TAMPERE UNIVERSITY
OF APPLIED SCIENCES

Leachate water from shooting ranges backstop berm

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Bachelor's thesis
October 2017
Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Environmental Engineering

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Bachelor's thesis 40 pages, appendices 3 pages
October 2017

Environmental protection act 2000/169 states that all shooting ranges in Finland have to have an environmental permit after the year 2010. This has lead the Finnish Defence Forces to implement environmental protection system to their shooting ranges. The main sources of pollution at shooting ranges are from shooting: noise pollution and heavy metals from bullets in the backstop berm. Bullets in the berm start to corrode in time and heavy metals become more soluble and start to move with leachate water. This water is usually treated before it can be discharged into groundwater.

In many shooting ranges, the environmental protection systems have already been implemented. The systems vary between shooting range areas and somewhat even between ranges in the same area. The variance between ranges and range areas is mostly because they are built and planned separately because of different environmental conditions.

The aim of this thesis is to collect information about the amount of leachate water per square meter of backstop berms in Finland. The continuous measuring device was also studied in this thesis. It was installed into a ditch that water from multiple shooting ranges is led, because it needs quite big flow to work accurately. It is being developed and it can already measure water parameters such as pH, temperature and the dissolved heavy metal concentration.

The most important factor affecting the water amount a berm structure collects seems to be the waterproof structure in the berm. Also, bigger structures seem to collect less per square meter of management area. Design storms that are used in storm water drain design seem to overestimate the flow in the system. From the continuous measurement results it seems that the dissolved lead concentration seems to change the most because of the pH change during the day. According to the results, flow variation did not seem to have effect on the dissolved lead concentration. The dissolved lead concentrations measured were very low and the actual values cannot really be trusted. Still the trends shown in the results are valid, although the magnitude might change when concentrations are higher.

Key words: backstop berm, lead, water flow, water leaching, shooting range

TIIVISTELMÄ

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Ympäristönsuojelulaki 2000/169 mukaan kaikilla ampumaradoilla Suomessa tulee olla ympäristölupa vuoden 2010 jälkeen. Tämän takia Puolustusvoimat ovat rakentaneet ympäristönsuojelujärjestelmiä heidän ampumaradoilleen. Pääasialliset päästölähteet ampumaradoilla ovat melu- ja raskasmetallipäästöt taustavalleista suotautuvaan veteen. Pääosin lyijystä tehdyt luodit alkavat hajota kun ne joutuvat kosketuksiin ilman ja veden kanssa, jolloin raskasmetallit muuttuvat liukoisemmiksi. Tämä vesi käsitellään tarpeen mukaan ennen kuin se johdetaan pohjaveteen.

Monilla ampumaradoilla, ympäristönsuojelujärjestelmät ovat jo rakennettu. Nämä järjestelmät eroavat toisistaan eri rata-alueilla ja joskus myös rata-alueen sisällä. Tämä vaihtelu johtuu siitä että ympäristönsuojelurakenteet on rakennettu kohdekohtaisesti, riippuen alueen erityispiirteistä.

Tämän opinnäytetyön tarkoituksena oli kerätä tietoa suotovesien määrästä ampumaradan taustavallin keräysjärjestelmissä per neliömetri eri ampumaradoilla. Tämä tieto auttaa rakenteiden mitoituksessa sekä käsittelymassojen vaihtovälin arvioinnissa. Myös jatkuvatoimista veden parametrien mittaria tutkittiin. Se asennettiin yhdelle ampumarata-alueelle, ojaan johon johdetaan jo käsiteltyä suotovettä. Mittari asennettiin tähän ojaan koska se tarvitsee kohtalaisen suuren virtaaman toimiakseen. Mittari on kehitysvaiheessa ja pystyy mittaamaan vedestä muun muassa pH-arvon, lämpötilan ja eri raskasmetallien liukoisia pitoisuuksia.

Tuloksien perusteella tärkein tekijä, joka vaikuttaa suotoveden määrään käsittelyjärjestelmässä vaikuttaa olevan tiivisrakenne vallin sisällä. Radoilla, joihin on rakennettu vesitiivis rakenne taustavallin sisään, ovat virtaamat samaa luokkaa. Myös suuremmat vallit näyttävät keräävän pienemmän vesimäärän käsittelyjärjestelmän neliömetriä kohtaan. Mitoitussateet joita käytetään hulevesisuunnittelussa yliarvioivat virtaaman käsittelyjärjestelmässä. Jatkuvatoimisen mittarin tuloksista voidaan nähdä liukoisen lyijyn vaihtelevan pääasiassa veden pH-arvon vaihtelun mukaan. Virtaamalla ei tulosten perusteella näytä olevan suurta vaikutusta liukoisen lyijyn pitoisuuteen suotovedessä. Mittarin havaitsemat lyijypitoisuudet olivat hyvin matalia, minkä vuoksi tulokset ovat vain suuntaa antavia eivätkä tulokset ole tarkkoja. Kuitenkin kuvaajien näyttämät vaihtelut ovat todellisia vaikka tarkkaa pitoisuutta ei voidakaan havaita.

Key words: backstop berm, lead, water flow, water leaching, shooting range

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1 INTRODUCTION

The single largest operator of shooting ranges in Finland is the Finnish Defence Forces. They have 37 operational shooting range areas. There are two main components in the environmental impacts of shooting ranges: noise and heavy metal leaching. This thesis will focus on the heavy metal leaching. This thesis was made for the Construction Establishment of Defence Administration.

Environmental protection act 2000/169 states that all outdoor shooting ranges have to have an environmental permit after the year 2010. These permits require the shooting ranges to have an emission reduction systems fitted with the best available technology (BAT). The best available technology for the shooting ranges is defined in the Finnish Ministry of Environments, Management of the Environmental Impact of Shooting Ranges. (Kajander S, Parri A, 2014)

The best available technology in the environmental protection act 2014/527 is defined as:

a) production-, clean-up-methods and planning- building-, maintaining and usage-methods, that are technically and economically as efficient and developed as possible in preventing environmental contamination or most efficiently reduce the contamination and that will apply as foundation for environmental permit.
b) technology is technically and economically viable when its widely available and can be applied in the field on concern with reasonable cost.
(Environmental protection act 2014/527 §5)

The main contaminants in leachate waters in shooting range areas are lead, antimony, copper and zinc. From these contaminants, maybe the most harmful to people and environment is lead. Lead in water is present in two forms, solid and dissolved. Lead is also the contaminant that is most present in leachate waters because bullets are mostly made of lead. Lead concentrations can be found mostly in the backstop berm behind the targets where the bullets hit and disintegrate. Some concentrations can also be found in front of the shooting places. These concentrations are caused by the shooting activity where small heavy metal particles land on top of the soil. (Kajander S, Parri A, 2014)

Lead is not very soluble as pure compound, but in soil it becomes more soluble due to weathering. The dissolving of lead is not a straightforward process and many parameters of soil, such as pH, affect the solubility of lead. The lead in the leachate, both dissolved and solid, have to be removed as well as possible, before the water can be released in to the environment. (Kajander S, Parri A, 2014)

There has been some indications that water flow rate in soil affects the amount of dissolved lead in water. In previous studies the increased water flow has seemed to correlate with increased dissolved lead concentrations. (Hourula,T 2017)

1.1 Hydrology

In Finland there are two main sources of water leading into the soil, rainfall and melting of snow. Rainfall changes a lot between seasons and years but it is the main source of water. In Finland, rainfall changes between 500 – 700 mm/year and evaporation in southern Finland is more than half at around 400 – 500 mm/year and in northern Finland 30-50% from the rainfall. The variation of rainfall and evaporation are large between years and seasons. Most evaporation happens in open areas, with non-permeable soil types and little to no vegetation. Statistically, the most rainy month in Finland is August and least rainy March. (Salaojayhdistys ry, 2013)

Melting of snow is important factor to leachate waters during spring, but for a quite short period. The effect is bigger in northern parts of Finland where more snow has accumulated and the melting lasts usually longer than in southern parts.

How water physically behaves in soil, is dependent on the type and size of the soil particles. From rainfall, some of the water evaporates, some moves on the soil as run-off and some infiltrates into the soil. The ratio of these three is dependent especially on soil type. The vegetation on top of the soil is also quite significant factor. In open areas evaporation is much higher than areas with lots of vegetation. Evaporation of rainfall can be very high, Run-off is highest in areas with low permeability soil, for example clay. In these area water will flow on top of the soil towards a water body and infiltration is low or non-existent. (Leppäranta M, Virta J, Huttula T, 2017)

Water that is not evaporated or run-off is infiltrated in soil. Underground water can be divided into soil moisture and ground water. Soil moisture is the water bound in the top layer of the soil and forms a saturated layer. This is the layer plants take their water and water flow is downwards. The soil moisture layer can also be divided into three phases: root zone, intermediate zone and capillary zone. Some of the rainfall will stay in the root zone and is removed by transpiration. Some of the water will leach through the intermediate zone into the capillary zone that is directly over groundwater. This is slow process driven by gravity and the velocity of the leachate water depends on the soil type. (Leppäranta M, Virta J, Huttula T, 2017)

1.1.1 Soil types

Soils are classified in different types by different industries. In this thesis, the soil classification for construction engineering is used.

Water movement and binding in soil is very much dependent on the soil type. Soil types are classified into mineral soil, organic soil and chemical sediments. Organic soil in Finland is usually a thin layer in top soil where plants grow in and below organic soil is the mineral soil. In some areas, the organic soil can also be much thicker, for example peat lands. In Finland the top soil freezes during winter which affects the yearly hydrological cycle. (Leppäranta M, Virta J, Huttula T, 2017)

Organic soil withholds a lot of rainwater and plants in the layer use it. During heavy rain and snow melting, water leaches through to the mineral layer. Mineral soils are classified into soil textures by their median particle size distribution. For movement of water in soil, the mineral soil is the most important part of the soil. (Leppäranta M, Virta J, Huttula T, 2017) The classification can be seen in Table 1.

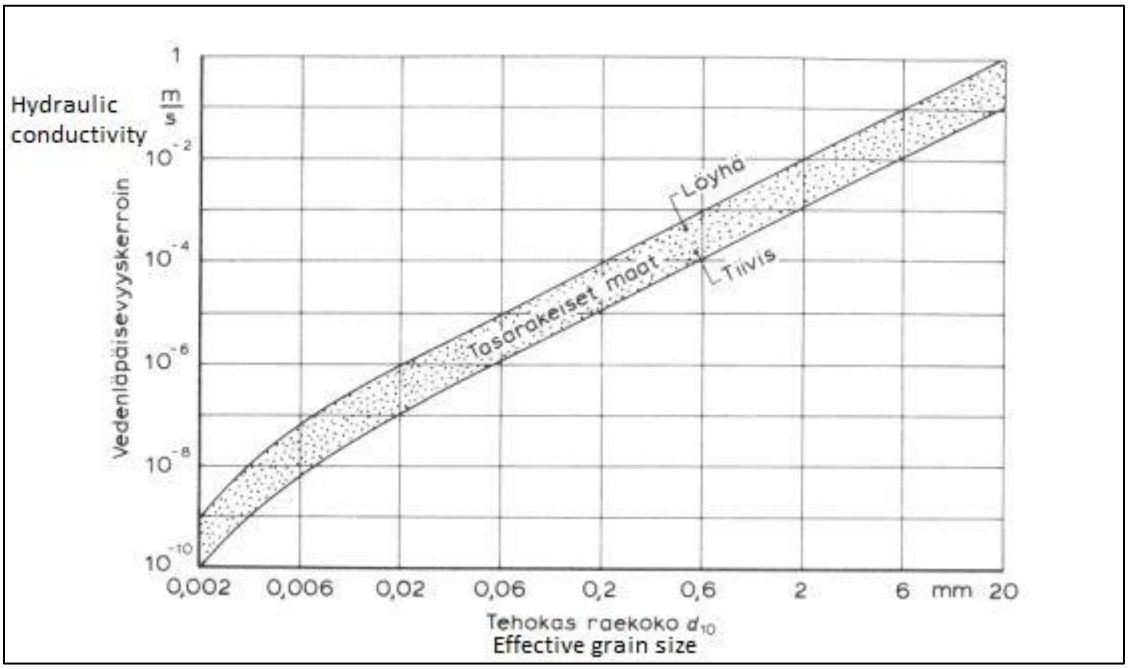
TABLE 1, Soil texture classification by median particle size (Leppäranta M, Virta J, Huttula T, 2017)

Soil texture	*Median particle size (mm)*
Clay	< 0,002
Silt	0,002 – 0,06
Sand	0,06 – 2
Gravel	2 – 20
Rock	20 – 600
Boulder	> 600

1.1.2 Permeability

Permeability, or hydraulic conductivity, describes waters ability to pass through soil. Permeability has a big range and it is affected by soil type, especially the particle size and particle size distribution in soil. The soil type is important for permeability, because different particles form different kinds of capillaries in soil. The absolute porosity is not the most important factor in permeability of soil. This is because for example with clay, porosity is very high but the capillaries are so small that water can pass very slowly, if at all. (Leppäranta M, Virta J, Huttula T, 2017)

The material used on surfaces of backstop berms is almost always stone dust, because of its low permeability. Stone dust has usually a grain size range of 0/2 mm, 0/3 mm or 0/6mm. (Rasimus, 2013) The stone dust used in Finnish Defence Forces shooting ranges is 0-5/6mm. (Hourula, 2017) Stone dusts permeability can crudely be estimated by the figure in picture 1.



PICTURE 1, permeability of different homogenous soil types (Pohjavesitilanteen tarkastelu alikulkusiltapaikoilla, 2011)

When smaller particles are present with bigger ones, they fill the pores in the soil and make it less permeable. (Brouwer C, Goffeau A, Heibloem M; 1985) Because the used stone dust is not homogenous, stone dust can be defined to have quite low hydraulic conductivity.

Table 3 shows the permeabilities of some soil types. This classification is crude and there are many middle grounds between soil types. The grain size of stone dust is similar to fine sand, and is considered to be semi-permeable.

TABLE 3, Permeability in different soil types, (Leppäranta M, Virta J, Huttula T, 2017)

Soil type	*Hydraulic conductivity (cm/s)*	*Quality of ground water reserve*	*Permeability class*
Clean gravel	$10^2 - 1$	Good	Permeable
Sand	$1 - 10^{-3}$	Good	Permeable
Clay with silt layering	$10^{-3} - 10^{-7}$	Bad	Semi-permeable
Clay	$< 10^{-7}$	Non-existing	Non-permeable

1.1.3 Dissolution and state of lead

Pure lead does not corrode easily. The lead used in bullets, is often recycled and it contains other elements that increase the solubility of lead. The lead in soil is in contact with water and air. This leads into physical and chemical processes that start the corrosion. The lead in soil can dissolve into water, it can precipitate into different compounds or bind in fine particles of soil. (Kajander S, Parri A; 2014)

There are two main components, that affect how much lead or other heavy metal contaminants end up in the environment. These are the permeability of the soil and the corrosion of the heavy metals. Both are affected by the physical characteristics of soil and somewhat by the chemical characteristics. Table 2 illustrates how solubility of different heavy metals changes when different soil characteristics change.
(Kajander S, Parri A; 2014)

TABLE 2, changes in solubility of some metals in different soil conditions (Kajander S, Parri A; 2014)

When soil characteristic increases	**Dissolution of lead (Pb)**		**Dissolution of copper (Cu)**		**Dissolution of antimony (Sb)**	
	Increasing	**Decreasing**	**Increasing**	**Decreasing**	**Increasing**	**Decreasing**
Humidity	x		x		x	
Temperature	x		x		x	
Clay content		x		x	x	
Humic matter content		x		x		x
pH		x*		x	x	

*With lead, the dissolution is not a straightforward process. It is least soluble when pH is neutral and increases in acidic and alkaline circumstances

Because the solubility of lead changes when pH of the medium it is in changes, it is an important factor for dissolved lead concentration in water. In water it is recognized that pH changes due to photosynthesis of algae and other organisms. This is because of sunlight. In sunlight, photosynthetically active tissue uptakes CO_2 and releases oxygen, the opposite reactions happens in the dark. Temperature is also important factor because photosynthesis needs certain temperature to function. (Edaphic Scientific, 2016)

CO_2 dissolves in the water and forms carbonic acid (H_2CO_3), which then disassociates into bicarbonate and hydrogen ions. When there is less CO_2 in water during the day, less free hydrogen ions are present in the water. The pH of water is the concentration of hydrogen ions in water so this is how the change in pH happens. (Edaphic Scientific, 2016)

1.1.4 Sub-catchment

Sub-catchment in this thesis means the water management area in the studied shooting ranges, which is basically the backstop berm and its surroundings. In this thesis, the area has been estimated from construction plans for the barriers

For example, the shooting range area 1 has a 150m rifle range that has 50 shooting places. From the construction plans, the width of the waterproof structure is about 90 m and the depth of the waterproof structure is estimated to be about 11 m because of the standard requirement of 6m high barrier and inclination of 1/1,5 plus the ditch in front of the berm. So by this, the water management area in each range is calculated

$$90\,m * 11\,m = \ 990\,m^2 \tag{1}$$

This calculation is done for all shooting ranges in all of the studied shooting range areas, so that the amount of water collected from different areas and water flow rates can be compared to the sizes of the water management areas. These areas are important when calculating the flow in regard to the size of the management area.

1.2 Design storm

Design storms are a statistical tool made from rainfall data collected. The design storms are different by their rain intensities and how often these kinds of rains occur. They are used is storm water drain design in urban areas, so that the drainage systems can be fitted in right dimensions cost-efficiently. It is based on statistical data about the rainfall events and their profiles in Finland. (Nissinen, 2017) The design storms are presented for example like 3,5mm 1/1a 5min. This means that this kind of rain happens once a year, it lasts for 5 minutes and in the 5 minutes, 3,5mm of water rains. Then this value is searched from library of statistical data that tells how much water falls per second in one hectare which is the intensity of the rain. One factor of how much of the water falling on the ground actually is collected by the system is the run-off coefficient that is dependent on the surface of the soil. It ranges between 0-1 meaning which percentage is collected. Formula 2 shows how this calculation is made which results in the theoretical flow in the system.

$$Q = q * \varphi * A \tag{2}$$

Where:
Q = water flow in the system l/s
q = intensity of the rain l/s per ha
φ = run-off coefficient
A = run-off area ha (in this case, same as water management area)
(RIL 124-2 Vesihuolto II)

The design storm closest to the actual rainfall was used for the calculations to estimate how well this kind of theoretical calculation estimates the water flow in the system. This calculation is used to compare the measured flows to the theoretical flows to estimate what kind of design storms are closest to the real flow. (Heinonen T, Kajosaari E…, RIL 124-2 Vesihuolto II)

2 ENVIRONMENTAL PROTECTION SYSTEMS AT SHOOTING RANGES

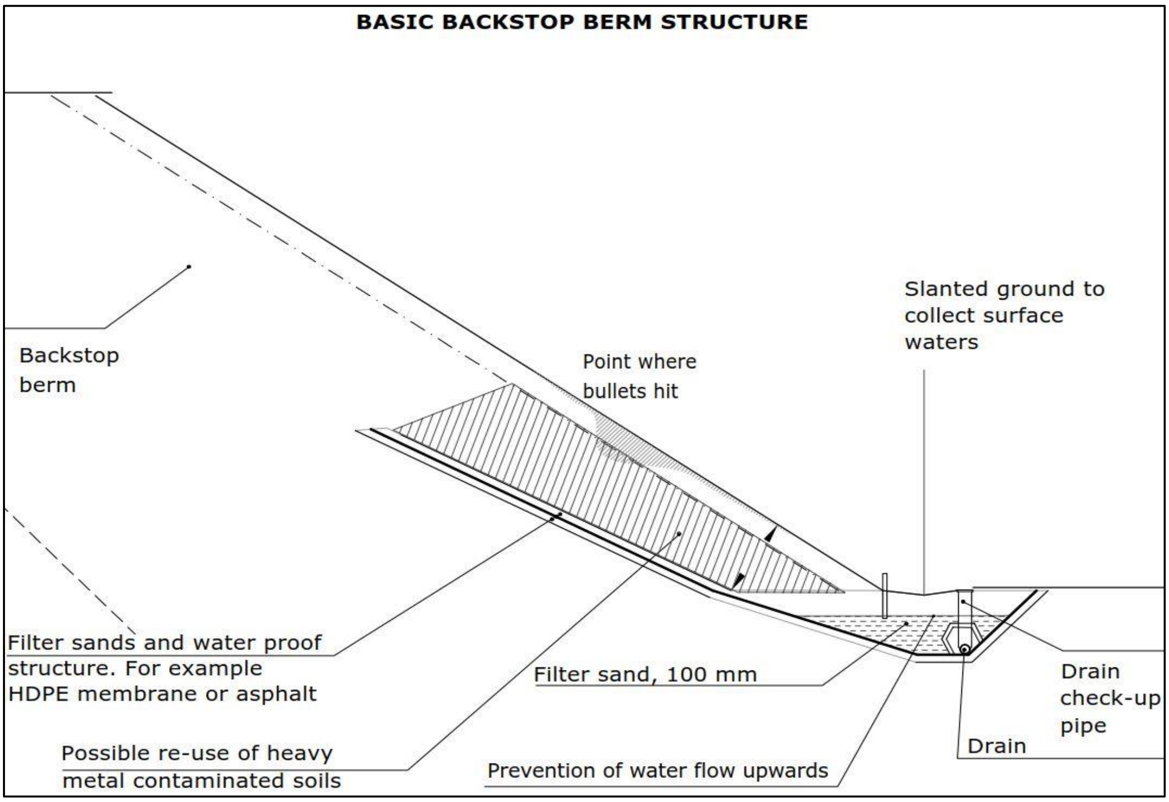
The soil structures in shooting range areas differ from natural soils. At modern shooting ranges, the soil is not usually in a natural state. The backstop berm is built by people to prevent bullets from spreading outside the area. At least the top of backstop berm is usually fine grained crushed stone material that water can pass through and so it can absorb the energy of the bullets and them from ricocheting from bigger particles such as rocks. The barriers usually have some plants growing on top soil, but it is mostly mineral soil or mix of organic and mineral soil. There can be some variation in the soil type between range areas. The soil that is available at the shooting range area is often used in the base and sometimes contaminated soils are utilized in the backstop berm. (Defence Administration technical documents)

The backstop berms are sometimes remediated to reduce the lead load in the berm and so reducing the amount of lead leaching into the water. It takes for a long time to accumulate enough lead in the berm so that the remediation is feasible. During this time the lead has time to start disintegrating and leaching to the water. In shooting ranges that only weapons using bullets are used, the area lead bullets are concentrated is quite small compared to shotgun ranges where small lead pellets are spread to big area. (Kajander S, Parri A; 2014)

The example pictures of environmental protection system structures are from Construction Establishment of Defence Administrations technical documents, and are originally made for them by Ramboll Finland. They are modified and used in this thesis with consent of the Defence Administration.

2.1 Structure of the backstop berm and water management system

The water management systems for Finnish Defence Forces shooting ranges have somewhat similar structures for the backstop berms in all their renovated shooting ranges with backstop berms made of soil. The renovated backstop berms are usually built to have incline of 1/1,5 and the surface material of the berm is stone dust. This structure is used so that the water would flow on top of the soil to the foot of the berm where it will be collected. The structure includes a sand trap that has a waterproof base made of asphalt, bentonite, plastic membrane or mix of these solutions. This waterproof structure is not built in every berm, depending on the site. This structure will collect the infiltrated water to the bottom of the backstop berm where the water flows in a drain. An example structure can be seen in picture 2.

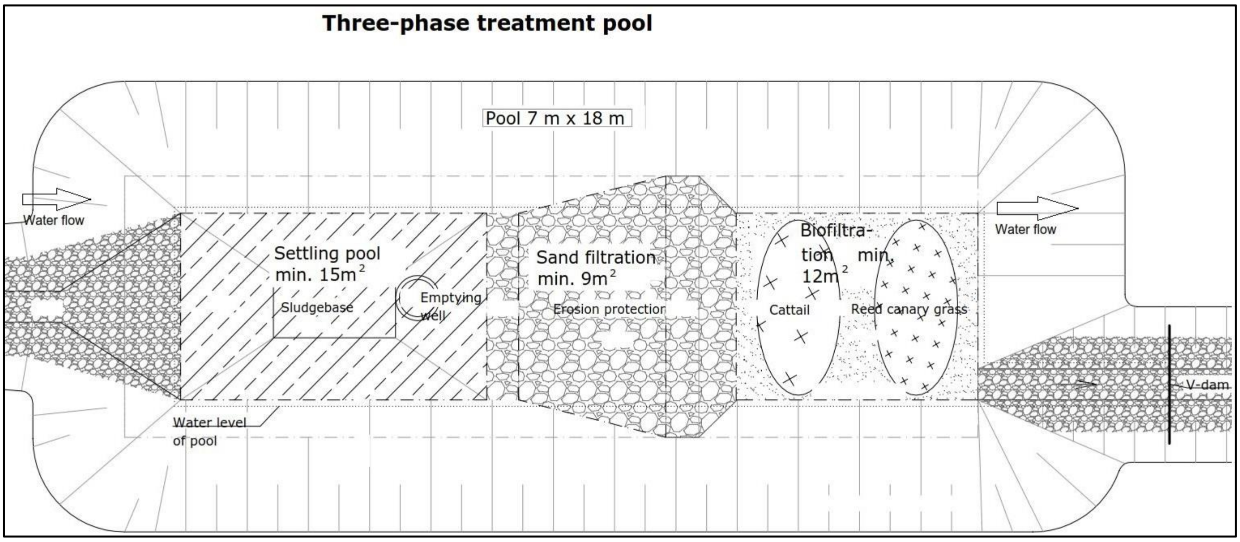


PICTURE 2, example of backstop berm structure (Defence Administration technical documents)

There are two main options for the water management at shooting ranges, depending if the soil at the shooting ranges is permeable or not. If the soil at the shooting range has high permeability, the water is drained into a treatment well and from there into an infiltration well where the water is released into groundwater. If the soil at a shooting range has a low permeability, the water is usually drained into a treatment pool and after treatment into a ditch or an infiltration well.

2.2 Three-phase treatment pool

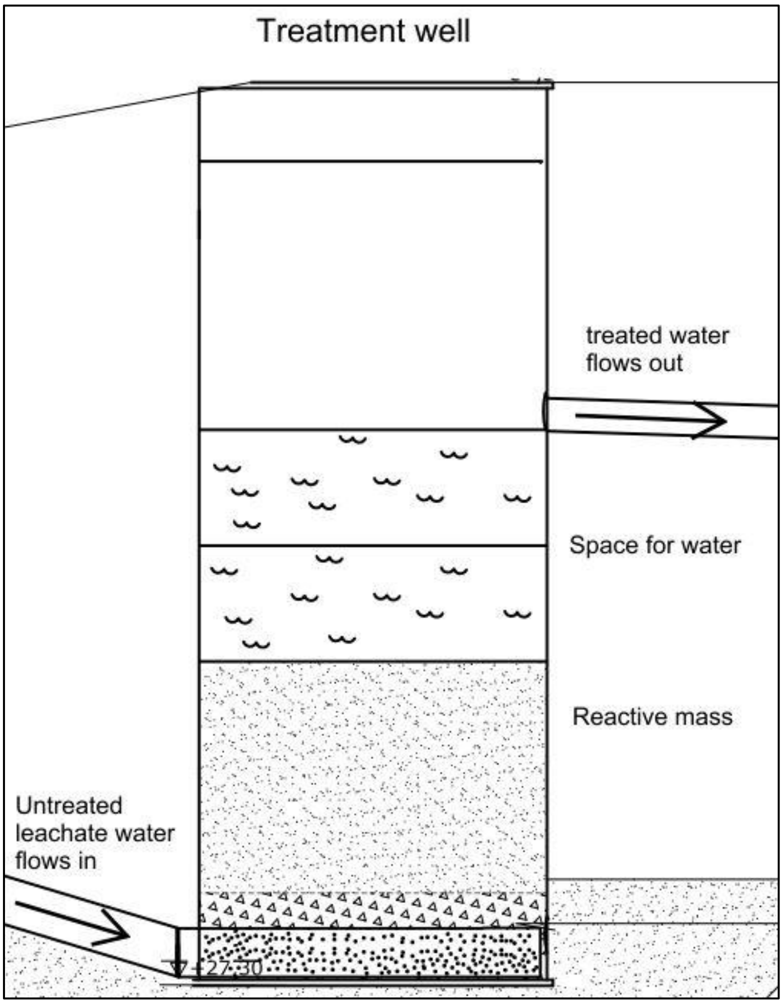
The three-phase treatment pool is implemented in shooting ranges that are in areas with low permeability soil. The water is led from the drain on foot of the backstop berm into the first phase of the pool, which is a settling pool. In the settling pool, the solid matter will settle in the bottom of the pool and can be removed. Then the water passes the sand filtration phase and flows to biofiltration phase where few selected species of plants and organic soil will absorb dissolved lead from water, for example cattail and reed canary grass. In the biofiltration phase, the important part is the mulch layer or growth layer. In this layer, the roots and organic soil are removing lead from the water. After the biofiltration, there is often a v-dam for water flow measurement and then the water is led into a discharge ditch. Picture 3 shows the planned structure of a treatment pool implemented in one of the shooting ranges.



PICTURE 3, example of three-phase treatment pool (Defence Administration technical documents)

2.3 Treatment well

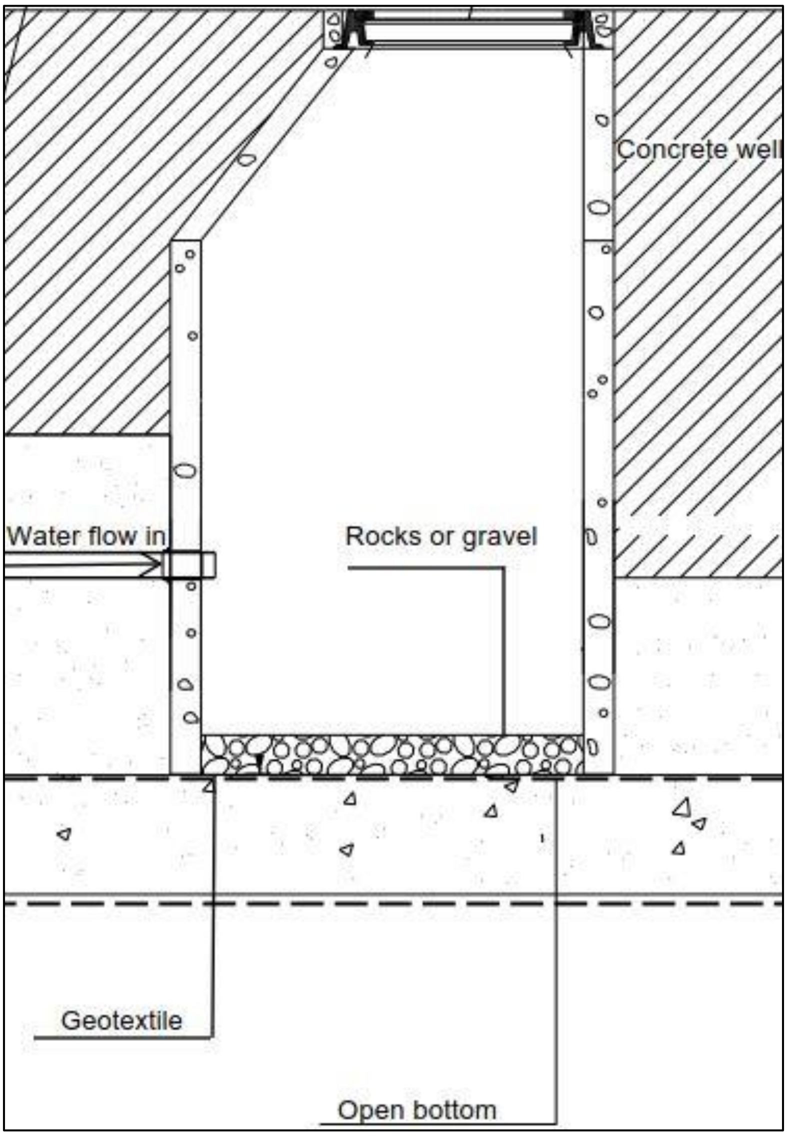
If the shooting range is located in an area with permeable soil, the open treatment pool for water treatment is not used because the pools would need to be equipped with waterproof membrane. In that case the water will be drained from the backstop berm through a sampling well into a treatment well where the water will be treated. Water is coming to the treatment well from near the bottom of the well and passes through and adsorption mass that removes heavy metals from the water. The well has to be large enough because the reactive mass that removes lead from the water needs retention time for the process. The system can also be fitted with sand filtration and pH adjustment systems with additional wells if needed. After the water has been treated, it is led out higher up of the well and into an infiltration well where the water is released into the surface of ground water. Structure of on treatment well used in a shooting range can be seen in picture 4.



PICTURE 4, example of treatment well structure (Defence Administration technical documents)

2.4 Infiltration well

The water is led from treatment pool or treatment well into a ditch or possibly into an infiltration well where it is released back into the groundwater. The structure is very simple, well with geotextile and possibly other filtration solutions such as gravel in the bottom where the water leaches through to the soil. An example of the structure can be seen in picture 5.



PICTURE 5, example of infiltration well (Defence Administration technical documents)

3 SCOPE

The aim of this thesis is to collect information about the amount of leachate water the water management structures in shooting ranges collect in Finland. The relationship between the amount of leachate water to the concentration of lead in the water is also studied. This information helps design the water management system in a right scale. In this thesis the studied shooting ranges are only bullet ranges, shotgun ranges are not studied.

A continuous measurement device for heavy metal concentrations was also studied. This device can measure concentrations of different dissolved heavy metals in water and also logs the temperature, pH and other parameters of water. By this data, the effects of different water parameters on solubility of lead, can be studied. This is a new device and the study gives information from both the device ability to measure lead concentrations and how the lead concentration changes.

4 MATERIALS & MEASUREMENT METHODS

A study about the same subject was conducted in one shooting range about the same subject. A see-saw type of water measuring device was installed to measure the amount of water the system collects. The see-saw was installed so that when its cylinder fills, it tips over and empties. Then a data-logger logs how often and how many times it tips over and the amount can be calculated because the volume of water the see-saw collects before tipping over is known. There were technical problems because of the conditions where the see-saw started to rust and freeze prevent the see-saw from tipping. (Kekkonen J, Setälä J; 2017)

The rainfall amounts for the this thesis were collected from the Finnish Meteorological Institutes (FMI) open data. The closest measuring station for each shooting range was used. All of the measuring stations are no more than few kilometres from the shooting range so the rainfall data is fairly accurate.

4.1 Shooting ranges

4.1.1 Shooting range area 1

The shooting range area 1 is located in central Finland. It has 3 shooting ranges that were studied and all of them different types. One of them is a rifle range, one is a pistol range and one is a moving target range. At shooting range area 1, a waterproof bentonite structure is built inside the backstop berms of all ranges.

Shooting range 1.1 is a rifle range and has 50 shooting places. It has a backstop berm water management area of 990 m² and has 50 shooting places so water management area of about 39,6 m² per shooting place.

Shooting range 1.2 is a pistol range. It has a backstop berm water management area of 583 m² and has 50 shooting places so water management area of about 11,7 m² per shooting place.

Shooting range 1.3 is a moving target range. It has a backstop berm water management area of 330 m² and has 2 shooting shelters. At this range only once in the measuring period the water flow could be measured. Shooting range 1.3 is not represented in the graph 1 because of the lack of flow.

4.1.2 Shooting range area 2

The shooting range area 2 is located in central Finland and only one shooting range discharge point was studied. Two ranges waters are collected to the system. The shooting range discharge point is named as shooting range 2.1. The shooting range 2.1 manages a pistol range with 30 shooting places and moving target range with two shooting shelters. The backstop berm water management area for the pistol range was calculated to be 401,5 m² and moving target range 220 m² so in total 621,5 m².

4.1.3 Shooting range area 3

Shooting range area four is located in southeast Finland. It has 3 studied shooting ranges. At shooting range area 3, the studied shooting ranges have bentonite waterproof structure in the backstop berms.

Shooting range 3.1 is a pistol range with 60 shooting places. It has a backstop berm water management area of 715 m² so about 12 m² per place.

Shooting range 3.2 is actually a set of four shooting ranges. It is still referred to as shooting range 3.2, since the ranges flows cannot be distinguished from each other. The range where the water management system is implemented is itself u-shaped and quite big. The water management system for this range is connected to three additional shooting ranges water led to the same water management system. The shooting ranges whose leachate water this system manages, are a situation range, 300 m rifle range, 150 m rifle range and another situation range. Because of all of the 4 ranges waters are led to the same place, the water flow measurements had to be proportioned to the water management area of all these 4 ranges. All the 4 backstop berm water management areas are in total about 4000 m².

Shooting range 3.3 is a moving target range that does not have same kind of shooting places but instead a shooting shelter. It has a backstop berm water management area of 350 m².

4.1.4 Shooting range area 4

This shooting range area is located in northern Finland and was studied quite a lot for this thesis. At this shooting range area, there are no waterproof structures built inside the backstop berm. The ranges in this area have stone dust surface on the backstop berm that water is supposed to flow on and be collected in the bottom of the berm with a ditch.

There was only one flow measurement logged in one of the three shooting ranges of the area during the spring and summer of 2017. That is why a measuring vessel was left under a discharge pipe and the water amount collected was measured couple of days or a week later. The biggest water amounts measured in these shooting ranges were in the beginning of May, which was the time snow was melting in the area. The flow rates were calculated by dividing the amount of water coming out of the system with the time between the measurements.

4.2 Water flow measurements

The measurements were made by different people in all shooting range areas. The areas are located around Finland and some measurements were made by Defence Administrations employees and some by consultants working at the range areas. They were given a form to fill out after every measurement where they logged the date, time and parameters such as water flow to treatment system, rainfall, temperature and if there was flow in the v-dam in places they were implemented. This form can be seen in Appendix 1. The v-dam measurements are not used because they were flooding or dry so often that no consistent measurements could be made.

The water flow measurements were made from discharge pipes leading to sampling well or to the treatment pool. They were made by putting a measuring vessel under the discharge pipe and measuring how long it takes for the vessel to fill up. This way the water flow at the moment could be calculated. For example at shooting range area 1 at 12.4.2017 it took 10:30 minutes to fill a 20 l measuring vessel so:

10:30 min = 630s

$$20\ l\ /\ 630\ s\ \cong\ 0{,}317\ l/s \tag{3}$$

At ranges that did not have any observable flow the vessel was left under the discharge pipe for longer periods of time, for example few days or a week. This amount was divided by the period of time it took to collect the water to calculate the flow.

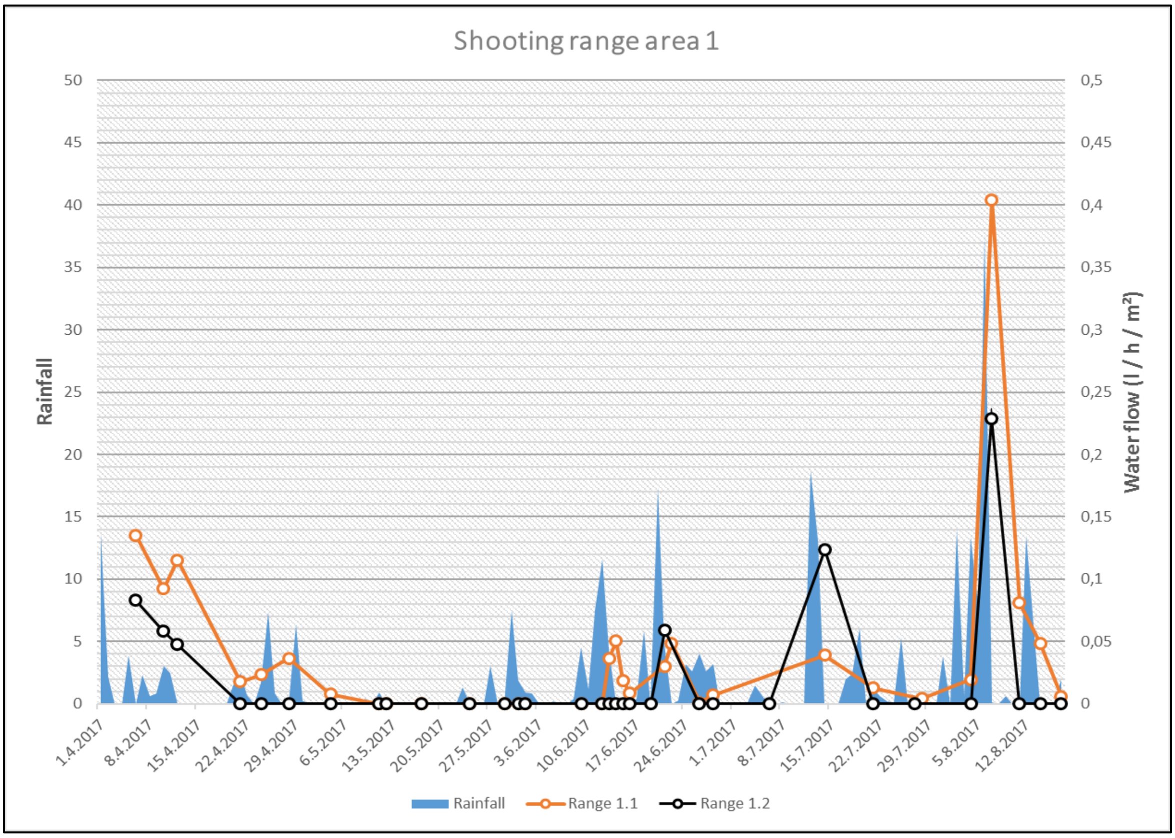
4.3 Continuous measuring

A device designed by EHP-Tekniikka for continuous measurement of metal concentrations of water was implemented in a ditch where the leachate water is led in one shooting range area. This ditch is at shooting range area 4 that is located in northern Finland. This device is being developed, and it provides data about the change in flow rate, pH and temperature of the water and is capable of measuring dissolved metal concentrations in real time. The device has multiple sensors installed to it with a data-logger and gsm/gprs-modem that sends the data into a server, so the results can be seen from a computer in real time. The measurement frequency can be adjusted, in this study it was about once in 30 minutes. The device was installed into a ditch where multiple shooting ranges discharge their leachate waters because the device needs high flow to function properly. (Hourula, 2017)

5 RESULTS

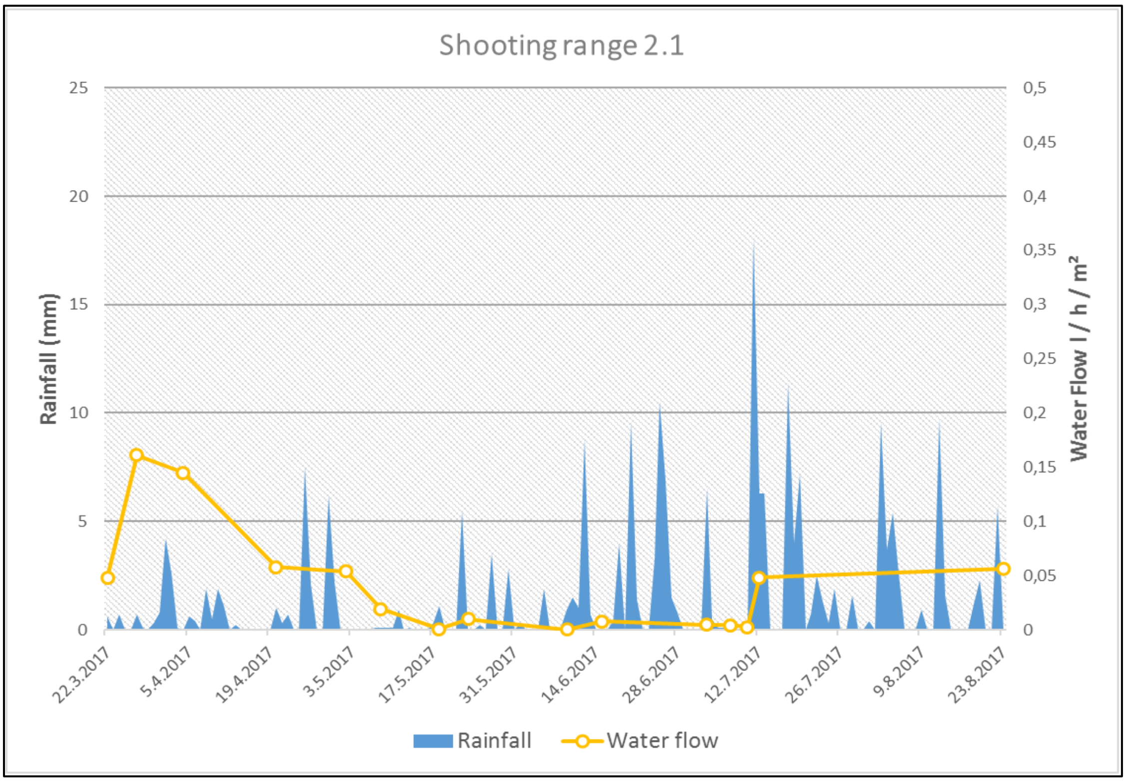
5.1 Water flow and amount measurements

The shooting range areas that are studied in this thesis are not named and are referred to as shooting range area 1, 2, 3 and 4. Graphs 1-3 show the water flow measurements made in three ranges areas, and graph 4 shows the lead concentration measurements made at range 1.1



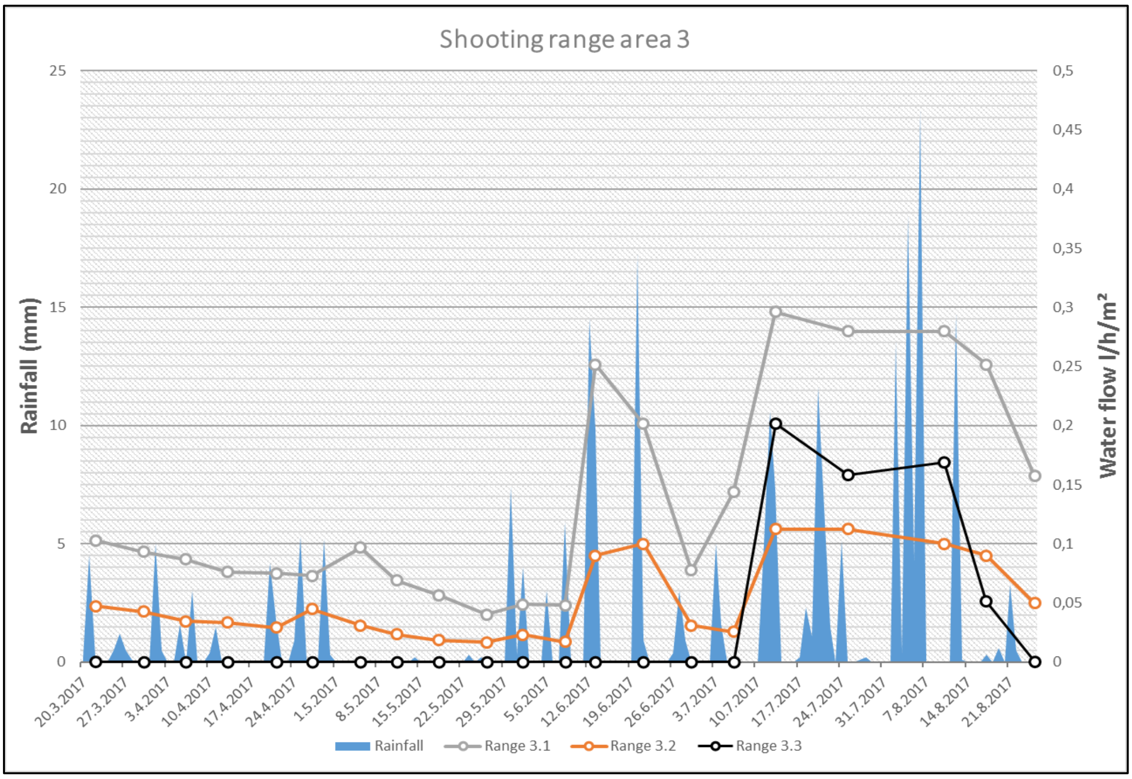
GRAPH 1, water flow rates at shooting range area 1

Some samples were also taken for laboratory analysis from shooting range 1.1. The lead concentration results in relation to water flow are shown in graph 4. At shooting range area 1 highest flows were caused by severe rainfalls, but significant flows were measured also during snow melting time



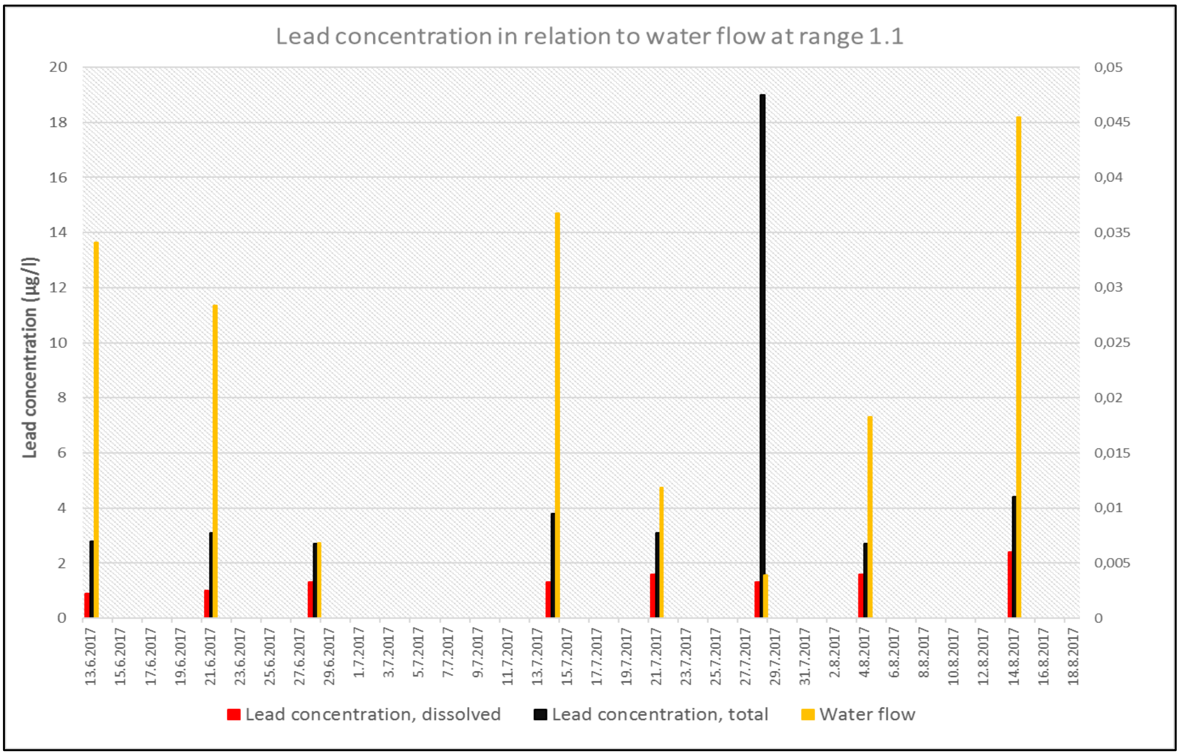
GRAPH 2, water flow rates at shooting range 2.1

At shooting range area 2, the highest flows were measured during snow melting time in spring. Only one shooting range discharge point, that has two shooting ranges discharging their waters into, was studied.



GRAPH 3, water flow rates at shooting range area 3

The range 3.1 has the highest flow per m² during the whole measurement period in this area. No flow could be measured at range 3.3 until July. Intense rainfalls seem to cause the highest water flows, snow melting time does not seem to have huge effect.



GRAPH 4, Water flow rates and lead concentrations at range 1.1

Eight water samples were sent to lab and analyzed from the untreated leachate water at shooting range 1.1. The heavy metal concentrations were analyzed, and the water flow at the sampling time was measured.

5.1.1 Statistical data and calculations from the flow measurements

The water flow measurement results made from shooting range area 1-3 were quite close to each other and calculations from all the results are presented in Table 3. Shooting range area 4 is presented as its own in Table 4, because the measuring method was different and the results are not comparable. Also Shooting range are 4 does not have waterproof structure inside the backstop berm, but a stone dust surface that leads the water to the management system.

TABLE 3, calculated values for water flow at range areas 1-3

	Range area 1	Range area 2	Range area 3	All 3 range areas
Amount of observations	63	15	65	138
Max flow (l / h / m²)	0,404	0,161	0,296	0,404
Min flow (l / h / m²)	0	0	0	0
Average flow (l / h / m²)	0,028	0,041	0,071	0,047
Median flow (l / h / m²)	0	0,019	0,047	0,017
Accumulated amount per year calculated with				
Average (l / m² / a)	249	361	620	410
Median (l / m² / a)	0	167	415	152

TABLE 4, calculated values for water flow at range area 4

Shooting range area 4	
Amount of observations	22
Max flow (l / h / m²)	0,00024
Min flow (l / h / m²)	0
Average flow (l / h / m²)	3,98E-05
Median flow (l / h / m²)	1,27E-05
Accumulated water amount per year calculated with	
Average (l / m² / a)	0,35
Median (l / m² / a)	0,11

Table 5 shows the rainfall amounts in different areas during measuring period.

TABLE 5, rainfall amounts in different shooting range areas

Rainfall		Shooting range area 1	Shooting range area 2	Shooting range area 3	Shooting range area 4
*March**	mm	11,8	6,5	7,2	4,8
April	mm	49,9	33,5	29,9	42,1
May	mm	15	14,8	8,4	34,1
June	mm	75,8	53,6	59,6	25,8
July	mm	56,2	69,2	58,1	56,3
*August**	mm	102,6	44,2	79,8	48,7
Whole period	mm	311,6	221,8	243	211,8
Average yearly rainfall in the area (RIL)	mm	686	694	727	666

*The whole month is not included in the calculations because no measurements were made during the whole month

The rainfall amounts in during the measuring period have been significant. They are not especially high in total but some months have been exceptionally rainy. The measuring period was about 5 months and about one third or more of the yearly average rainfall was measured. This means that the results can quite well be used to evaluate the yearly averages.

5.2 Design Storm

The results from theoretical comparison between results and statistical data from different shooting range area are shown in this chapter. Shooting range area 4 could not be included in this comparison since there was only one flow measurement. The most common design storms used in Finland are short and often occurring rains such as 1 / 1a, 5 min. (Nissinen, 2017)

5.2.1 Shooting range area 1

Table 6 shows some of the measured flows and the theoretical flows the design storm calculations give. This is a theoretical comparison that gives some idea of what kind of design storms are the most accurate for this system.

TABLE 6, Shooting range area 1 theoretical and measured water flows

Date	**Rainfall (mm)**	**Design storm, repetition and duration of rain**	**Range 1.1**		**Range 1.2**	
			Theoretical flow (l/s)	Measured flow (l/s)	Theoretical flow (l/s)	Measured flow (l/s)
10.4.2017	3	1 / 2a, 2 min	7,60	0,025	4,20	0,0095
21.4.2017	2,5	1 / 1a, 3 min	4,91	0,005	2,71	0
12.6.2017	11,6	1 / 1a, 60 min	1,05	0	0,58	0
13.6.2017	4,4	1 / 2a, 5 min	5,28	0,01	2,92	0
14.6.2017	0			0,014		0
20.6.2017	17,3	1 / 1a, 180 min	0,53	-	0,29	-
21.6.2017	4,8	1 / 2a, 5 min	5,28	0,008	2,92	0,0095
28.6.2017	3,2	1 / 1a, 5 min	5,28	0,002	2,92	0
12.7.2017	18,7	1 / 1a, 180 min	0,53	-	0,29	-
13.7.2017	13,1	1 / 1a, 90 min	0,74	-	0,41	-
14.7.2017	0		0	0,011	0	0,02
4.8.2017	13,4	1 / 1a, 120 min	0,74	0,005	0,41	0
5.8.2017	8	1 / 1a, 30 min	1,58	-	0,87	-
6.8.2017	37,6	1 / 2a, 720 min	0,26	-	0,15	-
7.8.2017	0,1		0	0,111	0	0,037

As can be seen in the table, the results from longer design storms seem to be closer to the measured flows, but still overestimate the actual flow. There are some theoretical values in the table even though there is no measurement because it gives information about the kind of flow certain rain will theoretically induce and if it has happened the day before the measurement, it can still influence the flow.

5.2.2 Shooting range area 2

Table 7 shows the theoretical flow and measured flow from the studied ranges in the area. There were not many measurements made in this shooting range area that could be used in this comparison but the ones that could be used, follow the same pattern as the shooting range area 1. So longer design storms portray the actual situation more accurately.

TABLE 7, Shooting range area 2 theoretical and measured flows

Date	**Rainfall (mm)**	**Design storm, repetition / duration of rain**	**range 1.1**	
			Theoretical flow (l/s)	**Measured flow (l/s)**
3.7.2017	6,5	1 / 1a, 15 min	0,93	0,008
11.7.2017	18,1	1 / 1a, 180 min	0,20	
12.7.2017	6,3	1 / 2a, 10 min	1,20	0,083
22.8.2017	5,7	1 / 1a, 10 min	1,07	
23.8.2017	0		0	0,097

5.2.3 Shooting range area 3

Table 8 show the theoretical and measured flows at shooting range area 3. In this shooting range area, the theoretical flows are much closer to the actual flows than the other two. But still, the longer design storm seem to be much closer to the reality than the short ones that last from few minutes to about 15 minutes.

TABLE 8, shooting range area 3 theoretical and measured water flows

Date	**Rainfall (mm)**	**Design storm repetition and duration of rain**	**Range 3.1**		**Range 3.2**		**Range 3.3**	
			Theoretical flow (l/s)	Measured flow (l/s)	Theoretical flow (l/s)	Measured flow (l/s)	Theoretical flow (l/s)	Measured flow (l/s)
21.4.2017	1,8	1 / 1a, 2 min	3,9	0,01	22	0,03	1,9	0,00
1.6.2017	4	1 / 1a, 5 min	2,5	0,01	14	0,03	1,2	0,00
8.6.2017	5,9	1 / 2a, 10 min	2,2	0,01	12	0,02	1,1	0,00
13.6.2017	9,8	1 / 1a, 45 min	0,8	0,05	4,2	0,010	0,4	0,00
13.7.2017	7,3	1 / 1a, 15 min	1,7	0,06	9,3	0,13	0,8	0,20

5.3 Continuous measuring

The continuous measuring device was installed into a ditch where leachate water is led. It started measurements of water temperature and pH on 3.4.2017 and monitoring of other parameters was started gradually afterwards. The flow measurement started 10.4 and lead measurements were started 6.5.2017. From this data, the effects of different parameters on lead concentration in water, can be observed.

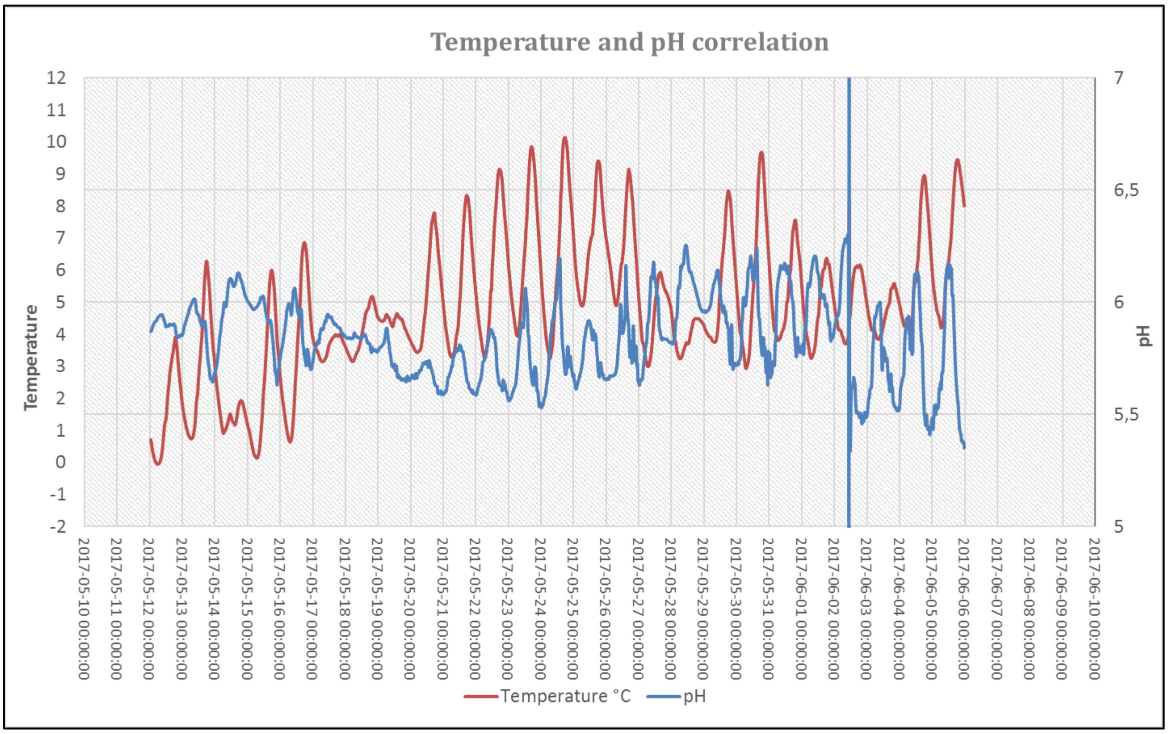
The following graphs represent the data gotten with the measuring device. The data used for these graphs was taken from a period of 6.5.2017 – 6.6.2017 because the effects were the clearest. At 6.6.2017 some maintenance work was started for the device and lasted for several weeks. After the maintenance the measurements did not have especially interesting results. The full graphs can be seen in appendix 2 and 3.

According to the manufacturer, the measuring device can only detect concentrations of over 10 µg/l accurately, but the trend it shows with lower concentrations is still fairly accurate. Also the devices limit of detection is 1 µg/l, which is the lowest lead concentration in all following graphs.

5.3.1 Effect of temperature on pH of the water

The pH of the water is supposedly affected by daylight because of photosynthesis of plants and algae in the water. The photosynthesis accelerates during day, making the pH of the water drop. This trend can be seen in the graph 7.

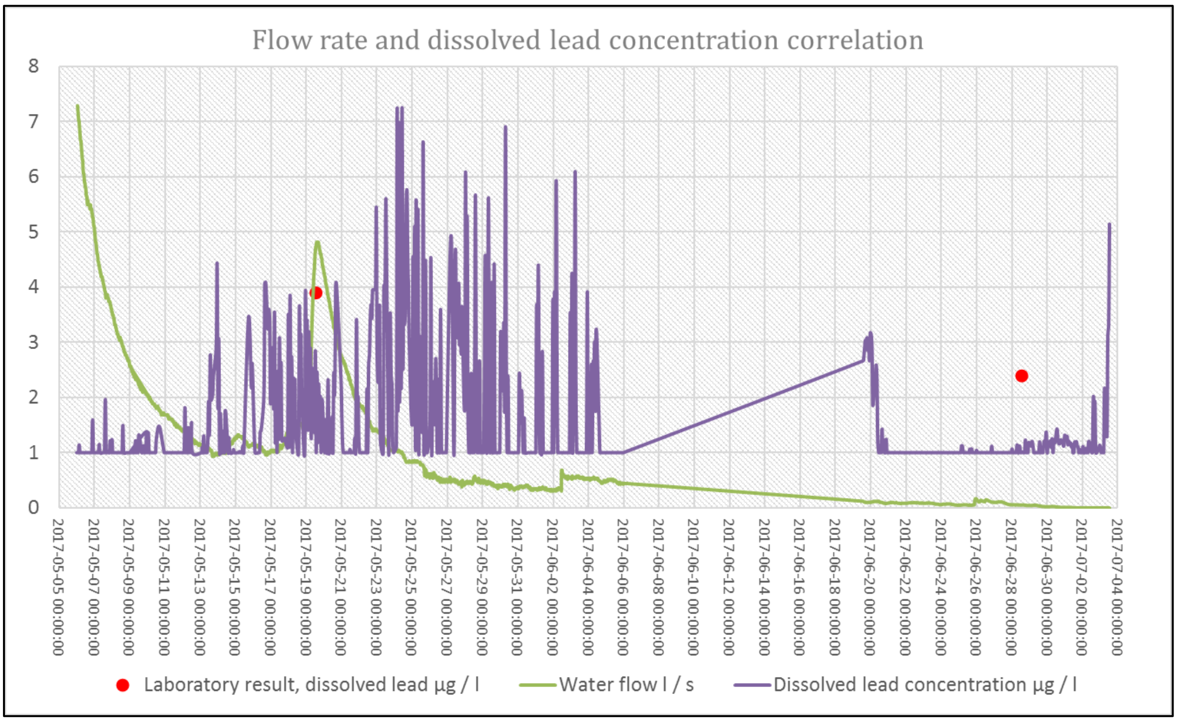
Every time temperature has a peak, which indicates day time, the pH has a peak in the opposite direction with a little delay. Because photosynthesis needs certain temperature to start, the effect could not be observed properly before middle of May. The high peak at 2.6.2017 is some kind of error in the measurement device and should not be taken into account.



GRAPH 5, the effect of daylight on the pH of water

5.3.2 Effect of flow rate to lead concentration

Previous studies made on the subject suggested that the water flow rate would have an effect on the dissolved lead concentration. Data gotten from the measuring device concerning water flow and dissolved lead concentration is shown in graph 8. Also couple of laboratory samples were taken from near the device and dissolved lead concentration from those samples are shown.

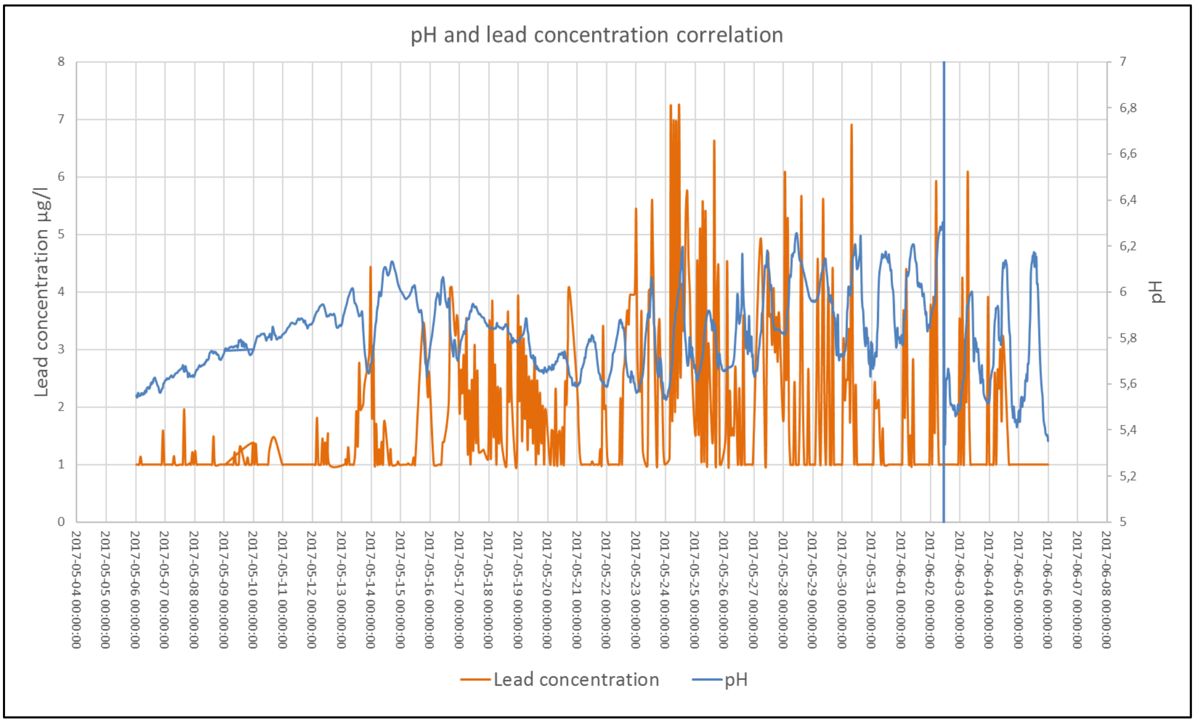


GRAPH 6, effect of flow rate on the dissolved lead concentration

According to the results, flow rate does not seem to have much of an effect on the dissolved lead concentration. Still, the dissolved lead concentration seems to decrease when there was a the peak in flow at 20.05.2017. The lead concentration are very low in the water and the results might be different with higher lead concentrations.

5.3.3 pH level and lead concentration

The premise was that the solubility of lead changes during the day because of the change in pH during the day. Graph 9 shows the change in dissolved lead concentration measured in relation to the pH of the water.

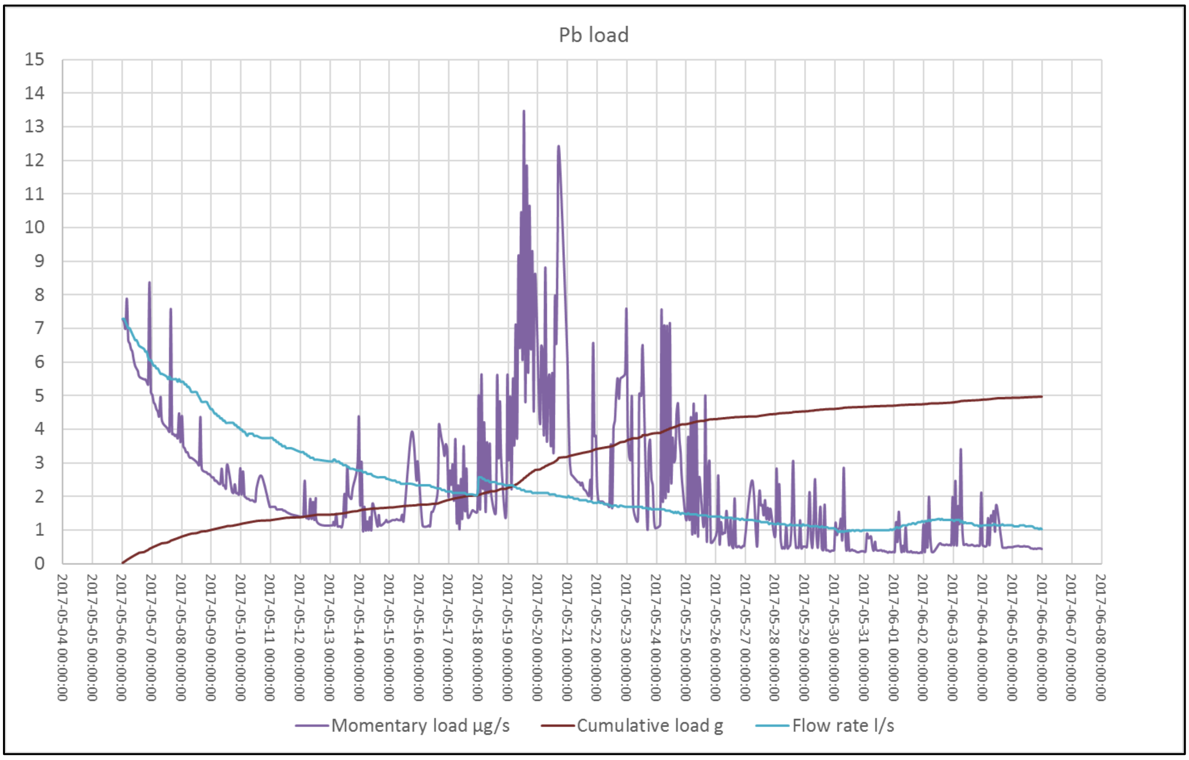


GRAPH 7, effect of pH to dissolved lead concentration

The spikes somewhat follow each other in inverse relation in the graph which indicates that during the day when pH drops lead becomes more soluble.

5.3.4 Lead load

The lead load of the leachate water was calculated by multiplying the water flow with the lead concentration measured by the device. With this the amount of dissolved lead per second is passing the detector. Graph 10 shows the momentary and cumulative load during the measuring period. Also the flow rate is shown in the graph. Only one month period, when the device was operational and logged results constantly, is shown. The whole graph can be seen in Appendix 2.



GRAPH 8, Pb load during the measuring period

The dissolved lead concentration did not change significantly during the measuring period, but the flow did which causes majority of the changes in the load.

6 DISCUSSION

6.1 Water flow measurements

The water flows from the backstop berms are in quite similar proportion (max flow 0,16-0,4 l / h / m^2 and average flow 0,028 - 0,071 l / h / m^2), but there is some variation between ranges in the same range area as well as between range areas. In shooting range areas 1 and 3, there is a pistol range in both and they have quite small backstop berms and by that quite small water management area. Both of these have the highest flow rate per square meter in their area. However, there is even smaller water management area in shooting range area 3 at range 3.3, but it does not have the highest flow rate. Also the average flows that are portrayed in the results can be a bit deceiving because of the variation between ranges, but the scale of the flow still seems to be quite the same within a range area.

Shooting range area 4 does not have any waterproof structures built in the backstop berm and only one water flow measurement could be made from the area. The calculations were made from the amount accumulated in a measuring vessel in a certain period time. The flow is smaller than at the ranges with the waterproof structure. All the calculated flow (min, max, average, median) were a lot lower than any other shooting range area. Although shooting range area 4 is also located in area with lower rainfall and had the lowest total rainfall amount in the measuring period.

Many ranges did not have any water flow even with waterproof structure before the rainfall was big enough, or rain occurred many days in a row. This is probably due to soil saturation, and is very much affected by the soil type and grain size of the soil. The soil first absorbs the water into its pores and when water soil is saturated, it starts to flow through the soil. (Hillel D, 1998) At renovated shooting ranges the top layers of waterproof structures in backstop berms are built from crushed stone material that has high hydraulic conductivity, but there is some differences between different areas.

Shooting range areas 1 and 2 seem to need at least rainfall of 10 mm/day to get actual flow in the system. Shooting range area 3 needs much less and a flow can be detected already with rainfalls of about 5 mm/day. Although there is a suspicion that groundwater might be discharging in the system. Longer periods of time with no rainfall may end up evaporating water in the soil and it takes longer rainy period to saturate the soil again. This can be seen as a difference between shooting range area 1 and 3. Shooting range 3.3 did not have any water flow until mid-July. It is a moving target range and has the smallest water management area of all three ranges in the area. When the flow actually happened in this range, this range had the second highest flow rate.

It seems that the effect of melting waters from snow is very much dependent on the geographical location of the range area. The melting snow does not seem to induce the highest flows in all water managements systems, but it does in one. In shooting range area 2, that is located in central Finland, snow melting caused the highest flows. In other range areas, rainfalls with high intensity seem to have bigger effect, but snow melting still does induce significant water flows. The differences in flows are probably caused by different amounts of snow and frozen ground at different areas in Finland.

The results gotten from the earlier study (Kekkonen J, Setälä J; 2017) same kind of patterns were observed as in this study. For example effects that the heaviest rain did not always cause the heaviest flow were observed. Also the effect that longer rainy periods affect the flow more because the soil is already saturated, were observed in both studies.

6.2 Continuous measuring

The continuous measurements gave some interesting results. It seems that the premise that leads solubility varies during the day, because of pH changes due to photosynthesis by organisms in the water, is valid. pH has been determined to be an important factor in solubility of Pb. Lead seems most stable in neutral pH and drops when pH decreases. (Ruby M, Davis A, Scoof R, Eberle S, Sellstone C; 1996). The relationship between the amount of sunlight and change in pH can be clearly seen in graph 7. The pH of the water varies between about 5.4 and 6,3. The change in pH also seems to have a clear impact on the solubility of lead since the measured lead amounts somewhat follow the change in pH. This effect can be seen in graph 9. The problem with these measurements is that the lead concentration in the water is quite small, and the device cannot detect such small concentration accurately. Because of the devices limitations regarding small concentration this is only indicational information.

The effect of water flow rate to the lead concentration was also one point of interest since there had been some indications in the Defence Administrations previous studies (Houtola; 2017) that higher flow rate would amount to higher dissolved lead concentration. These results do not seem to support that premise since in both laboratory measurements from shooting range 1.1, and the continuous measurement data, the dissolved lead concentration did not follow the flow rate very clearly. The only observable effects were that when the flow rate in range 1.1 was very low, the total lead concentration was significantly higher and some lowering of dissolved lead concentration when flow rate had a peak. Still the dissolved concentration remained quite similar. This effect was observed only in one shooting range where the measurements were made and only in one measurements. It is noteworthy that this is only one study with one measuring point where the dissolved lead concentrations were low to begin with and no ironclad conclusions about the subject can be made.

The lead load in the water was quite low during the measuring period. Still because the trend of the concentration change is real, it seems that the flow rate of water has the biggest effect on the load of the water since the concentration does not change very much during this experiment. One thing to keep in mind is that this device was installed into a ditch where treated water from different ranges discharge.

6.3 Design storm

When thinking about the design storm approach for designing water management systems in shooting ranges, the theoretical flow of longer rains seem to be much closer to the real flow. This might be caused by the fact that the backstop berms do not have a waterproof structure on top of it but instead inside the berm. This means that short and severe rainfall does not cause a flow in the system because the water cannot permeate the soil until the soil is saturated. Also it seems that the theoretical calculations overestimate the water amounts more if the management area is big. So smaller areas and longer rains seem to be more accurate, but still quite far from the actual flow.

6.4 Uncertainty factors

One factor causing uncertainties in this study is the way of measuring. The flow measurements were done only once a day, or few days or a week. This means that the way the water discharges cannot be known and all flow measurements only represent the time the measurement were made. Still, these results do give information about the magnitude of the flow and how certain kind of rainfalls affect the flow rate.

Another factor causing inaccuracies in this thesis is that the rainfall management areas in the backstop berms are only estimates made from the construction plans for the berms. The actual system may have been built bit differently or in different scale. Also the soil type changes between range areas and was not defined before the study, so the capillary volume in the soil is unknown. This means that the amount of water the soil withholds is not known and also changes between the ranges.

The calculations made from the flow measurements have some weaknesses. In some areas, measurements were made more often than in others, which means they affect the average and median results more than others. Also autumn, which is rainy period in Finland, is not presented in the results because of the timeline of this work.

With design storms, the biggest uncertainty comes from the profile of the rains that is unknown. Only the absolute amount of rainfall is known. The profile of the rain is very important factor because the soil can withhold certain amount of water and if the rain has fallen for example in two instances during a day, the soil might have dried between and the capillaries are filled again and the loss to the flow is then double. Also the design storms calculations in this thesis are very simplified because of lack of information about the details about the soil and rainfall. They do not take into account these kind of factors which is one reason why they overestimate the flow.

6.5 Suggestions for following studies

If the amount of water collected by the environmental protection systems at shooting ranges in studied more, there are some improvements to the way of conducting the study.

First of all, the measurement time does not need to be as long as it was now, but more measurements should be made in shorter period and preferably during rain as well as after it. If the water flow would be measured multiple times a day for couple of days during and after a rainy period, a discharge curve could be drawn from the measurements. If water flow is high enough, a continuous flow measurement device could also be used, it would give more exact profile of the flow. This curve would tell a lot about the way water discharges from the berms.

Also the implemented environmental protection systems may vary sometimes a lot from the construction plans. If more accurate dimensions would be studied and the soil type would be defined, it would help assess the way water discharges in other shooting ranges and shooting range areas with similar soil types.

7 CONCLUSIONS

Not all rainfall causes a flow in the water management system. Depending on the range area, 5-10mm rain will induce immediate water flow in the system. Smaller than 5mm rainfall does not seem to cause immediate flow, probably because the water is withheld in the soil and evaporated after rain or it takes longer time to reach the system. Also the waterproof structures seem to work well and range areas equipped with these structures have a lot higher flows than the ones without the structures.

The flow in proportion to the backstop berm water management area, is in same scale in all studied shooting ranges with a waterproof structure in backstop berms. There is some variation between ranges and range areas, but no very significant one.

According to the continuous measuring device results, the water flow rate does not seem to have a clear effect on the dissolved lead concentration. Although the concentrations were very low and effect might be clearer in higher concentrations.

The pH-level of the water in the ditch where the continuous measurements device was installed seemed to change quite a lot during a day, which resulted in more dissolved lead in the water. The variation was measured to be between 5,4 and 6,3, which is a significant variation during short period.

The design storms that are most often used in Finland do not predict the water flow in the water management systems in shooting ranges accurately. Longer design storms are more accurate but it is problematic way of estimating the flow because of the structure of the backstop berm.

The rainfall amounts recorded during the measuring period were quite average. During the 5 months of measuring period, the rainfall amount was about 1/3 to half of yearly average of the area. This means that the data can quite well be used to estimate the water flows during the whole year.

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APPENDICES

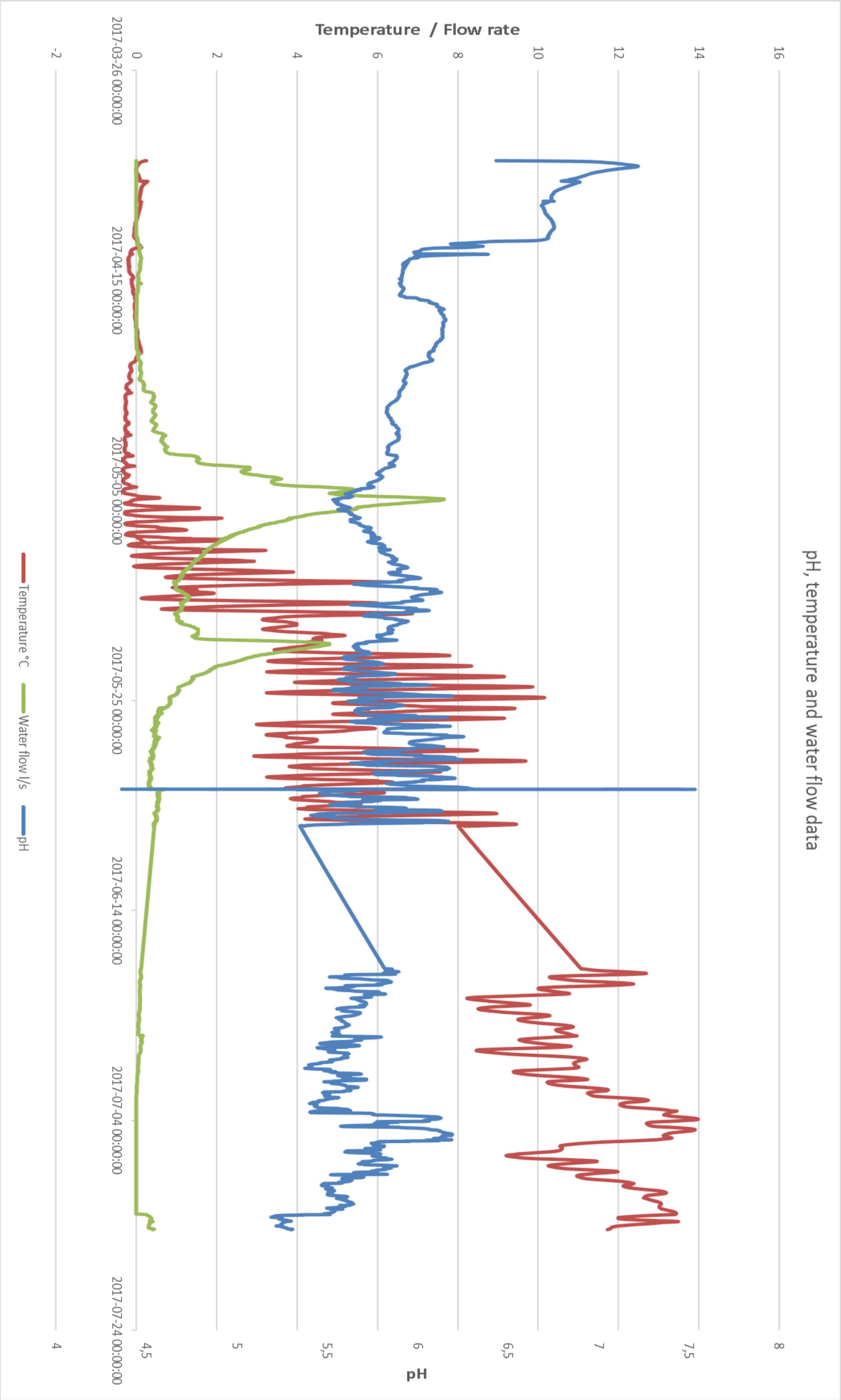
Appendix 1, measurement form given to people doing the measurements

Rata-alue	
Tarkkailupiste	

Ajankohta		Mittaukset								
pvm	klo	Kertynyt vesimäärä (l)	Kulunut aika (min)	V-pato 1 (cm)	V-pato 2 (cm)	Sademäärä (mm)	Lämpötila (°C)	Vesimäärä kaivossa (l)	Näyte laboratorioon (x)	Muut havainnot (sulamisvesiä tms)

V-pato 1 on puhdistusaltaaseen menevä ja V-pato 2 puhdistusaltaasta lähtevä

Appendix 2. Graph with original pH, temperature and water flow data



Appendix 3. Graph of lead concentration from the continuous measuring device