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Drainage of flooded water

-effects on baseflow in Awanui Stream, New Zealand

Anna Thorsell

Abstract

In the Heretaunga Plains area, New Zealand, parts of the low lying land adjacent to the Awanui Stream are flooded annually. The purpose of the study was to find out if the flooding water trapped in the field gets sealed off from infiltrating the soils in any way (and hence is unavailable to replenish the stream flow). What would be the effects on stream base flow if pumping of the flooding water would occur direct to the stream after wet periods and heavy rains?

The method of this project was to investigate the infiltration, soil type and ground water conditions in the field. The infiltration was investigated with the help of a double ring infiltration test, a disc permeameter that measures hydraulic conductivity, and pvc-pipes with core samples were saturated for an extended period of time to find out if there was any kind of seal forming during saturated conditions. The soil in field was sampled and a soil fraction test was performed. The potential evaporation was measured with an evaporation pan and calculated with data from a climate station in field. With flow records from the outgoing drain, potential evaporation and precipitation data a rough water balance model could be created.

The results showed that there is no seal formed in the top part of the soil profile preventing the water from infiltrating. The flooding water is the result of a rising groundwater table, on top of a thick clay layer seven meters down in the ground. Once the flooding water has drained and evaporated away there is nothing wrong with the infiltration rate in field.

There are very fine particles of silt and clay in the top soil that decreases the infiltration rate and can cause a separation of the ground water and the water above land surface.

When the project was finished two recommendations could be given to the landowner to solve the problem with the flooding. The recommendations were to either re-level the field to get the surface water to runoff towards the drains instead of being trapped in the current low parts of the field. Or to dig drains from Horonui Drain and Cambell Drain into the field's low parts and in that way drain the flooding water away.

Keywords: drainage, flooding, infiltration, pumice, peat, Heretaunga Plains.

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Referat

I området Heretaunga Plain, Nya Zeeland, översvämmas årligen delar av det låglänta området kring floden Awanui Stream. Syftet med den här studien var att ta reda på om översvämningsvattnet i fält hindras från infiltration i jorden på något sätt (och kan där med inte bidra till basflödet till floden). Vad skulle effekterna på basflödet i floden bli om översvämningsvattnet pumpades direkt ut i floden efter våtare perioder och större regn?

Metoden för att svara på detta var att undersöka infiltrationen, jordtyperna och grundvattenförhållandena i fält. Infiltrationen undersöktes med hjälp av dubbelring infiltrationstest, en s.k. disc permeameter användes för att undersöka den hydrauliska konduktiviteten och PVC-rör med borrkärnor ställdes under vattenmättadeförhållanden en längre tid för att ta reda på om infiltrationen då skulle förändras. Jorden i fält provtogs och ett kornstorlekstest utfördes. Den potentiella avdunstningen mättes med en evaporationspanna och beräknades med data från en klimatstation i fält. Med flödesdata från diket med utgående vatten, potentiell avdunstning och nederbördsdata kunde en grov uppskattning av vattenbalansen i fält göras.

Resultaten visade att det inte bildas någon hinna som hindrar infiltrationen av vatten i den övre delen av jordprofilen. Översvämningen är ett resultat av en stigande grundvattenyta, som stiger från ett tjockt lager av lera 7 meter ner i marken. När vattnet har dräneras och avdunstat bort är det ingenting som hindrar infiltrationen i fält.

Det är dock väldigt fina partiklar av silt och lera i den översta torvjorden som minskar infiltrationshastigheten och kan orsaka en separation av grundvatten över och under markytan.

När projektet var avslutat kunde två rekommendationer ges till landägaren om hur man kan lösa problemet med översvämningen. Rekommendationerna var att antingen skulle landägaren kunna göra om marknivån i fält för att få ytvattnet att rinna av mot dikena istället för att vara fast i de lägre partierna av fältet. Eller att gräva diken in i fältet från Horonui Drain och Cambell Drain in till de lägre översvämmade områdena i fält för att dränera bort översvämningsvattnet.

Nyckelord: dränering, översvämning, infiltration, pimpstensjord, torv, Heretaunga Plains.

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Preface

This Master Thesis was conducted at the Hawke's Bay Regional Council in New Zealand. It represents the last part of the MSc program in *Aquatic and Environmental Engineering* of 30 ECTS at Uppsala University.

The official supervisors of this study were, Rob Christie, Graham Sevicke-Jones and Gary Clode at the Hawke's Bay Regional Council. The subject reviewer was Allan Rodhe at the Department of Earth Sciences, Uppsala University.

Great thanks to the whole family Ritchie for making this project possible. Especially to Hugh and David Ritchie who have been very helpful during the whole project. Thank you for the support, discussions and for always being there.

Big thanks to Dan Bloomer at PageBloomer Associates Limited for consultation and support during the project.

I also want to thank Dave Horn and Anja Moebis who welcomed me at Massey University, made it possible and helped me to do the soil fraction analysis in their lab.

John de Ruiter, at Plant and Food Research in Christchurch, who provided data from the climate station that was placed in the field.

Thanks to Craig Goodier, at Hawke's Bay Regional Council, who helped me with all my questions regarding GIS.

To Brent Clothier and Karen Mason at Plant and Food Research in Palmeston North who helped me to do the examination of the hydrophobicity in the field and welcomed me into their laboratory. Even though we didn't have much time I am very grateful that you helped me on such short notice.

To all staff at the Hawke's Bay Regional Council for answering all my questions, helping me and making me feel welcome.

Finally I would like to thank Sharon and Hugh Ritchie for welcoming me into their home, again. Thank you so much!

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Populärvetenskaplig sammanfattning

Dränering av översvämningsvatten
– effekterna på basflödet i Awanui Stream Nya Zeeland
Anna Thorsell

I jordbruksområdet Heretaunga plains översvämmas varje år stora delar av det låglänta området omkring floden Awanui Stream. Vissa delar av detta område står under vatten så länge som 6 månader, vilket får stora följder för jordbruket då grödor översvämmas och dör. Det är både en resursfråga och en kostnadsfråga då alla i samhället förlorar på att föda går förlorad.

Om vattnet kunde pumpas nedströms i Awanui Stream strax efter ett större regn, för att förhindra att grödorna dör, skulle mycket vara räddat. Dock fanns misstanken om att detta vatten sakta infiltrerar i marken och fyller på grundvattenmagasinet som sedan håller uppe basflödet i floden Awanui Stream under den torra sommaren. Det minsta accepterade basflödet i Awanui Stream enligt Hawke's Bay Regional Council är 33 L/s, då många näringsidkare är beroende av detta flöde året runt.

Dock ser vattnet ut att hindras från infiltration då vattnet blir stående i fält under en väldigt lång tid utan större förändring. Efter förfrågan av markägare skulle det undersökas varför detta är fallet, och om infiltration sker eller inte.

Studien genomfördes genom att först undersöka infiltration, hydraulisk konduktivitet och markförhållanden. Resultat jämfördes mellan översvämmade och icke översvämmade områden. Potentiell avdunstning, infiltration och flöde i dikena användes för att sätta upp en grov vattenbalansmodell. Förändring av vattenytan i dikena omkring fältet och i stora gropar grävda i fält observerades och loggfördes.

Efter att ha jämfört kartor med satellitbilder och en noggrann topografisk karta med en egen topografisk inmätning stod det klart att det var samma områden som översvämmades varje år och att dessa även var de lägsta punkterna i fält. Efter att med ett pumptest visat att marken var mättad då översvämningsvattnet dränerat undan så pass mycket att det inte var något vatten ovan markytan längre, kunde slutsatsen dras att mättnaden orsakades av en stigande grundvattenyta. Detta bekräftades även av geologisk information från en tidigare borrad brunn, samt en grov vattenbalasberäkning som visade att det fanns mer än tillräckligt med vatten att orsaka denna översvämning då fältet är placerat precis i slutet av ett stort avrinningsområde.

Studien visade att översvämningen inte beror på att en hydrofobisk hinna bildats som avstöter vatten, vilket var en spekulation innan studien påbörjades. Det är en stigande grundvattenyta ovanpå ett tjockt lager av lera som ligger 7 under markytan. Dock finns det fina partiklar i det översta jordlagret som hämmar infiltrationen. Detta skapar på vissa ställen i fält en separation utav vattenmassan då vattnet börjar dränera bort, vilket leder till att vattenpölar ovan jord finns kvar längre än nödvändigt.

Vattnet i fält fyller inte upp grundvattenmagasinen som förser Awanui Stream med vatten under den torra sommaren. När sommaren kommer har marken torkat upp så pass mycket att översvämningsvattnet inte finns kvar för att tillföra något till flödet i Awanui Stream. Detta gör att markägaren kan pumpa bort översvämningsvattnet efter de stora regnen och därmed förhindra att hela skördar dränks. Dock skall man avvakta några dygn med pumpningen efter ett större regn för att minska flödestoppen nedströms.

Det här examensarbetet visar att det med enkla medel går att göra en stor och omfattande undersökning. Resultaten skulle kunna användas till att avgöra om pumpning kan ske i andra översvämmade områden omkring Awanui Stream om man då är medveten om att avrinningsområdet och geologin måste studeras. Resultaten och metoden kan även användas till att snabbare och mer effektivt fastställa översvämningsorsaker i andra områden.

Table of Contents

1. Introduction

In the Heretaunga Plains area, New Zealand, parts of the low lying land adjacent to the Awanui Stream are flooded annually. The land owner and farmer, wants to install a pumped drainage system in order to manage the ponded water and improve conditions for growing crops. Within the immediate area there are a number of water permit holders that rely on the Awanui Stream as water source for the operation of their farming and cropping activities. Additional flooding and conversely reduction in available water supply can have an adverse effect on their farming and cropping activities so it is important that the effects of the land owners pumping proposal are adequately understood. Just as importantly, a healthy aquatic ecology associated with the Awanui Stream depends on an adequate baseflow, and cumulative losses of the supply of water making up the stream baseflow are detrimental.

A pumping proposal that removes floodwater has the potential to remove water from land at a much greater rate than what currently takes place via groundwater infiltration and direct surface drainage to the open waterways. During periods of low flows in the stream, this water is a portion of the total water supply that helps sustain the water resource in the stream. There is a concern that by pumping flood water from properties, water is accelerated through the drainage network resulting in depleted availability of groundwater which contributes to sustaining the baseflow in the open waterways. This may affect the ability of existing water permit holders to take water and affect the aquatic ecology.

The Hawke's Bay Regional Council is responsible for water allocation in the region. It is therefore concerned with activities which may affect the availability of water. Without any indication of the scale of the effects of the proposed pumping, it is difficult for the Council to grant consent. The Council believes that there is a need for some specific study on the effects of storm water ponding on peat ground, if pumping has an adverse effect on the steam flows and if there is a loss to groundwater (and hence stream flows) due to anaerobic sealing. This would then help the Council with better informed decisions and it will also assist local farmers understand some of the complex issues with drainage of similar peat areas.

The study was done because of concerns with the effects on low flows in the Awanui Stream, if pumping occurs. The drain on the north-east side of the field is the Cambell Drain and on the south-west side there is the Horonui Drain.

In the field the soil profile consists of a top layer of peat soil that is about 20-30 cm thick across the field. Underneath that peat soil there is a very fine pumice soil, deposits from volcano eruption. The latest eruption of the Taupo volcano took place 1800 years ago. The deposits of ash and pumice settled in major rivers and valleys of the central North Island, (Froggatt 2010). The thick layer of pumice in the field is due to further deposits when the pumice and ash have been washed into the valley by the Ngarouro River.

The purpose of the study was to find out if the flooding water trapped in the field gets sealed off from infiltrating the soils in any way (and hence is unavailable to replenish the stream flow). Or if no seal is formed, why is the field flooded during this extended period of time? What is the reason that the water has a difficulty getting from the field into the drains? What would be the effects on stream base flow if pumping of the flooding water would occur direct to the stream after wet periods and heavy rains? Can the results of this study be applied in other parts of the Heretaunga Plains?

2. Description of the area

2.1 Location

The area under investigation is located on the middle-east cost of New Zealand's north island, in the region Hawke's Bay, just south east of the city of Hastings (Figure 1 and Figure 2).

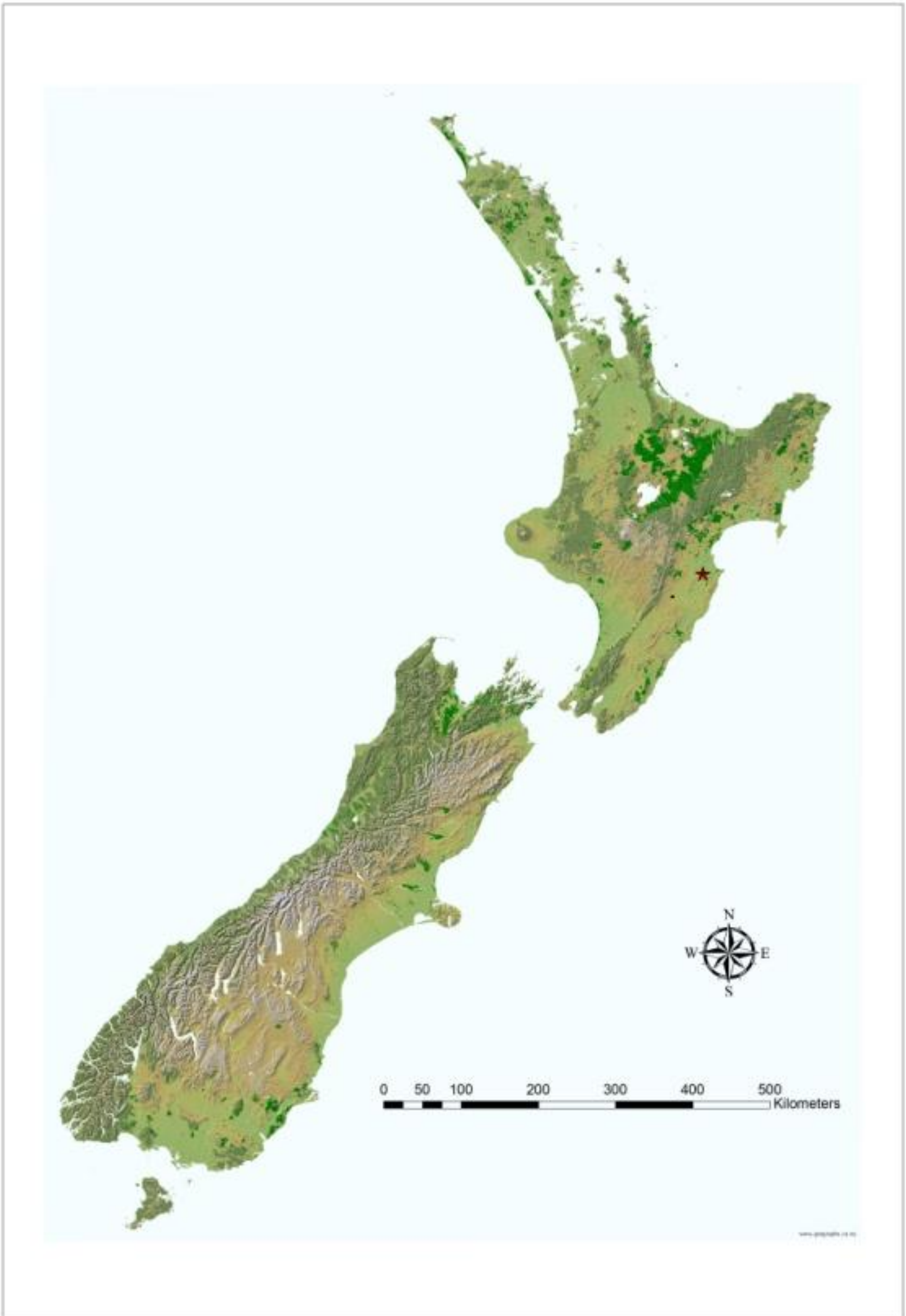


Figure 1: Map over New Zealand.

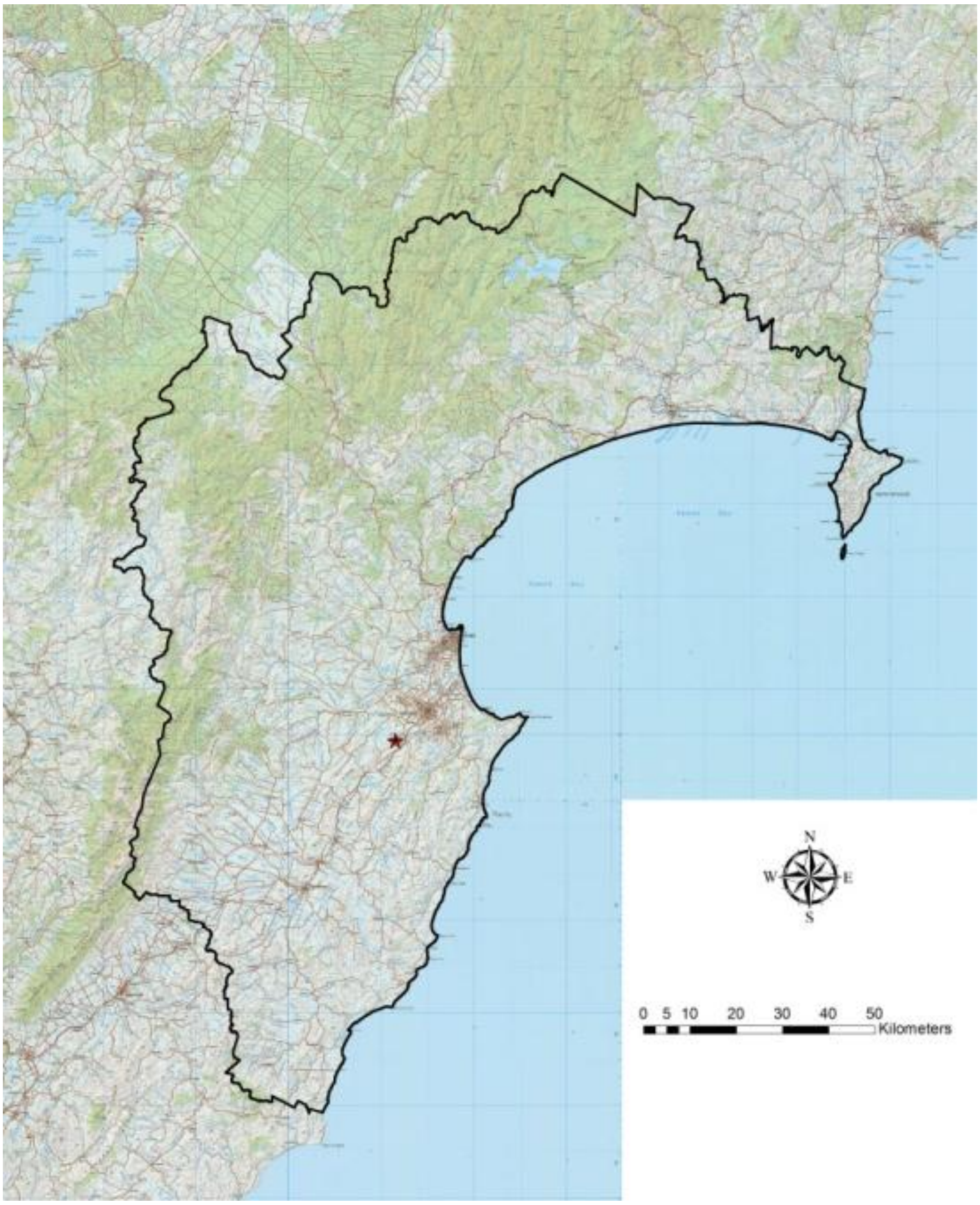


Figure 2: Hawke's Bay region.

2.2 Climate

Hawke's Bay has a generally dry and warm climate because it is sheltered on the west by the North Island's main mountain ranges. The region has 2,100–2,200 hours of sunshine each year, and the Heretaunga plains, which is the location of the study area, have even more. In summer the maximum daytime temperature is usually 19–24°C. In winter, which is cool but mild, the daily maximum is 10–15°C (Te Ara, 2010).

Rainfall is highly variable – summer can have droughts or heavy rains. The year of 2010, the year of the project, was a relatively dry year but with a very wet winter, with a total of 883 mm of rain, measured by the climate station in field between 23 January 2010 and 31 December 2010. In summer over the week end of 21 to 24 of January 2011 there was a very heavy rainfall of 156 mm, which caused ponding to occur on the study field. In winter Hawke's Bay is subject to cold southerly winds.

Data over precipitation in the area and flow in Awanui Stream are presented in charts Figure 3 and Figure 4. The precipitation data is recorded from a climate station placed in the field, by Plant & Food Research. The precipitation was logged from 23 January 2010 to 27 January 2011 (Figure 3). The flow is recorded continuously on the Awanui Stream in 15 minute intervals. Figure 4 shows the daily mean flow record for the Awanui for the period 1 Jan 2010 to 31 Jan 2011, with a maximum flow of 6600 L/s on the 2 June 2010, and a minimum flow of 35 L/s on the 20 January 2011. Minimum flow rate in Awanui Stream according to Hawke's Bay Regional Council is 120 m^3/h = 33 L/s

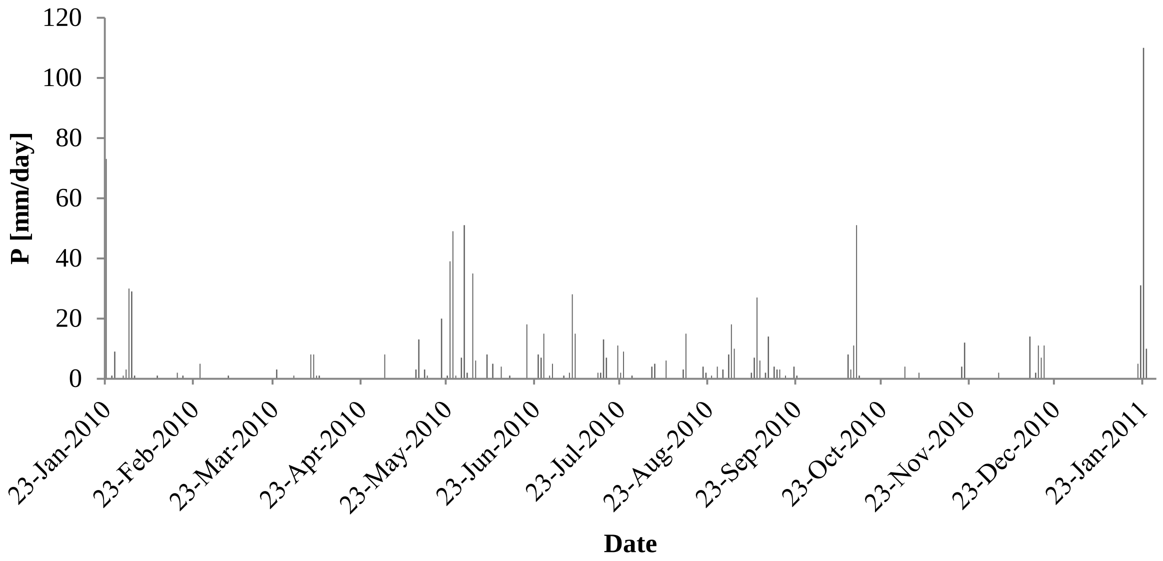


Figure 3: Precipitation in the field from 23 January 2010 to 27 January 2011.

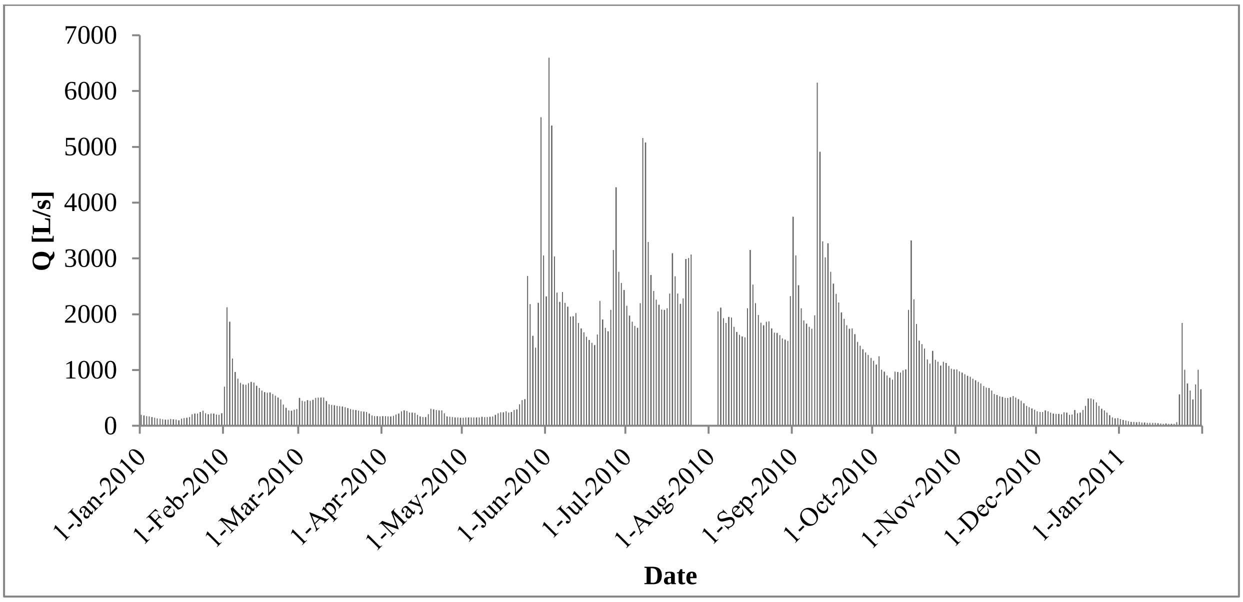


Figure 4: Flow rate in Awanui Stream from 1 Jan 2010 to 31 Jan 2011.

2.3 The field

The field is used for agricultural purposes and is placed in a valley with limestone hills surrounding it on both sides (Figure 6). Yearly flooding occurs in three main locations and lasts for a very long time; in 2010 the study area was flooded from May to October. After the field had dried up in October

2010, the flooding re-occurred after a heavy rain in January 2011. On each side of the field there are small drains that join up downstream with the Awanui Stream. This stream has important drainage and ecological values that need to be maintained and enhanced. Any loss of water feeding into the stream needs to be carefully managed to avoid water shortage problems downstream during dry periods.

The elevation map over the catchment, Figure 5, was obtained from the Hawke's Bay Regional Council's GIS files. The catchment area is 11.67 km^2.

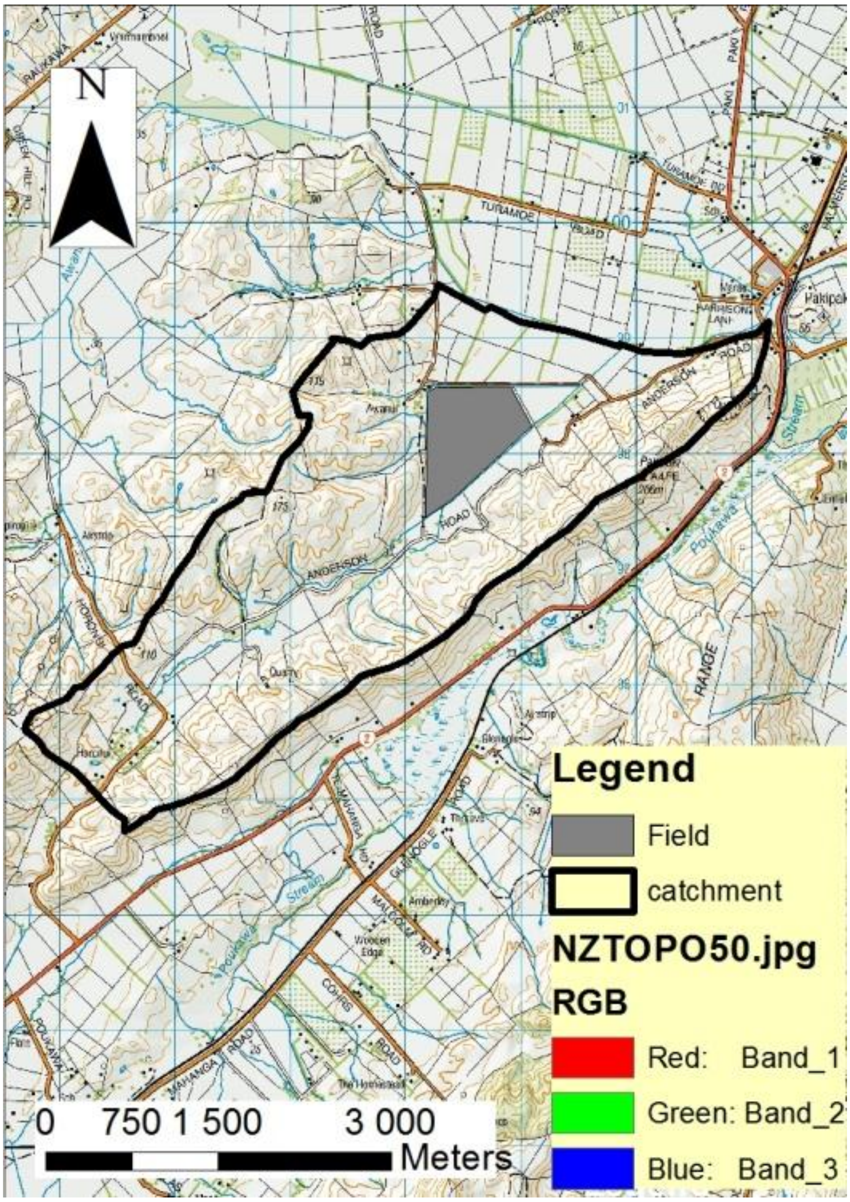


Figure 5: Map over catchment area.

2.3.1 Well

A well is located by the north-east side of the field. It is used to supply the irrigator for the field and water troughs in the surrounding area. A bore log was available from Hawke's Bay Regional Council and is shown in Appendix B. According to that bore log the geology in the area can be described as;

1.) 0 m to -0.5 m; top soil (peat)

2.) -0.5 m to -7 m; fine pumice

3.) -7 m to -36.5 m; different types of clay

4.) -36.5 m to -40.3 m; gravel and sand (this is where the water intake for the well is)

5.) -40.3 m to unknown depth; clay

The gravel/sand aquifer is confined with a pressure level, as observed in the well, above the ground surface.

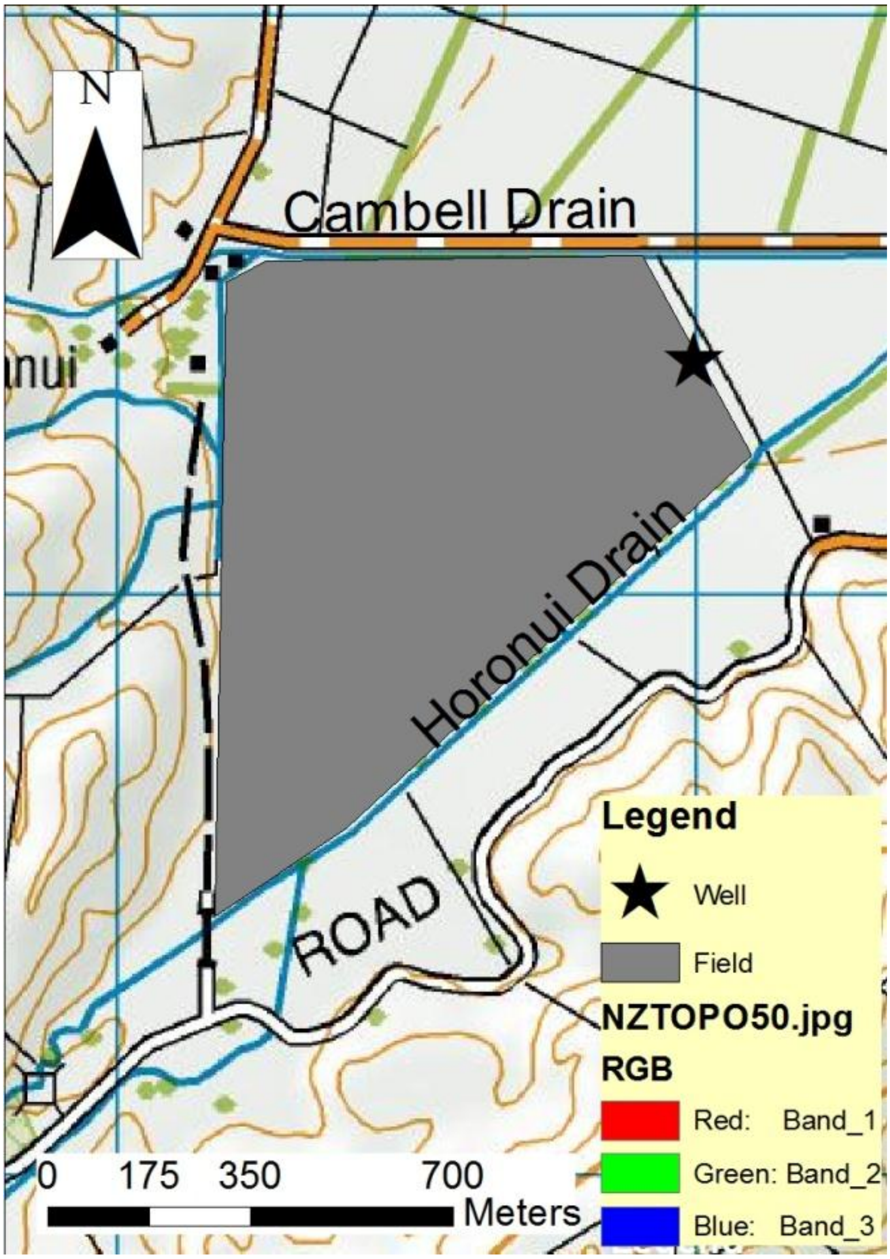


Figure 6: Map showing the field that is studied with, the topography for the area surrounding the field, location of drains and well.

3. Methods and models

To establish if there was any kind of seal formed in the soil profile the project started with studying the soil in the field. The soil profile was examined by observations in a grid pattern across the whole field. Soil samples were taken and a soil fraction test was performed to classify the soil types and to try to see if there was any difference between the soil in the flooded areas (wet) and the non-flooded (dry) areas. A satellite picture over the field was compared to photographs and a LIDAR map to study the location of the ponded areas. A level survey was performed to find out the accuracy of the LIDAR map. To establish if water infiltrates in the ground or not, a rough water balance study was made in field along with infiltration, hydraulic conductivity, compaction, soil moisture and saturation tests.

Plant and Food Research had a climate station placed in the study field. Data from that climate station was used to calculate potential evaporation in the study field for the water balance study. To back up the data from the climate station an evaporation pan was built to measure the potential evaporation, and a rain gauge was set up. The water balance study also included monitoring of the water level at different locations in the field. By measuring volume loss in one of the last puddles in field calculations could be made to find out if evaporation was the only factor that decreased the water level of the ponding water in field.

As the project developed a bore log, for the pump providing the field with water was used to get information about the geology in the area. A soil hydrophobicity test was made due to the fact that there were suspicions that the soil in field might repel water.

3.1 Soil analysis

The soil analysis was made in the purpose of getting as much information about the soil profile as possible. A previous study (Griffiths, 2001) was used and samples were taken to do a soil fraction analysis test at the laboratory at Massey University.

3.1.1 Previous study

A previous study, Soils of the Heretaunga Plains, was made by E. Griffiths and published by the Hawke’s Bay Regional Council in 2001 (Griffiths, 2001). An extract of the characteristics of the soil in the study area from that study is presented in Table 1.

Table 1: Characteristics of the soil in the study area (Griffiths, 2001 with permissions).

Table from Soils of the Heretaunga Plains	
Soil properties	
Parent material	Peat inter layered with alluvium from greywacke and pumice on Taupo pumice alluvium.
Characteristic site and soil feature	Swamp with peat inter layered with ashy loam (peaty ashy loam) on compact impermeable Taupo pumice alluvial silt and sand
Natural drainage and depth to gley	Very poor
and hence to water table after wet periods	0 cm
Potential rooting depth, texture and limiting layer and limiting layer	30-60 peaty ashy loam on Taupo ashy sand and silt
Available water capacity (AWC)	50-100 mm
Infiltration rate	Slow
Permeability rate	Slow to very slow
Susceptibility of soil to ploughing and compaction when wet	High
Susceptibility to wind erosion when dry	Very high
Unfavourable soil characteristics	Dry peat susceptible to wind erosion slowly permeable peat layers slowly permeable ashy silt Low pH - acid

Soil management

Artificial drainage is recommended in the area. Water table must not be lowered too much because peat will dry out and oxidize, which will lead to lowering of ground surface. To prevent compaction and wind erosion, cultivation of the soil is recommended when the soil is moist (Griffiths, 2001).

3.1.2 Grid for surface and soil observations

To get and good view of how the soil profile varies through the field a grid was made up, with 100 meters between the grid points. There were altogether 50 grid points (Figure 7). Each point was logged with GPS, and later on transferred into a Geographical Information System (GIS) to display location on the map. At each point the soil profile was examined. Conditions on the surface, depth and colour of the peat, structure of peat and pumice and amount of roots and earth worms were logged. The data for how the thickness of the peat layer varies is shown in Appendix C.

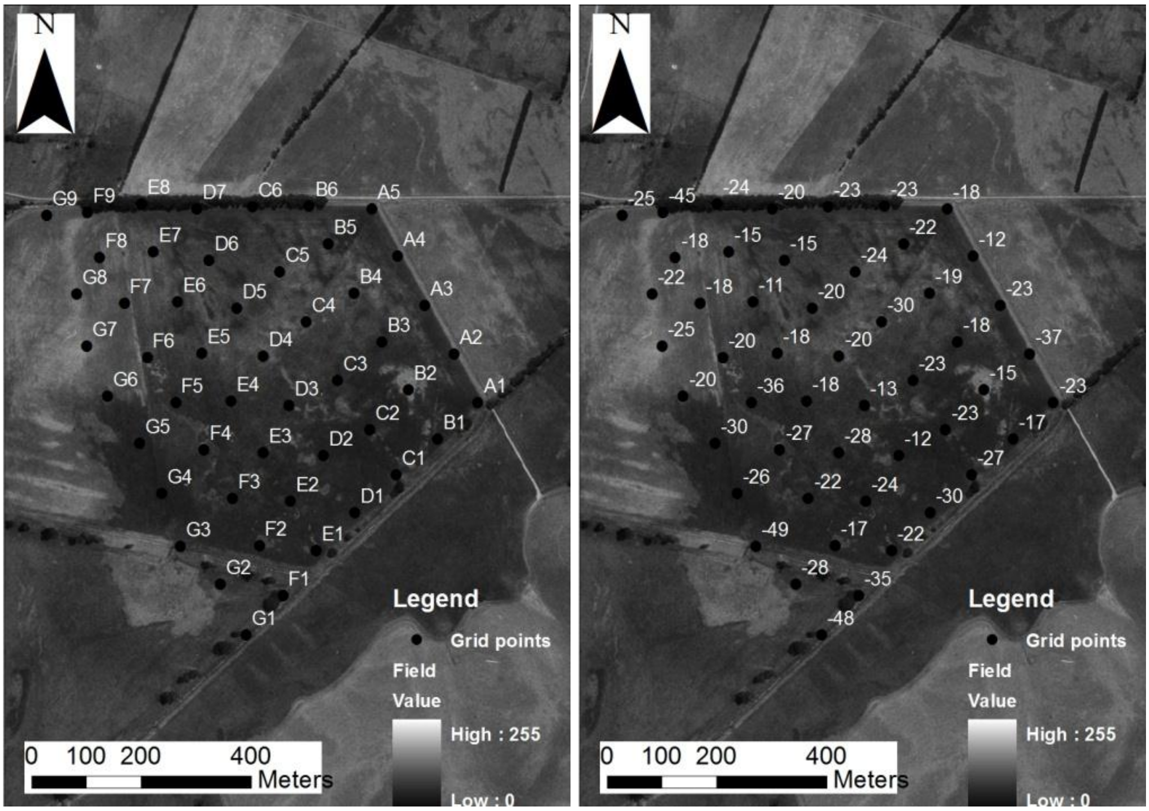


Figure 7: Grid points in the study area.

The information from the grid gave a good base knowledge of the conditions in the field, how the peat layer varies in thickness, and how the soil changes closer to ponded areas.

A soil profile picture from the field, showing the peat layer that is 20 cm thick and then the pumice soil with a coarse layer about 40 cm down in the ground is shown in Figure 8.

Figure 8: Soil profile in field.

3.1.3 Background of peat and pumice soil

Peat

The peat soil in the study area is a black soil with a high content of organic matter. The organic matter consists of decomposed plant materials, and was formed by decomposed plants and has accumulated since the volcano eruption almost 2000 years ago.

A soil is classified as a peat soil by the NZ Generic Classification as an organic soil that have horizons that consists of organic soil material and, within 60 cm of the soil surface, is either;
(i) at least 30 cm thick and entirely formed from wetland plants that have accumulated under wet conditions
or
(ii) at least 40 cm thick and is formed by partly decomposed or well-decomposed litter.

Mineral soil material is commonly present, but organic soil material is dominant (McLaren and Cameron, 1996).

According to the observations that were made when studying the soil profile in the grid pattern, does the peat layer in the study area vary from 11 to 49 cm. The soil in the field is therefore classified as both (i) and (ii) (NZ Generic Classification), but because of the high content of organic matter it is classified as a peat soil.

The organic soils are subdivided into groups, where one group is called *soilgenous* (rainfall supplemented by groundwater flow). They are commonly formed in valley basins or areas with a high water table. This soil can be relatively fertile, especially if fed by water flowing through rocks with a high content of basic cations (McLaren and Cameron, 1996). The peat soil in the study area can be assumed to be a soilgenous peat because of the two reasons that;

- The valley in the study area is surrounded by limestone, which will make the water flowing through the catchment area towards the field rich of Ca^{2+}-ions.
- The rich supplement of water in the field.

Because of the high fertility in the soil cropping opportunities for the area are very important for the land owner.

The porosity percentage in peat soil may be 92% (Shaw, 1983).

Pumice
A pumice soil is in the NZ Soil Classification described as soil that is dominated by pumice or pumice sand with a high content of natural glass (McLaren and Cameron, 1996). Pumice soils occupy a large area of the central plateau of the North Island, centred around lake Taupo. They are from the volcanic deposits erupted at intervals between 700 and 3500 years ago.

No value for the porosity of the pumice in the Heretaunga Plains could be found.

3.1.4 Soil fraction analysis

The purpose with this test was to compare the amount of very fine particles between an area that had been flooded for an extended period of time (wet) to an area that had not been flooded (dry). Before the test was performed the expectations of the test result was that the soil from the area with flooding problems would have more fine particles due to dust and lose particles being transported from the dry areas to the wet areas with the runoff water. Another source of fine particles was dust from the surrounding areas being blown and deposited in the field.

To improve the comparison between the samples from the two areas, investigations were made to find spots where the peat layer was of the same thickness. Figure 9 below shows where the samples were taken and the thickness of the peat layer was 20 cm at both of these places.

Two core samples were taken in the field; one from an area where there have been problems with ponding water and one from an area where no ponding problems have occurred.

The core samples (Figure 10 and Figure 11) were taken with pvc-pipes, with an inner diameter of 5 cm. They were hammered down in the ground with a sledge hammer and then the surrounding soil around the pipe was removed and the intact core sample was collected inside of the pvc-pipe. To protect and keep the samples as intact and undisturbed as possible the pipe was sealed with plastic in the bottom end and a plug of paper towel was pushed into the top of the pipe. Slots were sawed on two sides of each pipe to enable easy opening and examination of the samples at the lab.

Soil fraction analysis was carried out in the soil laboratory of Massey University by using wet sieving for grain sizes >63 µm and a pipette analysis for grain sizes <63 µm.

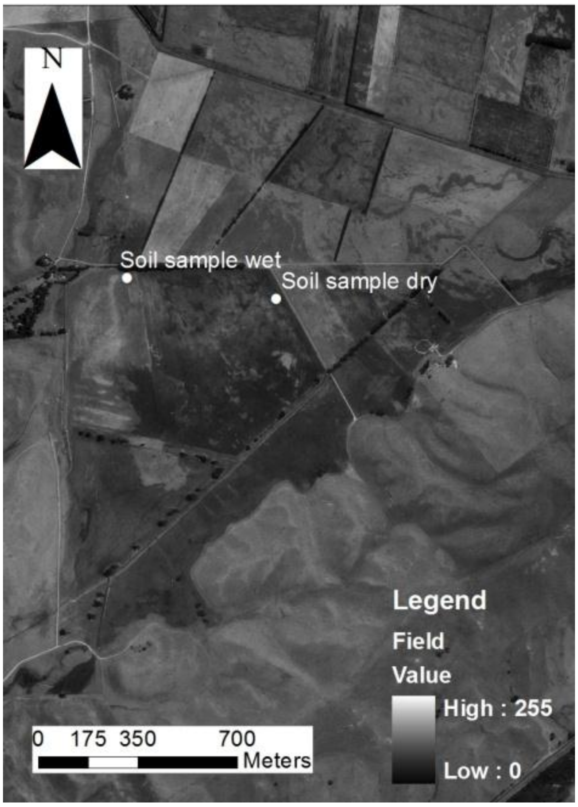


Figure 9: Location of soil samples for fraction sizes.

In the laboratory each core was split up into two samples; the top 10 cm and bottom 10 cm of the peat layer. The samples were named; Wet top, Wet base, Dry top and Dry base.

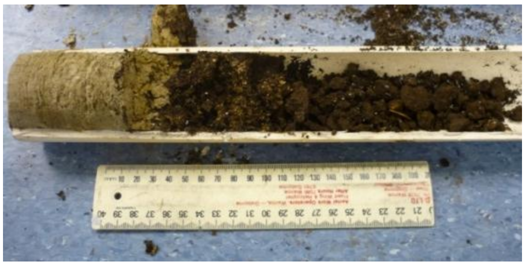


Figure 10: Core of soil sample "Dry".

Figure 11: Core of soil sample "Wet".

As noted above the pumice in the profile derives from the volcanic eruption in Taupo almost 2000 years ago. This gives us the information that the peat layer is accumulated soil and broken down organic matter over a period of 2000 years.

Analysis of organic matter

The samples were split up into 600 ml beakers and placed in a fume cupboard. Hydrogen peroxide (H_2O_2) was added to break down the organic matter in the soil. The reaction between the hydrogen peroxide and the organic matter results in heat and bubble development. The intensity of the reaction relates to the amount of organic matter, where a stronger reaction indicates more organic material. To settle down the reaction if reaction gets too strong Octan-2-ol ($C_8H_{18}O$) is used. When the worst reaction has settled, heat can be applied to speed the process along. The samples were kept in the fume cupboard, with a heat source and hydrogen peroxide added a few times per day, for three days to be certain that all the organic matter had been broken down.

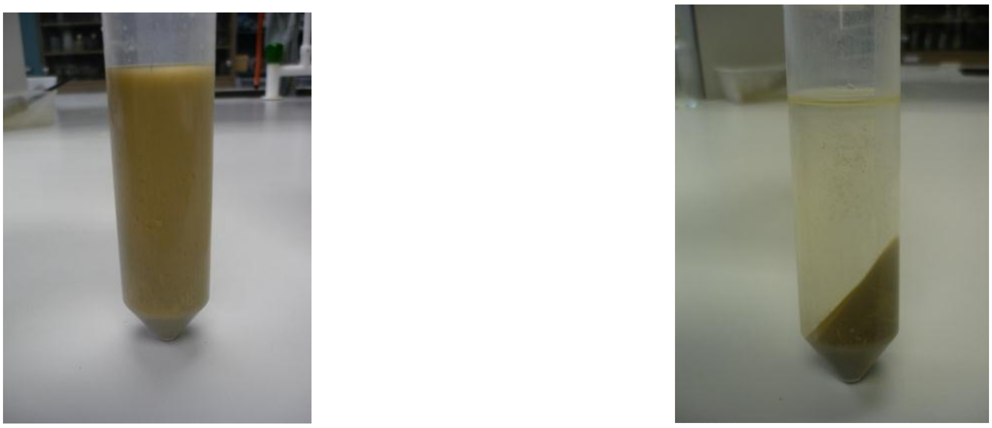


Figure 12 a): Soil sample before centrifuge. **b) Soil sample after centrifuge.**

To separate the soil sample from the hydrogen peroxide solution the samples were centrifuged at high speed, and the solution could be poured off (Figure 12).

Wet sieving

When all of the organic matter in the soil samples had been removed, were the samples sieved through the half phi sieve system, where the sieves let through the fraction sizes of 2 mm, 1.4 mm, 1 mm, 750 µm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, 90 µm and 63 µm. The fraction sizes were collected into small beakers and oven dried to be weighed.

Pipette analysis

The particle size determination method that is called the Pipette Method was used to determine the quantity of each of the fraction sizes that was <63 µm i.e. the silts and clays.

The method is a settling method that is based on Stoke's Law, where denser and usually larger particles sink faster than less denser and usually smaller particles. Two assumptions are taken for this method; all particles in the sample have the same density and all particles are spherical, even though it is known that neither of these assumptions can be true in reality.

The procedure of the pipette method followed directions from the Earth Science department at Indiana University (Particle Size Determination) and can be found in Appendix D.

The gaps in between the time steps in this chart are bases on the phi-system, and because the half phi system was used to determine the quantity of fractions from >2 mm to >63 µm, calculations were needed to establish the times to withdrawal samples with the half phi system.

Calculations of half phi steps

The withdrawal times from the phi time step chart were plotted in a chart and fitted to a power trend line. The equation of the trend line $y = 46699x^{-1,729}$ with an R^2 value of 0.9948 was used to determine the sampling time y [s], from the known fraction size x [µm].

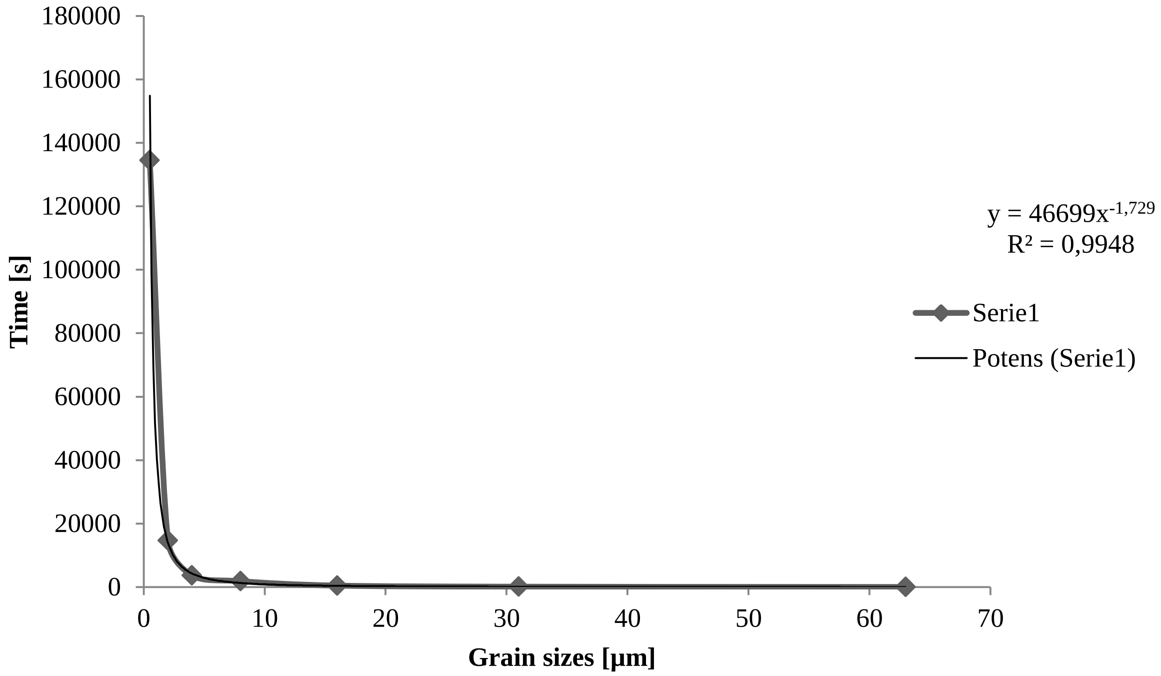


Figure 13: Withdrawal times Pipette Method.

When the grain sizes from 2 mm to 0.5 µm had been seperated, dried and weighed the program GRADISTAT, Version 4.0 (Blott and Pye, 2001) was used for analysis.

3.2 Locating ponding areas

To determine where in the field the ponded areas were located, four different methods were combined.

1. Mapping an image from Google Maps, showing the flooded areas on a satellite picture, in GIS using the Georeferencing tool.
2. Photographs from a nearby hill to get overview pictures throughout the time and where the ponded areas are located and how they change.
3. Using the LIDAR map with 100 mm contours to locate the lowest spots in the field.
4. A four section level survey to be sure that the contours in LIDAR matched the levels out in field.

3.2.1 Google Maps

A satellite picture from Google Maps (Figure 14) was used as one of the methods of locating the ponding areas. The picture was taken 25 October 2009 and shows areas of ponding water in the field. The purpose of using Google Maps was to see if ponding seems to occur in the same places every year.

Figure 14: Image from Google Maps.

3.2.2 Photographs

From a marked place on a nearby hill overview photographs was taken of the area during various stages of the ponding. This made it easier to get an idea of how large the ponding body of water was and how it changed over time. At a marked place on the hill a tripod and a digital camera were used to get the photographs as much alike as possible. Figure 15 shows placement of camera and Figure 16 shows one of the many pictures that were taken. The purpose of this method was to get a good view at placement and area changes of the ponding water.

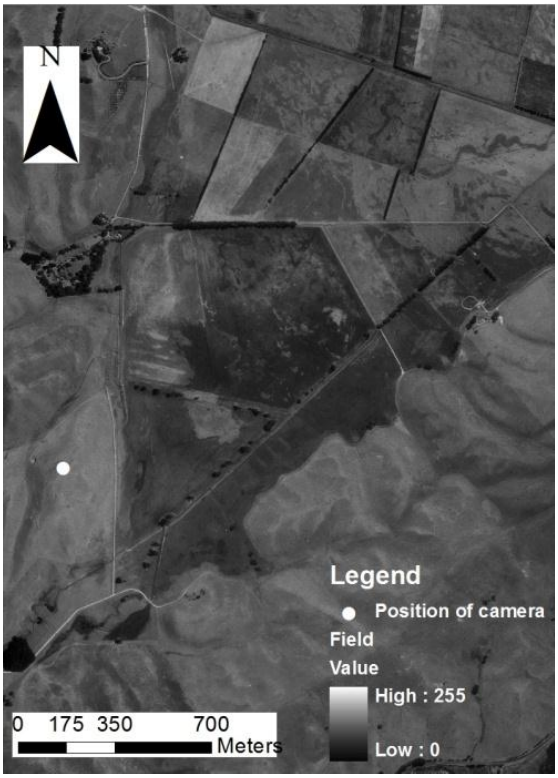


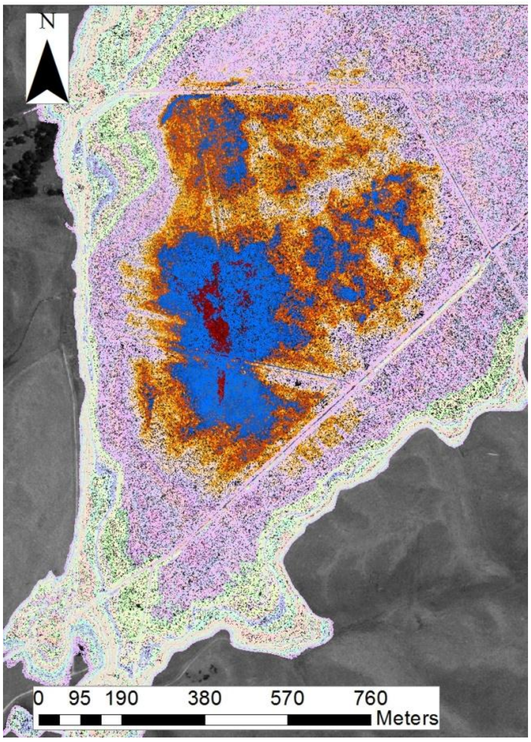
Figure 15: Position of camera for overview photographs.

Figure 16: Overview photograph.

3.2.3 LIDAR

Light Detection and Ranging (LIDAR) (Hawke's Bay Regional Council, 2003) is a remote sensing system used to collect topographic data. These data are collected with aircraft-mounted lasers capable of recording elevation measurements at a rate of 2,000 to 5,000 pulses per second and the map that was used in this project has a vertical precision of 100 mm, i.e. a new contour is drawn for every change of 10 cm in elevation. The elevation value of zero was set to 10 meters below sea level to avoid handling negative elevation.

When comparing the LIDAR map, Figure 17, the overview photographs and the picture from Google Maps it was clear that it was always the same areas that got flooded. These were areas that according to the LIDAR map were the lowest parts of the field. But because the LIDAR map was created in June 2003, it was not known what the conditions in the field were then, or what kind of crop that was growing in field at that time. To find out if that would have an impact on the contours, a level survey was used to confirm the accuracy of the LIDAR. Conventional survey cross sections were carried out in this survey. The cross sections cut through the flooding areas and could be compared to the LIDAR map. This is described below.



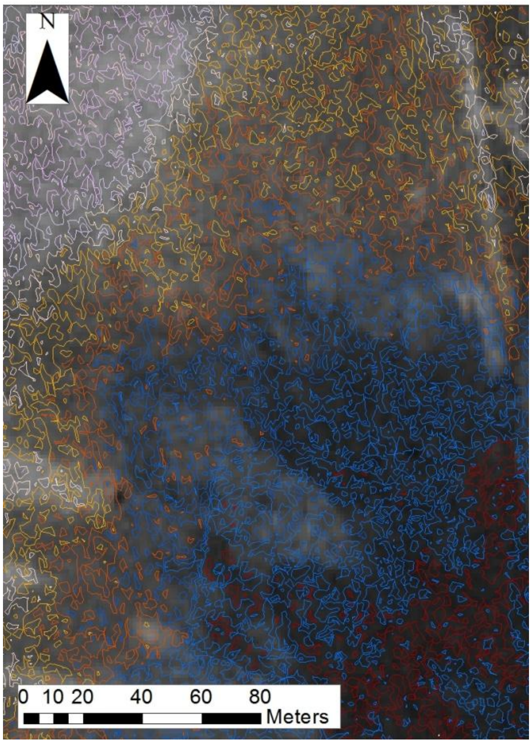


Figure 17: a) LIDAR map over the field. **b) Close up image of LIDAR map.**

3.2.4 Level survey

To establish the accuracy of the LIDAR map, a level survey was carried out in four cross sections over the field, Figure 18. The start and end points of each cross section were marked by using a GPS, and could therefore be related to the LIDAR map in GIS. Additional survey was carried out to pick up low spots in the field that the cross sections did not cut through. The level of the ponding water in field, the water table in the pits that were dug in field and the water level in Cambell and Horonui Drain were also included in the survey. With that information could a section of the water table between the drains be created.

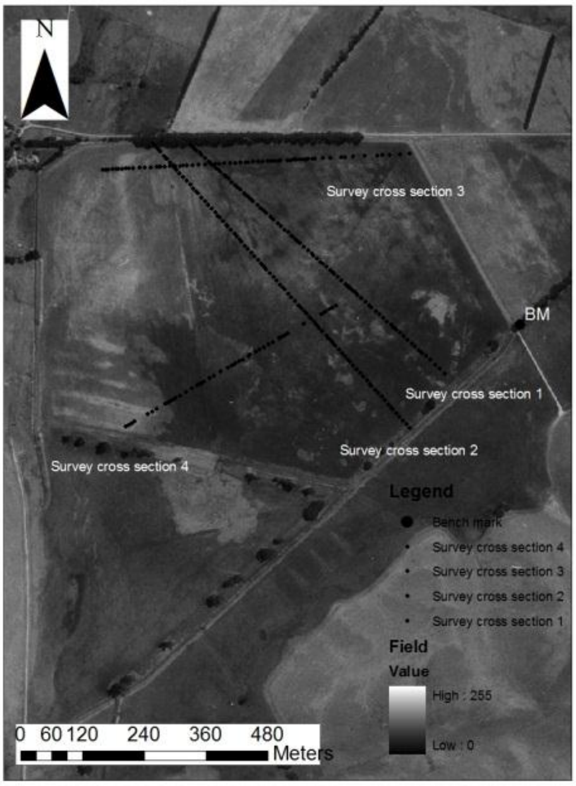


Figure 18: Cross sections for level survey.

3.2.5 Analysis of ponded areas

The Google Maps image, the level survey and the LIDAR map were compared to locate the exact position of the ponding areas, to establish if the flooding occurs in the same places every year and if the flooded areas could be related to the elevation in field. If the level survey also would show that the contours of the LIDAR map could be related to the present conditions in field, would the LIDAR map be a very good elevation map over the area.

3.3 Soil infiltration

To establish if the ponding water infiltrates in the ground at all or if there is something obstructing the infiltration, four different infiltration and soil tests were carried out. The purpose of the double ring test was to find out if there was any difference in the infiltration between the dry areas that never had been ponded and the ex-ponded areas that had been ponded from May to October 2010. The purpose of the Disc permeameter test was to find out if the water was infiltrating and if the infiltration was different at different levels in the soil profile. A Nuclear densometer test was carried out in the purpose to find out if the compaction of the soil was obstructing the infiltration, and if there were a drastic change in soil moisture in the top part of the profile. The Hydrophobicity/Water repellency test was carried out based on observations in field and because there was a suspicion about hydrophobicity before the project started and.

3.3.1 Double ring infiltrometers

Double ring infiltrometers (Figure 19) were used to measure the infiltration in field. This was done after the water had drained away and did not flood the field. The purpose of this test was to compare the infiltration rate between three different places in field: the lowest point in the field, the spot where the water drained away last, and a dry area where no ponding problems had occurred.

The tests were therefore divided into three groups;
Low; The lowest spot in field (according to both LIDAR map and level survey). Eight successful tests were logged.

Dry; A dry area in the field that had not been flooded over an extended period of time. Ten successful tests were performed.

Last; The area where the water drained away last in the field. A theory at this point in the project was that the problem was a rising water table. Therefore the decision was made to measure the infiltration in both the lowest part of the field and the part where the flooding water stayed the longest. Four successful tests were made.

Using the double ring infiltrometer is a way of measuring saturated hydraulic conductivity of the surface layer, and consists of an inner and outer ring inserted into the ground. Hydraulic conductivity can be estimated for the soil when the water flow rate in the inner ring is at a steady state (Miller, 2010).

The test can be done with both a single and a double ring. A double ring was used in this project to eliminate sideways water flow in the soil and only measure the vertical infiltration.

The annular space between the outside and the inside ring is kept filled up with water during the test. Sideways infiltration is minimized if the soil outside of the inner ring is saturated. The test starts when the inner ring is topped up with water. Inside the inner ring there is a marked line 40 mm down from the top. Every time the water level in the inner ring reaches that line, the time is logged and the water topped up again. The hydraulic conductivity is reached when the infiltration rate stabilises at a steady rate.

Figure 19: Double ring infiltrometer.

3.3.2 Disc permeameter

The hydraulic conductivity was assumed to vary in the peat layer depending on whether it was measured in the dry or the wet area. Because it was the same fine pumice throughout the whole profile in the field it was assumed that the hydraulic conductivity in the pumice layer was quite homogenous.

A disc permeameter (Figure 20) was used to measure the hydraulic conductivity in four layers (Figure 21) of the soil profile and compare an area that had been ponded (wet) to an area that had not been ponded (dry).

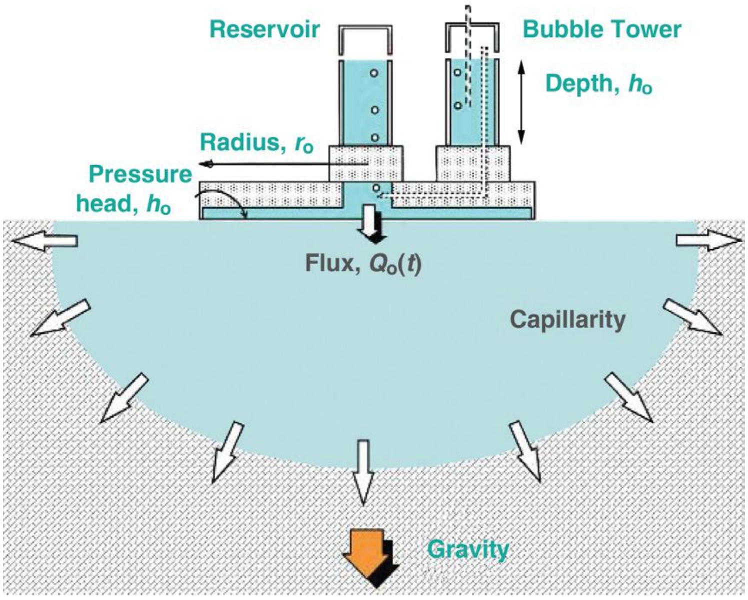


Figure 20: Disc permeameter.

The disc permeameter consists of a disc that has a filter cloth that is attached by use of a rubber band to seal off around the disc. The concept of the disc permeameter is that a head h_0 is set in the bubble tower by adjusting the pipes. When the disc permeameter is placed on fine sand that is the contact material between the disc and the ground, suction is created and the permeability can be measured by logging the water drop in the reservoir. The pressure heads that were used were; -100 mm, -40 mm and -5 mm. The higher the head is the easier is it for the water to infiltrate in the ground.

In field the disc permeameter was used to measure the hydraulic conductivity at the locations wet and dry, and in the purpose of finding out how the hydraulic conductivity varies by depth in the soil profile measurements were performed at four different levels at each measuring spot (Figure 21).

1; surface layer, top of the peat
2; middle of the peat layer
3; top of pumice
4; down in pumice

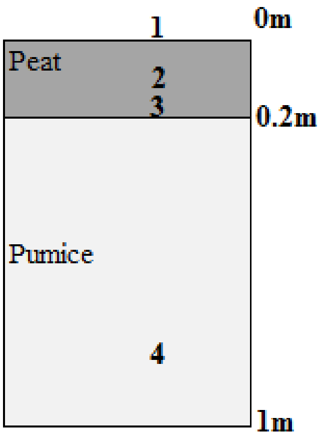


Figure 21 : Levels in the soil profile where measurements were done.

The pits where the measurements were carried out were dug by hand to have full control of location in the soil profile.

Figure 22: Set up before measurement with Disc permeameter is performed. Contact sand is placed on the ground in the shape of the disc.

3.3.3 Nuclear densometer

A nuclear densometer (Toxler 3440) was used to measure soil moisture and compaction in the soil. Measurements were made in the purpose of locating a possible seal that does not let water through and to find out the compaction of the soil. Highly compacted soil can prevent infiltration.

A nuclear densometer (Figure 23) is a geotechnical instrument that uses two radioactive sources to measure compaction and soil moisture.

Figure 23: Nuclear densometer.

The radioactive substance Cesium 137 is used to measure density and is located in the end of the rod. The rod was inserted in the ground to the desired depth, resulting in emission of gamma radiation. The detectors in the base of the gauge base (Figure 24) measure this radiation. Gamma photons that reach the detectors have to pass through the material in between the end of the rod and the detectors, resulting in a large number of photons colliding with electrons present in the soil. These collisions reduce the number of photons reaching the detectors, and the density of the soil can be calculated. The lower number of photons reaching the detectors, the higher is the density of the soil (Toxler Electronic Laboratories Inc, 2011).

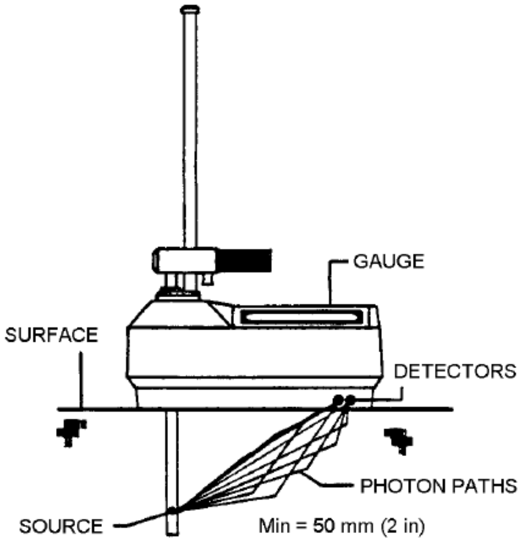


Figure 24: Nuclear densometer measurement.

Americium 241 is used for the moisture measurement and is found in the base of the gauge (Figure 24). The moisture is determined by emitting neutron radiation into the material. The high energy neutrons are moderated by the collision with hydrogen atoms in the moisture and only the low energy neutrons are detected by the Helium 3 detector (Turf Grass Association of Australia, 2010). Both soil moisture (M) and soil moisture % by weight (M %) were measured. M gives the soil moisture content of the soil in kg/m^3, while M% is the % by weight of soil moisture in the soil that was tested. M% is the mass of water divided by the mass of dry soil times 100.

To be able to get readings from the nuclear densometer, measurements had to be done when the field was almost dried up. Readings would not be correct in areas where ponding water was still resting on top of the ground surface. The purpose was to find out how the peat soil held the water compared to the pumice soil, and if there was a drastic change in water content somewhere in the top 250 mm of the soil profile. Measurements were done at three different locations of the field (Figure 25); Wet area, Dry area and Cross section. The areas marked with a white line represent the areas that were ponding when the field was flooded. A reading was done at five different depths; 50 mm, 100 mm, 150 mm, 200 mm and 250 mm at every measuring place. The method of how the nuclear densometer is used is described in Appendix E.

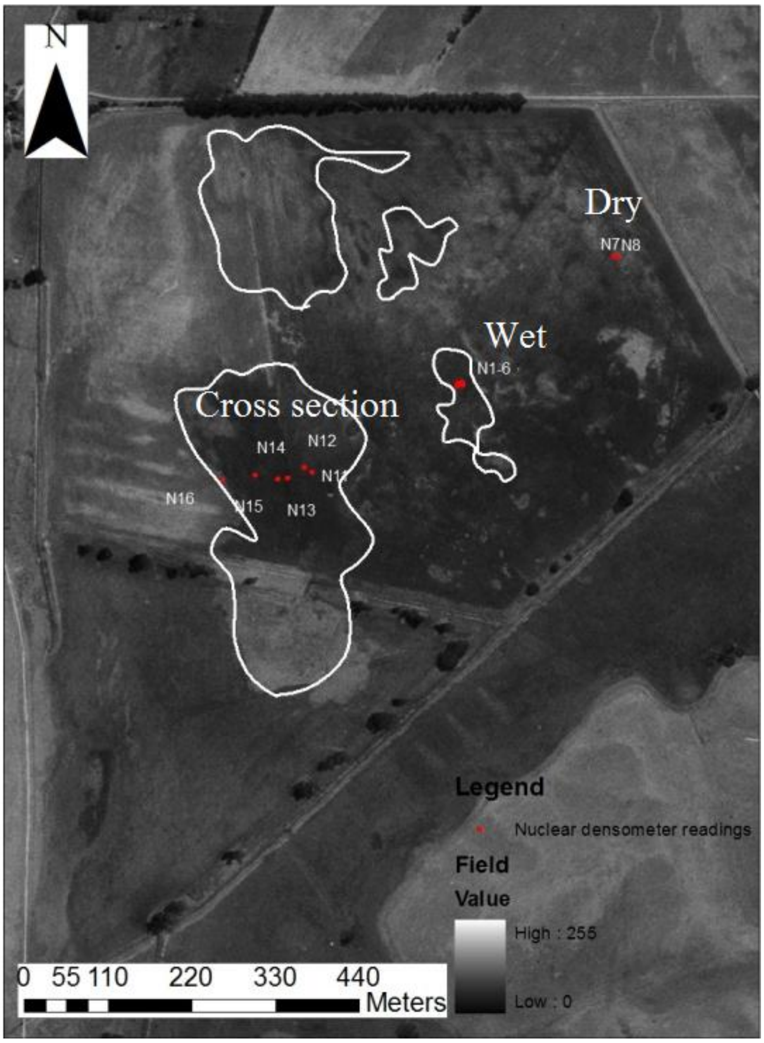


Figure 25: Locations of Nuclear densometer measurements. White lines are marking areas that were flooded.

Wet area

The location of the wet area were where the water needed the longest time to drain away and was therefore chosen for the measurements. In practice there was still a little bit of ponding water remaining, so six measurements were strategically placed around that pond of water. Because most of the water had drained away from the surface and caused cracks, the measurement points had to be adjusted slightly to avoid cracks in the top layer of soil. This was the same measuring spot that was named “last for the double ring tests, and “wet” for the disc permeameter tests.

Dry area

The dry area was chosen where no ponding problems had occurred and adjusted to where less grass was growing. If the test area had been chosen where lots of grass covered the ground, this would result in unnecessary disturbance of the soil during its removal. This area had never been flooded during the study period.

Because of time constraints and the fact that the tests were mostly done to understand what was happening in the ponded areas; only two readings were done in the dry area.

The dry area was the same area that was named “dry” for both the double ring tests and the disc permeameter tests.

Cross section

The cross section readings were performed from one end to another of the ponded area in the field that was the biggest when flooding occurred. This area was also the place in field that had the lowest elevation. These measurements were done when all the ponding surface water had drained away, the location of the measuring spots were adjusted to avoid cracks in the peat. The purpose was to see how the compaction and soil moisture varies in relationship to location in the ponded area. This was the same area that was named "low" for both the double ring tests.

3.3.4 Hydrophobicity

Before the project started, there were speculations about the soil being hydrophobic, i.e. repelling water. The theory was that the soil would have formed a hydrophobic seal somewhere in the top 20 cm of the profile which prevented the ponding water from infiltrating to the pumice layer and then to the stream baseflow. The theory was based on observations from the farmer that perceived the soil to be dry further down in the soil profile when digging in the field when it was ponded.

Hydrophobicity, or soil water repellency, is when the soil is not fully wetable, and occurs once the soil dries out below 'critical soil water content'. It gets triggered by drought and is therefore more of a problem in non-irrigated areas. There is an increased risk of runoff during summer and autumn (Deurer and Müller, 2010). A hydrophobic soil has a breakdown point, when the hydrophobicity is 'washed out' and the water starts infiltrating into the soil, often caused by a heavy rain. Every soil has their own specific breakdown point and it depends on the duration and intensity of the rainstorm, (Clothier, Vogeler and Megesan 2000).

Figure 26: Water beads on soil (Deuer and Müller 2010).

Soil water repellency (SWR) test

After a long dry period through December 2010 and January 2011 a heavy rainfall occurred over the four days of 21 to 24 January. That rainfall caused the field to flood and provided another opportunity to collect data to assist with the investigation.

To test the water repellency, 8 samples were taken, four from a dry area and four from a wet area. The dry samples were taken at a location that had not been affected by flooding, and the wet samples were taken at a location that at the time for sampling was flooded (Figure 27).

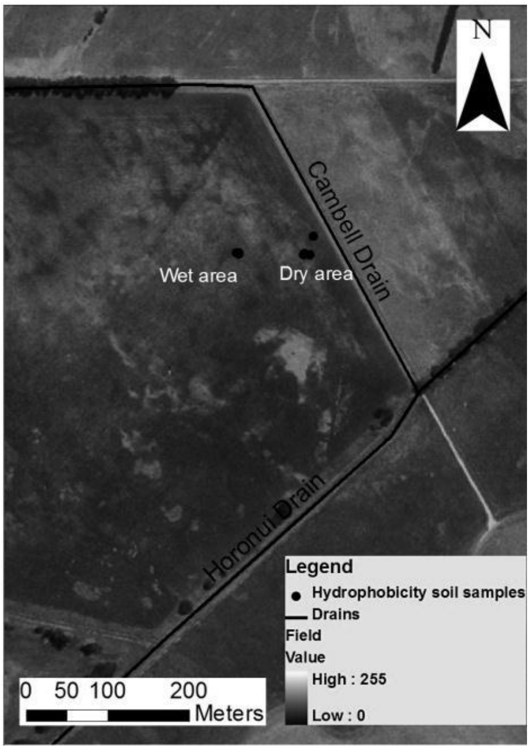


Figure 27: Location of samples for the hydrophobicity test.

Soil water repellency has three different characteristics; Persistence of SWR, Degree of SWR and Critical threshold.

- **Persistence of SWR → Water droplet penetration time test (WDPTT)**

Water droplet penetration time is measured by taking the time it takes for the droplet to penetrate the soil. The test is done to determine both actual and potential WDPTT. The top 4 cm of each sample was sieved through a 5 mm and a 2 mm sieve. WDPTT stands for Water Droplet Penetration Time Test, and is a measurement of how fast the water droplet is penetrating the soil.

Actual WDPTT
Actual in this case means that the water droplet penetration time for the field conditions is what is tested. Therefore is it important that the test is made as soon after sampling as possible, to get as close to field conditions as possible. It is the moisture content of the soil that has the largest impact on soils WDPTT. To prevent the moisture content to change from time of sampling to testing is the samples collected in plastic bags. The only preparation of the soil that is done is the sieving through the 5 mm and 2 mm sieves.

Potential WDPTT
This test is done on the soil when it has been dried in an oven at 65˚C until it is completely dry. If the soil is hydrophobic it will reach the peak of hydrophibicity when it is completely dry.

- **Degree of SWR → contact angle**

Soil water repellency is measured by the contact angle of the droplet placed on the soil. A soil is classified as hydrophobic if the contact angle between the droplet and the soil is larger than 90˚ (Deurer and Müller, 2010).

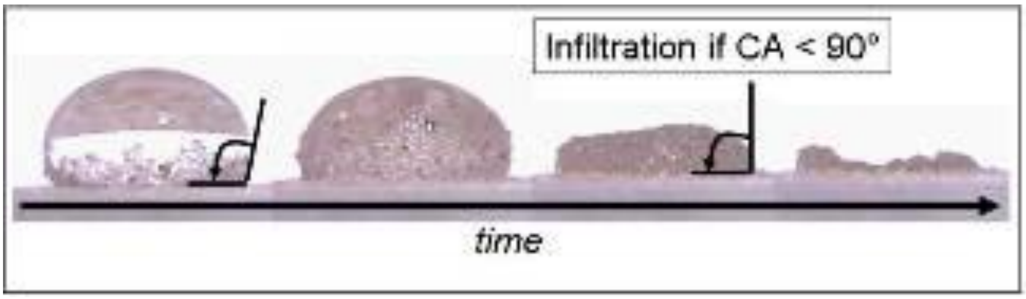
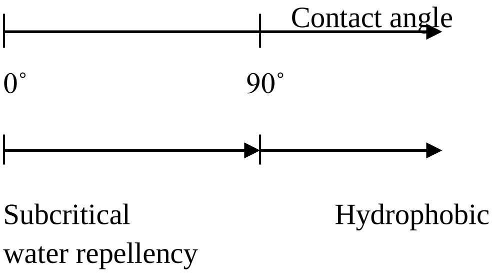


Figure 28: Illustration of contact angle, picture from Workshop: Towards a better understanding of the causes, effects and remediation of soil hydrophobicity.



The contact angle is measured with the molarity of ethanol droplet test.

- **Critical threshold of SWR**

This was not measured in this study, due to full infiltration of water droplets during the WDPTT tests.

3.3.5 Possible sealing of soil after extended period of saturation

To establish if the soil does form a seal after being under saturation for a longer period of time, soil samples were taken and saturated. Infiltration tests were then done after one and two weeks.

When the ponding water had dispersed, two soil samples were collected from the largest of the areas that had been under water. The soil samples were taken as a core of the profile with pvc-pipes with an inner diameter of 12 cm, and went down to a depth of 30 cm. The samples were removed from the field still inside of the pvc-pipes. A highly permeable cloth was attached to the bottom of each pvc-pipe with the soil sample inside in the purpose of not losing any of the samples during the test. To see if the infiltration rate changed or if even the soil created a seal when it was under water for a longer extent of time. Falling head tests were used as the method of measuring the infiltration rate. Measurements were done on the day of collection and then after one and two weeks under saturation.

3.4 Water balance in field

The water balance in field had to be studied to find out if the water infiltrated into the ground or if a seal prevented infiltration and the only factor removing the flooding water was evaporation. A climate station in the field was used to get climate data. It was discovered that the wind data from the climate station could not be used. Therefore a rain gauge and an evaporation pan were installed in field next to the climate station to back up the calculations that were based on data from the climate station. The outgoing flow in the drains was measured where Horonui Drain and Cambell Drain join up.

The water balance equation was used to do the calculations (Grip and Rodhe, 2003);

$$P = E + R + \frac{dS}{dt}$$

$$R = P - E - \frac{dS}{dt}$$

Where;
P- precipitation [mm/day]
R- Runoff[mm/day]
E- Evaporation [mm/day]
$\frac{\mathrm{dS}}{\mathrm{dt}}$ – Storage $= \mathrm{A}\frac{\mathrm{dh}}{\mathrm{dt}}$
A= Area [mm^2]
$\frac{\mathrm{dh}}{\mathrm{dt}} = \frac{\mathrm{h}_2 - h_1}{\mathrm{t}_2 - t_1}$ – Difference in water depth, h_2 and h_1, between two set times, t_2 and t_1.

3.4.1 Climate station

A climate station that is run by Dr John de Ruiter, Crop Physiologist at Plant and Food Research, has been used for collecting climate data during the project. A record of temperature, precipitation, radiation, relative humidity, leaf wetness, wind speed and wind direction was provided from 23 January 2010 to 28 January 2011. Location of the climate station in field is shown in Figure 29. Unfortunately it was discovered during the project that the wind data recorder was not working properly. Therefore could the Pennman equation not be used for the water balance calculations. Instead was the Thornthwaite equation used to calculate the potential evaporation with the data from the climate station. The Thornthwaite equation is more uncertain than the Pennman equation.

Figure 29: Location and image of climate station.

3.4.2 Calculation of potential evaporation

The data from the climate station was used to calculate the evaporation in field. Due to the fact that the field was flooded and there was a free water surface in large areas of the field does the evaporation equal the potential evaporation. Evaporation is said to equal potential evaporation when there is no limitation of the water supply, (Grip and Rodhe, 2003). This was the situation that existed in the study field. The Thornthwaite equation (1948) was used to calculate the potential evaporation.

Thornthwaite equation (Shaw 1983):

$$E_{pot} = 16N_m\,(\frac{10 \cdot \bar{T}_m}{I})^a$$

Where,

E_{pot} is potential evaporation [mm/day]

m is the months 1,2,3,...,12

N_m is the monthly adjustment factor related to hours of daylight

$\bar{T}_m$ is the monthly mean temperature [˚C]

I is the heat index for the year [˚C]

$$a = (6.75 \cdot 10^{-7})I^3 - (7.71 \cdot 10^{-5})I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.49$$

$$I = \sum_{i=1}^{n} (\frac{\bar{T}_m}{5})^{1.5}$$

3.4.3 Evaporation pan and rain gauge

To double check the data from the climate station a rain gauge was installed as well as an evaporation pan, which was built for the purpose of this project. The evaporation pan was built by using one third of a 200 litre drum that was sprayed on the inside with Aluminium spray to get the right reflection according Class A classification. The evaporation pan was placed next to the climate station on two pieces of wood to keep it off the ground and it was filled up to two thirds of the full volume with water. To measure the evaporation loss and rain gauge correctly without having reading problems caused by capillarity, a fence staple was used to measure the water level. The level was measured in millimeters.

On the fence pole next to the climate station a rain gauge was placed to measure the rainfall. Figure 30 shows the evaporation pan and the rain gauge next to the climate station out in field. To keep the evaporation pan away from sheep, it had to be moved to the other side of the fence. Weeds in the new location surrounding the evaporation pan were cleared as much as possible, but the high weeds and grass provided a little bit of shelter for the evaporation pan, and may therefore have caused a slightly lower reading.

Figure 30: Evaporation pan and rain gauge.

The reading from the evaporation pan will give a larger value than the true value. Therefore the logged value was corrected by $PET=0.8*E_{pan}$ (Bloomer 2010, personal communication).

3.4.4 Comparing calculated evaporation to evaporation pan

Due to the fact that the wind data turned out to be incorrect, a manual measurement of the evaporation was done with the evaporation pan and rain gauge. The calculated evaporation, based on the climate station data, was then compared to the manually measured evaporation to establish if the climate data seemed correct and if the calculated values were reasonable. The climate station logged the daily values at midnight every day, and the measurements in the evaporation pan were taken as often as possible, not every day, around midday. To be able to compare the two, were the measured data from the evaporation pan adjusted to give values from midnight to midnight. Because of the fact that the water drop in the evaporation pan was not measured daily some measurements were given as an accumulated value, water drop since the last measurement. The calculated evaporation was then adjusted to fit the intervals of manually measuring days. The same procedure was made for the rain data.

3.4.5 Flow to the drain

A FlowTracker was used to measure the discharge in the drain downstream from the culvert where Cambell Drain joins up with Horonui Drain. Horonui drain joins up with Awanui Stream further downstream. A gauging site was chosen about 10 metres downstream from the culvert where the drain becomes narrow. Location of the gauging site is showed in Figure 31. The FlowTracker measured the velocity of water across the drain section, from which the discharge was calculated.

Figure 31: Gauging site.

The measurements were performed by wading across the drain and taking measurements of water depth and velocity at every 10 or 20 cm.

3.4.6 Monitoring of water levels

To monitor the level of the water table across the field, four deep holes were dug with an excavator. They were all about 2 meters deep, and filled up with water soon after being dug. The water filled the holes by filling up through the sides of the holes in the pumice layer. The distance to the water level from the top of a pole placed in each pit was measured as well as the distance from a set measuring point above the water level to the drains. The measuring point for Horonui Drain was a nail in the bridge, and the measuring point for Cambell Drain was a nail in the fence crossing the drain. The measuring points for the holes and the drains were included in the level survey to get the relative level of the water table in field. Locations of the measuring points are shown in Figure 32.

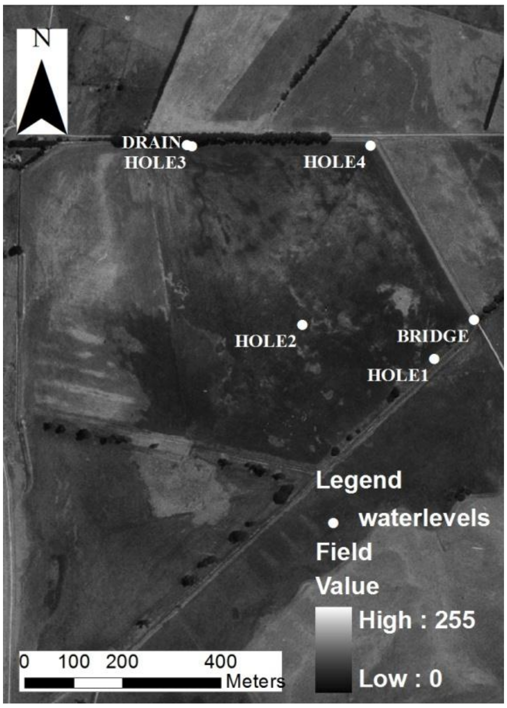


Figure 32: Location of measuring points for water levels.

3.4.7 Extrapolation of water level

During the summer the water levels in the holes dropped deeper than the bottom of the holes and measuring of the water levels ceased in the beginning of December 2010. Extrapolations of the water levels were therefore made to estimate the depth of the water level just before the heavy rain from 21 to 23 of January 2011. The method is described for calculations of the water level in Hole2 (Figure 32). Calculations for the estimated water level in Hole1, Hole3 and Hole 4 can be found in Appendix H, together with the data logs.

1. The measured drop from 18 Oct to 6 Dec 2010 was recalculated according to the level survey and plotted against time, Figure 33.

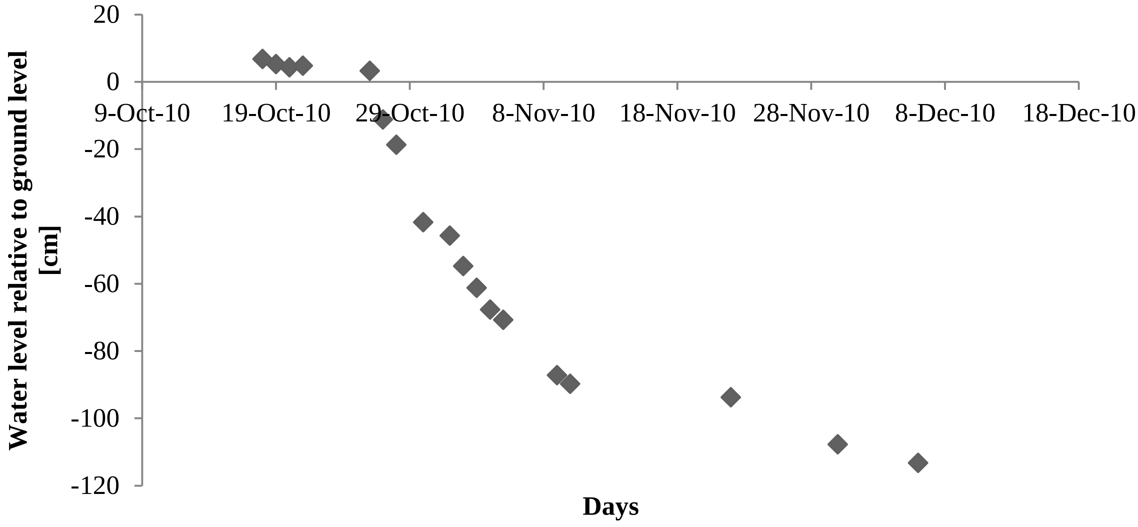


Figure 33: Water level over time in Hole2.

2. The drop of the water level matches the standard exponential drop that was expected. It started off with a rapid drop of the water level when the water started to drain away and it evens out in the beginning of November 2010.

3. To get the estimated water level at 21 January 2011, an extrapolation of the measured values was made by the using following exponential method;

$$h(t) - h_a = (h_0 - h_a)e^{-kt}$$

$$\ln(h(t) - h_a) = -kt + \ln(h_0 - h_a)$$

The estimated water depth was given by using a value of h_a that gave a straight line, and the R^2-value that is closest to 1.

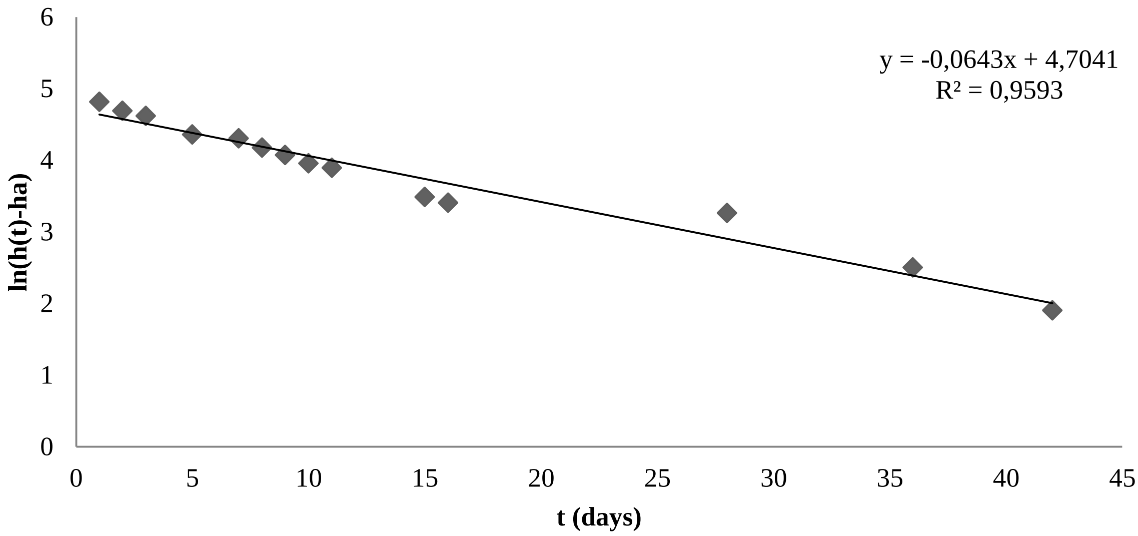


Figure 34: The ln-values of the water drop in Hole2 over time.

3.4.8 Study of pond and water level

When the flooded areas in field (Figure 25) had almost dried up, the last puddle with ponding water was put under investigation. By measuring the volume loss in the puddle while being able to calculate the potential evaporation, more information about the infiltration in field would be gained. A grid (10 m x 10 m) was made up, with 1 meter between the grid points, covering the puddle. At each grid point the depth of water was measured with a tape ruler. The water surface was defined as level zero and ground level above that was not taken in to consideration. A pole was placed in the puddle to have a set point from which the water level was measured. No consideration was taken to the land surface in-between the grid points, therefore an error is expected.

A three-dimensional image of the puddle was created in ArcScene by using the water depth measurements and grid point locations. When knowing how the water level dropped in the puddle, calculations could be made of how the area and volume decreased in the puddle. The infiltration rate was calculated by using the data of how the water level dropped and knowing the potential evaporation from the water surface during the time of the study.

Before the grid was made up, and the flooded area was bigger, it was observed that the water level in Hole2 (Figure 32), located right next to the puddle, was much lower than the water level in the puddle. In the beginning of the measurements of water levels in field, were the water level in Hole 2 and the water level forming the puddle in continuity. This indicated that there might be different infiltration rates in the peat soil and the pumice, as the water in Hole2 infiltrated much faster than the water resting on top of the peat soil forming the puddle.

3.4.9 Catchment area and storage

To back up the theory of a rising ground water table, calculations were made to establish if it was possible to fill up the storage room in the soil profile with the amount of rain that occurred during the rain storm that started on 21 January 2011. To calculate the volume of water, the catchment area and the rainfall data was used. The volume of water that was retrieved from those calculations was compared to the maximum storage volume in the soil profile.

The calculations will be an approximation and they include some assumptions;

- The depth of the water level in field that will be used for the calculations is the deepest value that was calculated with the extrapolation on 21 January 2011.
- The soil was completely dry before the big rain fall.
- No value for the porosity or specific yield for the pumice could be found. Therefore specific yield for fine sand, 21%, was used (Portage County, 2011). Observations in field established that the porosity and specific yield of the pumice at least is lower than for fine sand. Therefore the calculations will give a higher storage volume in the soil than what is actually true.
- Specific yield = porosity, even though specific yield ≤ porosity (Portage County, 2011). This is used to say that porosity in peat = specific yield peat.
- The total volume of water from the precipitation will flow towards the field that is located in the bottom of the catchment area.
- The outgoing flow in the drains is during the four days of rain is assumed to be the maximum flow measured with the Flow Tracker in the outgoing drain on the 14^{th} October 2010.

3.4.10 Pit refill observations

As mentioned before a heavy rain fall occurred during summer from 21 January to 24 January. Before that rainfall there had been a very long dry period and the water levels had gone below what could be measured. That rainfall caused the field to flood again and all the holes for water monitoring were filled. To establish from where the water in the hole comes, a pump test was performed in Hole3 (Figure 32). A pump (Figure 35) was used to pump the water out of the hole into the nearby drain (Cambell Drain) and the drawdown and the recovery of the water level were monitored.

Figure 35: Pump and Hole3 just after pumping started.

3.5 Programs and equipment that has been used

3.5.1 GPS

Throughout the project several points, places and tests were marked out in field with a GPS, Garmin 60. It is a hand held GPS that gives the location with an accuracy of ±5 meters. Because of the size of the field the decision was made that it would have a minor effect. The software DNR Garmin was used to convert the marked waypoints into shape file layers and imported to maps in ArcGIS.

3.5.2 GIS

The coordinate system for maps used in GIS has changed from New Zealand Map Grid (NZ MapGrid) to New Zealand Geodetic Datum 2000 (NZTM). Therefore the coordinate system had to be changed for all the imported data that was used to create shape files. The Spatial Reference tool was used to change the coordinate system and it is acceded through properties to the layer where the shape file is stored.

Another way of transferring a coordinate system is to use the website of Land Information New Zealand (LINZ). Important to remember when converting coordinates using this method is that the south coordinates have a negative value when the location is placed in the southern hemisphere.

3.5.3 Google Maps

From Google Maps a picture over the field was downloaded. The coordinate system was set to NZTM and the picture fitted to the shapefile "field" with the Georeferencing tool.

3.5.4 Xsect

The computer program Xsect was used to process the data from the level survey, and draw up the cross sections.

4. Results

The results from the soil profile analysis made it clear that there were many fine particles in the top soil that prevented infiltration. After observing and comparing the LIDAR map, the level survey, the map from Google and the photographs it was clear that it was the same areas that got flooded every year. The infiltration tests showed that there is nothing obstructing the infiltration once the field is dry. The nuclear densometer tests did not indicate that there would be either compaction obstructing the infiltration or a drastic change in water content in the top part of the profile. The pumping test that was made in a Hole3 to observe the refill showed that the soil profile was saturated. With that knowledge and the geological data from the bore log the conclusion could be drawn that the flooding water is caused by a rising ground water table on top of the clay layer having its upper surface 7 meters down in the soil profile.

The climate data and measurements of potential evaporation were used to create a very rough water balance. The purpose was to show that there was more than enough water coming to the field after a big rain fall in the end of January 2011 to cause the field to flood.

4.1 Soil analyses

As mentioned above did the soil profile analyses prove that there were very fine particles in the top soil preventing infiltration. The fraction of very fine particles was larger at the areas that got flooded. There were no indications that the thickness of the peat layer had any influence to where flooding occurred.

4.1.1 Grid for surface and soil observations

The soil profile in the area has a top layer of peat. That layer varies in thickness over the field from 11 cm to 49 cm. Underneath the peat there is some very fine pumice that got deposited in the area when the Taupo volcano had its big eruption almost 2000 years ago. According to bore logs for wells placed along the East and the North West side of the field is there a confined layer of clay about seven meters down in the soil profile underneath the fine pumice.

Approximately one meter down from land surface in the pumice there is a layer of bigger soil fractions and some small pumice rocks. This layer has therefore larger pores than the rest of the soil profile, and is important for lateral water flow (Figure 8).

The conclusion after examining the field and the soil profile with the grid was that the thickness of the peat layer cannot be related to the ponded areas. The peat layer varies over the whole field without showing a pattern (Figure 36, the data is presented in Appendix C). Because of the saturation of the soil, decreases the amount of earthworms and grass roots closer towards ponded areas.

The observations in the soil profile are consistent with the previous study by Griffiths (2001).

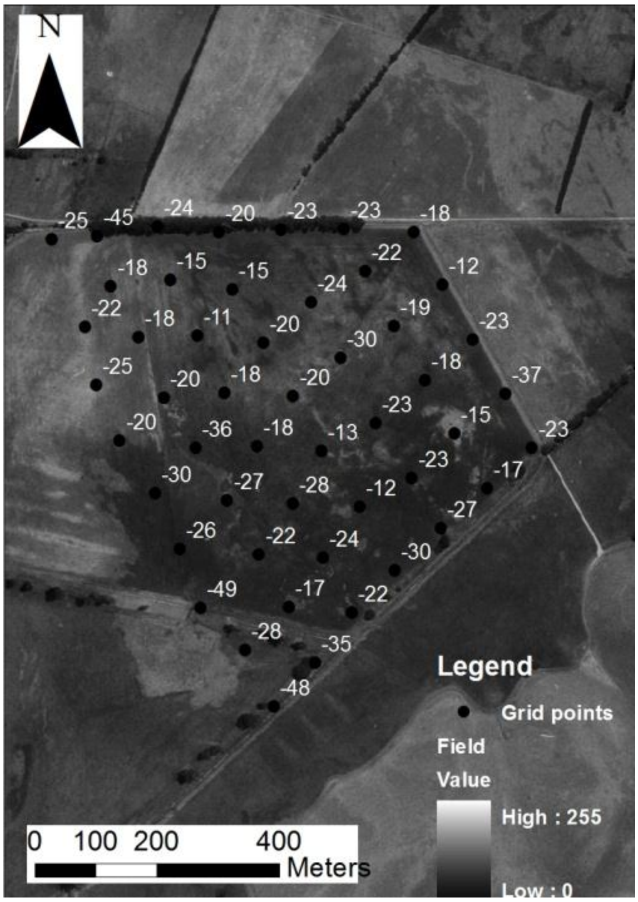


Figure 36: Depth of peat layer at grid points.

4.1.2 Results of soil fraction analysis

Fraction sizes for the four soil samples Wet top, Wet base, Dry top and Dry base were established by wet sieving and pipette analysis. Wet top represents the top 10 cm (0 cm – 10 cm from ground surface) of the peat soil in the core sample taken from a flooded area, and Wet base represents the peat soil from 10 to 20 cm. The same classification of the samples was used for the Dry samples.

Dry weights in percentage in the fraction sizes from 2 mm to 0.5 µm are presented below (Figure 37 to Figure 40).

The Wet samples had a larger fraction of smaller particles, which also was expected before the test. This can be explained by the fact that the flooding areas are located in low spots of the field. This results in runoff water flowing towards these areas carrying fine particles that will settle at the bottom of the flooded areas. It is also likely that a part of those fine particles is road dust from the farm tracks surrounding the field. The tracks are made up by lime stone and large clouds of dust are created when the heavy farm machines drive on them. The dust gets transported by the wind and will settle in the ponding water.

The results for the dry samples showed that the majority of the particles in the areas that were not flooded are within the sizes 125 µm to 16 µm, while the wet samples have a larger amount of smaller fraction sizes, 11 µm to 0.5 µm.

The table with data of the percentage for the different particle sizes can be found in Appendix F.

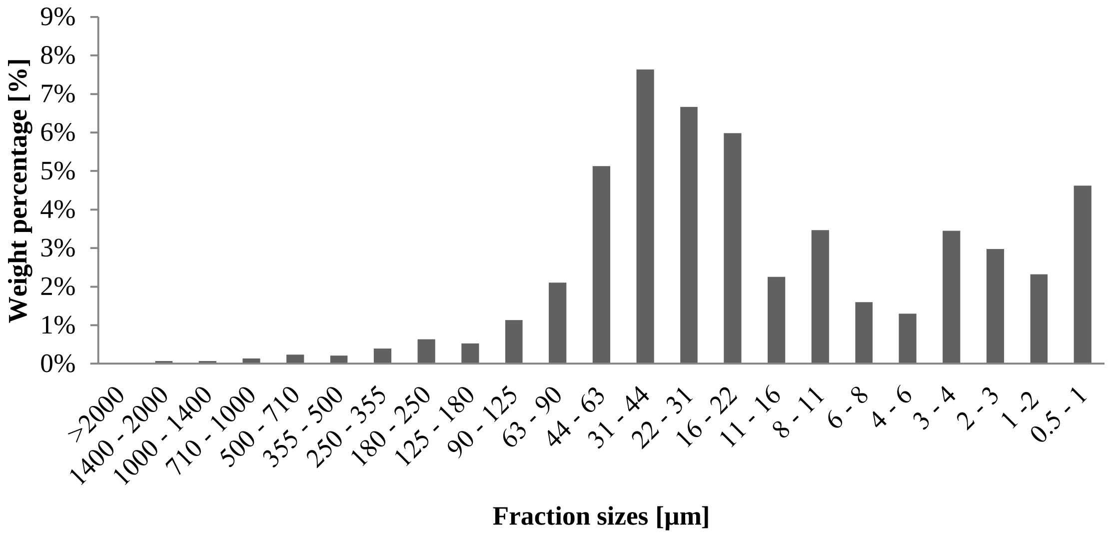


Figure 37: Fraction sizes in weight percentage for soil sample Wet top.

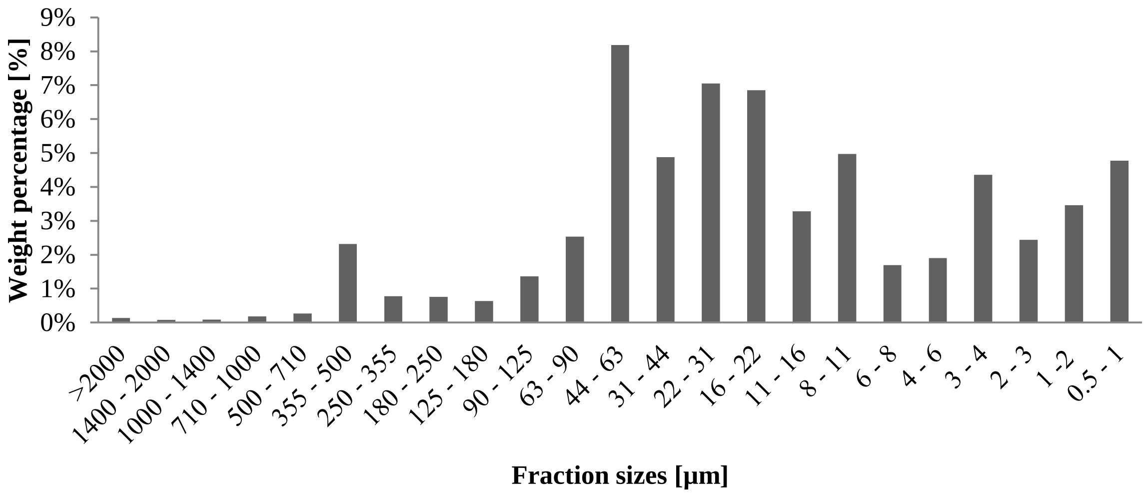


Figure 38: Fraction sizes in weight percentage for soil sample Wet base.

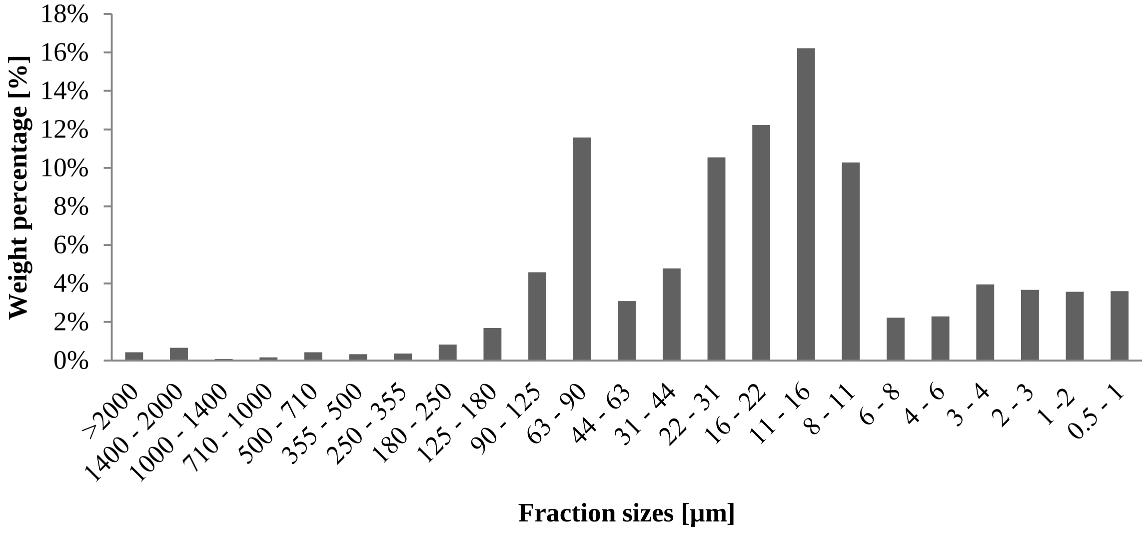


Figure 39: Fraction sizes in weight percentage for soil sample Dry top.

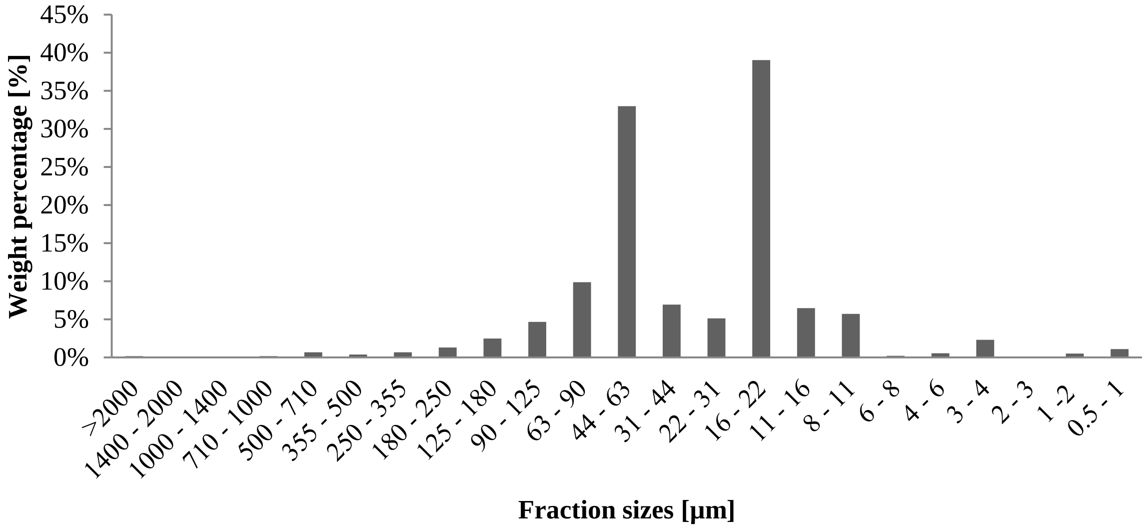


Figure 40: Fraction sizes in weight percentage for soil sample Dry base.

The textural groups for the soil samples were established by using the USDA textural classification chart.

The relatively big part of clay and silt (4 µm to 0.5 µm) that were found in the Wet soil samples, explains the infiltration obstruction that has been observed in field.

The soil fraction analysis was done in the purpose of explaining the ponding water and slow infiltration rates, therefore most focus was put on the very small fraction sizes during the analyses of the results. The USDA textural classification chart was used to determine the soil types. All four soil samples were classified as sandy silts in the silt:clay ratio diagrams (Figure 41).

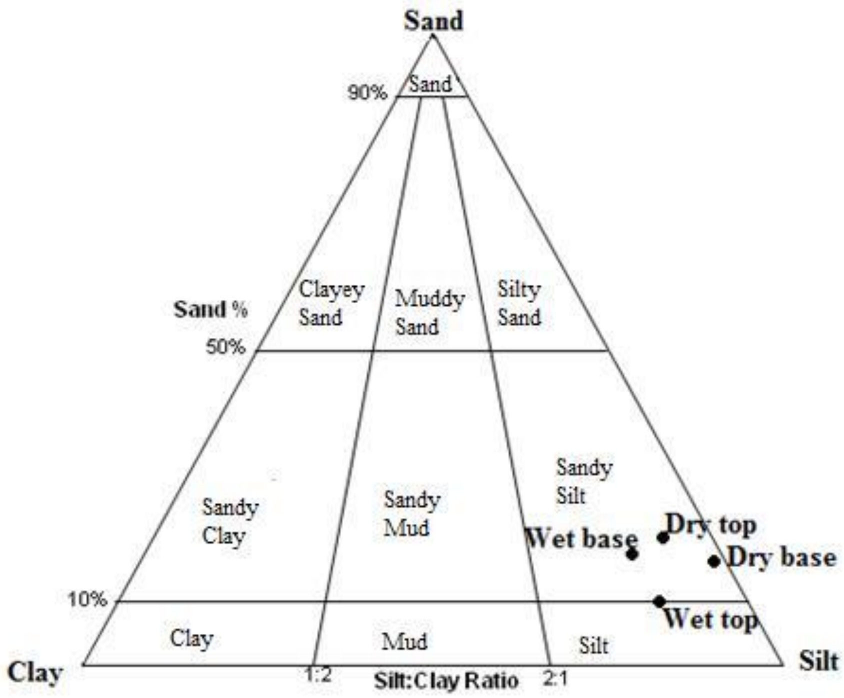


Figure 41: USDA textural classification chart.

Full presentation of the USDA textural classification charts can be found in Appendix G. Percentage for the fraction sizes for the four soil samples are presented in Table 2.

Table 2: Percentage of soil fractions for the soil samples.

	Wet top	Wet base	Dry top	Dry base
Gravel	0 %	0.2 %	0.4 %	0.1 %
Sand	10.6 %	18.6 %	21.3 %	17.2 %
Mud	89.4 %	81.2 %	78.3 %	82.6 %
Very Coarse Gravel:	0 %	0 %	0 %	0 %
Coarse Gravel:	0 %	0 %	0 %	0 %
Medium Gravel:	0 %	0 %	0 %	0 %
Fine Gravel:	0 %	0 %	0 %	0 %
Very Fine Gravel:	0 %	0.2 %	0.4 %	0.1 %
Very Coarse Sand:	0.3 %	0.2 %	0.7 %	0.1 %
Coarse Sand:	0.7 %	0.7 %	0.6 %	0.7 %
Medium Sand:	1.2 %	4.7 %	0.7 %	0.8 %
Fine Sand:	2.2 %	3.9 %	2.6 %	3.1 %
Very Fine Sand:	6.3 %	9.1 %	16.6 %	12.6 %
Very Coarse Silt:	23.6 %	19.3 %	7.9 %	32.2 %
Coarse Silt:	24.5 %	21.5 %	24.5 %	36.9 %
Medium Silt:	10.8 %	12.4 %	26.3 %	9.7 %
Fine Silt:	5.8 %	5.8 %	4.8 %	0.7 %
Very Fine Silt:	11.8 %	9.9 %	7.6 %	1.8 %
Clay:	13.0 %	12.3 %	7.2 %	1.3 %

When comparing the amount of fine silt, very fine silt and clay in the different samples (Table 3) it is clear that there is a larger fraction of fine particles in the soil samples from the wet area. The fine particles will clog up the pores and inhibit the infiltration of ponding water.

Table 3: Fraction of fine particles in the soil samples.

	Wet top	Wet base	Dry top	Dry base
Fine silt	5.8 %	5.8 %	4.8 %	0.7 %
Very fine silt	11.8 %	9.9 %	7.6 %	1.8 %
Clay	13.0 %	12.3 %	7.2 %	1.3 %
Σ	30.6 %	28%	19.6 %	3.8 %

Munsell soil colour chart

The colour test showed that the top part of both the Wet and Dry samples have a lighter colour while the lower part of the peat has a darker, Table 4 and Figure 42. This can be explained by the washing out of the top soil that occurs when there are smaller rainfalls in the area. When the rainfall is not big enough to cause a flooding the rain water will fall on the ground and infiltrate the soil.

Table 4: Munsell soil colour chart.

Sample		Colour	
Dry top		5Y-4/2	olive grey
Dry base	top 500 ml	2.5Y-3/1	very dark grey
Dry base	bottom 500 ml	2.5-2.5/1	black
Wet top		5Y-5/2	olive grey
Wet base		2.5Y-4/1	dark gray

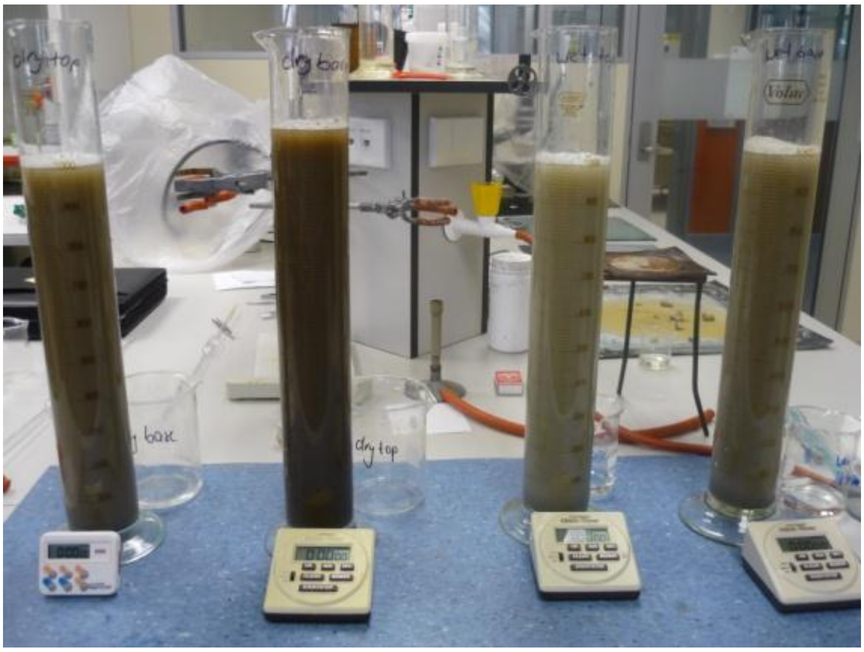


Figure 42: Soil samples before start of Pipette method. From the left: Dry top, Dry base, Wet top, Wet base.

4.1.3 Results of locating ponding areas

To determine exactly where the ponding areas were located in the field and to find out if there was a special reason that they were located where they were, a level survey, LIDAR map, and a satellite image from Google Maps were used.

Level survey

The results of the level survey (Figure 18) showed that the ponded areas were slightly lower than the area around, which had not been affected by the flooding. Generally the survey showed that the ground level of the ponded areas was 1.6 m lower than the reference point (BM). Along cross survey 3 and 4, offsets from the straight line were made. This was done in the purpose of including low spots that the cross surveys did not cut through in the measurements. The most important offset measurement was the 25 meter one along cross survey 4, which confirmed that the LIDAR map was correct when showing that spot as the lowest place in the whole field. That is also where the largest flooding occurs. After comparing the LIDAR map with the level survey the conclusion could be made that the LIDAR map (Figure 43) was accurate enough to use for topographic information in this project.

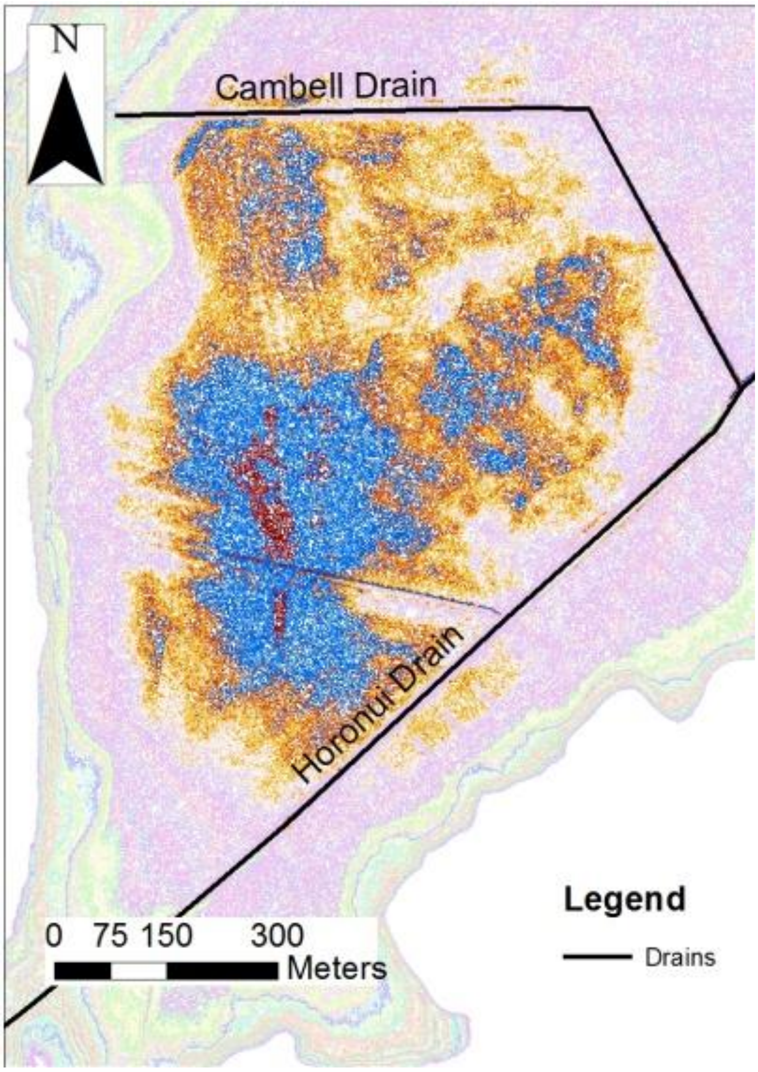


Figure 43: LIDAR map.

When studying the satellite photo from Google Maps (Figure 44) that was taken 25 October 2009, it is easy to see the flooded areas when the picture was taken. At a closer look it is also possible to locate the areas that had been flooded before the photo was taken, those are the areas where flooding water has caused the grass to die.

Figure 44: Photo from Google Maps 25 October 2009.

After comparing the level survey with the LIDAR map and comparing the LIDAR map to the picture from Google Maps it was clear that the ponded areas are the lowest spots in the field, and it is the same areas that gets ponded every year, Figure 45.

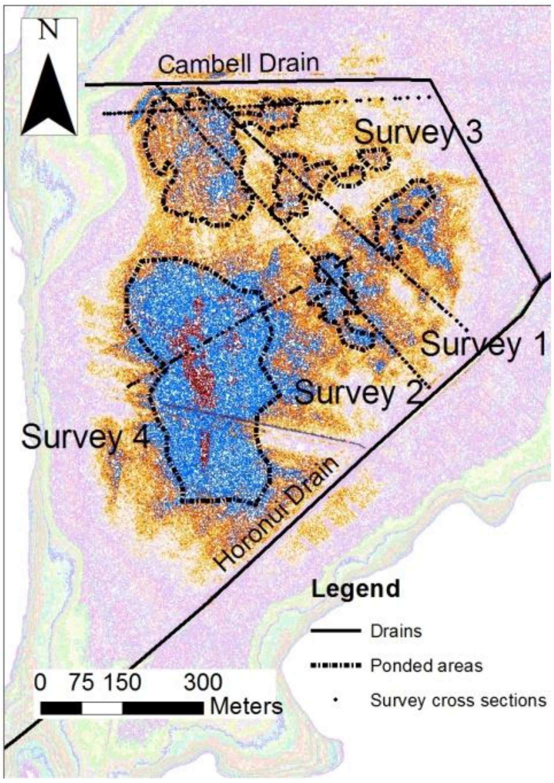


Figure 45: Comparing of level survey, LIDAR map and Google maps photograph.

4.1.4 Infiltration tests results

Double ring infiltrometers tests

The results from the double ring infiltration measurements are presented below in Figure 46 to Figure 48. They showed that it was a much slower infiltration in the dry area than in the two areas that had been ponded.

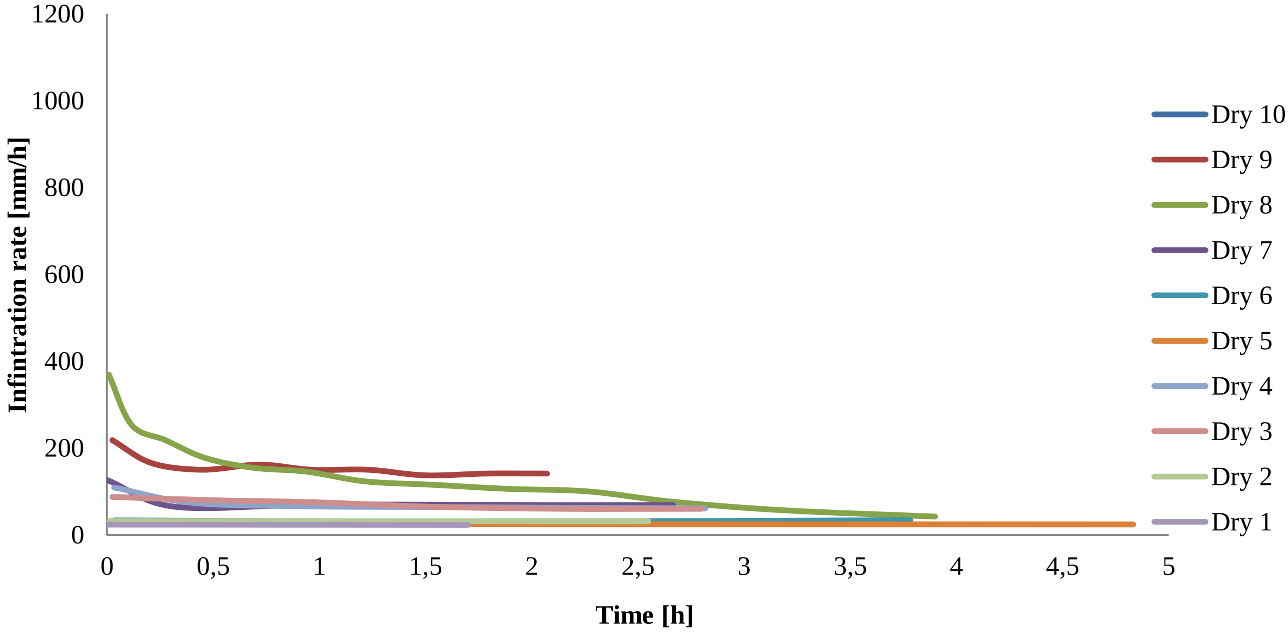


Figure 46: Infiltration rates for the dry area.

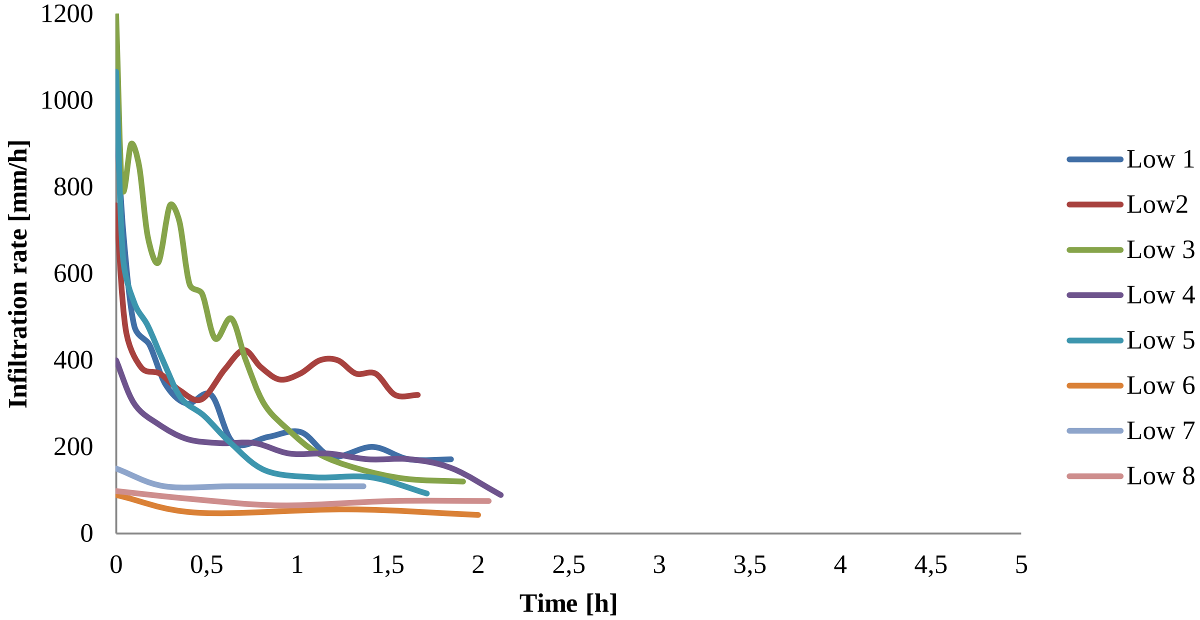


Figure 47: Infiltration rates for the lowest spot in field.

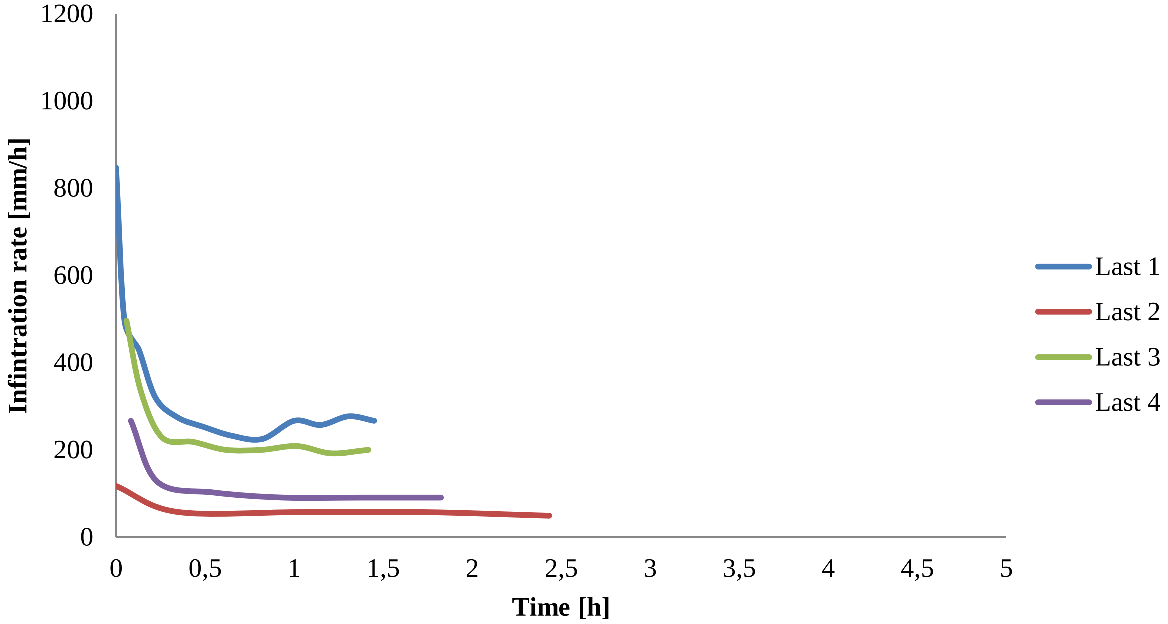


Figure 48: Infiltration rates for where the water drained away last in field.

The average infiltration rate for the Dry area was 44.5 mm/h while much faster infiltration rates were measured for the Low and Wet area where the average infiltration rates were 127.5 mm/h and 151.6 mm/h, Table 5. This shows that there is nothing obstructing the infiltration rate in the soil of the ponded areas, once the flooding water has drained away. The infiltration rate is about three times as good in the areas that were affected by ponding, where the infiltration was expected to be poor, compared to the dry area where no ponding has occurred.

Table 5: Average infiltration capacities with the double ring infiltration test.

Test	Average infiltration capacity [mm/h]
Dry	44.45
Low	127.45
Wet	151.56

4.1.5 Disc permeameter tests

Figure 49 shows the hydraulic conductivity in the peat soil for both the wet and the dry area. Dry 1 and Wet 1 are measurements done at ground surface and the diagram shows that the hydraulic conductivity, at low suction is much lower in the dry area.

When comparing Dry 2 and Wet 2 (Figure 49) it is clear that the hydraulic conductivity in the middle of the peat is much greater in the dry area. This indicates that it is very hard for water to penetrate the top layer of the peat in the dry areas, but once through that top compact layer the water moves easily through the pores. The permeability in the peat in the wet area is homogenous through the peat layer.

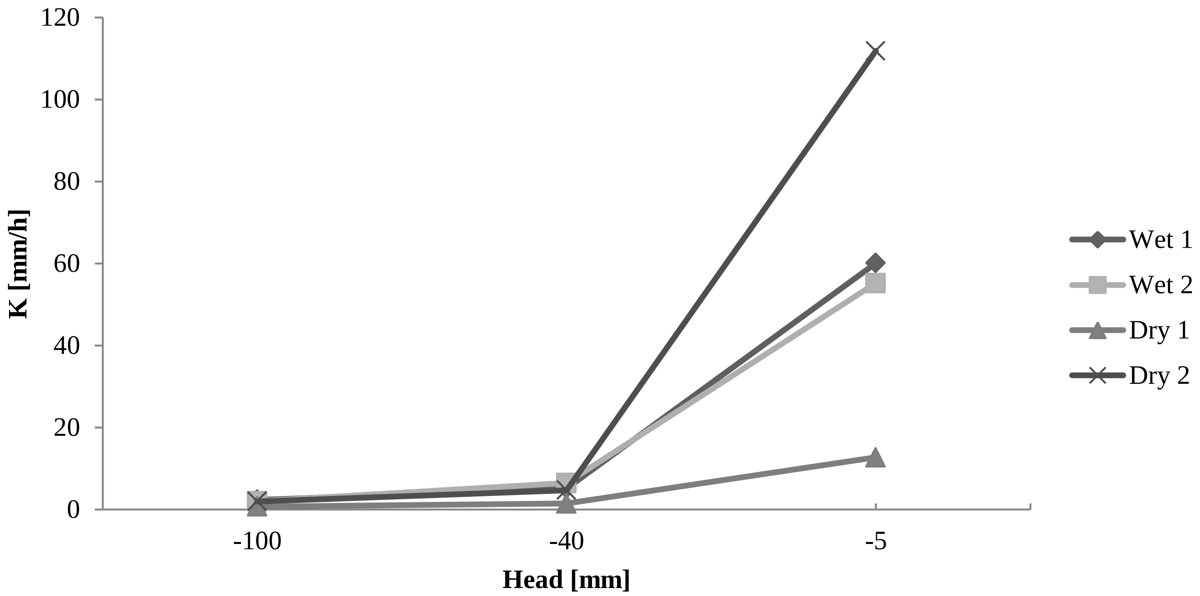


Figure 49: K (mm/h) in peat, 0 cm (Wet 1, Dry 1) and 10 cm (Wet 2, Dry 2) depth.

Figure 50 shows the results of the measurements in the pumice. Wet 3, top of the pumice, and Wet 4, in the pumice have a 50% higher hydraulic conductivity then Dry 3 and Dry 4. The variation is not big enough to say that the permeability in the pumice is different in between the dry and the wet area.

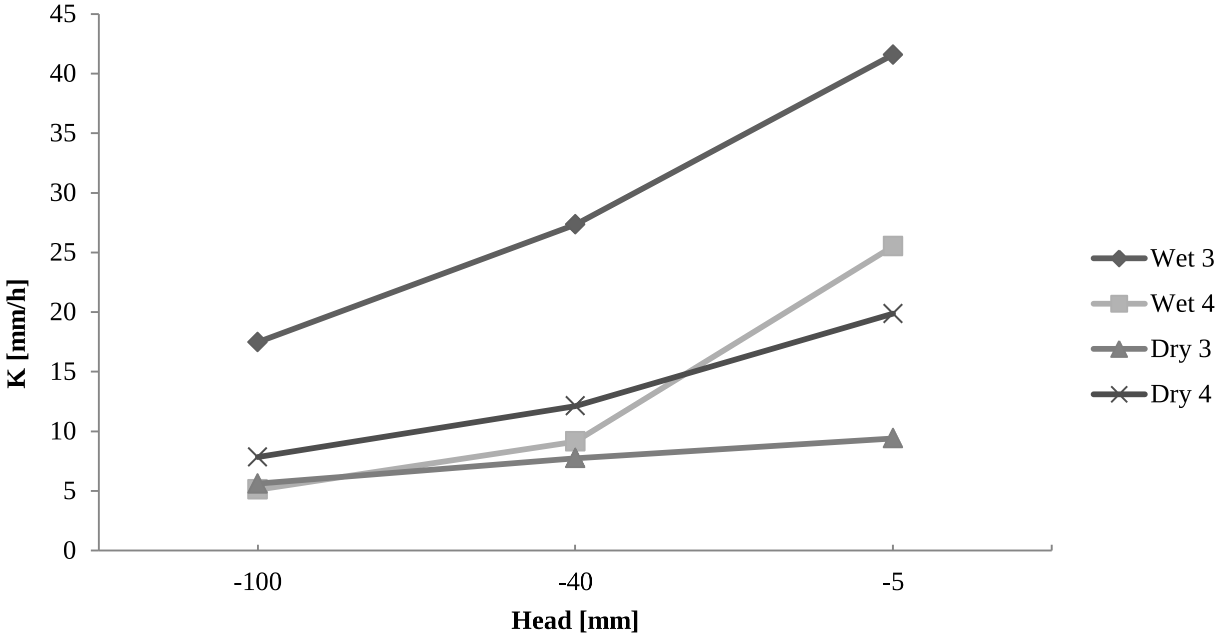


Figure 50: K(mm/h) in pumice, surface of pumice layer (Wet 3, Dry 3) and 10 cm down in pumice soil (Wet 4, Dry 4).

4.1.6 Nuclear densometer tests

The nuclear densometer was used to measure compaction, soil moisture, wet density and dry density in field and compare the differences between the dry area and the wet area that had been flooded. The results are presented by first comparing the wet and dry area and after that see what a cross section measurement from edge to edge of an ex-ponded area showed.

Compaction

Compaction in the top layer of the soil profile, i.e. the peat, was measured to explain the lower permeability in the top of the dry area compared to the wet area. Figure 51 shows the average values of the wet and the dry density in the peat layer in both the wet and the dry area. The results confirm the speculation that the top layer of the peat would be more compact in the dry area, and therefore reduce infiltration.

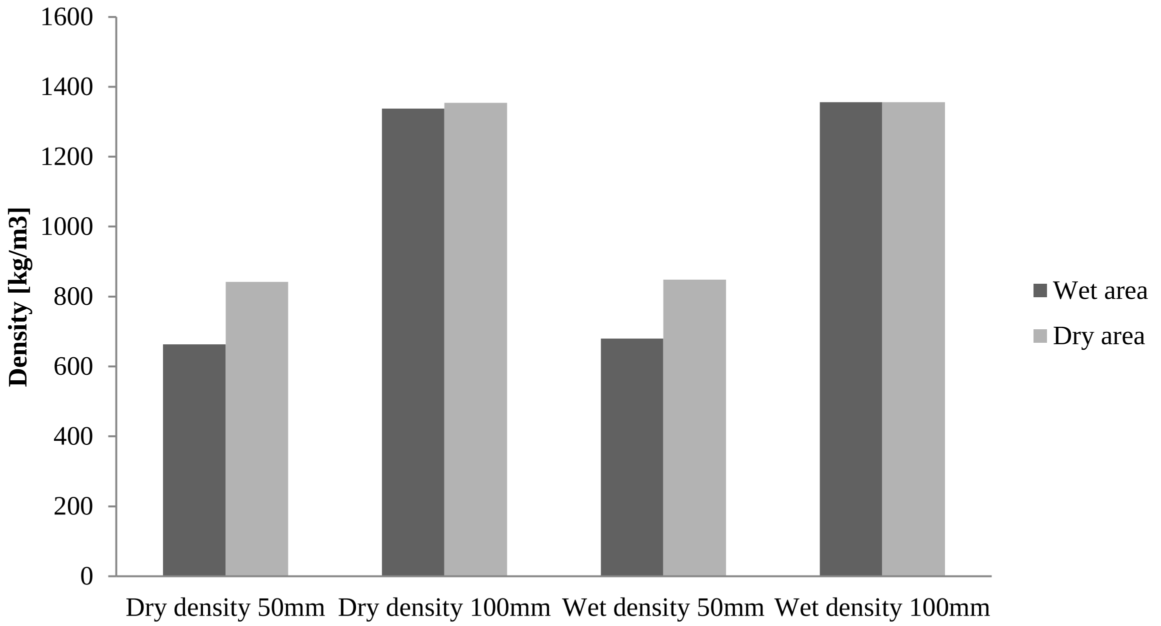


Figure 51: Comparing wet and dry density in peat.

The higher dry density in the dry area can be explained by several factors;

- The ponding water may have loosened the structure of the soil in the ponded areas. When the water drained away it left the soil with larger pores than in the dry areas.
- The dry soil has been exposed to more compaction processes like livestock, farm machines and rainfall.
- The transportation of lose particles towards the wet areas may cause the top layer of soil in the dry areas become more compact.

Soil moisture

Soil moisture (M) and soil moisture % by weight (M%) were measured at five different depths in the soil profile, from ground surface to a depth of 250 mm with the purpose of identifying a location of a less permeable layer. The disc permeameter gives the mean value for the measurements of the soil in between the probe and the soil surface; 0-50 mm, 0-100 mm, 0-150 mm, 0-200 mm and 0-250 mm. The results of the soil moisture and soil moisture % readings for both the wet and dry area are shown in Figure 52 and Figure 53.

As expected was the soil moisture higher in the wet area than in the dry area. At the time of measurements did three of the six measuring spots for the wet area have a wet surface with a little bit ponding water.

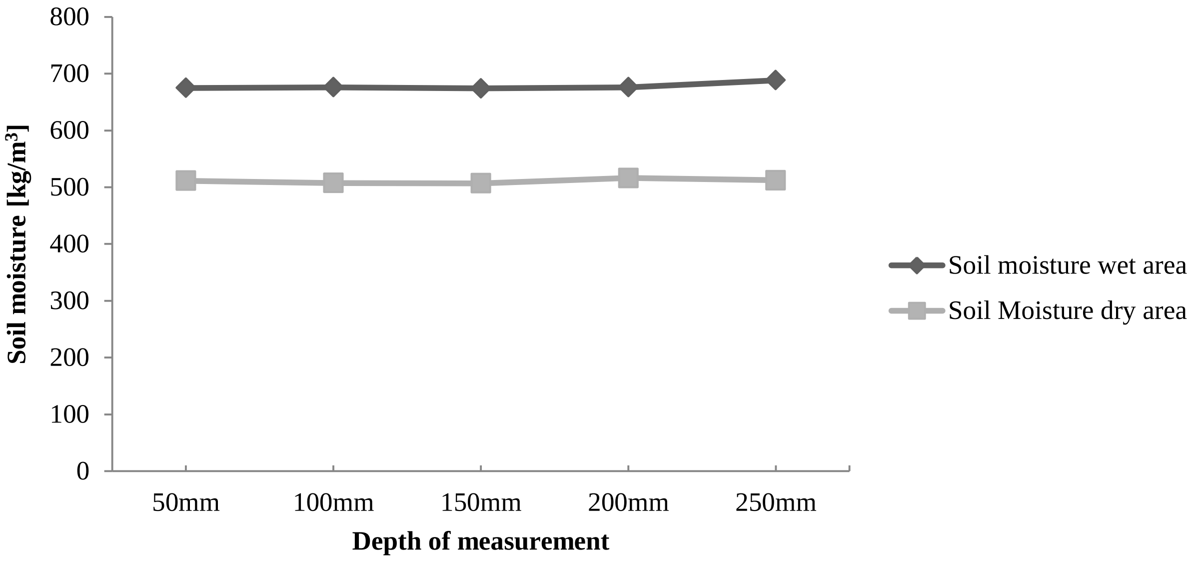


Figure 52: Average values for soil moisture in the wet and the dry area.

The soil moisture % by weight was at saturation around 100% in the wet area all through the profile to the deepest measuring level of 250 mm. Because of the drainage characteristics of pumice it can be assumed to be a soil moisture % by weight around 100% deeper than 250 mm as well, while the soil moisture % by weight was around 60% in the dry area.

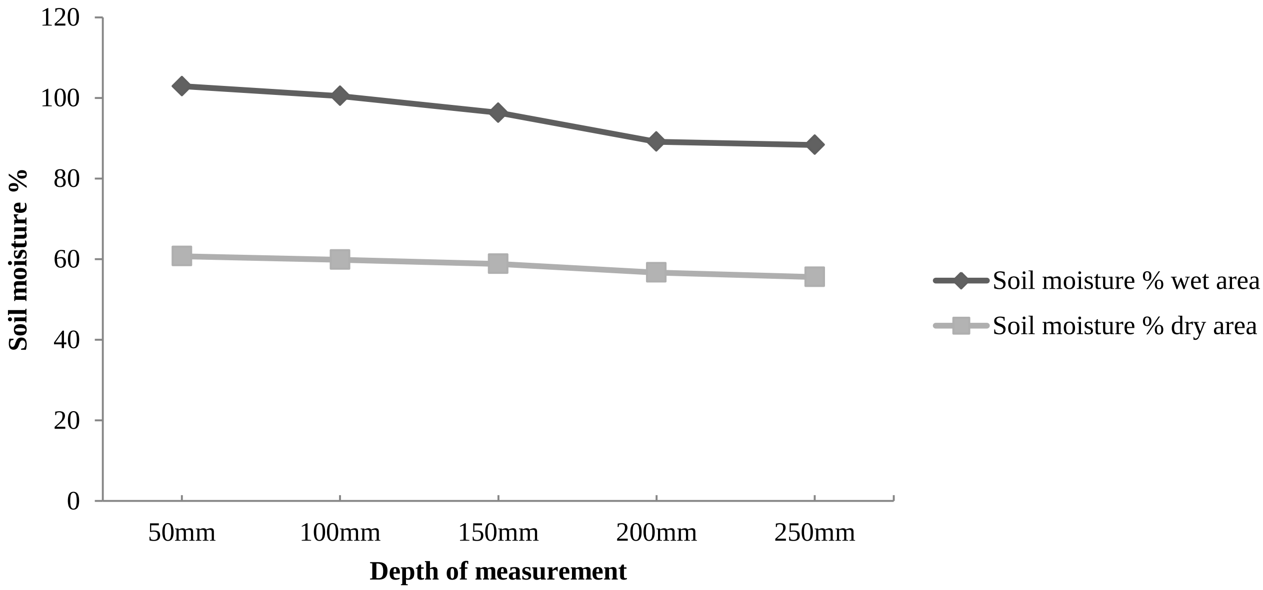


Figure 53: Average values for soil moisture percentage by weight in the wet and the dry area.

This shows that there is no drastic decrease in the soil moisture down to 250 mm depth. A sudden change of the soil moisture content on the soil would indicate that a seal preventing the infiltration would occur above the changing point.

Cross section

The cross section measurements (Figure 25) that were performed from side to side of the biggest ponded area in field showed that the soil moisture and soil moisture % by weight were homogenous along the cross section (Figure 54). It shows that the flooding of the field affected the soil moisture in the whole field and not just in the areas that were ponded.

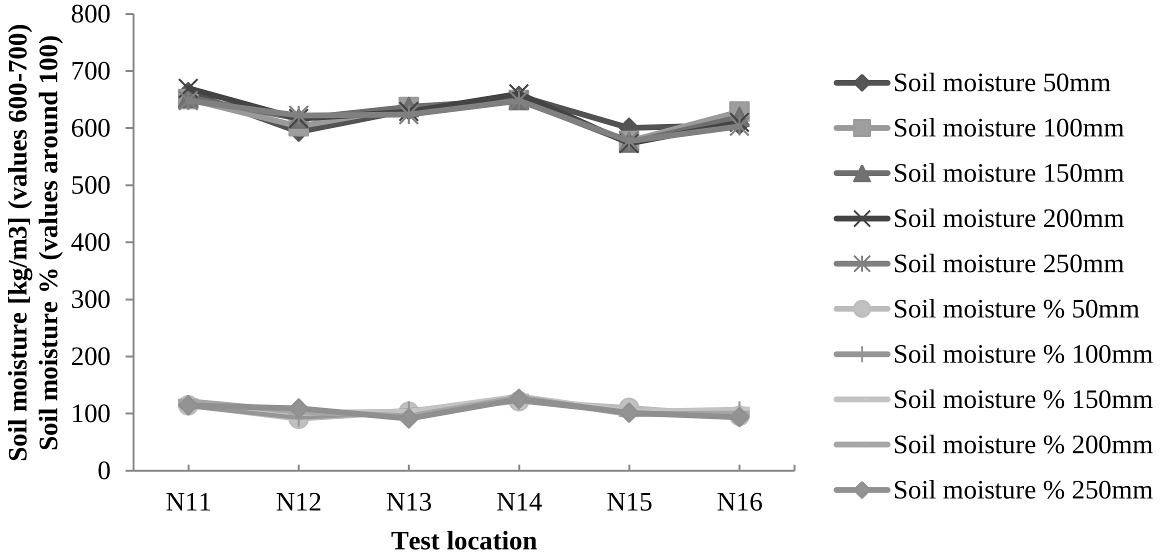


Figure 54: Average values for soil moisture and soil moisture % along the cross section.

The results from the density readings for the cross section are shown in Figure 55. The dry density (DD) measured from 537 kg/m^3 to 684 kg/m^3 for all readings, and the wet density measured from 133 kg/m^3 to 1307 kg/m^3 for all readings. There is a small indication that the density would be greater in the middle of the ex-ponded area, but the differences are not big enough to base any conclusions on.

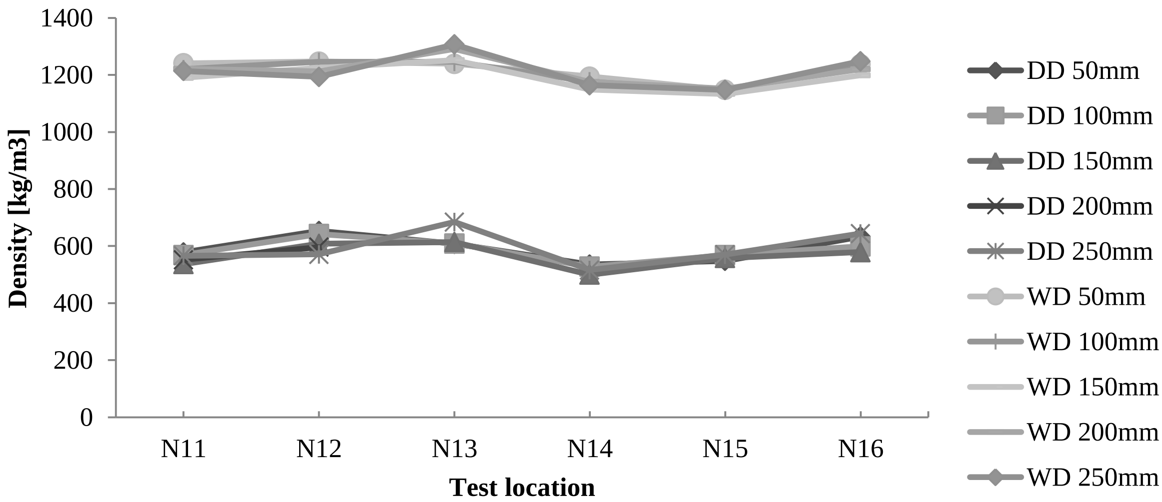


Figure 55: Average values for density along the cross section.

4.1.7 Hydrophobicity test

The hydrophobicity test was performed on four samples of peat soil at a late stage in the project. The top 4 cm of each sample was sieved through both a 2 mm and a 5 mm sieve. A small part of each sample was tested with the Water droplet penetration test. That gave both the water droplet penetration time and the contact angle.

Results for actual Water Droplet Penetration Time Test (WDPTT)

As Table 6 shows were there no sign of any actual water repellency, i.e. water repellency during current field conditions.

Table 6: Results actual Water Droplet Penetration Time Test.

Number	Sample	Sieve		Penetration time [s]	
			Drop 1	Drop 2	Drop 3
95	Dry 1	5 mm	0	0	0
94	Dry 1	2 mm	0	0	0
43	Dry 2	5 mm	0	0	0
29	Dry 2	2 mm	0	0	0
123	Dry 3	5 mm	0	0	0
89	Dry 3	2 mm	0	0	0
41	Dry 4	5 mm	0	0	0
105	Dry 4	2 mm	0	0	0
60	Wet 7	5 mm	0	0	0
70	Wet 7	2 mm	0	0	0
54	Wet 8	5 mm	0	0	0
18	Wet 8	2 mm	0	0	0
73	Wet 9	5 mm	0	0	0
86	Wet 9	2 mm	0	0	0
77	Wet 10	5 mm	0	0	0
12	Wet 10	2 mm	0	0	0

Results for potential Water Droplet Penetration Time Test

When the soil samples had been oven dried the potential water repellency was tested in the same way, Table 7.

Table 7: Results potential Water Droplet Penetration Time Test.

Number	Sample	Sieve	Penetration time [s]		
			Drop 1	Drop 2	Drop 3
95	Dry 1	5 mm	3	1	1
94	Dry 1	2 mm	1	1	2
43	Dry 2	5 mm	3	2	2
29	Dry 2	2 mm	6	3	7
123	Dry 3	5 mm	5	2	4
89	Dry 3	2 mm	6	4	5
41	Dry 4	5 mm	0	0.5	0.5
105	Dry 4	2 mm	0.5	0	0.5
60	Wet 7	5 mm	0	0.5	0
70	Wet 7	2 mm	2	2	1
54	Wet 8	5 mm	0.5	1.5	2
18	Wet 8	2 mm	0.5	0	0.5
73	Wet 9	5 mm	0	1.5	0.5
86	Wet 9	2 mm	0.5	0.5	0.5
77	Wet 10	5 mm	0	0	0.5
12	Wet 10	2 mm	0	0	0

There is a slight tendency showing that the samples from the dry area are a little bit more hydrophobic than the samples from the wet area. But because of the fact that none of the soil samples had a penetration time over 10 seconds, all of the samples were classified as non-hydrophobic.

The result from the soil water repellency test was that the soil does not show any signs of water repellency. For the potential WDPTT did the sample Dry 3, 2 mm show a penetration time longer than 10 sec (19 and 20 seconds) for two of the three droplets, and sample Dry 2, 2 mm (17 seconds) for one of the three droplets. This indicated that the Degree of SWR test and Molarity of ethanol droplet test could be performed on those samples. But when the Degree of SWR test started with the pure water solution did the samples not show any signs at all of water repellency. Multiple water droplets were placed on the soil to get a bigger range of tests to get a representative penetration time for the soils. This resulted in the conclusion that the representative penetration time for the droplets are the ones that are shown Table 7.

Even though this test did not show any signs of water repellency, the speculations that hydrophibicity still can occur in the field cannot be out ruled. Water repellency develops during dry periods and the samples for this test were taken close after a heavy rain that could have broken the hydrophobic layer.

4.1.8 Possible sealing of soil after extended period of saturation

To establish if any kind of seal forms when the soil is under saturation for a longer time, two soil cores were taken out in PVC-pipes with an inner diameter of 12 mm. They both contained the top 30 cm of the soil profile, which includes the whole peat layer and about 10 cm of pumice layer.

Saturated infiltration was measured on the soil samples inside of the PVC-pipe straight after collection from the field (Table 8). When the test was performed were the PVC-pipes immersed in water and saturated for an extended period of time.

Table 8: Infiltration rates before saturation.

Sample 1 -before saturation				
Infiltration [cm]	Time	Time [h]	T1-T2[h]	Infiltration rate [mm/h]
1	2 min 10 sec	0.036		
2	2 min 45 sec	0.046	0.0097	103
3	3 min 20 sec	0.056	0.0097	103
4	3 min 55 sec	0.065	0.0097	103
Sample 2 -Before saturation				
Infiltration [cm]	Time	Time [h]	T1-T2[h]	Infiltration rate [mm/h]
1	2 min 20 sec	0.039		
2	4 min 40 sec	0.078	0.0389	26
3	7 min 00 sec	0.117	0.0389	26
4	9 min 20 sec	0.156	0.0389	26

After being saturated for both one and two weeks the same infiltration test was performed again, Table 9 and Table 10.

Table 9: Infiltration rates after being under saturation for 1 week.

Sample 1 -after 1 week				
Infiltration [cm]	Time	Time [h]	T1-T2[h]	Infiltration rate [mm/h]
1	1 min 25 sec	0.024		
2	2 min 35 sec	0.043	0.019	51
3	3 min 45 sec	0.063	0.019	51
4	4 min 55 sec	0.082	0.019	51
Sample 2 -After 1 week				
Infiltration [cm]	Time	Time [h]	T1-T2	Infiltration rate [mm/h]
1	4 min	0.067		
2	8 min	0.133	0.067	15.00
3	12 min	0.200	0.067	15.00
4	16 min	0.267	0.067	15.00

Table 10: Infiltration rates after being under saturation for 2 weeks.

Infiltration [cm]	Time	Time [h]	T1-T2	Infiltration rate [mm/h]
Sample 1 -after 2 weeks				
1	1 min 25 sec	0.024		
2	2 min 35 sec	0.043	0.019	51.43
3	3 min 45 sec	0.063	0.019	51.43
4	4 min 55 sec	0.082	0.019	51.43
Sample 2 -After 2 weeks				
Infiltration [cm]	Time	Time [h]	T1-T2	Infiltration rate [mm/h]
1	5 min 40 sec	0.094		
2	11 min 20 sec	0.189	0.094	10.59
3	17 min	0.283	0.094	10.59
4	22 min 40 sec	0.378	0.094	10.59

There is nothing indicating that there would be any kind of seal forming when the soil is saturated for a longer period of time. The infiltration rate decreases but never seals off completely. The reason for the decreasing infiltration rate can be related to the silt and clay content in the top soil that under saturation will clog up the pores and effect the infiltration in a negative way.

4.2 Water balance in field

Climate data was used to calculate the potential evaporation, and to calculate the infiltration rate in field based on measurements. A rough water balance calculation was made to estimate if the rainfall in the end of January 2011 was enough to cause the field to flood.

4.2.1 Calculations of evaporation

Due to the fact that the readings of the water level in the evaporation pan were not done every day, the accumulated value of the evaporation was used when there is a time difference longer than one day between the readings. The accumulating time was given from the readings of the evaporation pan and applied to the data from the climate station when comparing the two.

Different logging times of the daily data for the climate station and the evaporation pan also had to be corrected. The potential evaporation that was calculated with the Thornthwaite equation was based on data from the climate station, which started and ended every day at 00:00 am. While the manually logged changes in the evaporation pan were usually taken around midday. This caused a 12 hour difference to occur that was corrected for the calculations in the purpose of comparing the calculated evaporation to the measured evaporation.

4.2.2 Climate station

The calculated potential evaporation (according to the Thornthwaite equation) and the precipitation from the climate station from 1 September 2010 to 27 January 2011 are shown in Figure 56 and Figure 57.

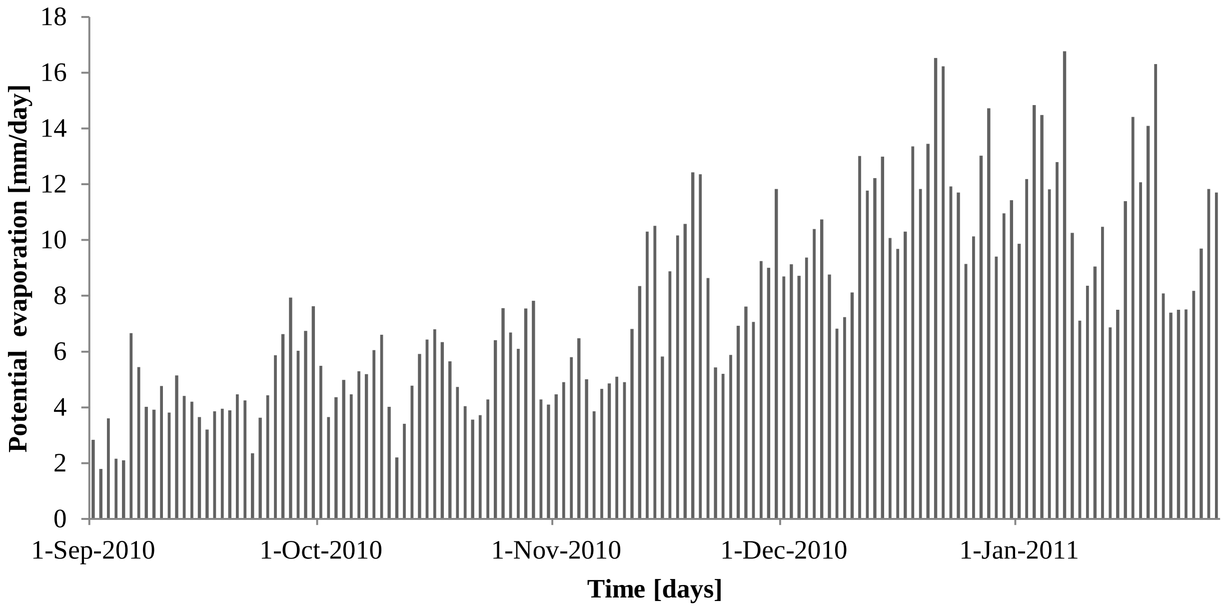


Figure 56: Calculated potential evaporation according to Thornthwaite equation.

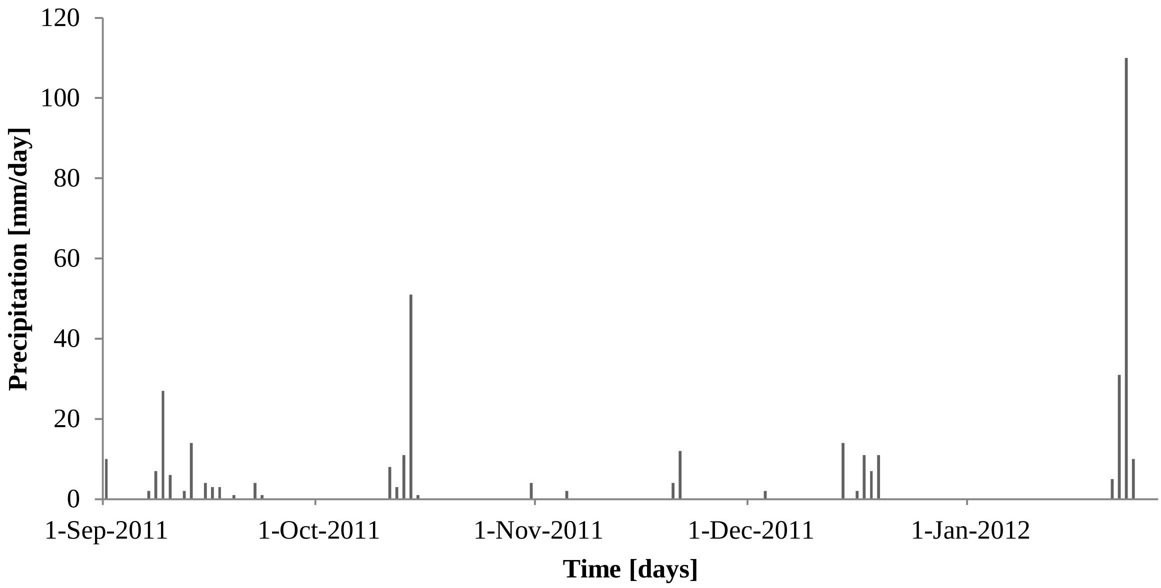


Figure 57: Precipitation from the climate station.

4.2.3 Evaporation pan

The water level in the evaporation pan was measured as regularly as possible throughout the project. The change in water level in the evaporation pan was logged with the amount of rain in the rain gauge.

By subtracting the precipitation logged from the rain gauge from the drop in the evaporation pan, the evaporation out in field was given.

Figure 58 and Figure 59 are showing the evaporation and precipitation data from 1 October 2010 to 6 December 2010. The evaporation has been corrected by the calculation PET =0.8*E_{pan} as explained above.

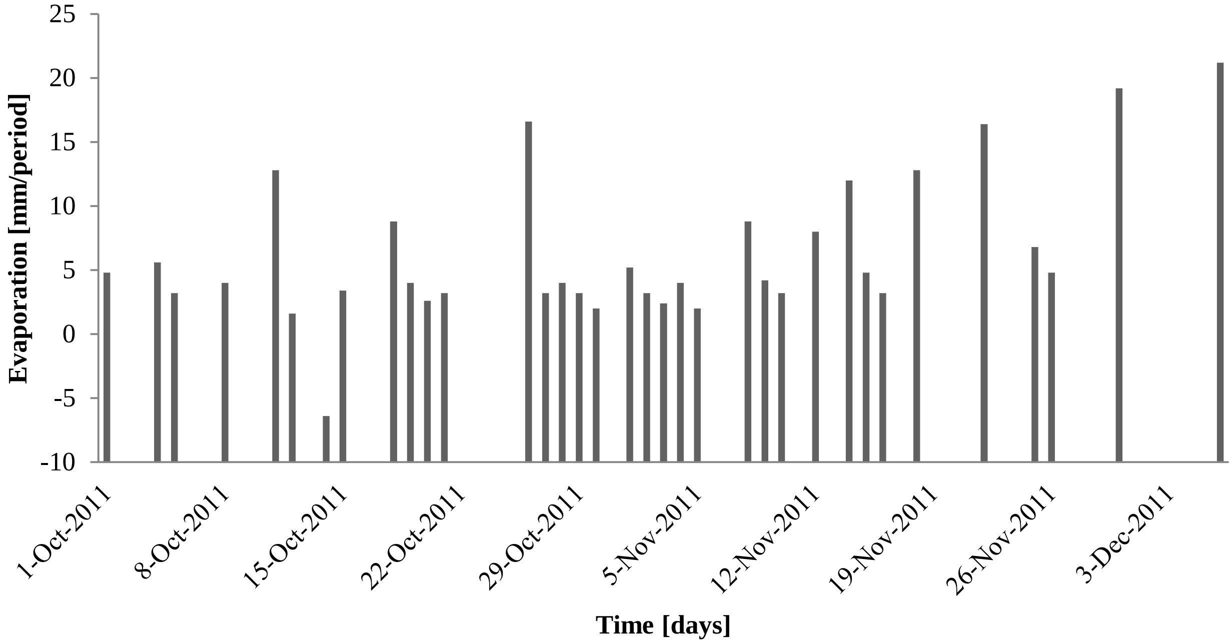


Figure 58: Measured evaporation from the evaporation pan, 1 October to 6 December 2010. Values after gap are accumulated (explained in 3.4.5).

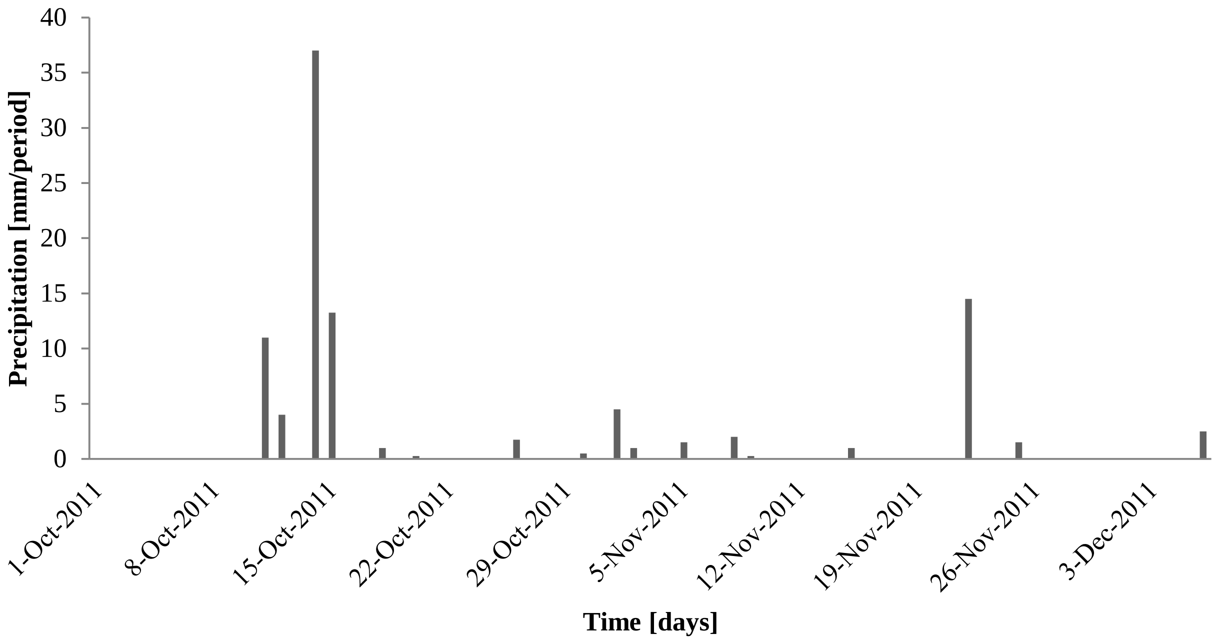


Figure 59: Measured precipitation from the rain gauge, 1 October to 6 December 2010. Values after gap are accumulated (explained in 3.4.5).

The information from the evaporation pan and the rain gauge was then used to compare with data from the climate station and the calculations of the potential evaporation with the Thornthwaite equation.

4.2.4 Comparing calculated evaporation and evaporation pan

When comparing the calculated results to the measured evaporation we can see that they are following the same pattern. It is clear though that the calculated evaporation shows a considerably larger value. Possible reasons of that are:

- Evaporation pan was placed sheltered by vegetation.
- Thornthwaite equation might overestimate potential evaporation in this area.
- The climate station did not have the same readings of precipitation as the rain gauge. The rain gauge in the field might have underestimated the rainfall.

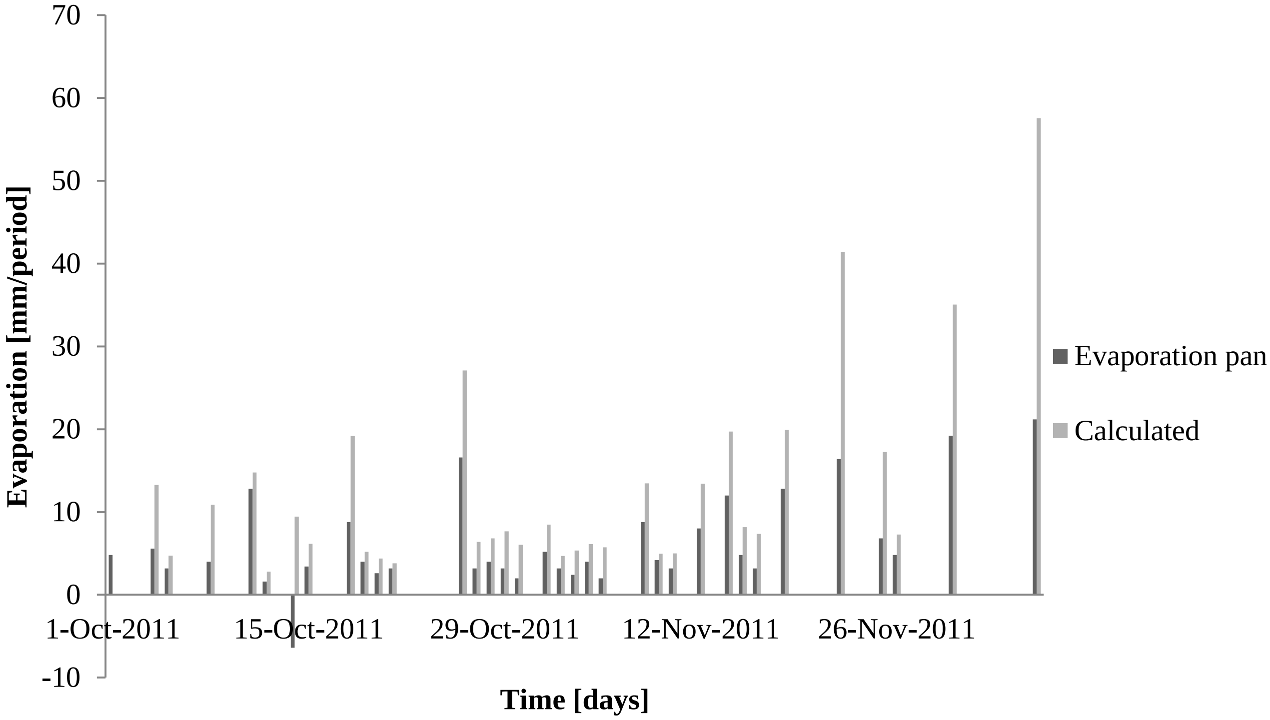


Figure 60: Potential evaporation from both Evaporation pan and calculations with the Thornthwaite equation. Values after gap are accumulated precipitation (explained in 3.4.5).

The decision was made though that the calculated evaporation would be used for calculations. The main reason to determine the evaporation in field was to be able to estimate how much of the ponding water that infiltrated and evaporated.

4.2.5 Results of measuring flow in drain

Measurements were done at six different occasions with different water levels in the drain. Figure 61 shows discharge vs. water level in the drain.

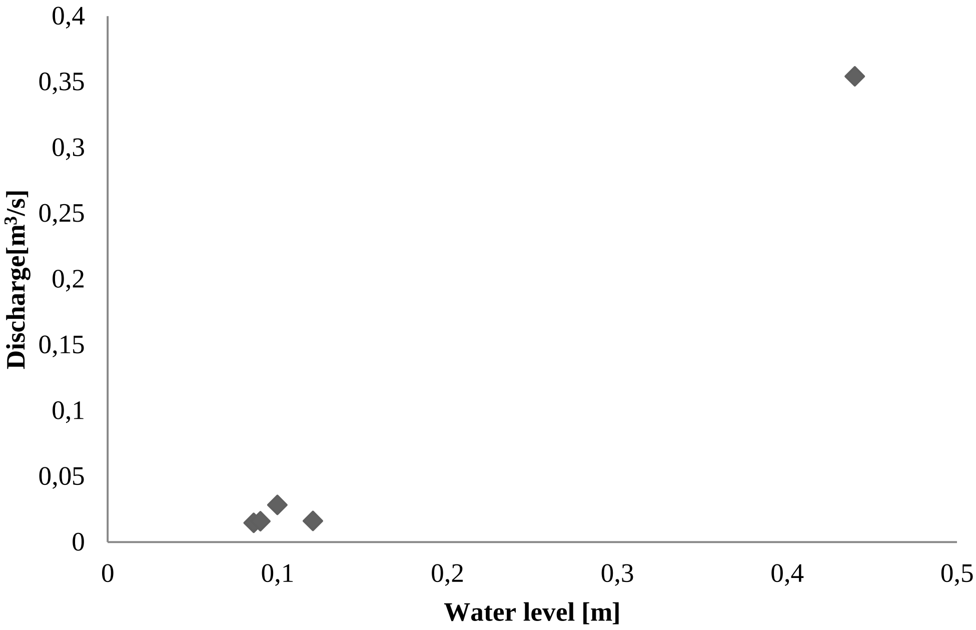


Figure 61: Discharge in drain.

The flow in the drain varied from 0.0087 m^3/s during low flow to 0.354 m^3/s soon after a big rainfall. More gauging would have been needed in different flow to get a complete rating curve.

Table 11: Results from gauging flow in drain.

Date	Time [h:min]	Discharge [m^3/s]	Water level [m]
8/11/2010	16:30	0.0087	0.085
26/10/2010	14:00	0.0145	0.086
5/10/2010	11:00	0.0157	0.09
21/10/2010	7:12	0.0282	0.1
24/09/2010	9:30	0.016	0.121
14/10/2010	11:30	0.3542	0.44

The discharge value from the gauging on the 14 October, 2010 was done directly after a heavy rainfall and is used as the value of maximum flow in drain for the storage calculations later on. During summer there was a steady flow in Horonui Drain while Cambell Drain dried up (see location in Figure 27).

4.2.6 Water levels

The measuring points for the water levels in Hole1 to Hole4 and drains were all included in the level survey and therefore shown relative to the fix point from where the measurements were taken. It shows that in October that the water levels in Hole 2 and Hole 3 were higher than the water level in Cambell Drain, on the north side of the field, and all the holes had a water level higher than the level in the drain by the bridge, Horonui Drain (Figure 62). As the field dried up the water levels in the field dropped and the measurements stopped in the end of November when the water levels dropped lower than the bottom of the holes. The measurements show three main things.

1. The water table had a convex surface between the two drains when the field was flooded. When the field dried up did the water table in field sink and the water table formed a concave shape between the drains (Figure 63).
2. The water table in field was higher than the water table in the drains when the field was flooded. It shows that the flooding water had a difficulty getting into the drains.
3. The flooding water dropped quite fast once the field started to dry up, and when the region was getting into the low flow season the body of water was already out in the system and will not affect Awanui Stream.

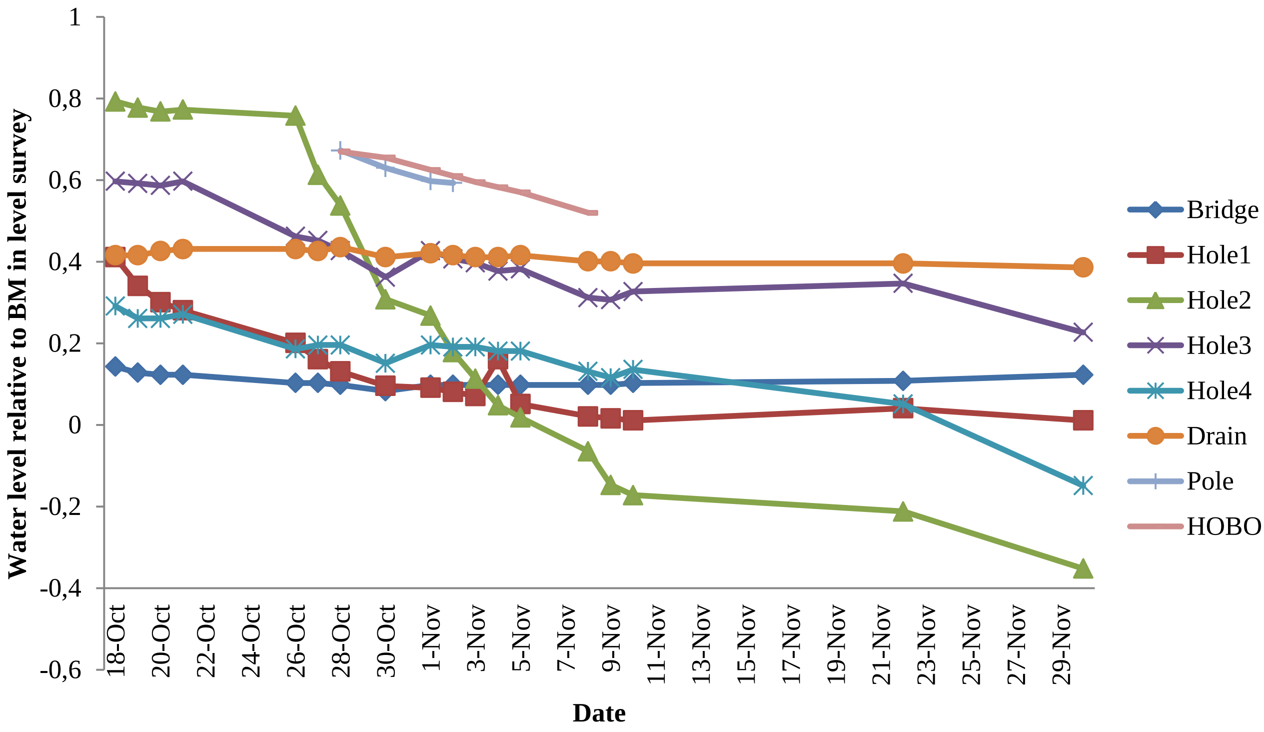


Figure 62: Water levels in the holes, drains and measurements of ponding water level above ground surface (Pole and HOBO).

The lines that show the water drops named Pole and hobo are measurements of how the flooding water dropped when the water in the holes started to drain away. The ponding water that had the water surface above the peat soil and formed little lakes or ponds close to Hole 2 had a steady dropping rate of 20 mm/day. That is another indicator that the fine particles of silt and clay in the peat soil prevent the water from dropping in the same rate as the water table in the pumice.

The concave and convex shape of the ground water table is shown when comparing the water levels from the middle of October to the water levels from the end of November (Figure 63). The water table is higher towards the middle of the field, and forms a convex shape when wet. As the field dries up does the water table drop and forms a concave surface between the drains with the deepest part in the middle of the field.

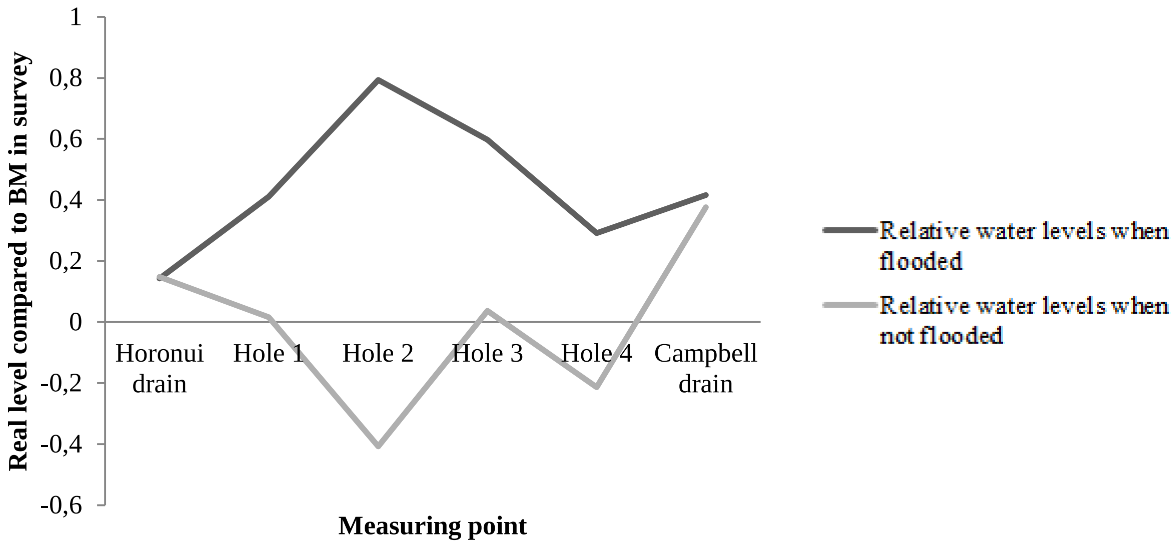


Figure 63: Relative water levels when the field was flooded 18 October 2010 compared to water levels when field was dry 12 November 2010.

This shows that the water table drops and that flooding never occurs during a low flow period. Once the low flow season starts the water is already out of the area. Therefore the volume of water in the flooded field cannot have an effect on the flow in Awanui Stream during summer.

Extrapolation of water levels

To estimate the water level of the ground water level in Hole1 to Hole4 at 21 January 2011, an extrapolation of the measured values was done. To be able to calculate the ground water level from the ground surface the exact level of the ground surface had to be calculated. Levels in field are presented in Table 12.

Table 12: Levels in the field [cm].

	Hole1	Hole2	Hole3	Hole4
Real level measuring point (RL MP)	78.1	83.8	124.7	108.1
Real level ground surface (RL GS)	109.9	72.6	75.3	106.
RL MP- RL GS [cm]	-31.8	11.2	49.4	2.1
Estimated water level on 21 January 2011	-91.3	-115.7	-150.0	-145.0

Where;

Real level measuring point (RL MP) - is the elevation value that was measured for the measuring spot at each hole. Every hole had a fix point close to ground level from where the water level was measured every time. These fix points were included in the level survey over the field.

Real level ground surface (RL GS) - is the elevation value for the ground surface at the measuring point from the level survey.

RL MP- RL GS - is the elevation value for the fixed measuring point minus the elevation value of the ground surface. These values were added to the measurements of the distance to the water level from the fixed measuring point to get all levels relative to the bench mark (BM) in the level survey.

Estimated water level on 21 January 2011 [cm]- is the depth of the water level in cm from the ground surface that was calculated with the extrapolation.

The estimated water level on 21 January 2011 will be used to calculate if it was possible for a rain storm that occurred on 21 January 2011 to flood the field again.

Extrapolation of water levels can be found in Appendix H.

4.2.7 Results of study of pond vs. ground water

As explained in 3.4.9 did the water in the puddle drain away much slower than the water in the holes. In order to find out if there was a difference in infiltration rate for the water above land surface (on top of the peat soil) compared to the water in the holes (in the pumice soil), was the last puddle in field studied just before drying up. By using a grid with 1 meter between the grid points and measuring the water depth at these points, an image could be created in ArcScene (Figure 64). The data of the measurements from the field and calculations from ArcScene are shown in Table 13. No consideration was taken to the land surface in-between the points, therefore an error is expected.

The pole where the measurements were done was not placed in the deepest part of the puddle, therefore was the volume of water not zero when the water depth at the measuring point was zero. Extrapolation was used to calculate the volume on the 31st of October, when no measurement was done. Evaporation for the time was given from the calculated potential evaporation, Thornthwaite equation.

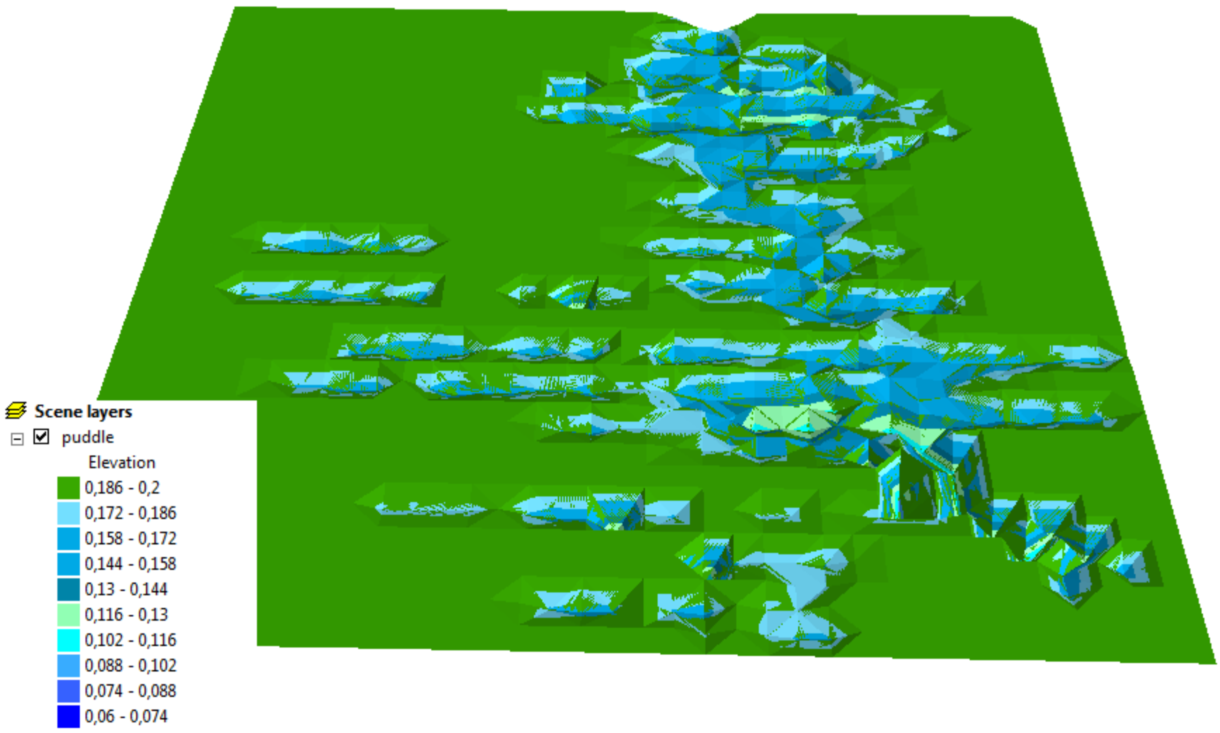


Figure 64: ArcScene image of puddle.

Table 13: Data for puddle in field, volume calculated in ArcScene.

Date	Depth of water [mm]	Evaporation [mm/day]	Infiltration [mm/day]	Volume [m^3]
28-Oct	80	7.54		182.56
29-Oct	60	7.82	12.46	175.54
30-Oct	37	4.29	15.18	153.05
31-Oct	No measurement	4.1		130.56
1-Nov	5	4.47	27.17	98.29
2-Nov	0	4.91	0.53	57.04

Figure 65 below shows how the volume of the puddle decreased over time. The calculations of the volume of water in the puddle were made in ArcScene. When a three-dimensional image is created in ArcScene, the program creates triangles in-between the grid points to draw the surface. This will give an expected error. Another error was caused by the fact that the depth of water only was measured at the grid points. The field had a very uneven ground surface that was not taken into consideration during these measurements.

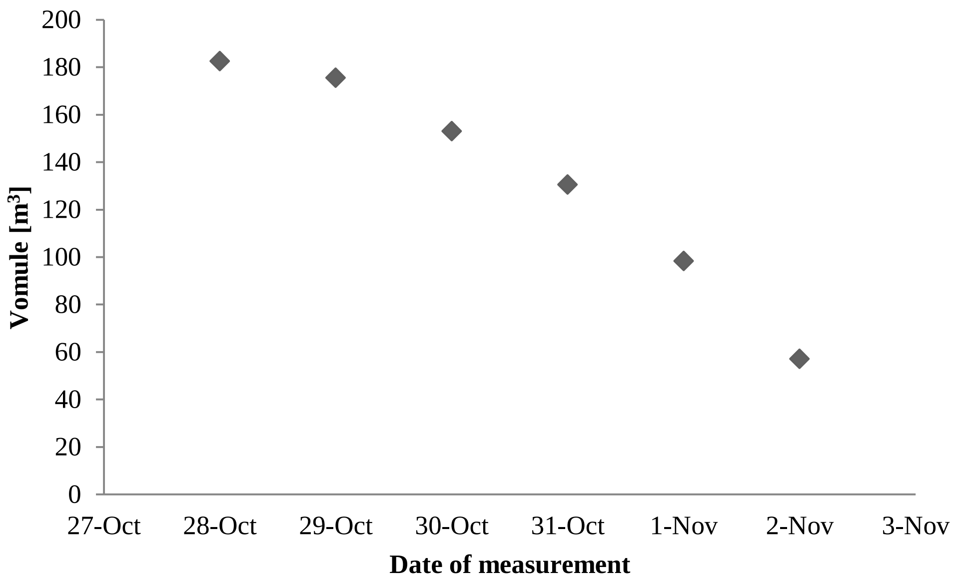


Figure 65: Change in volume of the puddle.

The drop of the water level in the puddle was compared to the drop of the water level in Hole 2, that was located very close to the puddle. When Hole 2 was dug, the water table was so high that the water table was above ground surface and the water in the pit was a part of the big puddle. The amount of water in the field decreased a bit during October 2010, but there was still a large ponding area and Hole2 was still filled up with water.

At the end of October a rapid drop of the water level in Hole 2 started, and that was when the model of the puddle was set up. The rapid drop of water affected the whole field and the puddle next to Hole2 was the last area in field with ponding water above land surface. The water in the puddle obstructed from infiltrating by the fine particles in the peat soil, while the water in Hole 2, dug deep in the pumice, infiltrated very rapidly. The measurements of the two water levels are shown in Table 14. All figures represent the change from the previous day.

Table 14: Comparing drop of water level in puddle and Hole 2.

Date	Evaporation [mm/day]	Drop of water level in puddle [mm/day]	Infiltration in puddle [mm/day]	Drop of water level in Hole2 [mm/day]	Infiltration in Hole2 [mm/day]
28-Oct	7.54				68.9
29-Oct	7.82	20	12.46	No measurement	
30-Oct	4.29	23	15.18	230	214.64
31-Oct	4.1	No measurement		No measurement	
1-Nov	4.47	0.5	27.17	40	31.61
2-Nov	4.91	0	0.53	90	85.53

The average infiltration rate in the puddle was 13.70 mm/day, while the average infiltration rate in Hole2 was 66.78 mm/day. The water in the pit, infiltrating through the pumice, had an infiltration rate that was 5 times faster than the infiltration rate for the water in the puddle infiltrating through the peat.

4.2.8 Results of storage and catchment area

The area of the catchment is 11.67 km^2 (marked with black line in Figure 66) and the approximate area that gets affected by the flooding is 1.5 km^2, (larger gray triangle in Figure 66). The area that gets affected by the flooding is about twice as big as the field (smaller grey triangle in Figure 66).

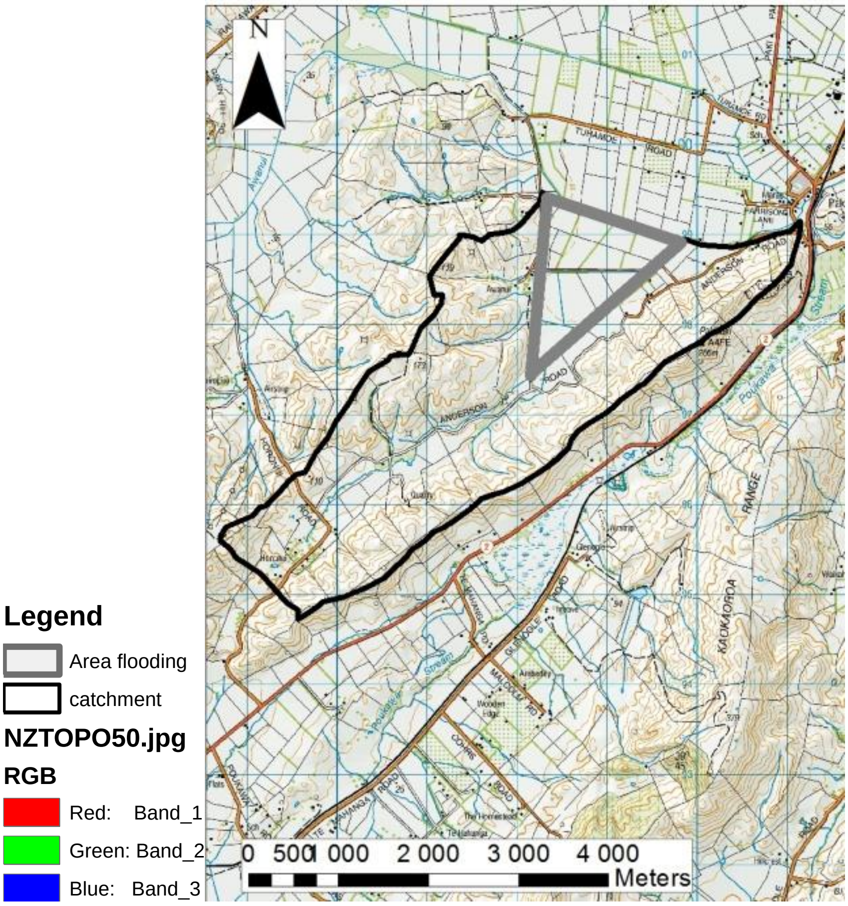


Figure 66: Catchment area and area effected by the flooding.

To find out the storage room in the soil profile was the porosity, for both peat and pumice needed. As mentioned above was no value for the porosity in the pumice soil found. Therefore was the specific yield used, and will result in a large storage room than the true value. The Porosity percentage of peat is 92%, (Shaw, 1983), and the specific yield of pumice is 21%, (Portage County).

These calculations were done in the purpose of analysing what happened out in field when there was a big rainfall of 156 mm in 4 days, which caused the field to flood again after being dry for a longer period.

The approximations set up before calculations were.

- Porosity = specific yield.
- Water depth in field at 21 January 2011 was 1.5 m. Deepest calculated water level after extrapolation.
- Thickness of peat is 0.3 m across the whole field.
- The constant outgoing flow in the drain during the time is set to the highest measured with the Flow Tracker, 0.3542 m^3/s.
- The soil above 1.5 m below ground surface is completely dry on the 21 January 2011.

All these approximations will result in a larger calculated storage room than the true value.

Table 15: Precipitation and evaporation data from 21 January to 24 January 2011.

Date	Precipitation [mm]	Potential evaporation [mm]
21-Jan-11	5	7.39
22-Jan-11	31	7.50
23-Jan-11	110	7.52
24-Jan-11	10	8.18
Sum	156	30.59

Calculations below show what influence that big rainfall could have on the level of the water table. Because the field is placed where the valley opens up at the bottom of the catchment, a rough assumption is made that all rainwater that falls within the catchment will end up in field.

$Catchment\ area = 11\ 670\ 000\ m^2$
$Area\ affected\ by\ flooding = 1\ 500\ 000\ m^2$
$Porosity = Specific\ yield\ peat\ soil = 0.92$
$Porosity = Specific\ yield\ Pucice\ soil = 0.21$
$Maximum\ water\ depth\ on\ 21\ January\ 2011 = 1.5\ m$
$Thickness\ of\ peat\ layer = 0.3\ m$
$Depth\ of\ dry\ pumice\ down\ to\ water\ table = 1.2\ m$
$Outgoing\ flow\ in\ drain =\ 0{,}3542\ m^3/s$

$$Precipitation - Potential\ evaporation = Supply\ of\ water\ into\ catchment$$
$$156 - 30.59 = 125.41\ mm = 0.125\ m$$

$$Area\ of\ the\ catchment \cdot (Precipitation - Potential\ evaporation)$$
$$= Total\ volume\ of\ water\ in\ catchment$$
$$11\,670\,000\, m^2 \cdot 0.125\, m = 1458750\, m^3$$

It is not taken into account the that the water depth in the flooding parts was about 30 cm when the field flooded because the water depth of 1.5 meters that is used for the calculation is an approximation.

The outgoing flow in the drain during the time period is assumed to be the maximum measured flow of 0.3542 m^3/s. That measurement was made during a big rainstorm on the 14th October 2010.

$$0{,}3542\ m^3/s \cdot 60 \cdot 60 \cdot 24 = 30603\ {m^3}/_{day}$$

The rainstorm lasted for four days, and results in a total volume of 122412 m^3 leaving the catchment.

$$30603\ {m^3}/_{day} \cdot 4 = 122412\, m^3$$

The storage room the area affected by the flooding is calculated below.

$$(1\,500\,000\, m^2 \cdot 0.92 \cdot 0.3\, m) + (1\,500\,000 \cdot 0.21 \cdot 1.2\, m) = 792000\, m^3$$

In order to find out if the total volume of water in the catchment is enough to flood the field again is the volume that is assumed to flood the field and the outgoing water subtracted.

$$1458750\, m^3 - 792000\, m^3 - 122412\, m^3 = 544338\, m^3$$

This indicates that there was more than enough precipitation from 21 January 2011 to 24 January 2011 to flood the field, even if the soil profile had been completely dry before the rainfall.

4.2.9 Pit refill observation

Hole3 (dimensions shown in Figure 67) where the pumping test was performed, contained an estimated volume of 4.1m^3 water.

$$4.6 \cdot 1.3 \cdot 0.7 = 4.1 m^3$$

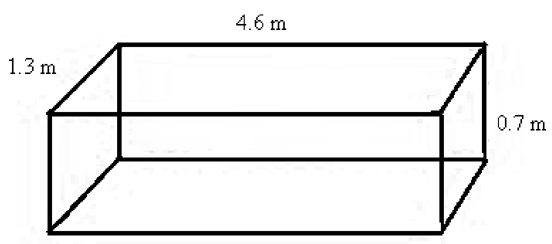


Figure 67: Dimensions of Hole 3.

The water was pumped out of the hole and the drawdown and re-charge of the water was logged every 5 min, Figure 68. When almost all the water was pumped out of the hole, was the pump turned off to see where from and how fast the water started to refill the hole.

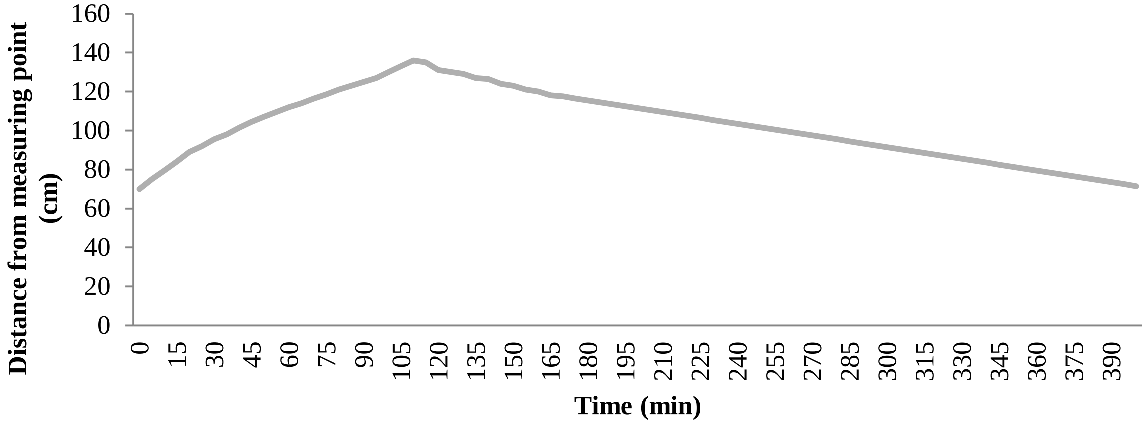


Figure 68: Discharge and recharge of water in Hole 3.

The water was flowing into the hole from the sides, and most water came into the hole through the coarse layer about 1 meter down in the profile, Figure 8. This showed that the whole soil profile is saturated and that the horizontal movement of water in the field is very good.

5. Discussion

In the beginning of the study it was expected to find a seal in the top part of the soil profile to explain the flooding water. No seal obstructing the infiltration could be found in field. It was clear though that the infiltration was prevented by fine particles in the peat soil, which makes the flooding last longer than necessary. It was also expected that the infiltration would be poor in the areas affected by flooding. The tests showed that the infiltration was higher in the areas that get flooded every year. The reason that the study was made was to find out if the flooding water could be pumped out of the field, in the purpose of saving crops.

The soil in field

The soil fraction analysis test showed a great difference in particles sizes between the wet and the dry area (Table 3). The test was though only performed on two samples, one from each area. There is a possibility that the difference in particle sizes between the areas is misleading because of the fact that no multiple samples were taken. My judgment is though that the reason to the lower infiltration rate in the ponded areas is that there are more fine particles. The fact that the flooding occurs in the lower parts of the field and that the dry areas have a more compact top layer of soil indicates that there should be more fine particles in the top soil of the wet areas.

Infiltration

The infiltration tests showed that the infiltration is better in the flooded areas than in the higher leveled dry areas, which was not expected in the beginning of the study. This can be explained by the fact that the top layer of peat soil was more compact in dry areas, this was proved by the higher density and observations in field. It may also be explained by less fine and loose particles in the top soil. The fine and loose particles in soil surface of the dry areas may get transported from the dry higher located areas towards the lower located areas with runoff water, which also contributes to the volume of water in the flooded areas. The soil surface in the dry areas is also more exposed to compaction from both livestock in the paddock as well as human transports with heavy machinery when the dry path is the easiest to take. The top soil in the dry area where double ring infiltration tests were done was so compact at ground surface that two infiltration tests failed because of very poor infiltration, below 6.67 mm/h. The water level in the inner ring never dropped to the re-rill mark.

The high infiltration rate in the wet areas, done when the water had drained away, can be explained by two different factors. First that the peat soil in the flooded areas gets disrupted every time sheep in the paddock moves through the field, and it takes very long time for the fine particles to settle, and they will not do so in the same structure as before. Larger pores are therefore created and will increase the infiltration rate in the soil once the ponding water has drained away. Adding to that affect is also that when peat soil dries up it usually shrinks, cracks and creases are formed where water easily can infiltrate.

The disc permaemeter tests in the pumice showed that the pumice is highly permeable, even when it is not saturated. Therefore was the conclusion drawn that there is no way that the holes dug in the pumice could be filled up with water without the whole soil profile being saturated by a rising ground water table. The disc permeameter tests also proved that there is nothing preventing the water to infiltrate sufficiently once the pond has drained away. But because of the high permeability in the pumice soil was it very hard to get stabilized values for the hydraulic conductivity, which may have caused errors in the measurements.

Seal in top part of soil profile
The nuclear densometer did not show that there was any drastic change in soil moisture in the top 250 mm of the soil profile. If there would have been some kind of a seal in the top part of the soil profile, there should have been a clear change in moisture content below that point.

The test “Possible sealing of soil after extended period of time” showed that the infiltration decreases when saturated during an extended period of time, but never seals off completely. The test method of taking out core samples in pvc-pipes could be improved though. There is no way to know if the infiltration along the inner walls of the pipe affected the result. I am aware that it might be a possibility though. The test did show though that something preventing the water from infiltrating when the soil is saturated for a longer period of time.

The pit refill observations established that the holes dug in field only could be filled with water if the soil profile above the clay layer was saturated.

Hydrophobicity
Hydophobicity or water repellency develops during dry periods and the samples for the hydrophobicity tests were taken close after a heavy rain that could have broken the hydrophobic layer, if one would have existed. No hydrophobicity could be shown when the test was performed, even though some of the potential WDPTT tests showed a slight tendency of water repellency.

Observations in field during very dry periods in November and December, before the hydrophobicity tests were done, made me believe that the dry areas (areas not affected by the flooding) probably have been more or less hydrophobic from time to time.

Storage and catchment area
A rough water balance budget was calculated in the area to see if there was enough water to support the theory of a rising ground water table, and to see if the big rainfall in the end of January could cause a flooding in the field. When calculations were made in the catchment area it was assumed that all water in the catchment would flow towards the field, in the bottom of the catchment. That assumption is a very rough assumption because no information about the geology further up in the catchment was available. It can be assumed that the clay layer that in field is located 7 meters below ground surface would get thinner further up in the catchment where the hills are. And therefore would some of the water from precipitation end up to feed into the confined aquifer under the clay. The values for specific yield that are used for the peat and pumice soil, are assumed to be larger than what they probably are. Therefore will the calculations give a lager storage space in the soil profile. The water depth that was used in the calculations was the value of the deepest expected water level at the 21 January 2011, and will also contribute to a larger calculated storage volume in the field. But in the end do the calculations show that there was more than enough water to fill up that storage volume and it proves that it is reasonable to assume that the rain from 21 January 2011 to 24 January 2011 was enough to flood the field.

Pumping
Based on the fact that the flooding can be explained by a rising ground water table, would pumping in the filed not affect the flow in Awanui Stream during summer. It can be discussed though if pumping wound be the best option to solve the problem. When the flooding in field was at its highest point was a larger area than only within the study fields boundaries flooded. It is reasonable to assume that all the flooding water is in continuity. Pumping the water in field would then imply trying to lower the water table in the whole valley in the bottom of the catchment area. And since the top soil in the wet

areas was very loose could pumping the water from above cause clogging problems in machinery if soil particles get sucked up.

Method

A lot of tests were done in this study. I am sure that the same result would have been reached with only a few of these tests. But since we didn't know much about the area, soil profile or water in the field when the project started, was it a very reasonable start to try to find out as much as possible. Every test that was done added a little bit of information and led us in the right direction.

6. Conclusion

There is no seal formed in the top part of the soil profile preventing the water from infiltrating. The flooding water is the result of a rising groundwater table on top of a thick clay layer 7 meters down below land surface.

Once the flooding water has drained and evaporated away there is nothing obstructing the infiltration in field, except from the fact that some parts of the dry areas have poor infiltration.

The most important conclusions of this study are summarized below.

- The soil fraction test showed that there very fine particles in the peat soil, and that there are a larger fraction of very fine particles (silt and clay) in the wet area compared to the dry area.

- After comparing the LIDAR map to the results of the level survey and the satellite image from Google maps. It was clear that there are the same areas in field that gets flooded every year and these areas are also the areas with the lowest elevation.

- The infiltrations tests showed that when the flooded water has drained away, there is actually better infiltration in the areas that were affected by the flooding compared to the areas not affected by the flooding.

- The test when water was pumped out of Hole3 and then refilled proved that the whole soil profile is saturated.

- By studying the water level in the puddle and the water level in Hole2 the separation of the ground water table was noticed and could be explained by the fine particles in the peat soil.

- Extrapolation of the water levels and the Water balance calculations showed that it is possible that the flooding is caused by a rising ground water table. There was more than enough water in the catchment area to flood the field after the big rain storm in the end of January 2011.

The situation in field is that there are very fine particles of silt and clay in the top soil that decreases the infiltration rate and can cause a separation between the ground water and the water above land surface. When that separation occurs there is a pond of water resting on top of the peat soil that infiltrates very slowly. This separation makes the flooding last longer than necessary. The main part of that water that gets trapped above land surface evaporates away, while the ground water below the peat layer is dropping much faster in the permeable pumice. The fine particles can be assumed to be transported to the flooded areas located at lower levels with runoff water from the dry areas and settling dust from the surrounding farm tracks.

Another issue is that the water above land surface that is flooding the low spots in field has a great difficulty to get to the drains. The water level in the surrounding drain is lower than the water table in field. The flooding water should therefore be able to runoff towards the drains. This does not happen due to the elevation in the field and the water holding capacity of the peat soil.

There is nothing indicating that pumping the flooding water in the field would have a negative effect on the flow in Awanui Stream during summer. The flooding problems occur during the wet periods when there is plenty of water in the area. When the low flow season starts, is the flooding water in field already out of the area.

The results of this project cannot be used to assume that all the flooding areas close to Awanui Stream can be pumped on water without affecting the flow in Awanui Stream. The result that pumping can occur is based on the fact that the flooding water is a rising ground water table on top of a thick clay layer. Without knowing the geology in the other areas no conclusion can be drawn that the conditions are the same. And this field is placed in the bottom of a big catchment area.

But by studying the geology and the catchment area of other flooded areas, the cause of the flooding could be found in a more efficient way. And hopefully the conditions are the same, which then may allow pumping.

7. Recommendations

When the project was finished it was clear that the planned solution with pumping away the flooding water through Horonui Drain would not work in the extent it was planned. Pumping the water in Horonui Drain to speed up the water movement in the valley and "suck" the water out of the field would only lead to a separation of the body of water and the ponding water above land surface would still cause problems. I had two different ways of solving the flooding problem in field that I gave to landowner H. Ritchie as recommendations after the project was finished.

7.1 Recommendation scenario 1

To re-level the field, remove the top soil with a bulldozer and use available GPS-equipment to re-level the field and create a smooth surface with and angle leaning toward the drains. With this method the low spots in field that gets flooded would get filled in and the slope of the field would lead to natural drainage of surface water into the drains.

This is a very expensive and time consuming solution.

7.2 Recommendation scenario 2

Create side drains from Horonui Drain and Cambell Drain into the field going through the ponded areas. The loose and fine particles in the peat get transported with the runoff water and there is a possibility that they will clog up these drains and prevent the drainage. A solution to that could be to fill up the side drains with a coarse material, for example shingle, that will prevent the peat to form a layer with low permeability.

This solution would cause constant draining of the field, but due to the fact that the ground water table on top of the clay layer is very low when the dry summer starts it is not considered to be a problem. A very advanced irrigation technique that is installed in the field can also adapt to create the most efficient way of using the water during those conditions.

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Appendix A: Biological study

Vegetation

In the ponding areas, the grass that was planted and supposed to grow in the field died because of the flooding. Grass that stands under water dies from the lack of oxygen. Other, more tolerant, plants then started to grow. The most common ones were sent for identification to Landcare Research in Christchurch and were identified as; Pink water speedwell, Poison buttercup also called Celery-leaved buttercup and Water starwort, Figure 69.

Pink water speedwell grows in drains and swampy places (Johnson, 1998).

Poison butter cup grows in drains, ponds, damp pasture, wet roadsides, stream banks, lagoons and swamps. Water starwort grows in and around areas of still and slow-moving water, also commonly in swampy areas on mud, (Webb et al, 1988).

Figure 69: Plants in the ponded areas. From the left: Poison buttercup, Water starwort, Pink water speedwell.

These plants are all water tolerant and given the right conditions they surpass the grass. The field is a part of a large cropping enterprise and is not intended to be a wet land. During winter when the grass is growing in the field and the ponding problems are at their worst, the celery-leaved buttercup grows in large quantities at the same time as the field is used as pasture for sheep. The butter cup is poisonous to sheep and the farmer risks losing livestock with the plant growing in the paddock.

Earth worm count

A worm count test was done to compare the differences in biomass of earth worms between the ponding and the non-ponding areas. Worms indicate aired and well drained soils. The test followed guide lines from Minnesota Worm Watch Program, University of Minnesota.

There are different ways of calculating the biomass of earth worms. The plan for this project was to show how the biomass of earth worms changes with distance from the ponding area. Therefore only the dry biomass was calculated, i.e. weight of dry worms with no gut content.

To eliminate the problem in variability due to gut contents the worms were kept in a plastic container without any food for 48 hours. This is enough time for all worms to empty their guts, (University of Minnesota).

To eliminate the variability due to moisture content, the earth worms were dried in an oven at 25°C for 30 hours, (University of Minnesota).

Blood worms

A large population of blood worms, Chironomus zealandicus, lived in the sediment of the ponded areas, which indicates that the water has low levels of dissolved oxygen and turns anoxic during saturation. The haemoglobin in their bodies enables them to live in oxygen-poor water and sediments, (Evans, 2010). The tough conditions make it hard for other aquatic insects to live and that gives the Chironomus zealandicus the opportunity to build up large numbers in their population without any competition. The bright red colour comes from haemoglobin (blood protein that carries oxygen), which helps them tolerate poorly oxygenated water, (NSW Department of Infrastructure).

Dissolved oxygen

To prove that the conditions are poor in the ponding areas, which was indicated by the large population of blood worms, the dissolved oxygen is measured in-situ. A HQ Series Portable Meter with a Luminescence-based Oxygen sensor was used to measure the dissolved oxygen. The probe measures the light emission characteristics of a luminescent reaction. Dissolved oxygen concentration is inversely proportional to the luminescence lifetime of the light emitted. The lower DO concentration there is, the greater the signal to noise ratio will be, (Jackson, 2004).

Dissolved oxygen (DO) is a critical factor in aquatic ecology. The DO concentration is affected by temperature, plant respiration, amount of organic material present, etc., (Sutherland, 2006).

Oxygen is necessary for all life forms, when DO levels drop under 5 mg/l, aquatic life is put under stress. Lower concentration results in greater stress. DO levels that remain under 1-2 mg/l only for a few hours can cause large fish deaths, (Lenntech, 2010).

There are three main reasons to low oxygen levels in bodies of water.

Causes

High temperatures

When the temperature in water raises the molecular activity increases. The molecules of the warm water push the oxygen molecules out of the spices between, (Water research center, 2010).

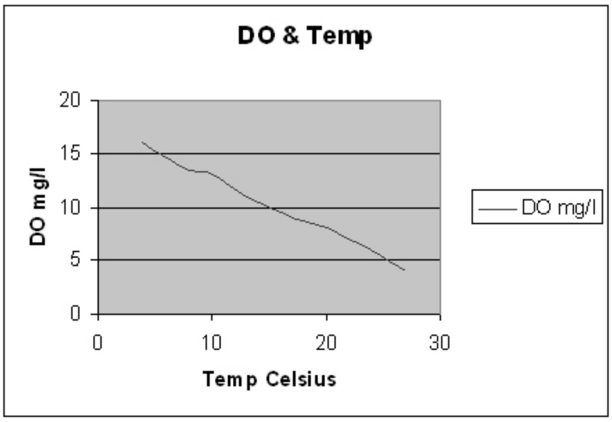


Figure 70: Relationship between DO and water temperature, Finger Lakes Institute.

Bacteria

Decreased DO levels may also indicate that there are too many bacteria in the water. This will cause an excess amount of BOD (Biological Oxygen Demand) which use up DO. An increase of bacteria can be caused by high temperatures in the water (Water research center, 2010).

Fertilizer

When fertilizer is applied to plants in water they grow better. An overcast that lasts over a few days will cause that the respiring plants will use much of the DO while failing to photosynthesize. This after a while will lead to that the plants will die. Dead plants in the water will support the increasing of bacteria (Water research center, 2010).

Photosynthesis

H2O + CO2 + light energy ---> carbohydrate + O2

Respiration

carbohydrate + O2 ---> CO2 + H2O + energy for respiration

Observations in field have made me believe that all three factors above do have a part in the low DO levels in field. The temperature in the ponding water has been very high. And sheep has been places in the paddock during long periods of the ponding that will give an increase in fertilizing. As well as the grass that was growing in the ponding areas died after being under water for a longer period of time.

Results for biological profiling

Results for analyse of vegetation

The flooding water has caused the grass to die. The new environment has opened up the possibility for other more water resistant plants to grow.

Results for analyse of earth worm count

Every sample is collected from one square foot of soil, 15 cm deep at a certain distance from the water. All the earth worms found within that amount of soil was collected as one sample.

Sample 1.1 and 2.1 was taken 1 meter from the waterline; samples 1.2 and 2.2 to 1.7 and 2.7 were taken 5 meters apart on a straight outgoing line from the ponded area. Locations of all samples are shown in figure Figure 71. No worms were found until a distance of 21 meters from the water line was reached i.e. no worms was collected in samples 1.1, 2.1, 1.2, 2.2, 1.3, 2.3, 1.4 and 2.4.

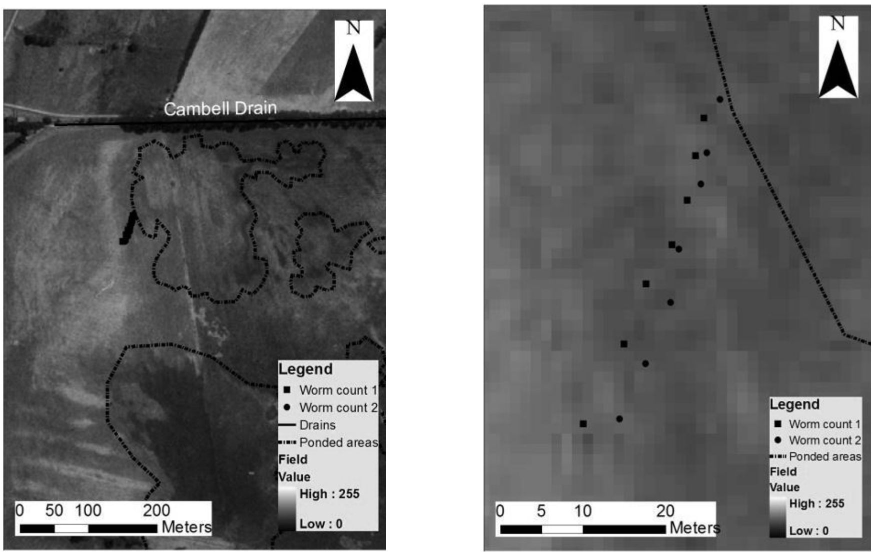


Figure 71: Location for the worm counts.

As Figure 72 shows the number of earthworms and the biomass decreases steady the closer to the ponded area the sample is taken. This shows that within and around the ponding area there are no earthworms airing and working the soil, which does not improve the infiltration conditions in the soil.

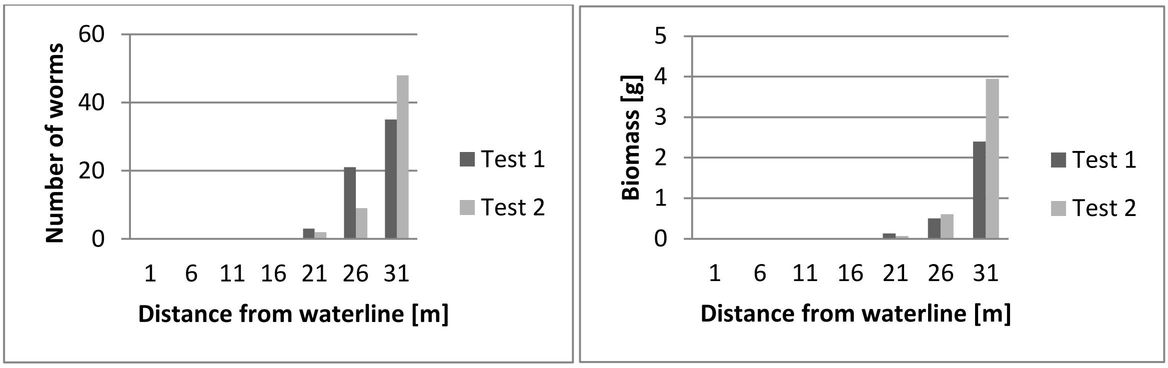


Figure 72: Number of worms and Biomass of worms relative to distance to ponded area.

Results of blood worms and dissolved oxygen

The presents of Chironomus zealandicus or Blood worms, Figure 73, indicates very poor conditions in the ponded areas with low dissolved oxygen levels.

Figure 73: Blood worms from one of the ponded areas.

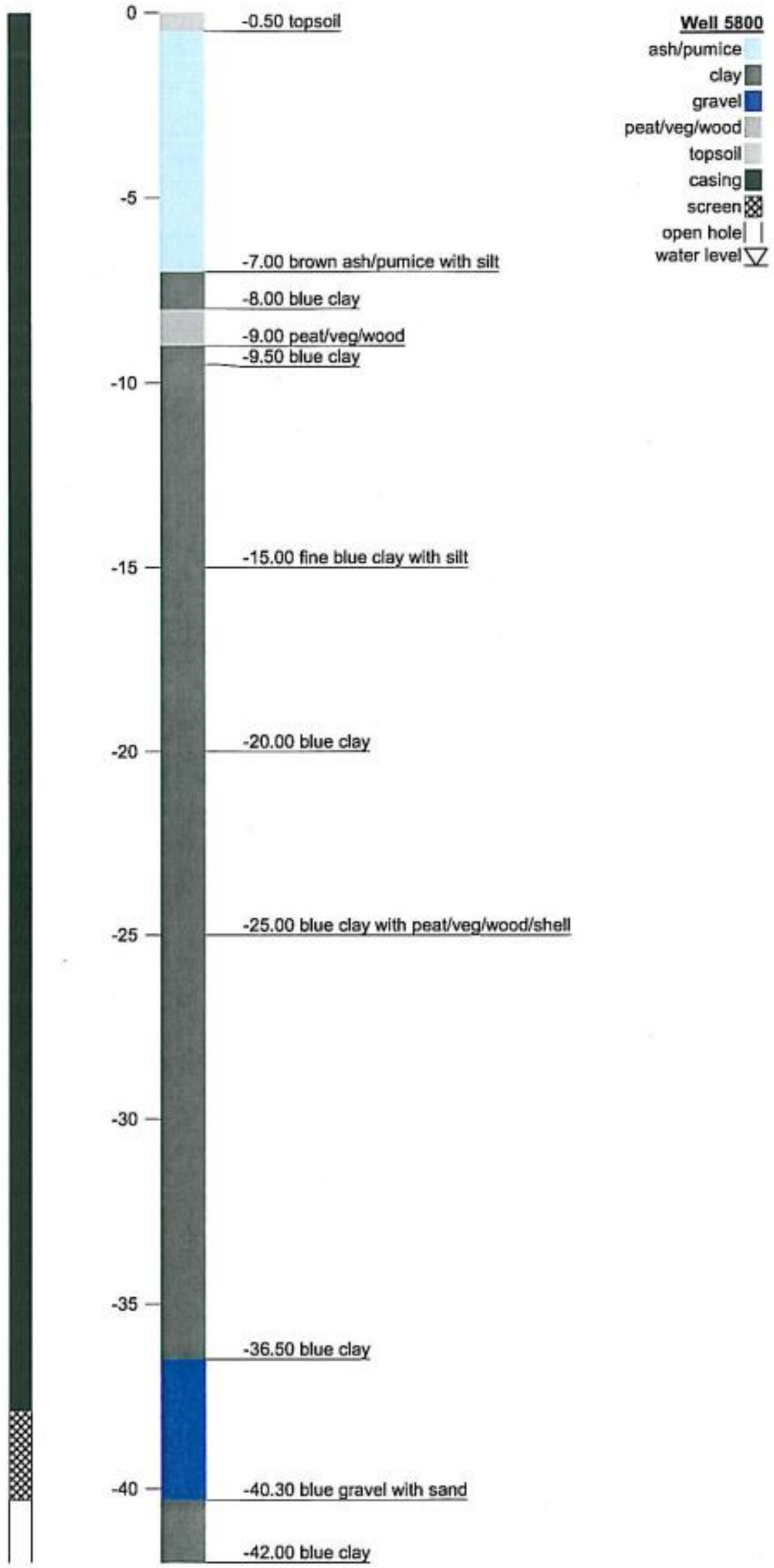
Because of the absence of plants and living organisms (besides blood worms), in the ponding water, dissolved oxygen levels were measured in-situ on Friday 1 October. The results can be found in Table 16 below.

The measurements of dissolved oxygen levels were done in the middle of the day. As explained above does DO levels decrease when photosynthesis increases, but the rate of respiration remains the same, which would happen during night when no sunlight is available, (Finger Lakes Institute, 2010). There for the assumption can be done that the DO levels shown in Table 16 are within the lower range of what the levels can sink to in the field.

Table 16: Dissolved oxygen in ponded area.

	mg/l	%
	0.88	10.8
	0.92	11.3
	1.34	16.6
	1.56	19.2
	1.35	16.6
	1.41	17.4
	1.48	18.3
	1.36	16.7
	1.43	17.6
Average:	**1.303333**	**16.05556**

Appendix B: Bore log



Appendix C: Thickness of peat soil in field

Grid point ID	Depth of peat layer [cm]	Grid point ID	Depth of peat layer [cm]
A1	23	**E1**	22
A2	37	**E2**	24
A3	23	**E3**	28
A4	12	**E4**	18
A5	18	**E5**	18
B1	17	**E6**	11
B2	15	**E7**	15
B3	18	**E8**	24
B4	19	**F1**	35
B5	22	**F2**	17
B6	23	**F3**	22
C1	27	**F4**	27
C2	23	**F5**	36
C3	23	**F6**	20
C4	30	**F7**	18
C5	24	**F8**	18
C6	23	**F9**	45
D1	30	**G1**	48
D2	12	**G2**	28
D3	13	**G3**	49
D4	20	**G4**	26
D5	20	**G5**	30
D6	15	**G6**	20
D7	20	**G7**	25
		G8	22
		G9	25

Appendix D: Pipette method

The procedure of the pipette method, Particle Size Determination (Pipette Method):

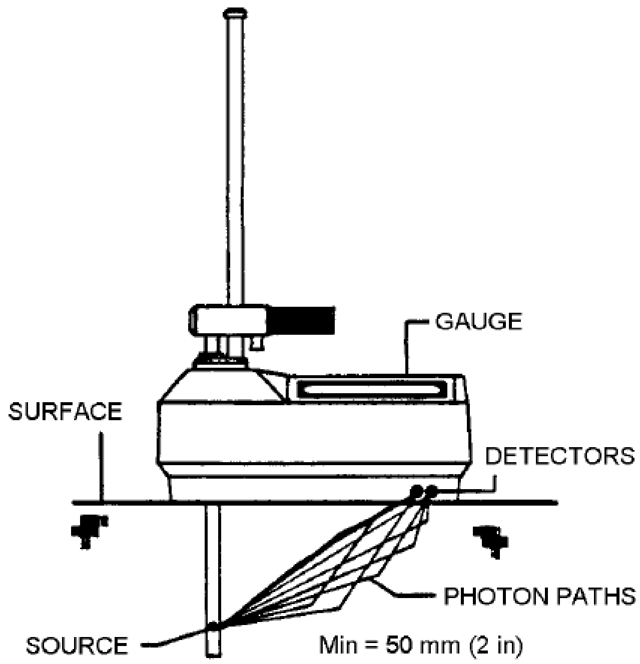
1. Weigh the oven dried sample the get the weight of the whole sample that is used in the Pipette Method.
2. Gently break up the sample in water until all the fractions have loosened up in the water. In this analysis 5 drops of ammonium was added to increase this process.
3. Pour the solution into a 1000 ml cylinder, and fill up with water to the 1000ml mark
4. Stir the sample and start the timer at the same time as the sample is left to settle.
5. A sediment sample is pulled, with a pipette, from a depth of 10 cm from the water surface at the times that are determined according to the settling chart (Table 17) based on water temperature.
6. Dispense the sediment sample from the pipette into a beaker, and place in oven to dry.

Table 17 Settling chart (in phi time steps), based on a water temperature of 20˚C.

Diameter of particle (mm)	<0.63	<0.031	<0.016	<0.008	<0.004	<0.002	<0.0005
Depth of withdrawal (cm)	10	10	10	10	10	10	10
Time of withdrawal	29s	1m55s	7m40s	30m40s	1h1m19s	4h5m	37h21m

Appendix E: Method Nuclear densometer

The base plate is placed on the flat ground where a reading will be taken. Through one of the holes a rod is hammered down to create a hole that the densometer's probe can be inserted to. The rod has got lines to indicate the depth of the hole every 50 mm. The maximum measuring depth is 250mm. The base plate and the rod are removed and the nuclear densometer is placed in that spot with the opening for the probe above the hole. The probe is inserted in the ground by unlocking the handle and pushing it down. When the probe is exposed in the ground the densometer can be given a light push sideways to eliminate any air in between the probe and the wall of the hole. Every reading takes one minute and gives an average of dry density, wet density, soil moisture and soil moisture % for the soil between the probe and the base of the densometer.

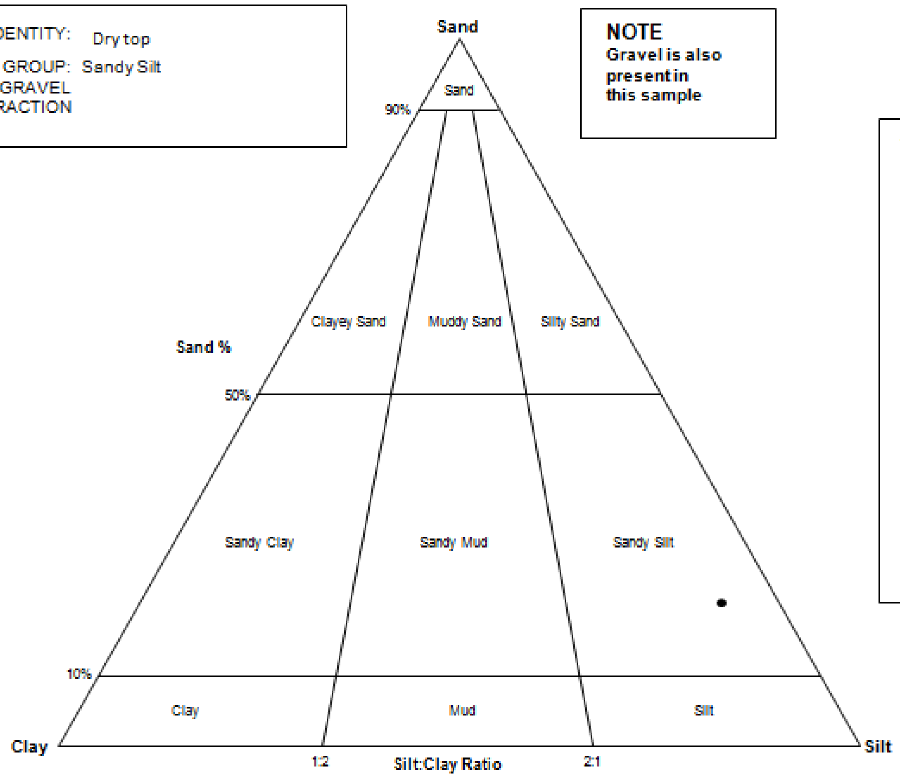


Appendix F: Percentage soil fractions

Percentage of fraction sizes Weight of whole sample	<2000 >1400	<1400 >1000	<1000 >710	<710 >500	<500 >355	<250 >180	<180 >125	<125 >90	<90 >63	<63 >44	<31 >22	<22 >16	<16 >11	<11 >8	<8 >6	<4 >3	<3 >2	<2 >1	<1 >0.5
Wet top: 23,4988	0.07%	0.07%	0.13%	0.23%	0.21%	0.40%	0.63%	0.52%	1.13%	5.13%	7.64%	6.66%	5.98%	2.26%	1.60%	1.30%	3.45%	2.98%	2.32%
Wet base: 19,4928	0.14%	0.08%	0.08%	0.18%	2.32%	1.18%	1.37%	2.12%	3.74%	8.18%	7.05%	6.85%	3.28%	4.98%	1.69%	4.36%	2.44%	3.46%	4.77%
Dry top: 28,713	0.43%	0.65%	0.07%	0.16%	0.32%	0.83%	1.69%	4.58%	11.57%	3.08%	10.55%	12.22%	16.21%	10.27%	2.23%	3.95%	3.67%	3.57%	3.60%
Dry base: 24,6487	0.15%	0.04%	0.03%	0.16%	0.36%	1.30%	2.48%	4.65%	9.85%	32.96%	5.11%	39.01%	6.45%	5.68%	0.20%	2.31%	0.06%	0.49%	1.08%

Appendix G: USDA textural classification charts

SAMPLE IDENTITY: Dry top
TEXTURAL GROUP: Sandy Silt
IGNORING GRAVEL FRACTION

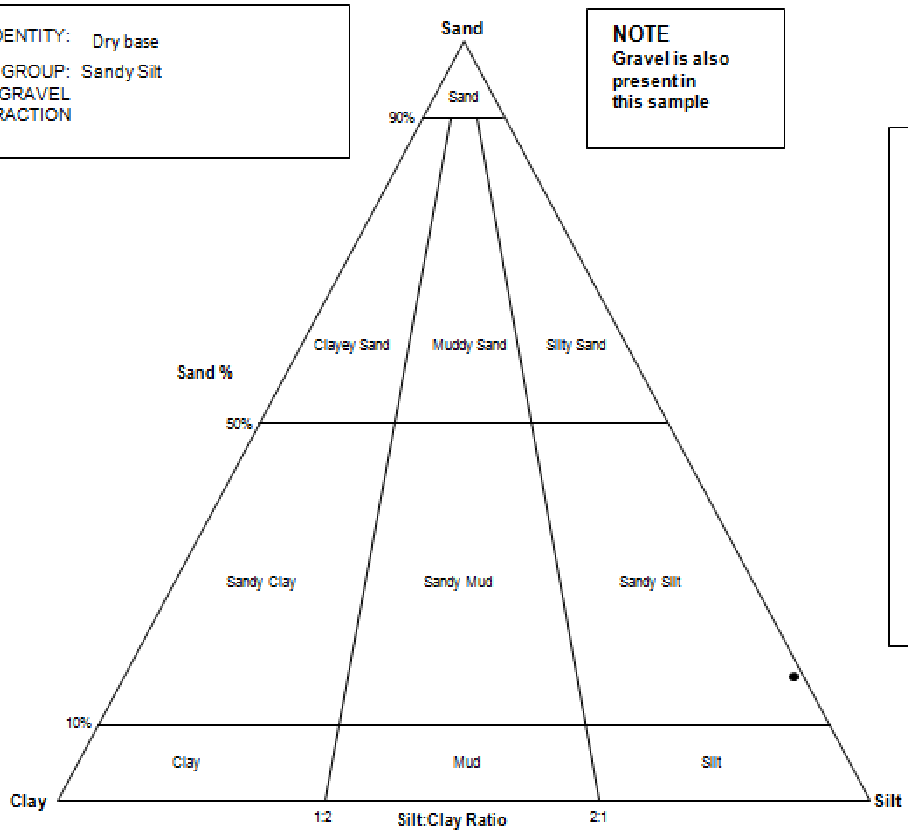


NOTE
Gravel is also present in this sample

Gravel: 0,4%
Sand: 21,3%
Mud: 78,3%

Very Coarse Gravel:	0,0%
Coarse Gravel:	0,0%
Medium Gravel:	0,0%
Fine Gravel:	0,0%
Very Fine Gravel:	0,4%
Very Coarse Sand:	0,7%
Coarse Sand:	0,6%
Medium Sand:	0,7%
Fine Sand:	2,6%
Very Fine Sand:	16,6%
Very Coarse Silt:	7,9%
Coarse Silt:	24,5%
Medium Silt:	26,3%
Fine Silt:	4,8%
Very Fine Silt:	7,6%
Clay:	7,2%

SAMPLE IDENTITY: Dry base
TEXTURAL GROUP: Sandy Silt
IGNORING GRAVEL FRACTION



NOTE
Gravel is also present in this sample

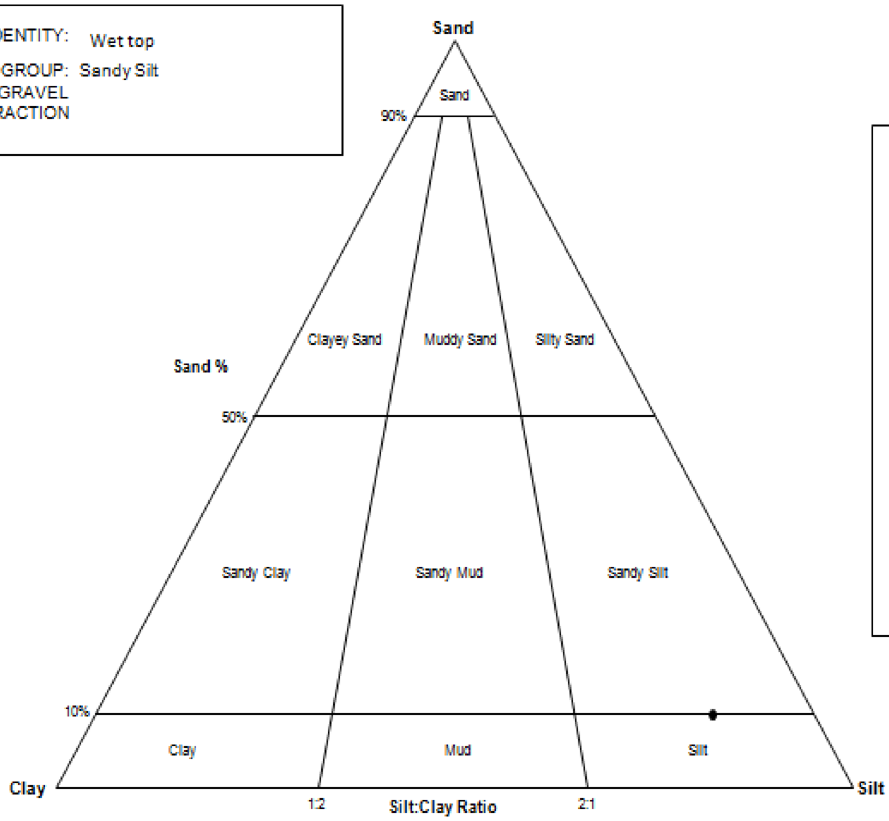
Gravel: 0,1%
Sand: 17,2%
Mud: 82,6%

Very Coarse Gravel:	0,0%
Coarse Gravel:	0,0%
Medium Gravel:	0,0%
Fine Gravel:	0,0%
Very Fine Gravel:	0,1%
Very Coarse Sand:	0,1%
Coarse Sand:	0,7%
Medium Sand:	0,8%
Fine Sand:	3,1%
Very Fine Sand:	12,6%
Very Coarse Silt:	32,2%
Coarse Silt:	36,9%
Medium Silt:	9,7%
Fine Silt:	0,7%
Very Fine Silt:	1,8%
Clay:	1,3%

SAMPLE IDENTITY: Wet top
TEXTURAL GROUP: Sandy Silt
IGNORING GRAVEL FRACTION

Gravel:	0,0%
Sand:	10,6%
Mud:	89,4%

Very Coarse Gravel:	0,0%
Coarse Gravel:	0,0%
Medium Gravel:	0,0%
Fine Gravel:	0,0%
Very Fine Gravel:	0,0%
Very Coarse Sand:	0,3%
Coarse Sand:	0,7%
Medium Sand:	1,2%
Fine Sand:	2,2%
Very Fine Sand:	6,3%
Very Coarse Silt:	23,6%
Coarse Silt:	24,5%
Medium Silt:	10,8%
Fine Silt:	5,8%
Very Fine Silt:	11,8%
Clay:	13,0%

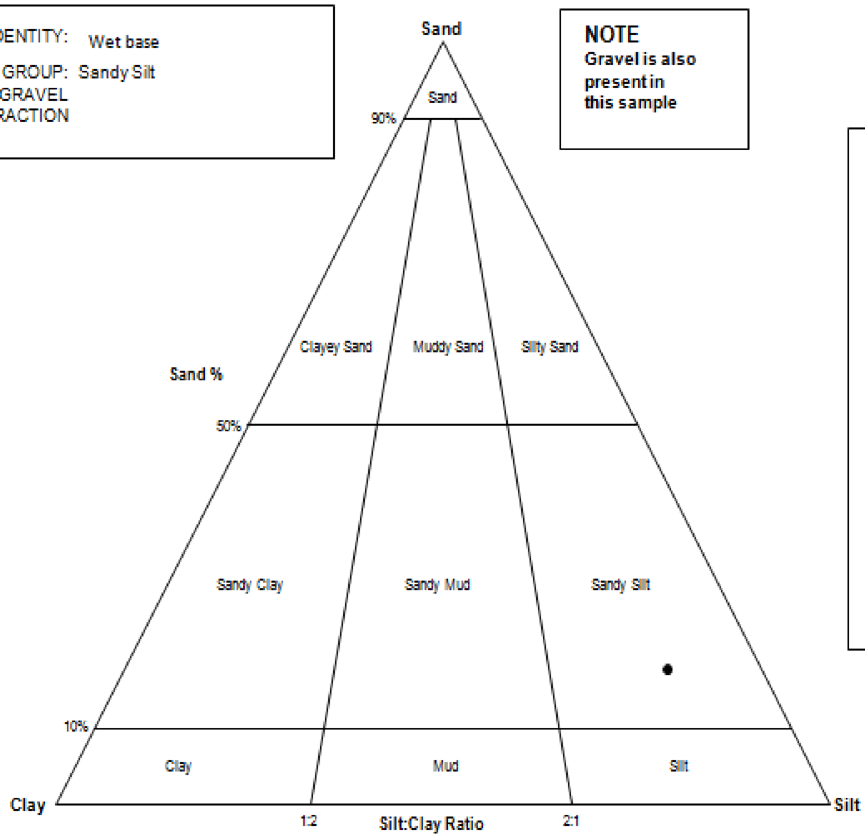


SAMPLE IDENTITY: Wet base
TEXTURAL GROUP: Sandy Silt
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	0,2%
Sand:	18,6%
Mud:	81,2%

Very Coarse Gravel:	0,0%
Coarse Gravel:	0,0%
Medium Gravel:	0,0%
Fine Gravel:	0,0%
Very Fine Gravel:	0,2%
Very Coarse Sand:	0,2%
Coarse Sand:	0,7%
Medium Sand:	4,7%
Fine Sand:	3,9%
Very Fine Sand:	9,1%
Very Coarse Silt:	19,3%
Coarse Silt:	21,5%
Medium Silt:	12,4%
Fine Silt:	5,8%
Very Fine Silt:	9,9%
Clay:	12,3%

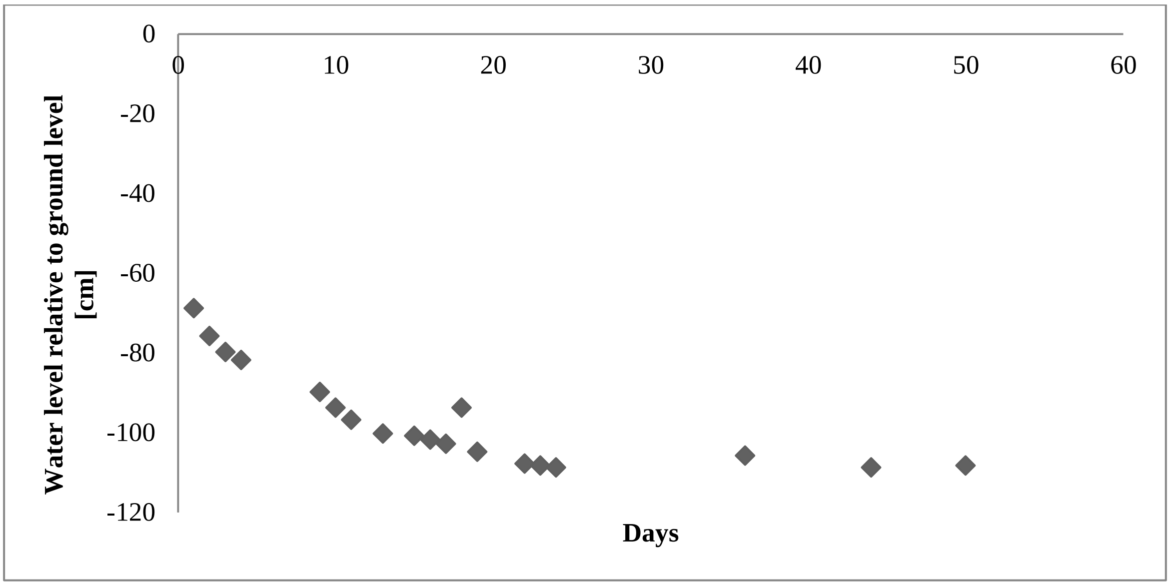


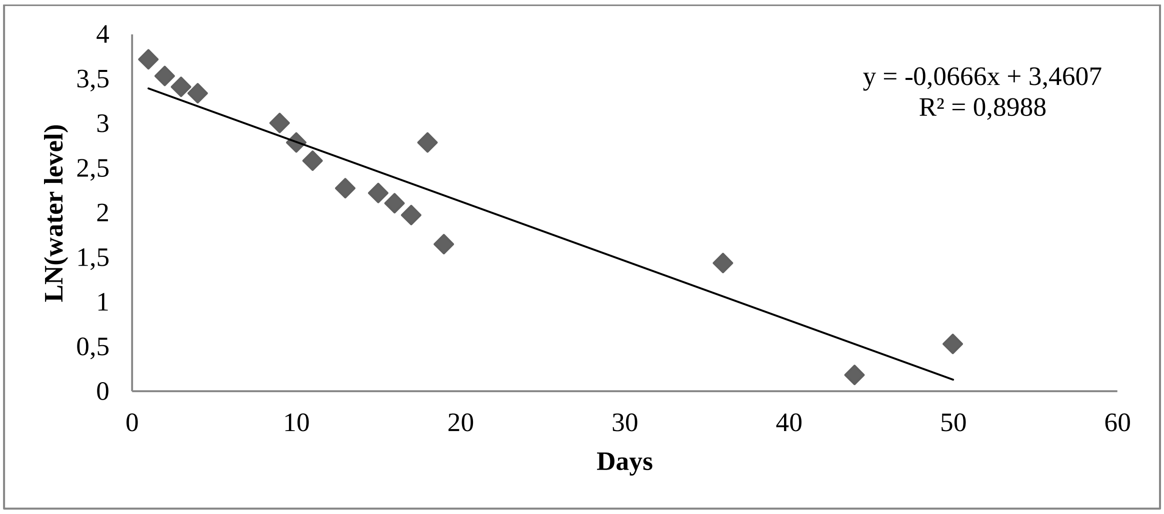
Appendix H: Extrapolation water levels

Hole 1

Day	Date	Measured distance	Distance relative BM	a+z	ln(-(a+z))
1	18-Oct	37	-68,8	-41,2	3,71843826
2	19-Oct	44	-75,8	-34,2	3,53222564
3	20-Oct	48	-79,8	-30,2	3,40784192
4	21-Oct	50	-81,8	-28,2	3,33932198
5	22-Oct				
6	23-Oct				
7	24-Oct				
8	25-Oct				
9	26-Oct	58	-89,8	-20,2	3,0056826
10	27-Oct	62	-93,8	-16,2	2,78501124
11	28-Oct	65	-96,8	-13,2	2,58021683
12	29-Oct				
13	30-Oct	68,5	-100,3	-9,7	2,27212589
14	31-Oct				
15	1-Nov	69	-100,8	-9,2	2,21920348
16	2-Nov	70	-101,8	-8,2	2,10413415
17	3-Nov	71	-102,8	-7,2	1,97408103
18	4-Nov	62	-93,8	-16,2	2,78501124
19	5-Nov	73	-104,8	-5,2	1,64865863
20	6-Nov				
21	7-Nov				
22	8-Nov	76	-107,8	-2,2	0,78845736
23	9-Nov	76,5	-108,3	-1,7	0,53062825
24	10-Nov	77	-108,8	-1,2	0,18232156
25	11-Nov				
26	12-Nov				
27	13-Nov				
28	14-Nov				
29	15-Nov				
30	16-Nov				
31	17-Nov				
32	18-Nov				
33	19-Nov				
34	20-Nov				
35	21-Nov				
36	22-Nov	74	-105,8	-4,2	1,43508453
37	23-Nov				
38	24-Nov				
39	25-Nov				
40	26-Nov				
41	27-Nov				
42	28-Nov				

43	29-Nov				
44	30-Nov	77	-108,8	-1,2	0,18232156
45	01-Dec				
46	02-Dec				
47	03-Dec				
48	04-Dec				
49	05-Dec				
50	06-Dec	76,5	-108,3	-1,7	0,53062825

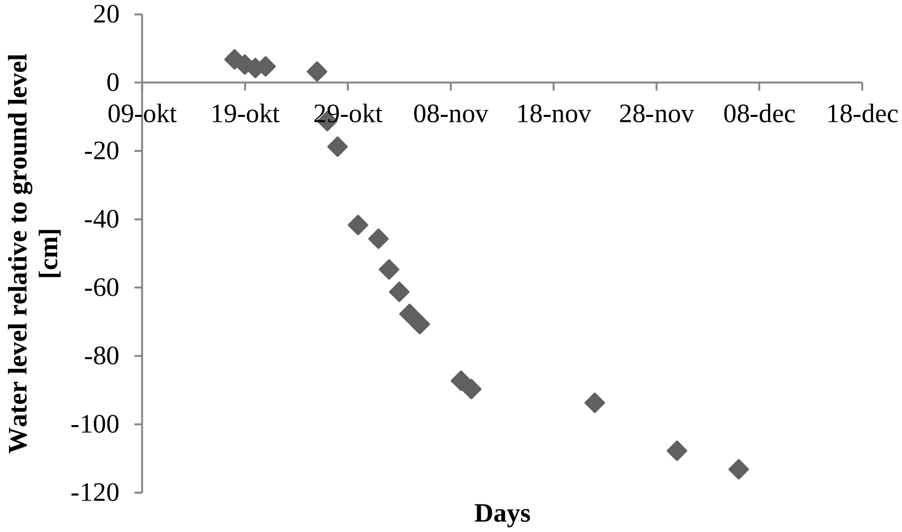


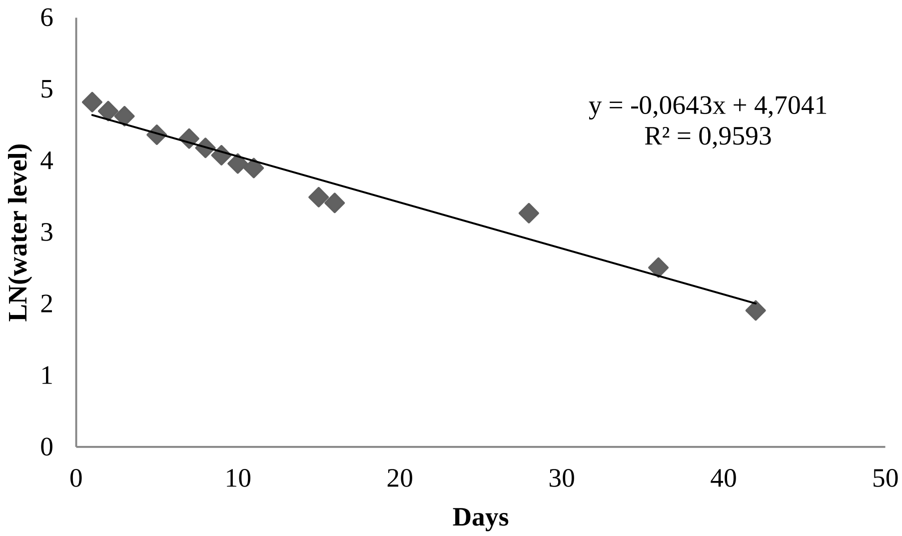


Hole 2

Day	Date	Measured distance	Distance relative BM	a+z	ln(-(a+z)
1	18-Oct	4,5	6,7	-121,7	4,801559
2	19-Oct	6	5,2	-120,2	4,789157022
3	20-Oct	7	4,2	-119,2	4,780802755
4	21-Oct	6,5	4,7	-119,7	4,784988613
5	22-Oct				
6	23-Oct				
7	24-Oct				
8	25-Oct				
9	26-Oct	8	3,2	-118,2	4,772378105
10	27-Oct	22,5	-11,3	-103,7	4,641502115
11	28-Oct	30	-18,8	-96,2	4,566429358
12	29-Oct				
13	30-Oct	53	-41,8	-73,2	4,293195421
14	31-Oct				
15	1-Nov	57	-45,8	-69,2	4,237000863
16	2-Nov	66	-54,8	-60,2	4,097672352
17	3-Nov	72,5	-61,3	-53,7	3,983413002
18	4-Nov	79	-67,8	-47,2	3,854393893
19	5-Nov	82	-70,8	-44,2	3,788724789
20	6-Nov				
21	7-Nov				
22	8-Nov				
23	9-Nov	98,5	-87,3	-27,7	3,321432413
24	10-Nov	101	-89,8	-25,2	3,226843995
25	11-Nov				
26	12-Nov				
27	13-Nov				
28	14-Nov				
29	15-Nov				
30	16-Nov				
31	17-Nov				
32	18-Nov				
33	19-Nov				
34	20-Nov				
35	21-Nov				
36	22-Nov	105	-93,8	-21,2	3,054001182
37	23-Nov				
38	24-Nov				
39	25-Nov				
40	26-Nov				
41	27-Nov				

42	28-Nov				
43	29-Nov				
44	30-Nov	119	-107,8	-7,2	1,974081026
45	01-Dec				
46	02-Dec				
47	03-Dec				
48	04-Dec				
49	05-Dec				
50	06-Dec	124,5	-113,3	-1,7	0,530628251

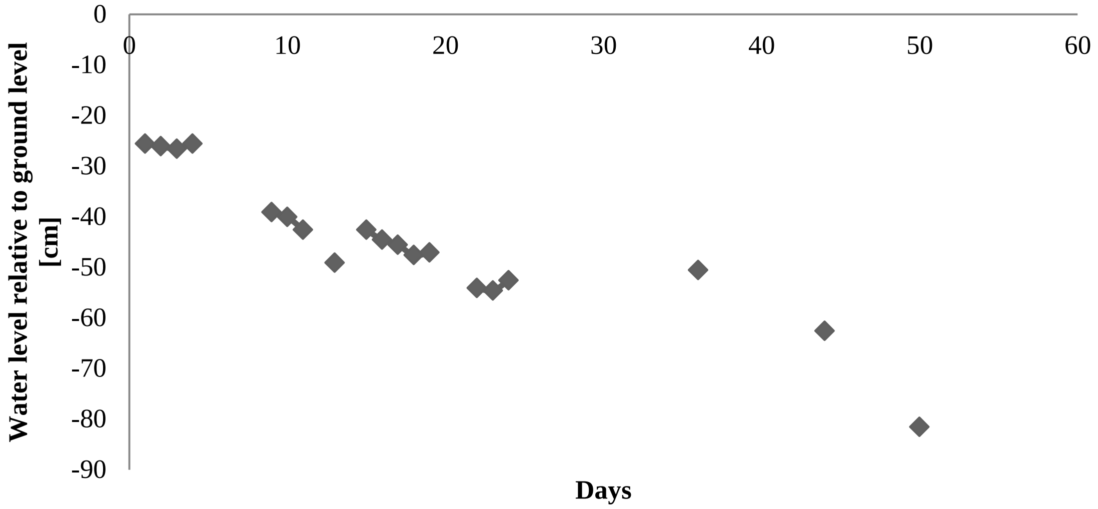


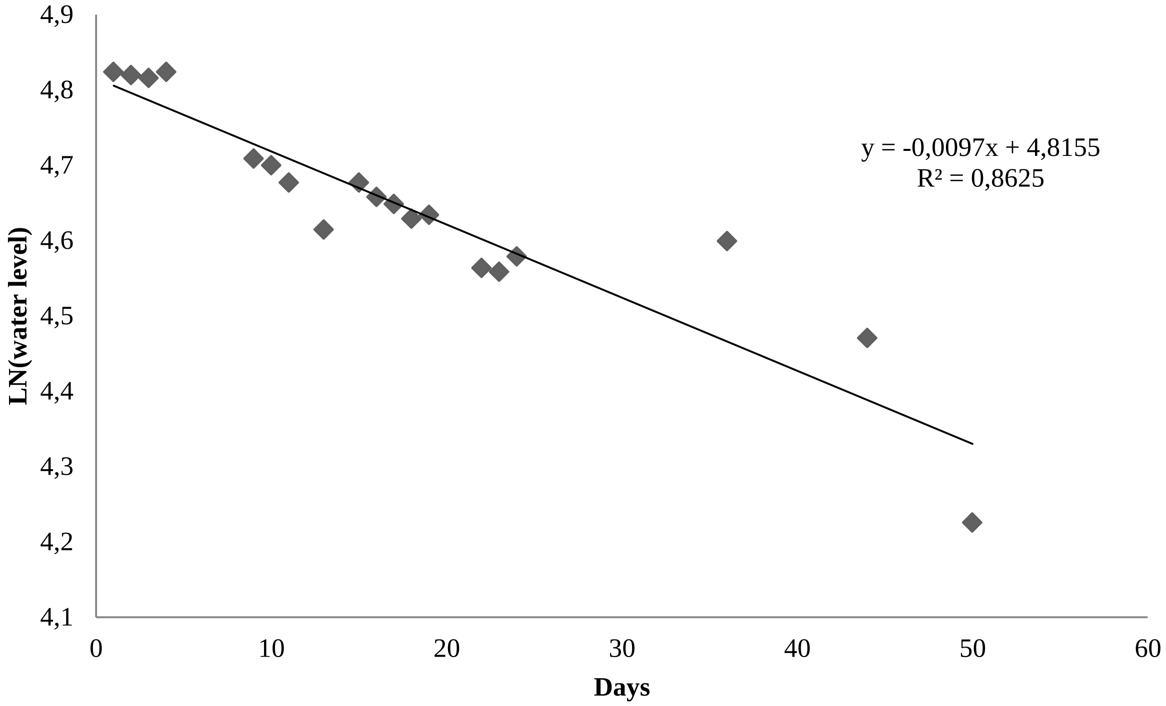


Hole3

Day	Date	Measured distance	Distance relative BM	a+z	ln(-(a+z))
1	18-Oct	-75	-25,6	-124,4	4,8235022
2	19-Oct	-75,5	-26,1	-123,9	4,8194748
3	20-Oct	-76	-26,6	-123,4	4,8154311
4	21-Oct	-75	-25,6	-124,4	4,8235022
5	22-Oct				
6	23-Oct				
7	24-Oct				
8	25-Oct				
9	26-Oct	-88,5	-39,1	-110,9	4,7086289
10	27-Oct	-89,5	-40,1	-109,9	4,6995709
11	28-Oct	-92	-42,6	-107,4	4,6765602
12	29-Oct				
13	30-Oct	-98,5	-49,1	-100,9	4,6141299
14	31-Oct				
15	1-Nov	-92	-42,6	-107,4	4,6765602
16	2-Nov	-94	-44,6	-105,4	4,6577626
17	3-Nov	-95	-45,6	-104,4	4,6482297
18	4-Nov	-97	-47,6	-102,4	4,6288867
19	5-Nov	-96,5	-47,1	-102,9	4,6337576
20	6-Nov				
21	7-Nov				
22	8-Nov	-103,5	-54,1	-95,9	4,563306
23	9-Nov	-104	-54,6	-95,4	4,5580786
24	10-Nov	-102	-52,6	-97,4	4,5788262
25	11-Nov				
26	12-Nov				
27	13-Nov				
28	14-Nov				
29	15-Nov				
30	16-Nov				
31	17-Nov				
32	18-Nov				
33	19-Nov				
34	20-Nov				
35	21-Nov				
36	22-Nov	-100	-50,6	-99,4	4,5991521
37	23-Nov				
38	24-Nov				
39	25-Nov				
40	26-Nov				
41	27-Nov				
42	28-Nov				
43	29-Nov				
44	30-Nov	-112	-62,6	-87,4	4,4704953

45	01-Dec				
46	02-Dec				
47	03-Dec				
48	04-Dec				
49	05-Dec				
50	06-Dec	-131	-81,6	-68,4	4,2253728





Hole4

Day	Date	Measured distance	Distance relative BM	a+z	ln(-(a+z))
1	18-Oct	-79	-76,9	-68,1	4,2209772
2	19-Oct	-82	-79,9	-65,1	4,1759245
3	20-Oct	-82	-79,9	-65,1	4,1759245
4	21-Oct	-81	-78,9	-66,1	4,1911687
5	22-Oct				
6	23-Oct				
7	24-Oct				
8	25-Oct				
9	26-Oct	-89,5	-87,4	-57,6	4,0535226
10	27-Oct	-88,5	-86,4	-58,6	4,0707347
11	28-Oct	-88,5	-86,4	-58,6	4,0707347
12	29-Oct				
13	30-Oct	-93	-90,9	-54,1	3,9908342
14	31-Oct				
15	1-Nov	-88,5	-86,4	-58,6	4,0707347
16	2-Nov	-89	-86,9	-58,1	4,0621657
17	3-Nov	-89	-86,9	-58,1	4,0621657
18	4-Nov	-90	-87,9	-57,1	4,0448041
19	5-Nov	-90	-87,9	-57,1	4,0448041
20	6-Nov				
21	7-Nov				
22	8-Nov	-95	-92,9	-52,1	3,9531649
23	9-Nov	-96,5	-94,4	-50,6	3,9239516
24	10-Nov	-94,5	-92,4	-52,6	3,9627161
25	11-Nov				
26	12-Nov				
27	13-Nov				
28	14-Nov				
29	15-Nov				
30	16-Nov				
31	17-Nov				
32	18-Nov				
33	19-Nov				
34	20-Nov				
35	21-Nov				
36	22-Nov	-103	-100,9	-44,1	3,7864598
37	23-Nov				
38	24-Nov				
39	25-Nov				
40	26-Nov				
41	27-Nov				
42	28-Nov				
43	29-Nov				
44	30-Nov	-123	-120,9	-24,1	3,1822118

45	01-Dec				
46	02-Dec				
47	03-Dec				
48	04-Dec				
49	05-Dec				
50	06-Dec	-129,5	-127,4	-17,6	2,8678989