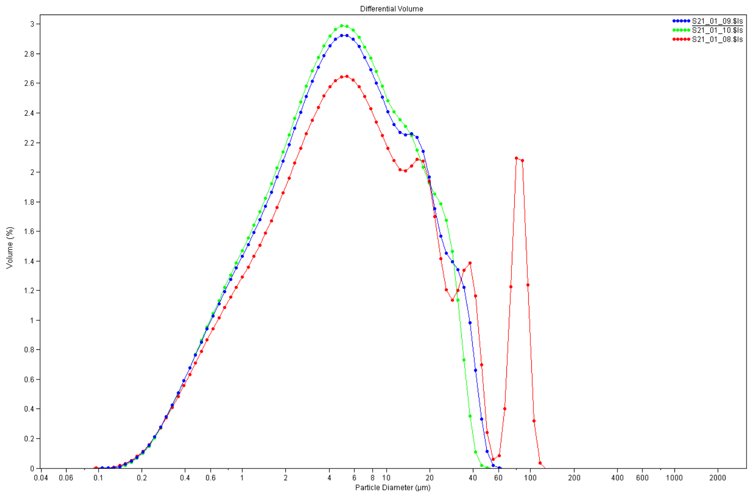

Figure A.1: Particle distribution of sample S21

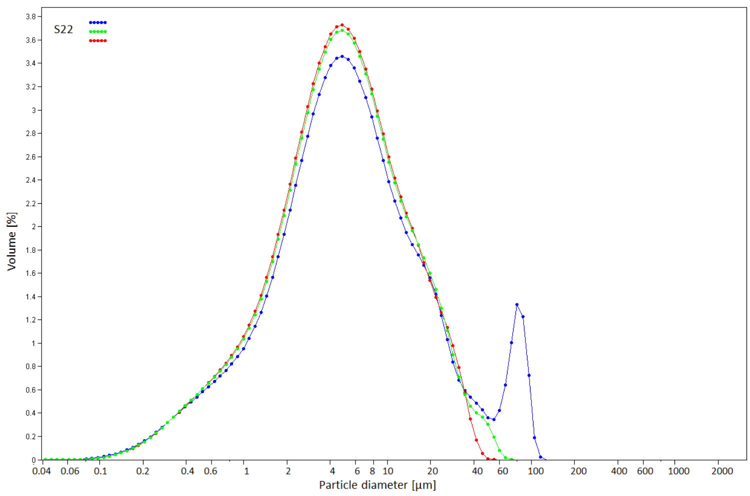

Figure A.2: Particle distribution of sample S22

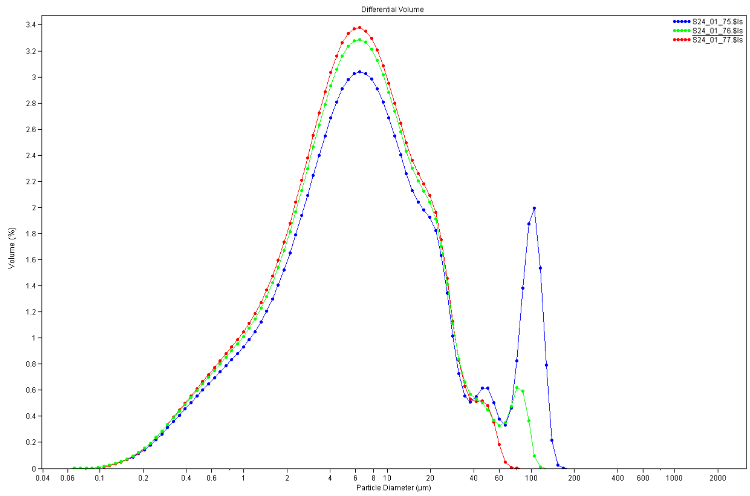

Figure A.3: Particle distribution of sample S24

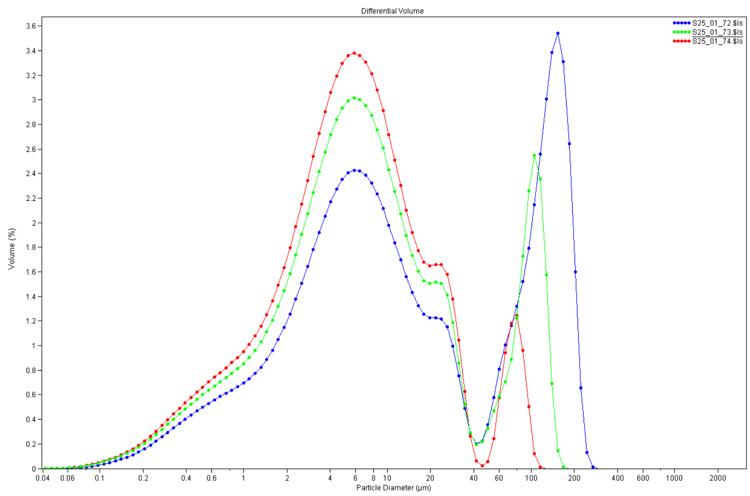

Figure A.4: Particle distribution of sample S25

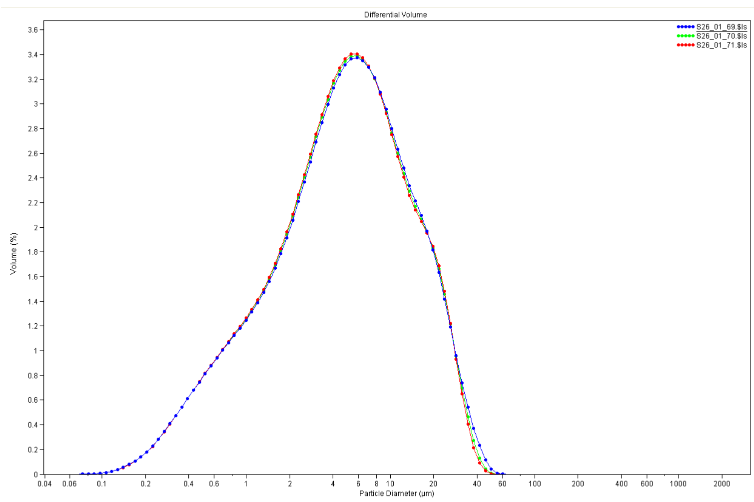

Figure A.5: Particle distribution of sample S26

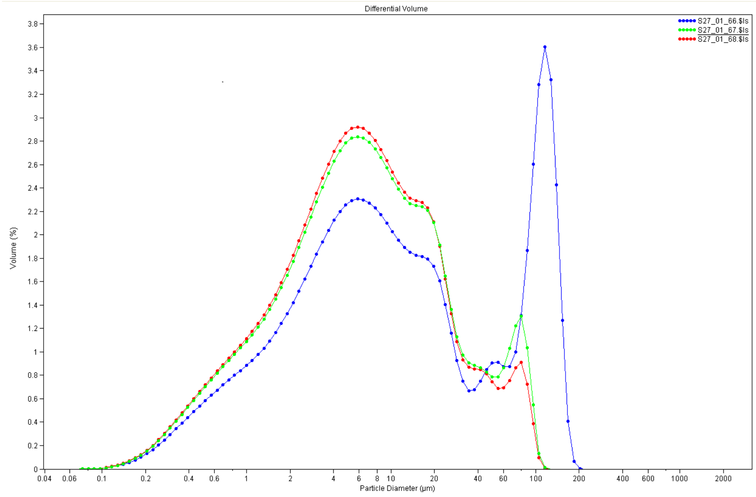

Figure A.6: Particle distribution of sample S27

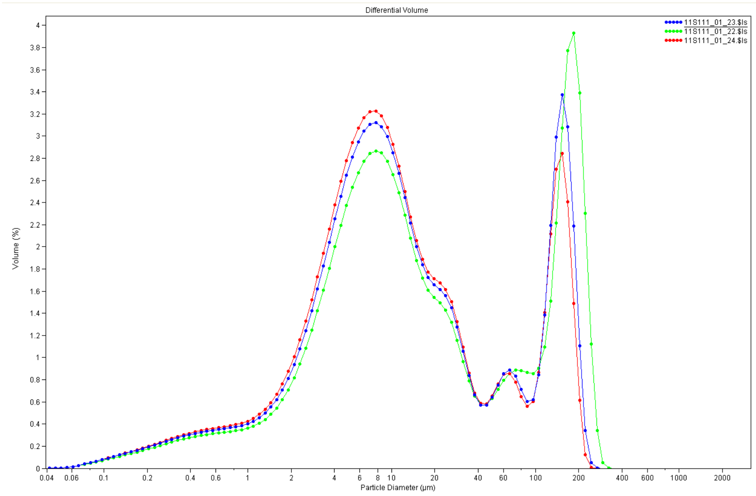

Figure A.7: Particle distribution of sample S28

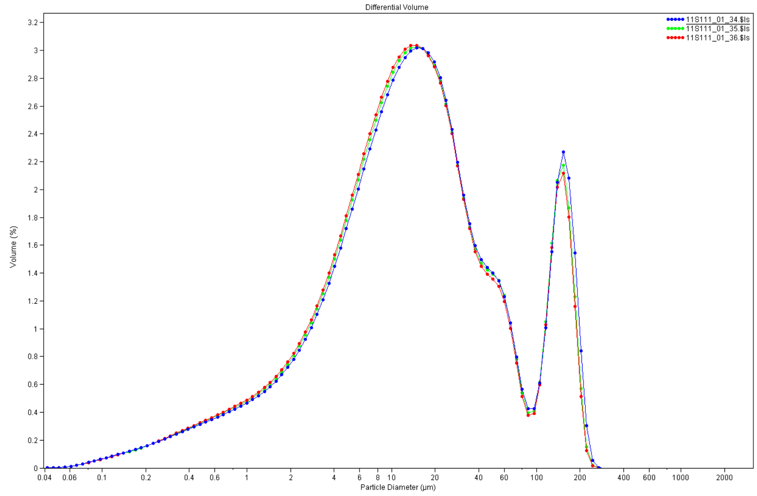

Figure A.8: Particle distribution of sample S210

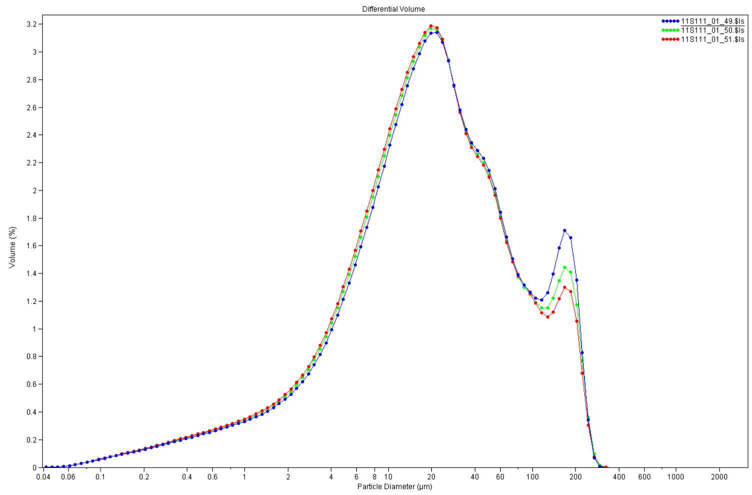

Figure A.9: Particle distribution of sample S211

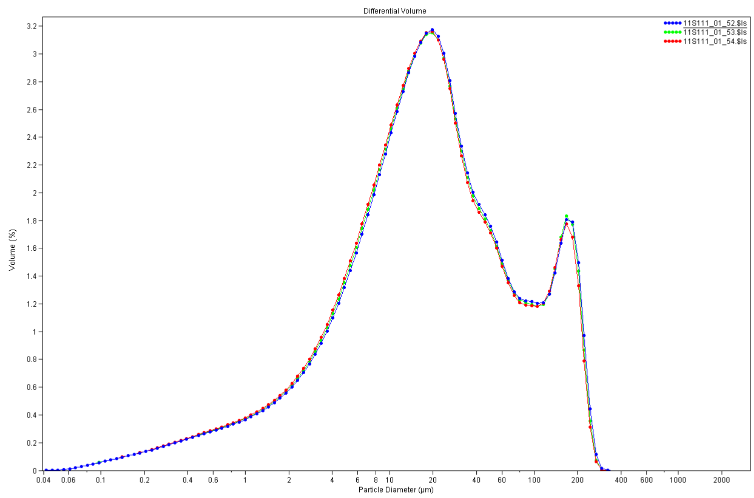

Figure A.10: Particle distribution of sample S212

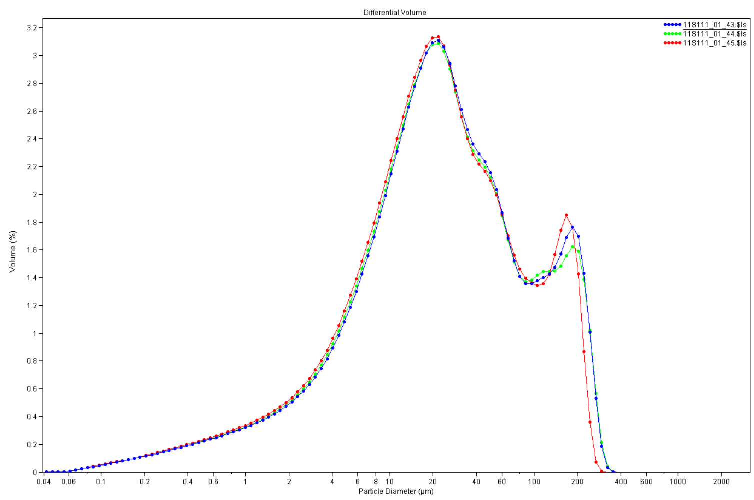

Figure A.11: Particle distribution of sample S213

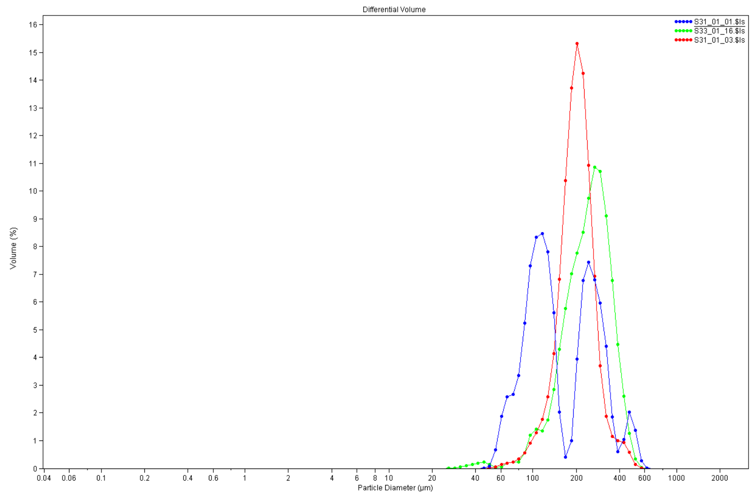

Figure A.12: Particle distribution of sample S3

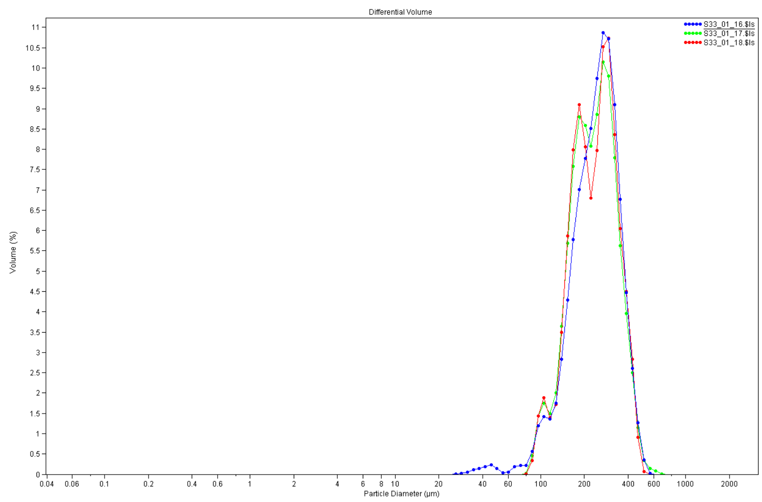

Figure A.13: Particle distribution of sample S33

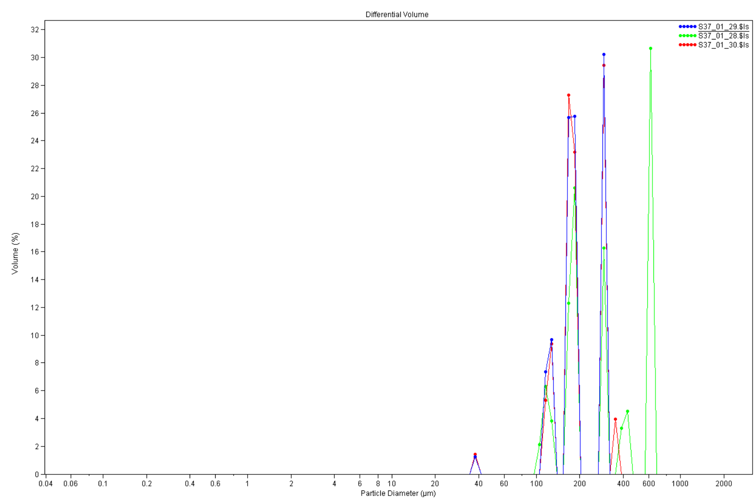

Figure A.14: Particle distribution of sample S37

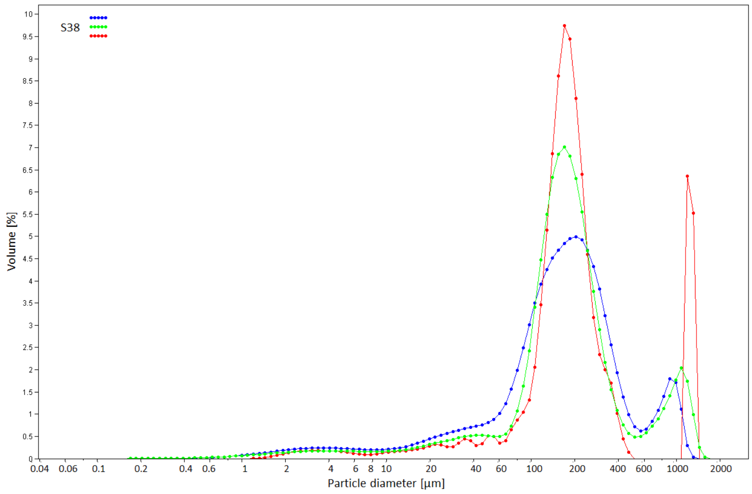

Figure A.15: Particle distribution of sample S38

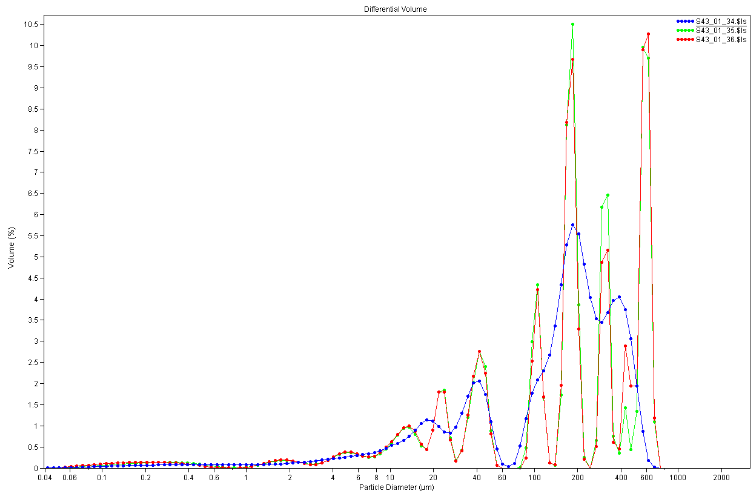

Figure A.16: Particle distribution of sample S43

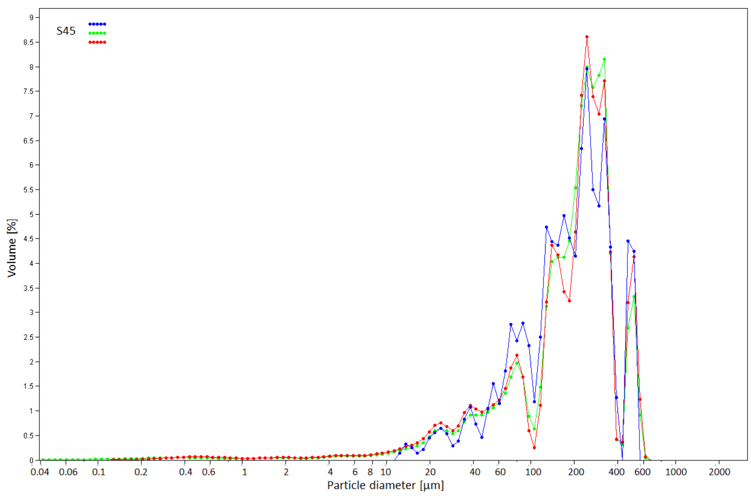

Figure A.17: Particle distribution of sample S45

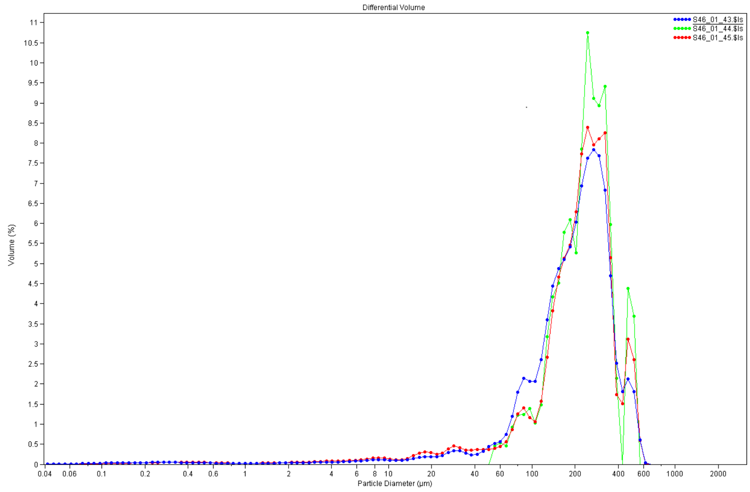

Figure A.18: Particle distribution of sample S46

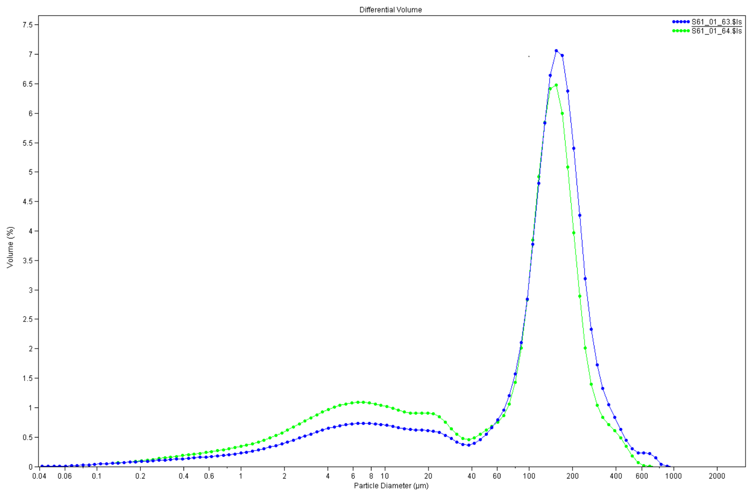

Figure A.19: Particle distribution of sample S61

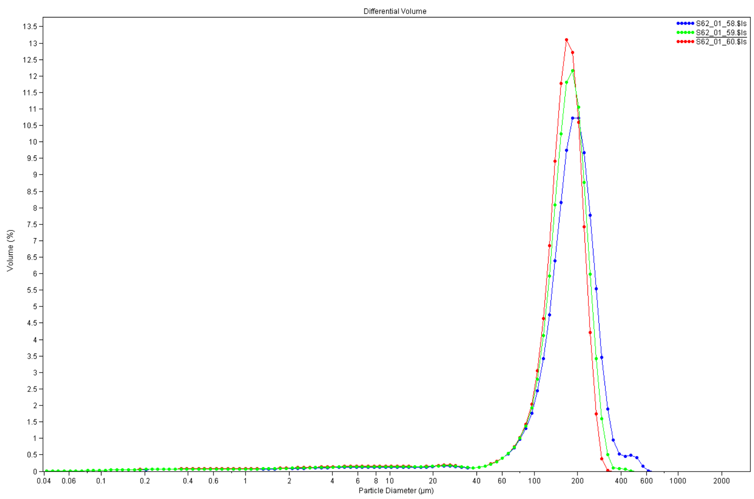

Figure A.20: Particle distribution of sample S62

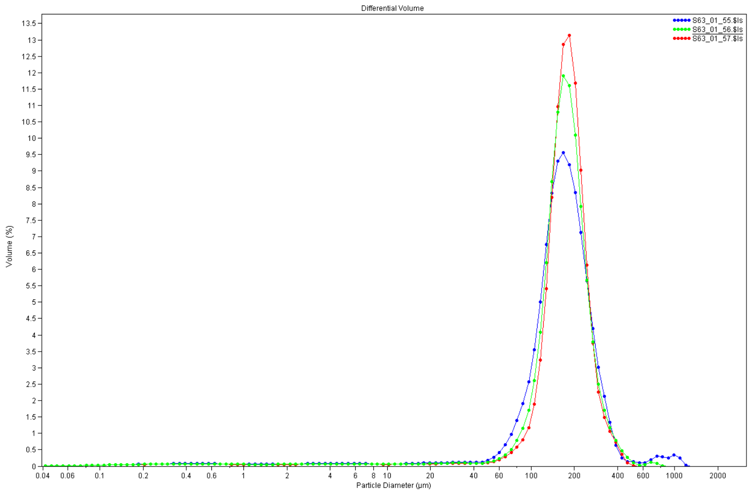

Figure A.21: Particle distribution of sample S63

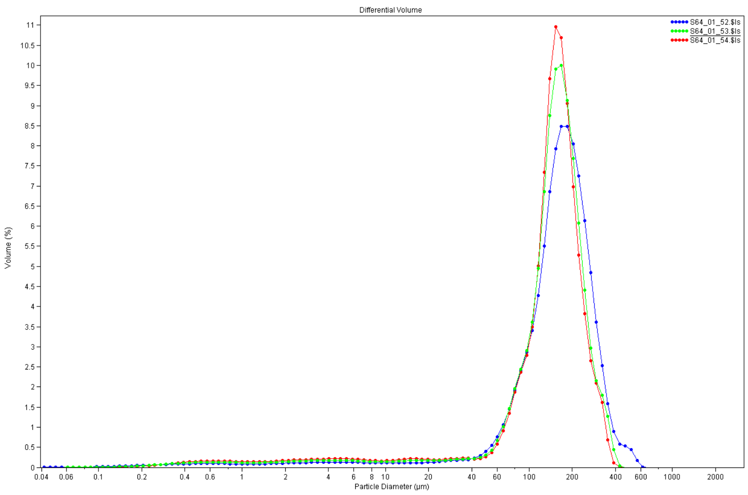

Figure A.22: Particle distribution of sample S64

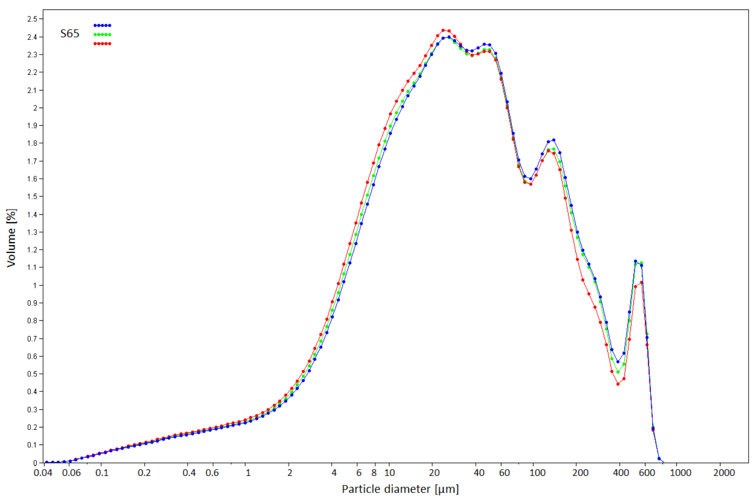

Figure A.23: Particle distribution of sample S65

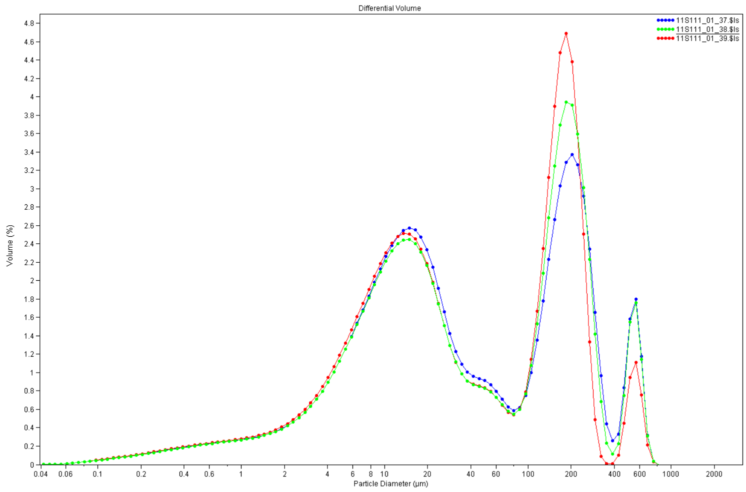

Figure A.24: Particle distribution of sample S66

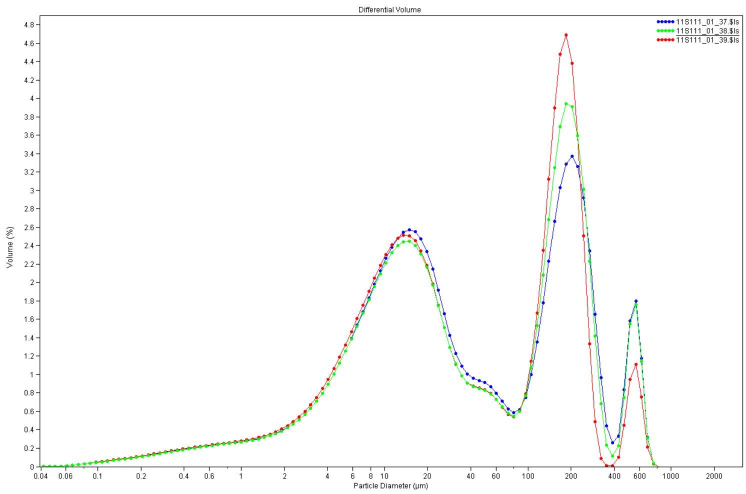

Figure A.25: Cummulative particle distribution of sample S66

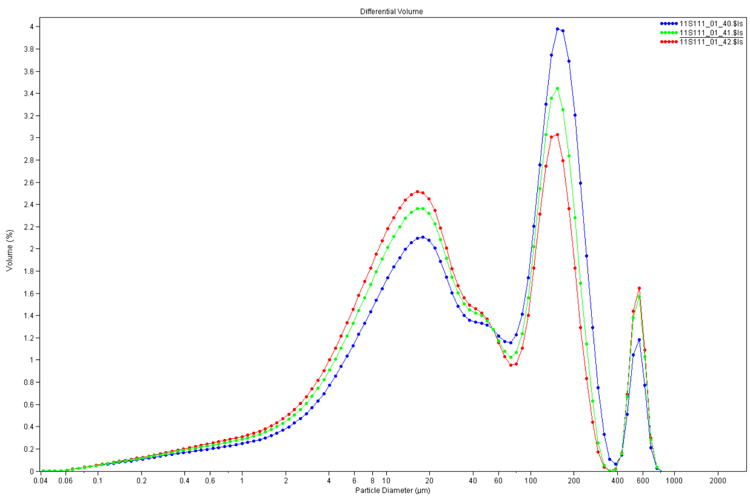

Figure A.26: Particle distribution of sample S67

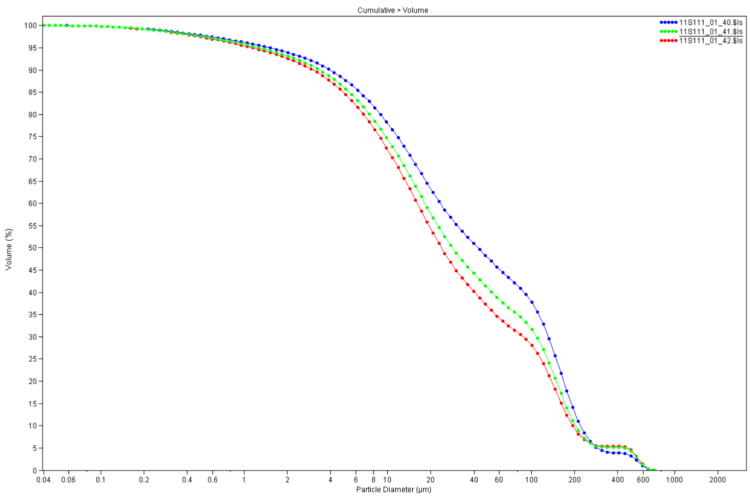

Figure A.27: Cummulative particle distribution of sample S67

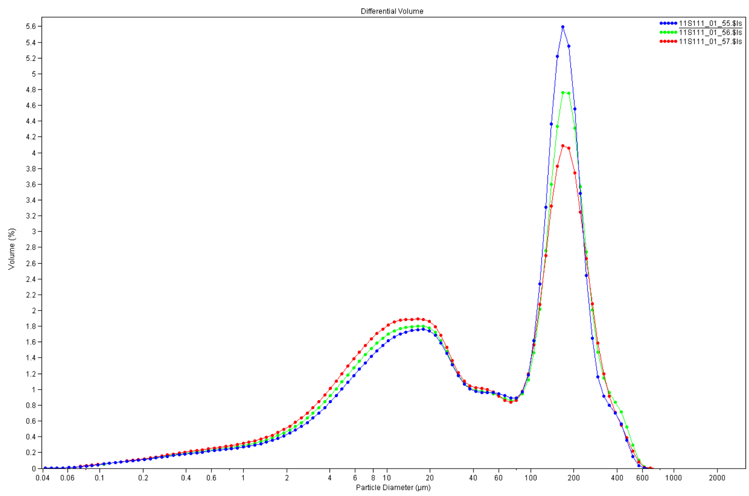

Figure A.28: Particle distribution of sample S68

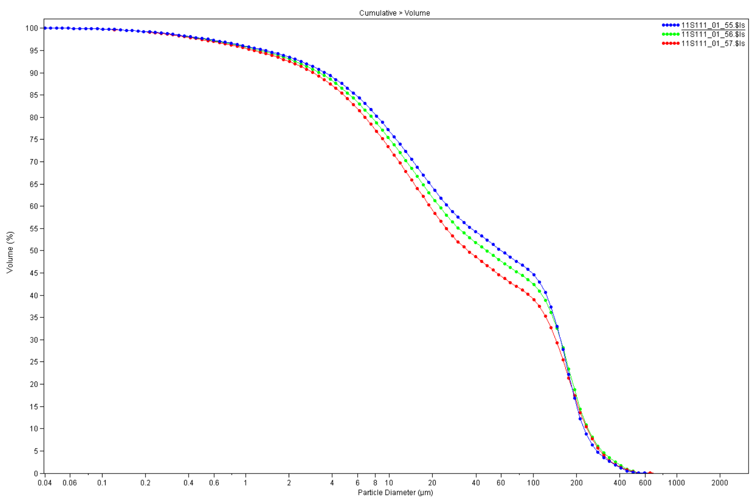

Figure A.29: Cummulative particle distribution of sample S68

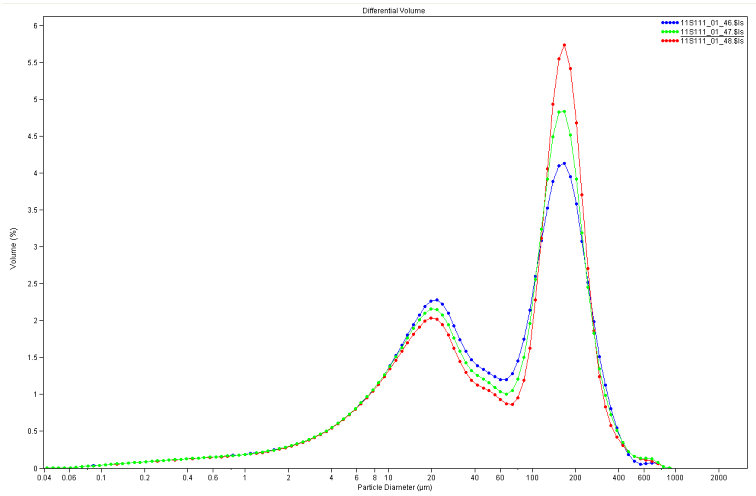

Figure A.30: Particle distribution of sample S69

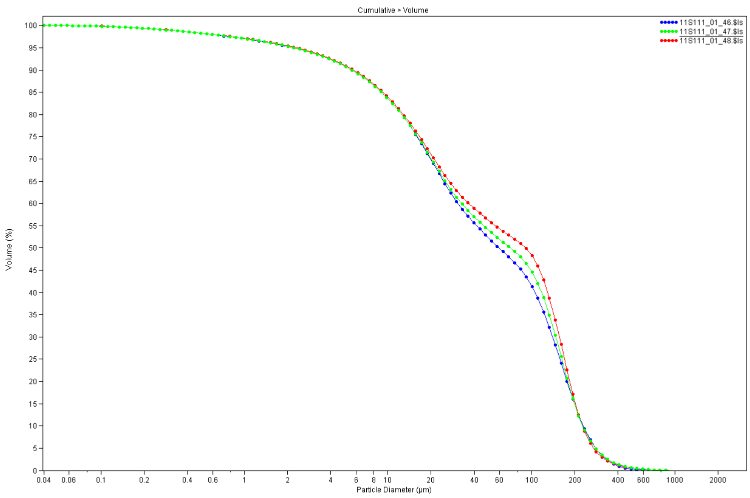

Figure A.31: Cummulative particle distribution of sample S69

B

Scatter Plots of TSS vs Metals

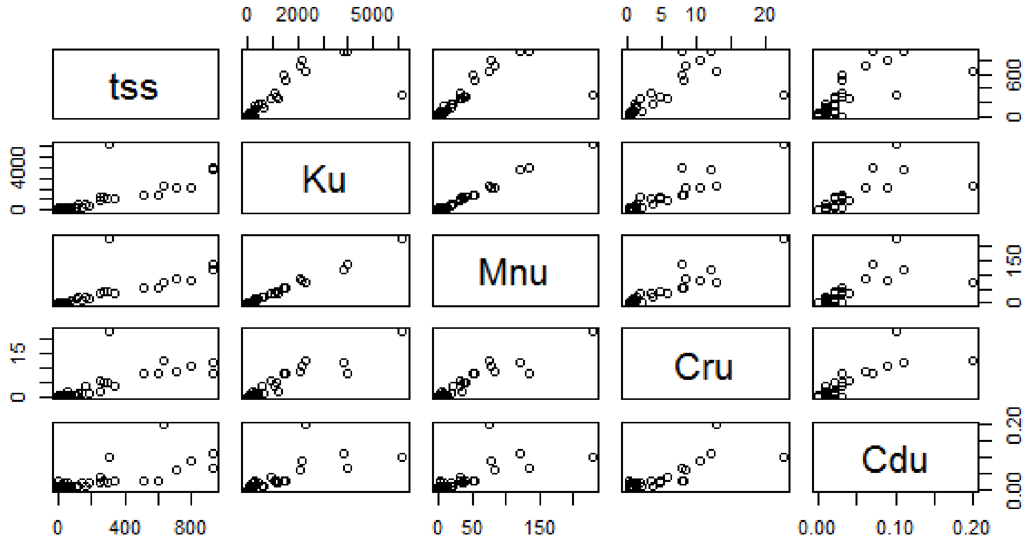

Figure B.1: Scatterplots of tss vs K, Mn, Cr and Cd

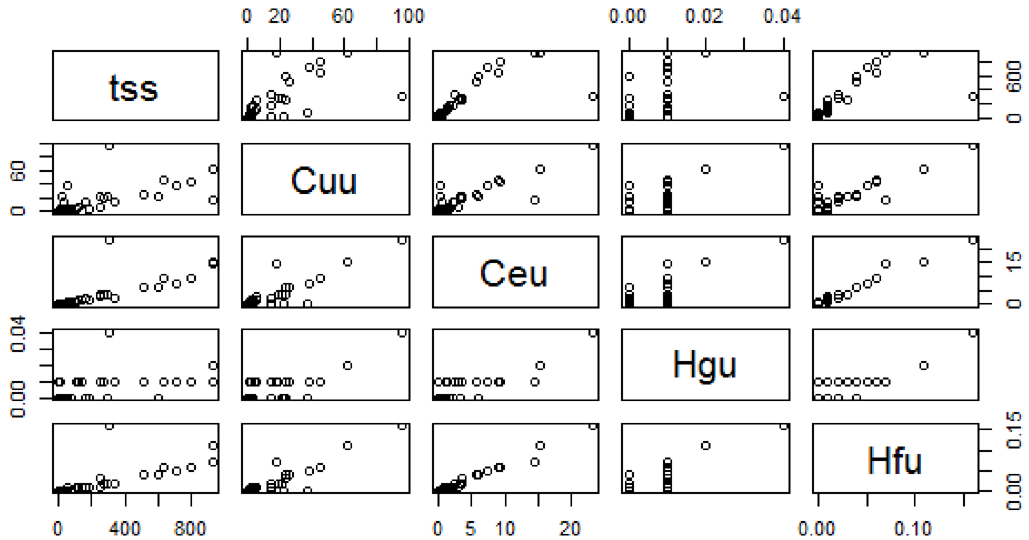

Figure B.2: Scatterplots of tss vs Cu, Ce, Hg and Hf

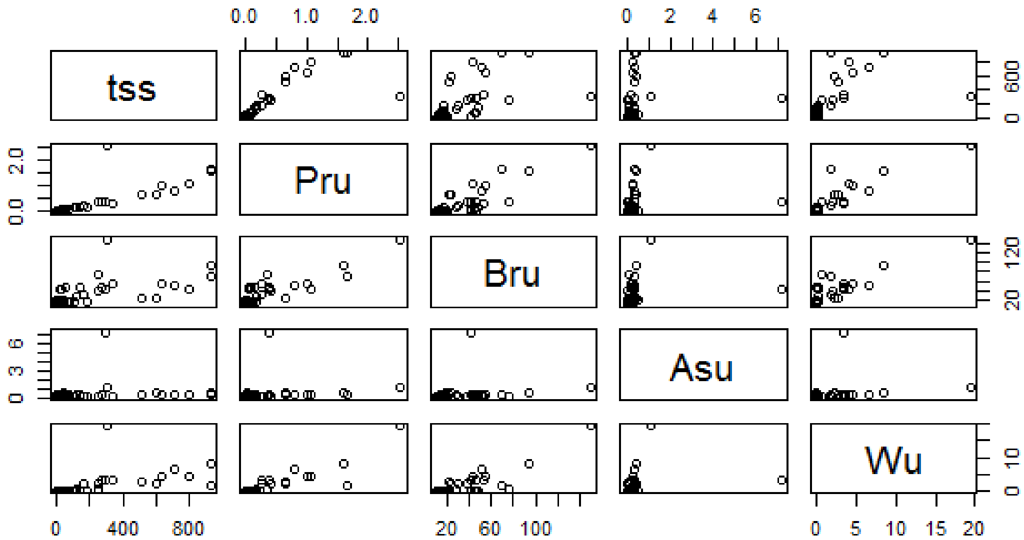

Figure B.3: Scatterplots of tss vs Pr, Br, As, and Wu

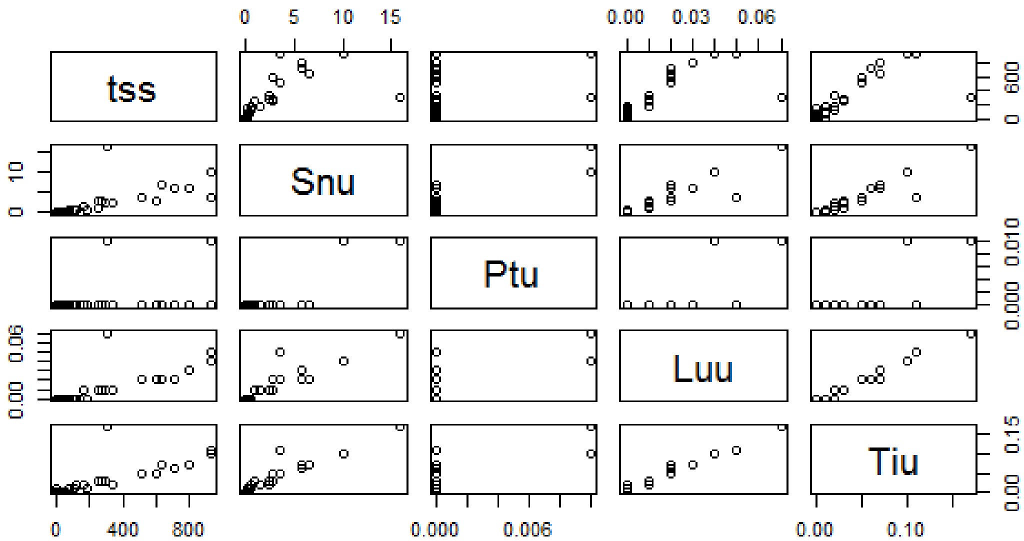

Figure B.4: Scatterplots of tss vs N, Pt, Lu an Ti

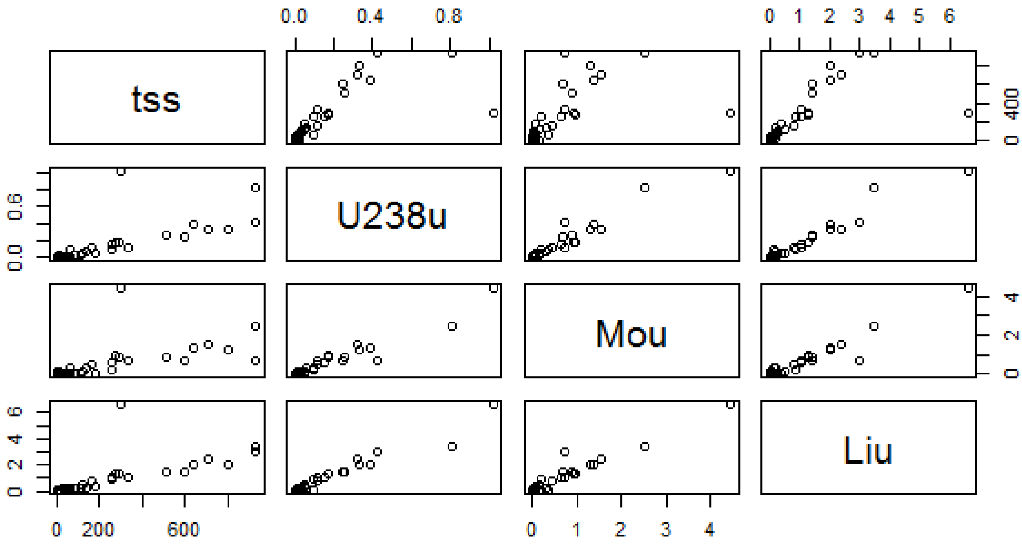

Figure B.5: Scatterplots of tss vs U238, Mo and Li

C

Comparison of dip wells and stormwater selected parameters

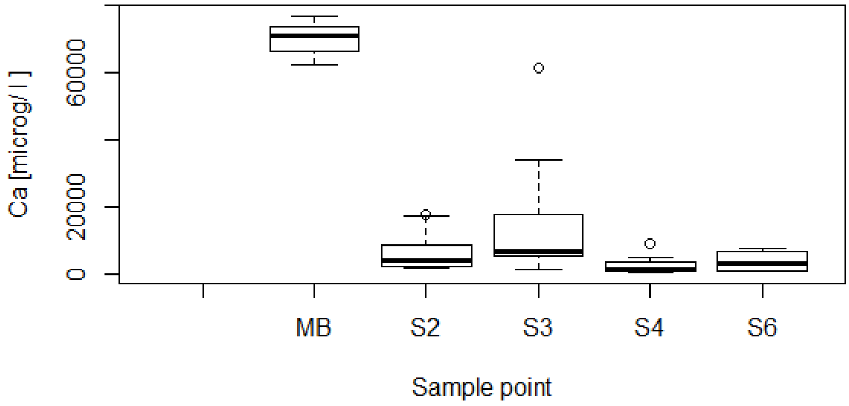

Figure C.1: Calsium level from the sample points compared to the dip-well(MB) where the samples are filtrated

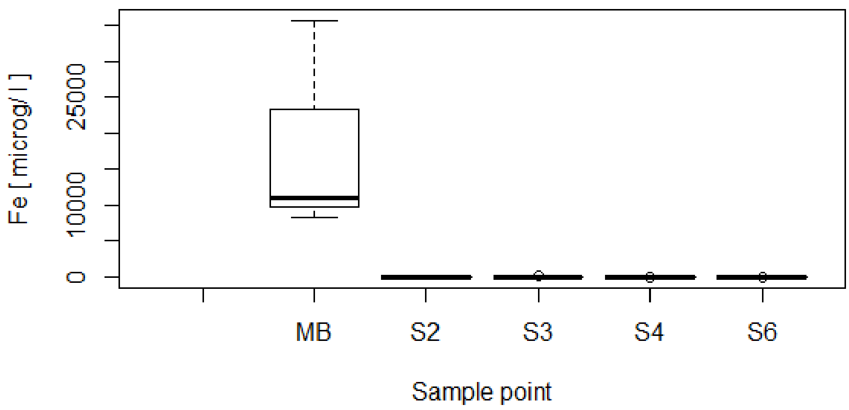

Figure C.2: Fe level from the sample points compared to the dipwell(MB) where the samples are filtrated

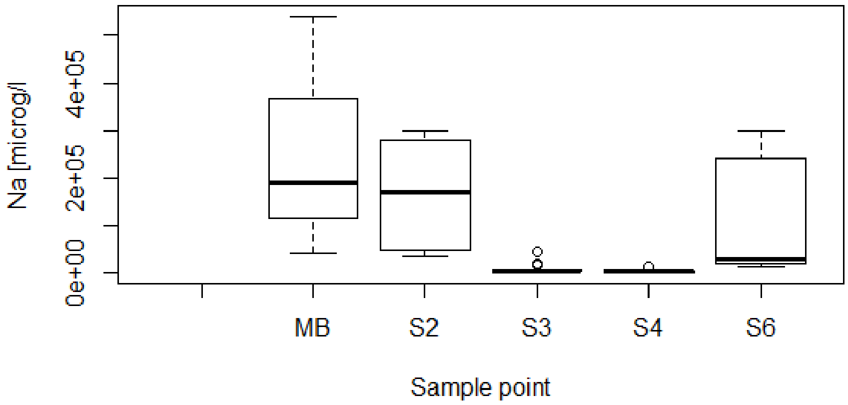

Figure C.3: Na level from the sample points compared to the dipwell(MB) where the samples are filtrated

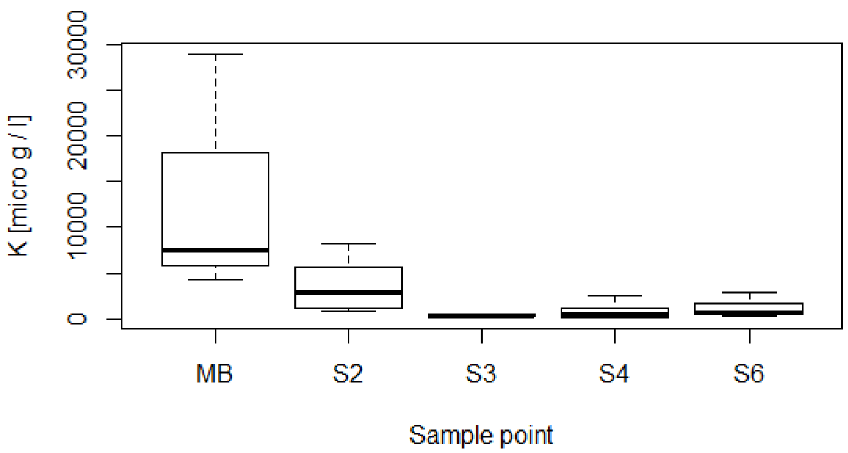

Figure C.4: K level from the sample points compared to the dipwell(MB) where the samples are filtrated

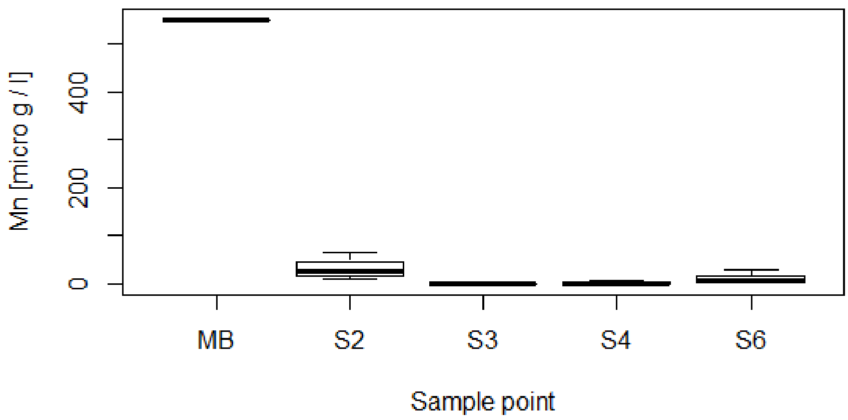

Figure C.5: Mn level from the sample points compared to the dipwell(MB) where the samples are filtrated

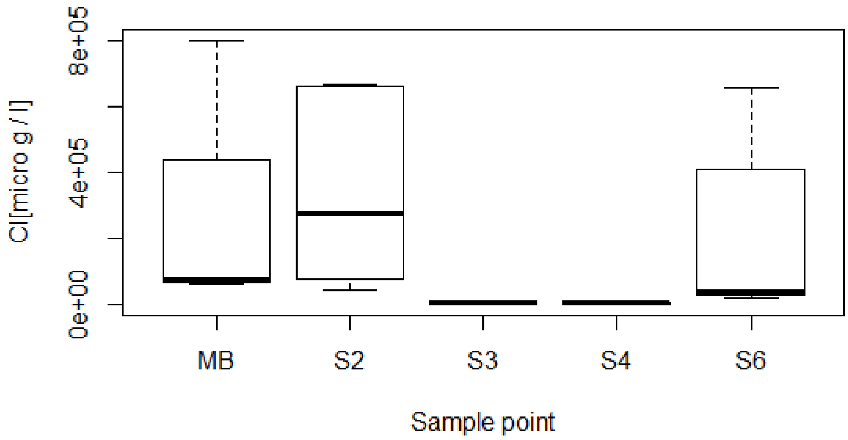

Figure C.6: Cl level from the sample points compared to the dipwell(MB) where the samples are filtrated

Table 16: Correlation analyses, calculation of R, level of significance 99%

	Cd	Mo	Ce	Lu	W	Pb	Na	Mg	Al	S	Cl	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Ag
Cd	**1.00**																		
Mo	**0.17**	**1.00**																	
Ce	**0.08**	**0.31**	**1.00**																
Lu	**0.31**	**0.38**	**0.79**	**1.00**															
W	**0.21**	**0.77**	**0.19**	**0.38**	**1.00**														
Pb	**0.59**	**0.21**	**0.16**	**0.21**	**0.20**	**1.00**													
Na	**0.26**	**0.70**	**0.19**	**0.42**	**0.69**	**0.20**	**1.00**												
Mg	**0.14**	**0.81**	**0.27**	**0.29**	**0.70**	**0.10**	**0.62**	**1.00**											
Al	**0.11**	**0.50**	**0.72**	**0.44**	**0.41**	**0.14**	**0.33**	**0.62**	**1.00**										
S	**0.32**	**0.78**	**0.37**	**0.32**	**0.33**	**0.10**	**0.45**	**0.71**	**0.48**	**1.00**									
Cl	**0.27**	**0.69**	**0.11**	**0.39**	**0.76**	**0.15**	**0.81**	**0.84**	**0.39**	**0.45**	**1.00**								
Ca	**0.03**	**0.55**	**0.52**	**0.29**	**0.09**	**0.06**	**0.10**	**0.58**	**0.61**	**0.83**	**0.20**	**1.00**							
Cr	**0.09**	**0.26**	**0.37**	**0.37**	**0.41**	**0.16**	**0.07**	**0.00**	**0.27**	**0.05**	**0.02**	**0.00**	**1.00**						
Mn	**0.39**	**0.77**	**0.16**	**0.45**	**0.90**	**0.14**	**0.79**	**0.71**	**0.23**	**0.44**	**0.83**	**0.14**	**0.18**	**1.00**					
Fe	**0.08**	**0.47**	**0.93**	**0.68**	**0.42**	**0.09**	**0.30**	**0.45**	**0.84**	**0.43**	**0.27**	**0.52**	**0.47**	**0.31**	**1.00**				
Ni	**0.42**	**0.37**	**0.11**	**0.25**	**0.39**	**0.00**	**0.50**	**0.31**	**0.11**	**0.39**	**0.41**	**0.05**	**0.02**	**0.48**	**0.15**	**1.00**			
Cu	**0.42**	**0.25**	**0.10**	**0.24**	**0.37**	**0.02**	**0.24**	**0.21**	**0.06**	**0.27**	**0.28**	**0.00**	**0.18**	**0.38**	**0.14**	**0.90**	**1.00**		
Zn	**0.62**	**0.24**	**0.19**	**0.22**	**0.19**	**0.90**	**0.17**	**0.13**	**0.19**	**0.04**	**0.13**	**0.13**	**0.15**	**0.12**	**0.13**	**0.04**	**0.05**	**1.00**	
Ag	**0.54**	**0.43**	**0.37**	**0.77**	**0.52**	**0.08**	**0.53**	**0.37**	**0.17**	**0.38**	**0.61**	**0.21**	**0.31**	**0.69**	**0.36**	**0.45**	**0.44**	**0.08**	**1.00**

section

Correlation between Metals