Title: Do trees reduce water runoff during flood events? An assessment of soil hydrological properties in three different land-use types of varying tree density.

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Do trees reduce water runoff during flood events? An assessment of soil hydrological properties in three different land-use types of varying tree density

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by

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Abstract

The effect of trees on soil hydraulic and physical properties has been of interest for several centuries. While a variety of relevant studies have been undertaken in Europe, Northern America, Asia and Africa, very few studies have been conducted in New Zealand. This study aims to add some understanding and awareness to the overall pool of knowledge regarding New Zealand's ecosystems, soils and the link to its vegetation. Three different land use types were tested; a grassland paddock (P), a 20-year-old restoration forest (RF) and a 400-year-old native Kahikatea dominant forest (KF). The main assessments included infiltration rate measurements (IR) and soil moisture content (SM). Hereby a single-ring infiltrometer and a Time Domain Reflectometry (TDR) device were used. The average infiltration rate values tended to KF > RF > P, with the Kahikatea forest soil scoring 18 times higher (200.58mm/hr) than the pasture (10.97mm/hr) and 9 times higher than the restoration forest (21.92mm/hr). The average soil moisture content resulted in P = RF > KF with an overall difference of only 10.6% between the paddock/restoration forest and the Kahikatea forest (74.2%). The experiment proved that trees promote infiltration rates, water storage capacity and reduce surface runoff, hence decreasing the risk of perpetuated flood events. Trees are therefore a suitable tool for practicing natural flood management, to slow the spread and lower the level of a possible flood.

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Chapter 1: Introduction

Flooding is New Zealand's (NZ) most frequent natural hazard (Ministry for the Environment, 2008, p. 1). With evidence showing that climate change and global warming are on the rise (IPCC, 2018, p. 1), potential consequences and impacts need to be taken seriously. Some studies report that climate change and global warming promote weather changes, such as prolonged and intensified precipitation events which influence water levels and flow patterns, thus encouraging more frequent flooding events (Kellens et al., 2013, p. 24; Miller & Hutchins, 2017, p. 346*;* Christidis & Stott, 2015, p. S47; Ferguson & Fenner, 2020, p. 1*).* The most recent flood event in Southland, New Zealand, happened earlier this year in February and was triggered by a three-day long rain period. It caused considerable destruction to properties, public infrastructure, local economy, and natural resources. Natural Flood Management (NFM) is an effective approach practiced to reduce downstream flooding risks by relying on 'natural' asset tools, such as vegetation, instead of man-made structures and artificial defences to reduce peak flow, promote water infiltration and storage (Ferguson & Fenner, 2020, p. 2; Marapara, 2016, p. 10).

Soils, conjoint with the right vegetation, in natural and managed ecosystems can provide crucial services such as flood control (Binkley, 1995, p. 4-5; Adhikari & Hartemink, 2016, p. 102; Hümann et al., 2011, p. 638). This depends on their physical and hydraulic properties as well as the vegetation that has been planted on them. Beneficial soils with enhanced infiltration rate have been found in land-use types that are covered by vegetation, such as trees, shrubs and bushes (Archer et al., 2015, p. 1). Studies have highlighted that monoculture ecosystems, like pastureland, reduce the water storing capacity of the catchment area as well as encourage surface runoff over the land further increasing flood risks (Carrick et al., 2018, p. 2; Marshall et al., 2011; Pan et al. 2017, p. 1). Planting trees in these types of ecosystems/land-use types could therefore be a plausible technique of NFM to reduce this kind of risk.

This study analyses soil hydrological properties critical for reducing runoff and consequently flood risk. The main focus hereby is an assessment of infiltration rate in different soils. Infiltrometers filled with water are used to allow constant water pressure on the ground which therefore creates the sensation of a stagnant flood. Soil moisture measurements are also recorded for all plots. The chosen test sites that are compared, are grazed pastureland, a reforestation forest and an established Kahikatea dominant forest. The study area is located on a privately-owned property at Bushy Point in Otatara, Invercargill.

1.1. Rationale

Identifying the causes of flood risk is complex and intricate; however, Kundzewicz et al. (2013, p. 8) explain that "among the principal climate-system factors that determine flood risk are the water-containing capacity […] of the atmosphere and the characteristics of intense precipitation […]". While this statement is simple and to the point, various other factors play an equally important role in flood related processes. Evapotranspiration, snowmelt, changing temperature, soil moisture content, as well as groundwater and surface water levels all influence flood possibility and a change in climate can alter any of those factors, consequently promoting increased flood risk (Kundzewicz et al., 2013, p. 8). With climate change underway and temperatures rising, probabilities of frequently occurring floods are increasing as well.

Currently, the predominant land use types in Southland consist of agricultural pastures and they have been particularly vulnerable to flood events, which was evident during the latest flood in February 2020. With a higher predicted flood frequency, due to reasons discussed in the previous paragraph, more control measures must be taken into consideration. 'Hard' engineering approaches such as man-made constructions and structurally engineered defences have been traditionally and more commonly used worldwide in controlling flood risk (Carrick et al., 2018, p. 2). Other studies acknowledge, that the use of 'soft' approaches, such as changes in vegetation cover or improved land management to enhance infiltration rates and water storage capacity, is a cheaper and more environmentally friendly alternative to reduce the risk of flooding (Archer et al., 2015, p. 1). Trees and shrubs not only promote a faster infiltration rate in soils, but they also reduce the erosion effect that naturally occurs when too much water flows over hills and slopes (Basher, 2013, p. 367). Flooding peaks downstream of a river can even be reduced by up to 30% in a catchment if more trees and shelterbelts are planted on farms (Monbiot, 2014, p. 1). Archer et al. (2015, p. 1) also describe that water penetrates the soil under trees at 60 times the rate at which it infiltrates into the soil under grass and water runoff volumes are decreased by 78% in forest land.

The ability of trees or forests to ameliorate soil properties for flood risk mitigation varies according to species type, age, soil type, land management practices, climate, and topography, among other factors (Archer et al., 2018, pp. 2-3; Marapara, 2016, p. 21,23). Therefore, it is vital to investigate the impact of land use practices in NZ settings. Several studies conducted in the United Kingdom have already proven that monoculture landscapes are more susceptible to damage from flood events and that trees mitigate runoff (Marshall et al., 2011; Pan et al., 2017, p. 1; Marapara, 2011, p. 1). On the contrary, more research needs to be undertaken in NZ's context; thus, this study aims to add knowledge to this field through analysing test results and assessing the soil hydrological benefits of tree versus pasture area in the specific setting of the test site in Bushy Point, Invercargill. In any case, the results of this research could potentially help to create new designs of agricultural landscape layouts and land use management techniques by incorporating certain tree species onto the farming landscape. It will also assist in comprehending relationships between vegetation, soil and their ecosystems in a location specific manner for Southland.

1.2. Aim

This research aimed to investigate whether soil under different land use types with varying density of vegetation promotes water absorption and storage capacity and therefore potentially mitigates adverse effects on the environment during prolonged flood events.

1.3. Objectives

- To collate information and results from similar studies for comparison purposes
- To quantify the soil moisture content under the different land use types
- To quantify infiltration rates and analyse the meaning of possible different outcomes
- To establish whether trees benefit soil hydraulic properties

1.4. Time frame

Table 1

Gantt chart of proposed time management for the entire research project

Tasks	2020									
	January	February	March	April	May	June	July	August	September	October
Planning	🟩	🟩								
Online researching	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Designing			🟩	🟩						
Implementing				🟩	🟩					
Data collection						🟩	🟩			
Result Analysis							🟩			
Writing up the rest of the report							🟩	🟩	🟩	🟩

During the planning stage, a research project was chosen, and a research proposal was created. The online research phase spanned out over the entire period of the project since online research was part of every step of writing the report. During the design stage, suitable methodology was researched and decided. During the implementation phase, the methodology was further developed, and equipment was organised. Data collection was undertaken in June and July after it was postponed due to the national COVID-19 lockdown in New Zealand. Results were analysed after all measurements were taken and the final report was written up in the months between July and October.

1.5. Budget

Most of the equipment was purchased or constructed by the researcher. The TDR probe for testing soil moisture content was borrowed from the Environmental Management Department of SIT. Other costs were mostly related to transportation to travel to the test site in Otatara, Invercargill.

Table 2

Expenses during the research experiment

Costs	
Material	Price in NZD
PVC pipe offcut 1m	10
handsaw	15
stopwatches	24
Red and blue tape	5
level	20
rubber hammer	9
fuel	50
Total	133.00

1.6. Health and Safety

Health and Safety was considered and assessed during the data collection phase. The mandatory disclaimer forms, research activity plans, risk analysis and safety management forms were attached to the final research report. The project was undertaken without any influence or help by industry firms or professionals; therefore, a memorandum of joint understanding was not necessary.

During the experiment, research assistants were inducted and made aware of their role while working on the project as well as being informed about all health and safety procedures and precautions. They were also included on the health and safety forms, that were attached to the report.

1.7. Ethics

This research was covered by a blanket approval by the SIT Human Ethics Committee. Contact with human subjects, other than the landowners, and animals were not anticipated therefore no further ethical issues were encountered and additional approval was not needed. Furthermore, permits to access the premises were deemed unnecessary as the research was conducted on privately-owned property and the owners gave their consent.

1.8. Delimitations

Financial restrictions represented limitations to the extent that certain equipment had to be constructed in a simple and economically efficient manner. A PVC pipe was used to make single ring infiltrometers for infiltration rate measurements.

The possibility of incorrect data collection due to the self-constructed single ring infiltrometers was assessed and awareness was brought to the fact of a chance of incorrectly displaying test results and therefore misrepresenting the data.

1.9. Limitations

Since the research was part of the final year of the Bachelor Programme of Environmental Management, the research was undertaken and completed within a certain time frame. This was a limitation regarding the size of the project. With more available time the research could have been extended to a larger catchment scale with multiple test site to compare to each other.

In the beginning of the year 2020, a global outbreak of the corona virus took place. With a nation-wide lockdown of all New Zealanders during the months of March-April, the actual data collection had to be put on hold and postponed to June which pushed back the entire research schedule.

Chapter 2: Literature Review

This chapter will give some context and broaden the perspective of this study by conducting a literature review. It will discuss how previous studies have accomplished their objectives and aims, and how methodologies were designed to achieve the best possible results. According to that, the following chapter will clarify how this study engages with ideas and methods from previous studies and expands them to add knowledge to the pool of existing research papers. Several studies have been selected, to contrast proof of missing information in the field, successful research with anticipated results and development and outcomes in different countries. Various methodologies are reviewed, summarised, critiqued and compared in the following subchapters. Decisions and explanations, as to why certain methods were integrated into the study or not, are also evaluated in this chapter.

2.1. Flooding hazards and flood control strategies

Natural disasters like flooding have been imperative and are part of the inherent cycle of the environment. These events usually have natural causes, such as varying rainfall patterns increasing a river's/lake's water level; however, within the last century flooding events have become more frequent and origins are often linked back to anthropogenic activities. In New Zealand (NZ), flooding is recognised as the most frequent natural hazard (Ministry for the Environment, 2008, p. 1) with at least seven '150 year' storms since the 1990s and over a dozen flood events that have each caused damage in surplus of one million NZD (Smart & McKerchar, 2010, p. 69-70). Inevitably, solutions are sought out to decrease flooding risks and to protect people's lives, properties, infrastructure, natural resources and vulnerable ecosystems. Wingfield et al. (2019, p. 744) explain that different sources of flooding (fluvial, pluvial, coastal or groundwater flooding) usually occur in combination instead of separately, which calls for precautions and management techniques that are able to manage all at the same time. Traditionally, so called 'hard' approaches are favoured to control flood risks (Carrick et al., 2018, p. 2). Those are man-made constructions such as dams, flood banks or sea walls, that physically stop high tides or storm waves from advancing inland. 'Soft' approaches usually use more natural methods, including planting vegetation/forestation, diverting waterways/reintroducing meanders or constructing sand dunes (Carrick et al., 2018, p. 2), and are used to slow down flooding events rather than completely stopping or preventing them. The third approach is the passive way, where no action is taken to prevent floods, but focus shifted on community education, compensations for victims and subsidising insurance policies (Carrick et al., 2018, p. 2).

Natural Flood Management (NFM) can be categorised under the 'soft' approaches and mimics the natural hydrological processes in ecosystems to reduce water flow and improve storage capacity by relying on 'natural' asset tools, such as vegetation cover, instead of man-made structures and artificial defences to reduce peak flow (Wingfiel et al., 2019, p. 743; Ferguson & Fenner, 2020, p. 2). NFM approaches are usually more cost effective compared to large engineered constructions, however they are mostly used in combination with 'hard' approaches because of a lack of proof of performance on a grand scale (Wingfiel et al., 2019, p. 743). To ensure certainty of appropriate flood protection from NFM approaches, large-scale research is required that combines huge catchment areas both on land and water to provide the sufficient data and verification (Wingfiel et al., 2019, p. 743). Other studies also acknowledge that the use of 'soft' approaches, such as changes in vegetation cover or improved land management enhance soil infiltration rates, water storage capacity and reduce surface runoff (Archer et al., 2015, p. 1; Binkley, 1995, p. 11).

2.2. Impact of vegetation on flood control

Soils, conjoint with the right vegetation in natural and managed ecosystems, can provide crucial services such as flood control (Adhikari & Hartemink, 2016, p. 102; Hümann et al., 2011, p. 638). Several studies have proven, that tree ecosystems positively influence the soil and its properties, such as increasing infiltration rate, water storage capacity and decreasing bulk density and soil moisture (Price et al., 2010, p. 257; Özkan & Gökbulak, 2017, p. 164; Hümann et al., 2011, p. 647). These characteristics ensure that water infiltrates faster into the soil during a prolonged flooding, an extensive precipitation event or large volumes of stormwater runoff. However, random varieties of vegetation do not suffice, as the type of vegetation and performance of certain activities on the land plays an important role in influencing soil properties. For example, forestry activities may negatively impact compaction rate as well as infiltration and water storage capacity, due to usage of heavy machinery and establishment of vast networks of forestry roads, which seal the top layer of the soil (Hümann et al., 2011, p. 647).

Archer et al. (2015, p. 2) analysed multiple ecosystem with widely different vegetation types and age groups (grasslands, 6-year-old plantations – 4000-year-old ancient forests), proving that infiltration rate and water storage capabilities in soil increase with the age of the forest. Since Archer et al's study was located in the Northern Hemisphere (United Kingdom), native plants differ to the New Zealand context. However, with similar climate zones (NZ and UK being both in the temperate zone), this study serves as a useful guideline as the tested ecosystems are found in comparable climatic conditions. It would be hard to compare infiltration rates between an arid and a humid zone as water availability plays an important role in trees influencing the hydrological processes in the soil. Hümann et al. (2011, p. 647) agree, that soils under established forests generally are more porous and have high infiltration rates compared to agricultural land use areas. Grassland sites tend to have less developed soil matrix, with barely established pore spaces and pore connectivity (porosity/permeability) resulting in lower hydraulic conductivity for water flow (Archer et al., 2015, p. 12) and therefore making monoculture landscapes more susceptible to damage caused by flooding.

Studies resulting in conclusions that trees do not benefit hydrological soil properties equally exist. Carrick et al. (2018, p. 6) and Ferguson & Fenner (2020, p. 2) describe in their journal articles, that the effect of trees minimising runoff only has a statistically small effect, especially in larger catchment areas (greater than 10km^2). Carrick et al. also point out that not any one method is the best, but a combination of management techniques including upgrading tree cover and additional other 'hard' approached, have a higher chance to reduce flood risk.

2.3. Infiltration rate measurement

Infiltration is the process of water seeping from the ground surface into the soil (Gregory et al., 2005, p. 1). Soil infiltration rate indicates the speed at which the water infiltrates into the soil and is calculated as change in volume over time. It is directly linked to bulk density, structural stability, porosity and permeability (Azooz et al., 1996, p. 143), hence it represents an important indicator for the soil's ability to reduce stormwater runoff and prolonged flooding. Various methods can be used to determine the infiltration rate of soil. The most common ones are single and double ring infiltrometers, disc tension infiltrometers, well permeameters, rainfall simulator and methods where the infiltration data is fitted mathematically to infiltration models (Cheng et al., 2011, p. 135; Stanley & Eriakha, 2011).

Even though there are disadvantages to the single ring infiltrometer, it was chosen as method for this study, because it is simple to operate as well as cost-efficient. Some of its weaknesses are the fact that infiltrometers with less than 20cm in diameter have a higher chance of producing measurement errors (Gregory et al., 2005, p. 1). The larger the diameter, the less measurement errors are predicted. Gregory et al. (2005, p. 1) describe that to get the most accurate results, one should use a ring with a diameter of approximately 100cm. However, they also acknowledge that it is impractical transporting and moving such a big ring in the field and that the large volumes of water needed to fill the ring, would also prove it to be an inefficient method.

2.4. Soil moisture content tests

The most effective way to measure soil moisture content is through regular sampling with data loggers and measuring devices that are left on site to automatically take the SM content reading after a certain time interval or after/before a rainfall event (Little et al., 1998, p. 80). However, since computerised soil moisture measuring devices weren't accessible for this experiment, soil moisture was taken manually in every land use type and measured with a Time Domain Reflectometry (TDR) probe once per sampling round.

2.5. The effect of climate change on flooding

Evidence that extreme weather events and climate change are contributing to increasing flood rates, can be found in various studies (Carrick et al., 2018, p. 2; Pan et al., 2017, p. 1; Miller & Hutchins, 2017, p. 346). Warmer air resulting from global warming, carries more moisture than cooler air, therefore creating intensified precipitation events, hence increasing the chance of larger floods (Smart & McKerchar, 2010, p. 74). Özkan and Gökbulak (2017, p. 165) also point out that climate change and global warming promote change in vegetation distribution and biodiversity, which in turn will affect soil moisture, temperature and soil chemical characteristics. Therefore, it is vital in the future that climate change and its repercussions are being acknowledged by land managers, consultants and researchers before recommending and endorsing certain techniques or methods regarding land use management and flood risk management.

Chapter 3: Methodology

3.1. Introduction

This chapter explains the methods and procedures that were used to conduct this research study. The fieldwork proportion of this project was predominantly built on two tests / measurements, soil moisture and infiltration rate. These were chosen as they are critical indicators of soil compaction, permeability and water content, and therefore influence the ability of soil to reduce surface runoff, consequently delaying peak flow and reducing flood risk (Solgi et al., 2018, p. 247). Methods used for this research were slightly adjusted to fit the layout of this study and the chosen test site.

3.2. Materials

This chapter records all the tools and equipment needed to undertake the data collection. Explanations as to what to do with them and how to use each of these items, is detailed in the applicable chapters below.

- PVC plumbing pipe
- Handsaw
- Hammer, spade, shovel
- Wooden board
- Level
- Pen and paper
- Ruler
- Red and blue tape
- Wooden pegs
- Stopwatch or phone
- Water bottles / water
- TDR probe (see figure 1)
- Torch

Figure 1
TDR device used for soil moisture measuring

Note. A portable TDR device used to measure soil moisture levels. From *Soil Lab Modules*, by Maja Krzic, n.d., (https://labmodules.soilweb.ca/time-domain-reflectometry/)

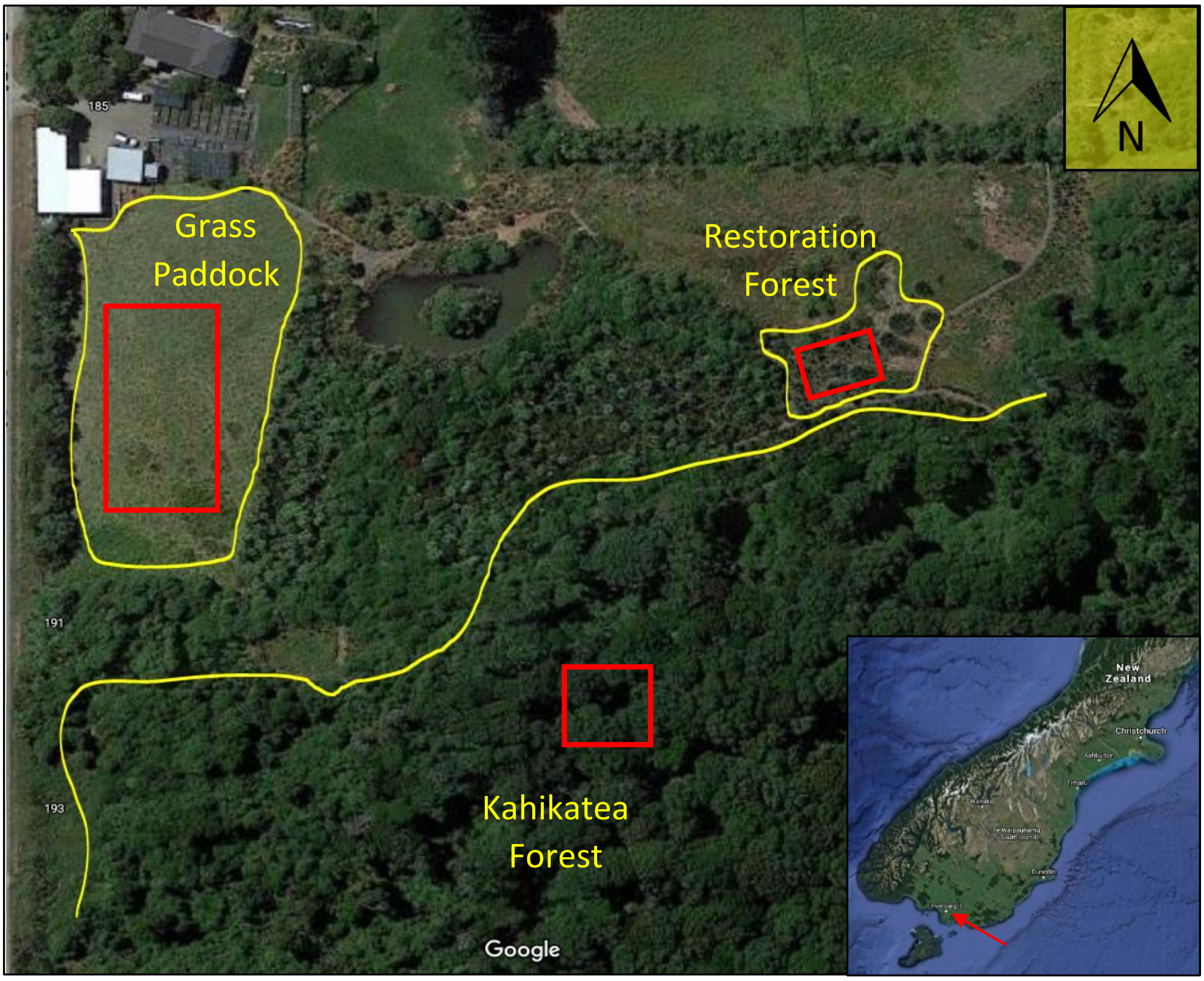
3.3. Experimental site

3.3.1. Site selection

A privately-owned land block in Bushy Point, Otatara was selected as test site for this study. There are three main land use types present: an unmodified and fully established kahikatea dominant forest (with trees around 400 years old), a young restoration area with plants no older than 20 years and a grass paddock that is intermittently used for grazing sheep (see figure 2). Soil moisture and infiltration rate were measured in all three land use types and compared at the end of the experiment. Sampling locations were chosen at random in each land use type.

Figure 2

Map of test sites



Note. Aerial view of the property where data collection took place. The red squares indicate the sampling sites in all three land use types. In the bottom right is a map of the lower half of the South Island of New Zealand; with a red arrow pointing to Invercargill, where the test site is located. From *Google Maps*, (https://www.google.co.nz/maps/)

3.3.2. Site setup

A $10x10m^2$ transect square was established in the kahikatea forest, a $10x8m^2$ square in the restoration area and a $32x22m^2$ square was established in the paddock. The reason behind the different size sampling transects was that the infiltration rate measurements in the paddock were taken before the transect was established. Since the sampling plots were to be included in the transect square, the paddock transects square had to be quite large as the sampling plots were far apart. Transect squares for the RF and the KF were set up before sampling spots were determined. However, the restoration area was not large enough to accommodate a $10x10m^2$ transect square so a $10x8m^2$ square was established.

To set up the transect squares, four ropes were measured and cut to 12m length as well as marked at every 2m point. Wooden pegs were used to mark the corners and every 2m of the transect lines. Once the first corner was established, the rope was extended to its full length, pegs were hammered into the ground along the rope every 2m and the second corner was set up at 10m. Once this first line was established the rope was extended from the second corner in a 90-degree angle to the first line to establish the second border of the transect square. This was repeated until all 4 perpendicular sides of the square were established (see figures 3 and 4). After that, the inside of the square was measured, and wooden pegs set up every 2m the same way as the border of the square. Blue tape was attached to the four corner pegs to be easily distinguished as the corners of the transect square. Further comments regarding organisation and planning the initial setup can be found in the recommendation chapter.

Figure 3

10x10m² Transect Square for the Kahikatea Forest with Wooden Pegs at each Intersection Marked by the Blue Dots

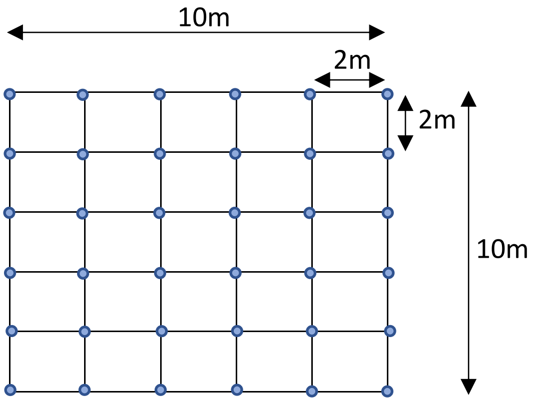
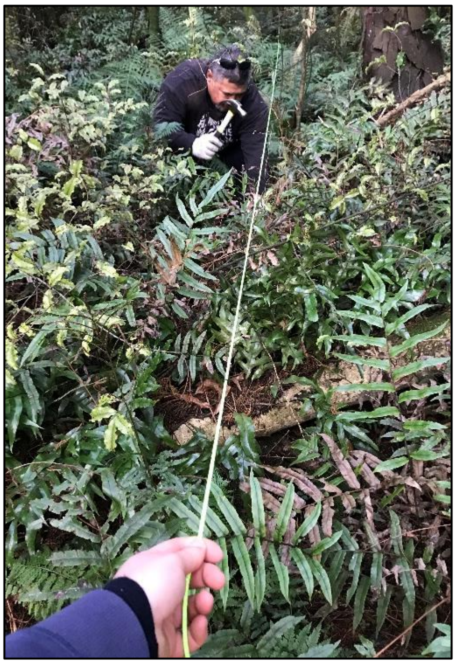


Figure 4

Wooden Pegs being set up after every 2m along the 10m long Transect Border Line



3.3.3. Frequency of testing

Once the transect square was established, soil moisture levels were measured at each of the intersections of the lines. Infiltration rate sampling spots were chosen at random, under the one condition to be positioned within the transect square. Six spots were chosen for each of the areas and the same spots were tested repeatedly for each of the 3 sampling rounds, which were undertaken over a time span of 3 weeks. The first round of testing was done on June 25th-27th 2020, the second round on July 2nd and 3rd 2020 and the last round was done on July 11th and 12th 2020. The total number of infiltration rate measurements per land-use type was therefore 18 and the overall total number of infiltration rate measurements was 54 (see table 3).

Table 3

Amount of Infiltration Rate Tests per Site and in Total

		Total number of infiltration rate measurements per land use type per sampling round	Total number of infiltration rate measurements
Number of different land use types	3	18	54
Number of sampling spots in each land use type	6		
Number of sampling rounds per land use type	3		

3.4. Data collection methods

3.4.1. Infiltration rate

Due to budget reasons a single ring infiltrometer was constructed from a PVC plumbing pipe, a heavy-duty plastic cylinder pipe, instead of buying one from a supplier. The pipe was bought from a local hardware store and cut to a length of 15cm per infiltrometer with a hand saw. The diameter of the pipe was also 15cm, as recommended by Xu et al. (2012, p. 36) and Marapara (2011, p. 27). On each infiltrometer ring 5cm were measured and marked to ease the setup in the field, where the ring was inserted into the initially unsaturated soil to a depth of 5cm. Hereby the wooden board was laid across the top end of the infiltrometer and driven into the ground with a rubber hammer. A level was used to ensure that the infiltrometer was level to avoid uneven water levels. Care needed to be taken that the ring wall sat tightly against the soil, as a poor connection between the two could have promoted leaks along the ring wall, thus resulting in an overestimation of infiltration rate (Gregory et al., 2005, p. 2). A ruler was taped inside the ring to keep it stabilised and secure during the process of refilling water and changing water levels. A known amount of water of 1 litre was then poured into the cylinder, the water level reading was taken, and the stopwatch was started. During the first 5 minutes a reading was taken every 1 minute. Between 5 and 30 minutes a reading was taken every 5 minutes and until 60 minutes a reading was taken every 10 minutes. After that a reading was taken every 15 minutes until 1 h 30 min. A torch was used to shine light inside the pipe, when the ruler measurements were hard to read.

Figure 4

Levelling the Infiltrometer to Ensure Even Water Levels

Figure 3

Infiltrometer Filled with Water and Ruler to Read Water Level

The water level readings at the appropriate time intervals were noted in a table. Later, this data was transferred onto an excel spreadsheet. An example of such a spreadsheet can be found below (table 4). If the water was seeping into the soil too fast to get a suitable reading at the desired time interval, 1 litre of water was refilled when needed, the time on the stopwatch was recorded and the water level was taken before and after the refill.

Further explanations for the columns inside table 4 can be found below:

- Column 1: time recorded on the stopwatch
- Column 2: time difference between each of the readings
- Column 3: cumulative time of the length of the experiment for this particular site
- Column 4: the left side shows the water level readings from inside the infiltrometer, the right side shows the water level readings after 1 litre of water was refilled
- Column 5: the amount of infiltration in mm between each reading
- Column 6: infiltration rate in mm/min for the time between the readings, calculated by dividing the infiltration (column 5) by time difference between readings (column 2)

- Column 7: infiltration rate in mm/hr, calculated by multiplying the infiltration rate mm/min (column 6) by 60 (because there are 60 min in 1 hr)
- Column 8: the accumulated water infiltration in mm from the first second to the last minute of the experiment

Table 4

Example of Spreadsheet Table Used to Fill in Field Data (showing the first 4 minutes of the infiltration rate testing)

Kahikatea #1.1		27.06.2020 - 11:30-1:00							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min	min	min	mm	mm	mm	mm/min	mm/hr	mm
	0	0	0		44				0
	1	1	1	35		9	9.0	540	9
	2	1	2	30		5	5.0	300	14
	3	1	3	27		3	3.0	180	17
	4	1	4	23		4	4.0	240	21
	…	…	…	…	…	…	…	…	…

Once all the data was processed and spreadsheets were created for each of the testing sites for every round, the average infiltration rate was calculated as change in volume of water in the single ring over time and resulted in a number with the unit of mm/hr. This was done by averaging the data of infiltration rate mm/hr (from column 7 in the table = IR_t) to find out the average infiltration rate during the entire timespan of the experiment (t). The average infiltration rate per 1 hour (IR_{1hr}) was then calculated with this formula:

$IR_{1hr} = 60 \text{ min} / t * IR_t$

IR_{1hr} = infiltration rate in mm/hr for 1 hour

t = total time needed to finish infiltration test per site

IR_t = infiltration rate in mm/hr for total time of infiltration test

An example of the calculation of the average infiltration rate in mm/hr for the Kahikatea Forest #1.1 can be found below:

Kahikatea Forest #1.1

$t = 1\text{ h }30\text{ min} = 90\text{ min}$

$IR_t = 211.58$ mm per 1h 30min

$IR_{1hr} = 60\text{ min} / 90\text{ min} * 211.58 = 141.06$ mm/hr

$IR_{1hr} = 141.06$ mm/hr

The average infiltration rates in mm/hr for every site were compiled into a table to be able to compare the results for each land-use type (see table 6 in chapter 4: results).

3.4.2. Soil moisture

Soil moisture measurements were taken on the same day as the infiltration rate measurements. This meant that each land use type had its soil moisture recorded once per sampling round. Soil moisture was taken manually and measured with a Time Domain Reflectometry (TDR) probe, which was provided by SIT. The probe consisted of the main body that housed the batteries, the display and two buttons to navigate through the menu. This was connected via a cable to a measuring device on which two 12cm steel rods were screwed onto. The device was turned on, and the buttons were used to select the correct measuring mode of 12cm. The rods were then fully inserted into the soil to record the moisture content (see figure 7).

Figure 5

TDR probe in use

The following amount of soil moisture readings were taken in each of the land-use types:

- Pastureland: 108
- Restoration Area: 30
- Kahikatea Forest: 36

No issues were encountered when measuring in the pasture and in the restoration forest. However, with fully established trees in the kahikatea forest, the root system in the ground was also equally vast. While penetrating the first soil layer with the steel rods, roots were constantly in the way and hindering the rods to fully insert into the ground. When this occurred, the probe was removed out of the ground and reinserted again a few centimetres to the side of the first entry point. This process was repeated until a spot was found where the probe could be inserted fully into the ground.

3.4.3. GPS device

A GPS device was supplied by SIT to take the coordinates of all infiltration test site as well as of all the soil moisture test sites to ensure that measurements were taken from the same spot during every round. The recorded coordinates were in the World Geodetic System format and needed to be changed into the NZ Transverse Mercator Projection format. Each soil moisture measurement was then able to be paired with its coordinates and inserted into ArcGIS to create a visualised soil moisture map of each area.

Chapter 4: Results

4.1. Infiltration rate

This chapter summarises the results of the infiltration rate measurements during all three data collection rounds. Table 5 showcases an example of the tables that were created to illustrate the infiltration rate results for each of the sampling sites during every sampling round. The heading of the table shows the land use type, the number of the sampling site and during which round the measurements were taken; Paddock #3.1 means sampling site 3 and sampling round 1. Next to the heading, the date and the time of the experiment was recorded.

Table 5

Infiltration Rate Data for Sampling Site 3, Round 1 in Paddock

Paddock #3.1		25.06.2020 - 11:15-3:45							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings (WLR)	WLR after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min	min	min	mm	mm	mm	mm/min	mm/hr	mm
	0	0	0	▨	67	▨	▨	▨	0
	1	1	1	67		0	0	0	0
	2	1	2	66		1	1	60	1
	3	1	3	66		0	0	0	1
	4	1	4	66		0	0	0	1
	5	1	5	65		1	1	60	2
	10	5	10	64		1	0.2	12	3
	15	5	15	63		1	0.2	12	4
	20	5	20	63		0	0	0	4
	30	10	30	61		2	0.2	12	6
	40	10	40	59		2	0.2	12	8
	50	10	50	58		1	0.1	6	9
1 h	60	10	60	56		2	0.2	12	11
1 h 10	70	10	70	55		1	0.1	6	12
1 h 20	80	10	80	54		1	0.1	6	13
1 h 30	90	10	90	52		2	0.2	12	15

1 h 40	100	10	100	50		2	0.2	12	17
1 h 50	110	10	110	49		1	0.1	6	18
2 h	120	10	120	47		2	0.2	12	20
2 h 10	130	10	130	44		3	0.3	18	23
2 h 20	140	10	140	41.5		2.5	0.25	15	25.5
2 h 30	150	10	150	40		1.5	0.15	9	27
2 h 40	160	10	160	38		2	0.2	12	29
2 h 50	170	10	170	35		3	0.3	18	32
3 h	180	10	180	33		2	0.2	12	34
3 h 10	190	10	190	29		4	0.4	24	38
3 h 20	200	10	200	25		4	0.4	24	42
3 h 30	210	10	210	21		4	0.4	24	46
3 h 40	220	10	220	14	75	7	0.7	42	53
3 h 50	230	10	230	73		2	0.2	12	55
4 h	240	10	240	70		3	0.3	18	58
4 h 10	250	10	250	68		2	0.2	12	60
4 h 20	260	10	260	66		2	0.2	12	62
4 h 30	270	10	270	64		2	0.2	12	64

The results for Paddock #3.1 show an average infiltration rate of 3.39 mm per one hour.

The same table was created for each of the other sampling sites in every land-use type. They can be found in appendix 1. An average infiltration rate in mm/hr was also calculated for each sampling site. A table of the average infiltration rates in mm/hr for each site is below:

Table 6

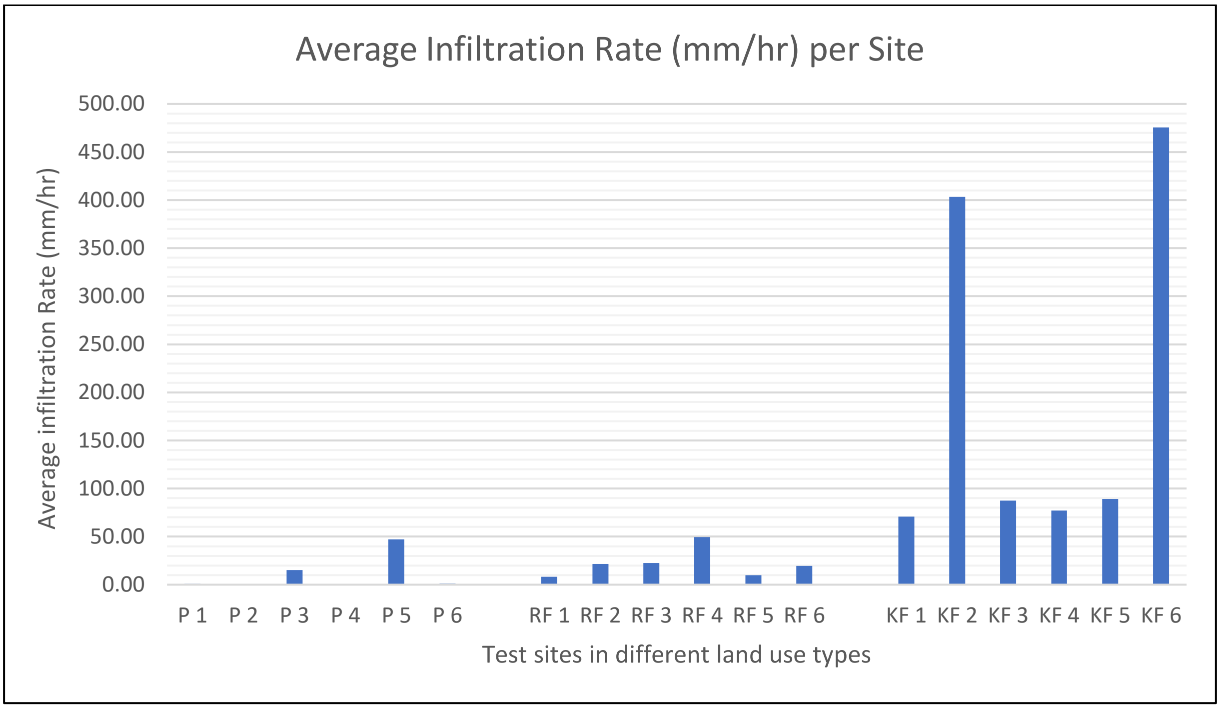
Average Infiltration Rates in mm/hr of all Sampling Sites

Land use type	Site number	Round 1	Round 2	Round 3	Total average per site	Total average per land use type
Paddock (P)	1	1.88	0.92	0.00	0.93	10.97
	2	0.74	0.17	1.07	0.66	
	3	3.39	25.42	16.89	15.23	
	4	0.55	1.33	0.18	0.69	
	5	93.29	41.78	6.13	47.07	
	6	3.08	0.00	0.71	1.26	
Restoration Forest (RF)	1	11.60	7.64	5.87	8.37	21.92
	2	30.13	28.98	5.78	21.63	
	3	6.72	42.93	18.30	22.65	
	4	55.95	70.25	22.40	49.53	
	5	7.21	11.91	10.04	9.72	
	6	18.55	27.20	13.07	19.61	
Kahikatea Forest (KF)	1	141.06	61.78	9.96	70.93	200.58
	2	445.77	529.23	234.93	403.31	
	3	248.75	9.06	4.89	87.57	
	4	181.22	40.00	9.96	77.06	
	5	114.26	133.68	19.20	89.05	
	6	515.63	804.81	106.22	475.55	

The shading of the colour in table 6 represents a general pattern of infiltration rate whereby green means high infiltration and red means low infiltration. The general impression is that the infiltration rate is much higher at the forest site compared to the grass pasture site. To visualise this data even further a column chart can be found below to compare differing infiltration rates between the various land use types. Hereby, the y-axis portrays the average infiltration rate in mm/hr and the x-axis shows the according land use types with their sites. P stands for Paddock; RF stands for Restoration Forest and KF stands for Kahikatea Forest.

Figure 6

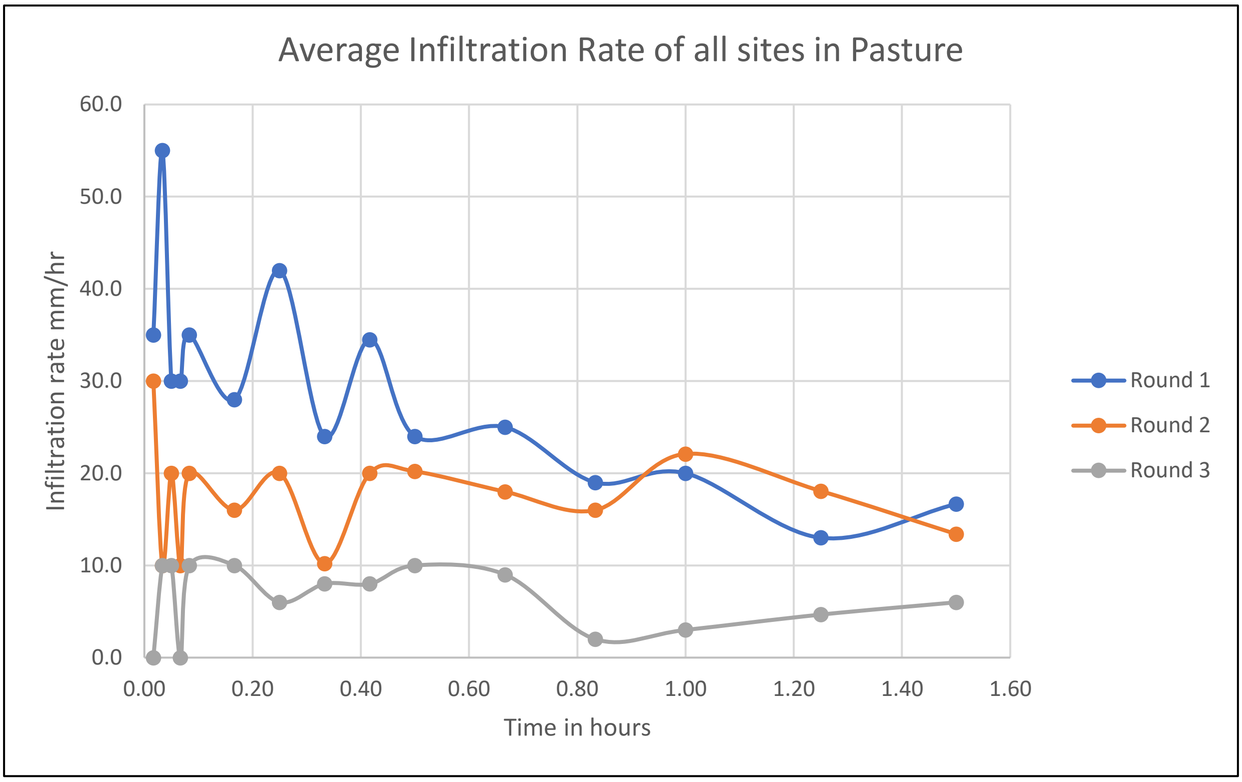
Comparison of Average Infiltration Rates (mm/hr) per Land-Use Type



Figures 9, 10 and 11 show the average infiltration rate results in mm/hr for all the measurements in each of the three land use types. This means that all 6 sampling sites per land use type were averaged out to portray one line in the graph. The blue line represents 6 measurements from the first round, the orange line the second round and the grey line the third round of measurements. Infiltration rates in the pasture turned out to be the lowest during the entire experiment. On average the highest infiltration rate in the paddock at any one time was recorded during the first round of testing at 55mm/hr. The lowest infiltration rate was 0mm/hr which occurred regularly and more so later in the experiment during the last round of testing.

Figure 7

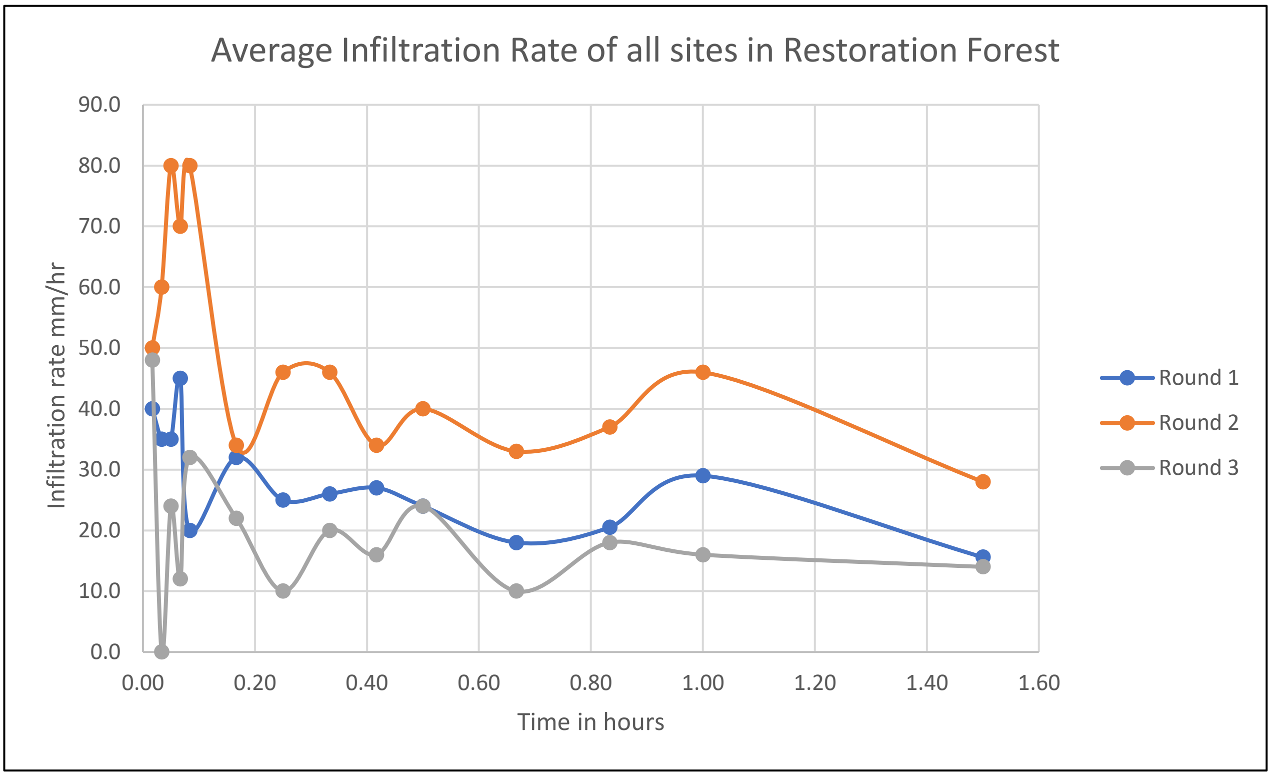
Average Infiltration Rate (mm/hr) of all Sampling Sites in Pasture



The results for the RF showed higher infiltration rates than the paddock but lower than the KF. The average results from the second round of testing show the overall highest infiltration rates in the RF (see figure 10 below). This is different to both the paddock and the KF where the first round of testing showed the highest infiltration rates. On average, the highest infiltration rate for the RF was 80 mm/hr.

Figure 8

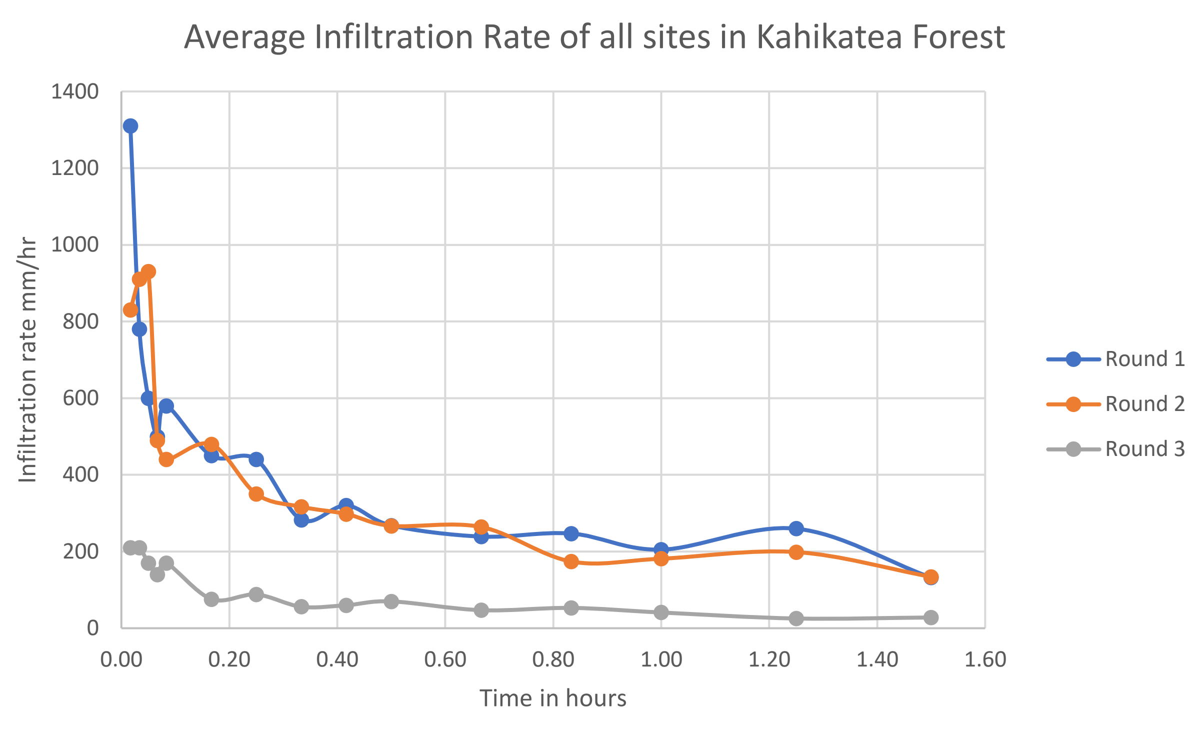
Average Infiltration Rate (mm/hr) of all Sampling Sites in the Restoration Forest



Average infiltration data for the kahikatea forest shows that the results from the first and second sampling rounds are very similar. However, results for the third round are considerably lower. The highest average infiltration rate was 1310 mm/hr while the lowest average infiltration rate was 25 mm/hr. The graphs also show a clear trend of higher infiltration rate in the first 10-20 minutes before continuing to an almost stable line yet still show a slight decline.

Figure 9

Average Infiltration Rate (mm/hr) of all Sampling Sites in the Kahikatea Forest



4.2. Soil moisture

The soil moisture results were recorded in map-like grids with coloured slots marking the infiltration rate sampling sites (see below). Soil moisture was recorded in percentage. The following tables provide the average soil moisture data from data collection over 3 weeks. Raw SM data for each separate sampling round can be found in appendices 2-4.

#1	#2	#3	#4	#5	#6

Table 7

Average Soil Moisture in % in the Paddock

81.3	82.0	84.0	88.7	78.3	84.0	88.3	87.0	87.0	89.0	87.0	88.0
84.7	81.7	82.7	83.7	88.0	86.0	88.7	86.7	84.7	88.7	88.3	88.0
80.0	80.7	82.7	84.0	85.7	85.0	86.7	87.3	83.0	90.3	88.0	87.0
81.3	77.7	85.0	84.7	85.7	87.0	91.0	90.3	81.7	90.0	85.3	89.0
87.0	81.7	86.3	84.0	87.7	84.0	87.3	86.3	87.0	84.7	88.7	88.0
83.3	81.7	86.7	88.0	85.7	84.3	86.7	88.0	82.3	86.7	85.3	86.0
82.3	86.3	82.7	78.0	84.7	83.7	85.7	83.0	88.0	83.0	86.3	83.0
85.0	83.0	83.3	87.7	83.7	82.7	89.0	87.3	87.7	89.7	91.3	89.3
84.0	82.3	84.3	87.3	89.3	85.7	83.7	81.7	87.0	87.0	84.0	88.3

Table 8

Average Soil Moisture in % in the Restoration Forest

87.3	86.0	84.0	91.7	87.0
86.0	87.0	84.0	89.7	89.7
86.0	91.0	89.7	90.7	91.0
89.3	83.0	83.3	72.7	92.3
89.7	82.3	80.3	80.7	77.7
80.7	86.3	83.3	89.3	82.7

Table 9

Average Soil Moisture in % in the Kahikatea Forest

99.7	84.7	51.7	84.0	89.0	90.7
85.7	88.0	81.3	85.0	84.3	80.0
85.7	88.7	57.3	81.3	88.0	79.3
83.7	60.7	58.3	85.0	94.7	86.7
59.0	78.3	62.3	33.3	58.3	71.3
45.0	79.7	94.0	50.7	54.7	32.3

Figures 12 and 13 are the visualised versions of soil moisture maps for tables 7 and 9. A soil moisture map for the restoration forest was created, however due to technical difficulties was corrupted and cannot be portrayed in this report. Figure 12 shows the predominantly wetter area on the east side of the site with majority of the soil having a moisture content of 87% or above. The west side shows moisture content of around 78-85%. In the overall scale however, statistically the difference was not found to be significant as the soil moisture content difference from one side to the other is only around 10-15%.

Figure 10

Soil Moisture Map of the Pasture

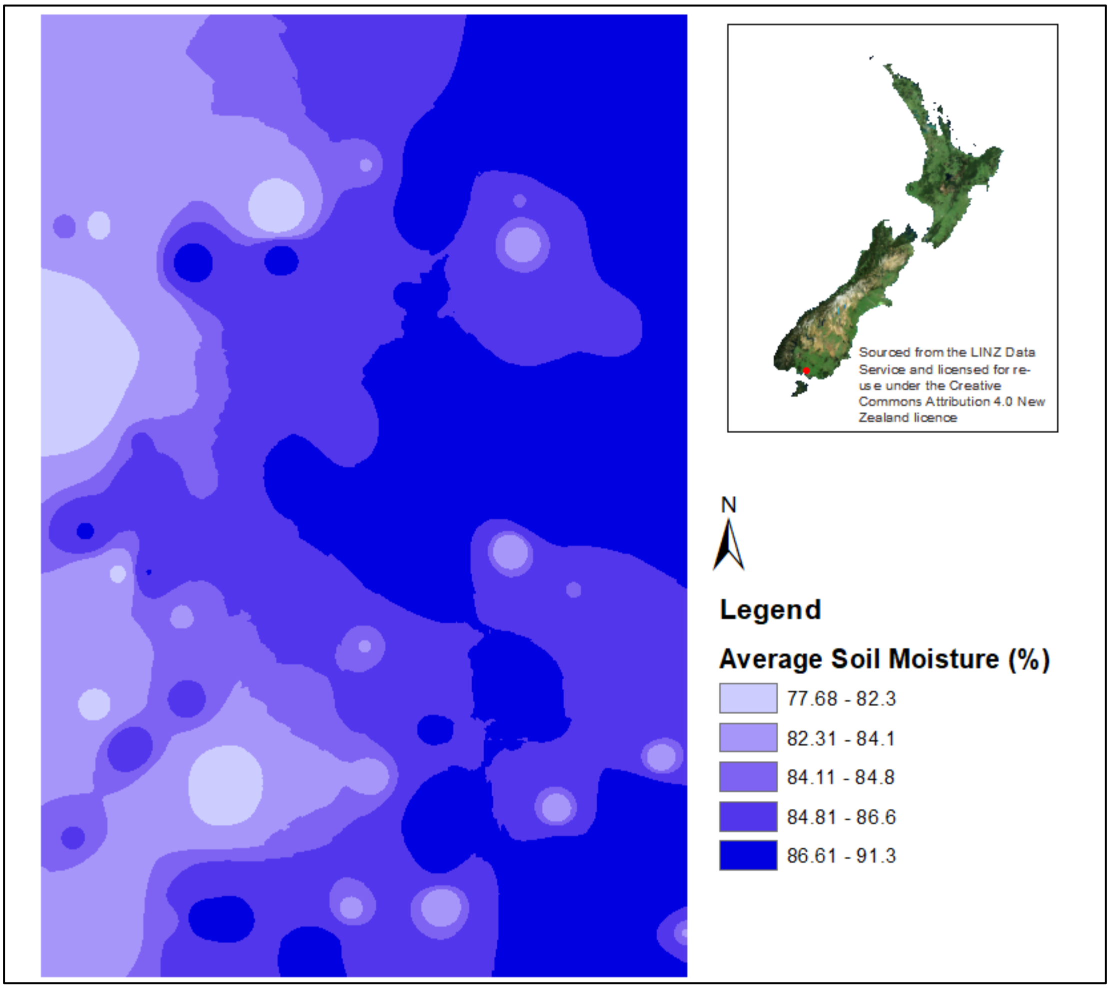
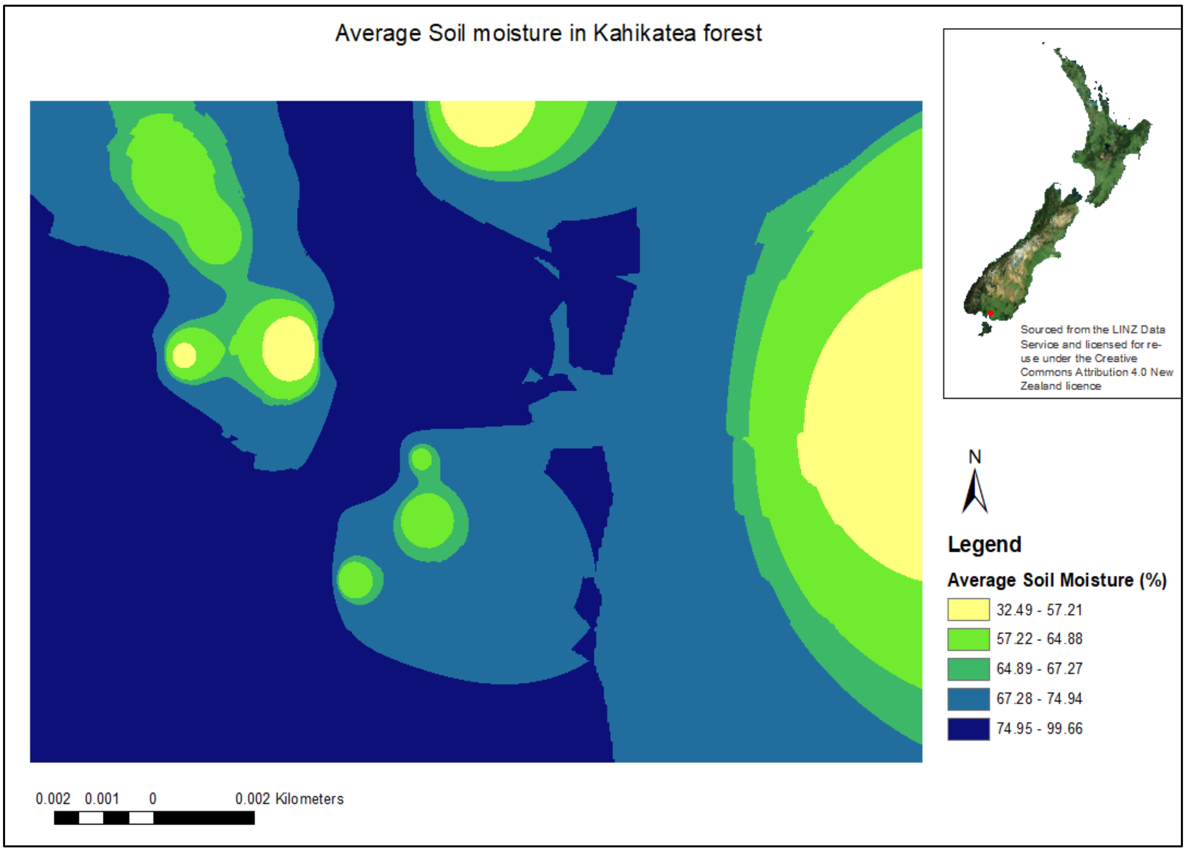


Figure 13 shows a great variation of soil moisture content withing the kahikatea forest site. The south west side of the area shows to be the most saturated with a moisture content of 75-100%. The east side has low soil moisture content with 33-57%.

Figure 11

Soil Moisture Map of the Kahikatea Forest



Chapter 5: Discussion

This chapter discusses the results of this research experiment, stating reasons and explanations why certain outcomes eventuated.

5.1 Infiltration rate

It was expected that the water infiltrating into the ground would be initially fast to moderate and would then approach a slower constant state when the maximum saturation capacity [1]of the soil was reached (Bagarello et al., 2014, p. 4843). This was portrayed in all land use types but more so in the Kahikatea forest where this trend was very prominent. In the restoration area and the pastureland, this prediction was also reconstructed, however random spikes in the infiltration rate would appear further along during the test which was non-existent in the kahikatea forest.

Measurement times during the first round of data collection ranged from 1 to 4,5 hours per test site. Such long testing times occurred because of the aim to reach the soil's maximum saturation capacity. However, after the first round of measuring, it was decided to undertake all infiltration tests for a duration of 1,5 hours regardless if the maximum saturation capacity of the soil was reached or not. This was decided after testing in the kahikatea forest, where water was rapidly infiltrating into the ground and the single ring infiltrometers had to be refilled very regularly, sometimes within minutes of the last refill. As all the equipment and the full water bottles were carried into the forest, and the bottles had to be refilled at the water tank near the house, countless refill trips were undertaken, which was not sustainable for the amount of refills the forest soil needed. Therefore, a limit of 1,5 hours per test site was stipulated for future tests. This method can partially explain the huge difference between the infiltration rate results in paddock and forest soil, as longer test times could have enabled the forest soil to slow down infiltration rate over a longer time period.

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[1] Maximum Saturation Capacity: When all soil pores are full of water and no additional water can infiltrate into the soil

On average, infiltration rate in the kahikatea forest soil was 18 times higher (200.58mm/hr) than in the pasture (10.97mm/hr) and 9 times higher than in the restoration forest (21.92mm/hr). This trend was expected, as several studies had found forest land to increase infiltration rate (Peskett et al., 2020, p. 1; Price et al., 2010, p. 257; Archer et al., 2015, p. 12). The enormous difference in infiltration measurements is likely explained by an extensive tree root system in the forest subsoil, which is greater in length, depth and range than that of herbaceous plants like grasses (Price et al., 2010, p. 257). Tree root systems create large amounts of macro pores in forest soils, which immensely promote infiltration rate and permeability of the soil (Olorunfemi & Fasinmirin, 2017, p. 178). The difference in infiltration rate between the KF and the RF is likely due to the age and the development stage of the vegetation. Trees in the fully established KF are more than 400 years old while the shrubs and trees in the RF are comparatively young with the oldest plants being 20 years of age. Older and better developed vegetation tends to also have a more mature and evolved tree root system, providing greater benefits within the soil than younger plants with smaller, juvenile root systems that are still growing and evolving. Therefore, these results suggest that mature trees indeed reduce the amount of surface runoff and hence the risk of flooding.

Another reason for the drastic difference between KF and the pasture could be attributed to low bulk density in forest areas which promote increased soil porosity and permeability (Price et al., 2010, p. 257). This is usually due to dense root systems, more leaf litter and organic matter as well as abundant burrowing fauna in forest ecosystems (Pirastru et al., 2013, p. 342; Olorunfemi & Fasinmirin, 2017, p. 178). Compared to that, bulk density in pastureland is expected to be higher, due to stripped organic material in topsoil from tillage practices, low faunal activity, less extensive and shallower root systems from lack of a diversity of woody plants, and livestock grazing the area and compressing the soil with their hooves (Pirastru et al., 2013, p. 342; Price et al., 2010, p. 256). High bulk density usually decreases infiltration rate in any soil. However, bulk density was not measured during the present research due to the unavailability of needed equipment, and it is recommended to undertake bulk density measurements for these areas in a future study to add valuable knowledge to this topic and to further investigate the theory that as bulk density increases, infiltration rate decreases and vice versa.

Adding more trees and woody plants to agricultural land therefore is a feasible option to practice natural flood management (NFM) and fight natural disasters with natural tools instead of altering the environment drastically or building man-made structures into ecosystems to prevent certain unwanted outcomes of nature (i.e. floods). Soil under shelterbelts was not tested in the present study but several studies have found similar beneficial physical and hydrological soil properties under shelterbelts compared to forest strips, if not to an extent of an entire large-scale forest (Haddaway et al., 2018, p. 2; Ryszkowski & Kedziora, 2007, p. 391; Kedziora, 2010*,* p. 140). However, as the environment and ecosystems are complex and dynamic it is important to plant trees in the right location, as in some instances forest strips in certain areas can interrupt hydrological processes rather than benefit them (Peskett et al., 2020, p. 2). Climate zones (arid, humid, temperate, etc.) are also to be taken into consideration, as shelterbelts influence sun, shade and wind conditions, depending on the climate, in a positive or negative way (Kedziora, 2010*,* p. 140). However, approached in the correct way, tree planting projects can prove successful like Ferguson & Fenner (2020, p. 3) discuss in their research. Positive impacts of catchment-scale tree planting projects in a catchment area in West Yorkshire, UK, at a size of around 18 m^2, resulted in a reduction of peak flow by 13.4% in a 20-year event, shortening the duration and delaying the timing of the flooding event (Ferguson & Fenner, 2020, p. 9).

5.2 Soil moisture

The experiment confirmed the expected phenomenon of a higher moisture level in the pastureland compared to the forest area with a difference of 11.3% (P:85.5%, KF:74.2%). Contrary to these findings, Prince et al. (2010, p. 265) found higher soil moisture in forest soils by a factor of 20%. Soil moisture levels in the restoration area compared to the paddock were almost identical with only 0.3% of a difference. It is likely that soil moisture levels are lower in the KF compared to the pasture as infiltration rates are also much higher in the forest soil, thus transporting the water deeper into the soil horizon while moisture tends to accumulate on top of and in the topsoil of pastureland. Özkan and Gökbulak (2017, p. 164) have shown in their research, that clearance of trees can cause an increase in SM of 16% (Özkan & Gökbulak, 2017, p. 164). These results affirm the theory of trees reducing water content in soil and therefore reducing small flood events by promoting higher infiltration rates. Lower soil moisture levels in the forest can also be explained due to evapotranspiration processes and interception of rainwater from trees. It was confirmed that vegetation cover significantly influences the soil matrix especially regarding soil hydraulic conductivity and water storage capacity (Price et al., 2010, p. 256; Archer et al., 2015, p. 2; Pirastru et al., 2013, p. 342). Trees reduce the available water amount in ecosystems due to interception of rainwater by the canopy, through evapotranspiration and by blocking out solar radiation that could warm up the soil surface and promote condensation processes of water in the topsoil layer (Özkan & Gökbulak, 2017, p. 158*;* Kedziora, 2010, p. 139). Generally, this means that tree ecosystems have lower moisture levels compared to agricultural grasslands, which was confirmed in the present study.

Soil moisture levels generally vary at different depths of soil layers. It is important to notice that the present study only measured SM in the topsoil layer at a depth of 12 cm. This was decided as the moisture level of topsoil influences the infiltration rate and therefore potentially reduces surface runoff and further flood risk. Özkan and Gökbulak (2017, p. 164) also point out that SM under trees is significantly lower in greater soil depths as tree root systems draw out water of the subsoil (Özkan & Gökbulak, 2017, p. 164). Whereas grass roots in a paddock are comparatively much shorter and therefore only use water in the topsoil as they cannot reach moisture in the deeper layers.

Soil moisture measurements showed that the southeast boundary of the paddock site was more saturated than the northwest corner. This is most likely caused by the topography of the land, which is higher towards the north and slowly slopes down towards the south, causing rain and water to run to the bottom of the paddock where the water sits in puddles before it eventually infiltrates into the ground. Multiple <99% SM readings were taken in that part of the paddock on the last day of data collection because of the rainy weather and the accumulated water on the soil in the pasture.

Problems occurred measuring SM in the Kahikatea forest as root systems complicated the procedure to insert the steel rods of the probe into the ground. In some spots, the rods were fully inserted, however with ‘empty’ cavities and macro pores in the root system, the probe couldn’t efficiently measure soil moisture levels as it was not snuggly surrounded by soil but stuck in a cavity in the roots system. Due to the SM measurements taken at specific points along the intersection points of the transect lines, large variations in the location were not possible. Measurements were taken where the rods were able to be fully inserted into the ground and were moved to such a location when obstructed by roots or other obstacles in the ground.

5.3 Weather interference during data collection

The overall soil moisture levels for all three land use types were higher during the third sampling round because of a two-day rain period before and during the time of data collection. This also resulted in overall lower infiltration rate measurements as the soil was already close to its maximum saturation capacity due to the soil soaking up the rain before testing began. On the day before and the first day of the third sampling round, the weather was cloudy and rainy. On the first day, data collection was undertaken in the pastureland and the restoration area. Since there were no canopy trees or other structures to provide shelter from the elements, the rain proved to be a problem as rain falling inside the infiltrometers and topping up the water levels would have affected the results and therefore fabricated the experiment. To avoid this from happening, buckets were placed upside-down over the infiltrometers to avoid rain from falling inside. The buckets were partially removed when it was time to take another reading. This strategy provided the readings to be as accurate as possible. Data collection for the kahikatea forest was undertaken on the second day of the third sampling round. However, on that day it was only showering sporadically, and the canopy trees provided enough shelter, so no rain reached the infiltrometers.

Chapter 6: Recommendations for future research studies

Future research should concentrate on large scale catchment projects to be able to extend the knowledge base that has already been collated with small case examples. Including bulk density measurements into future research attempts, would also add valuable knowledge to the overall picture. Assessing the relationship of infiltration rate, soil moisture and bulk density will offer additional explanations to the interconnection of vegetation and soil characteristics. It is suggested to take core samples to get a snapshot of the soil profile and better understand the soil matrix in the ecosystem to assess how it is altered by certain vegetation types. Shelterbelts and their benefits to soils in agricultural landscapes have not been evaluated during this study, but it would be beneficial and further research into this topic is recommended. It is also recommended to fully establish a plan of the layout of the proposed test site before starting to collect data. An adequately established transect quadrat makes it easier for the researcher in the long run, when repetitions of tests need to take place. Another recommendation is regarding the time frame, which should be extended to 1-2 months to get the most accurate and non-bias results possible.

Chapter 7: Conclusions

With flooding being New Zealand’s number one most frequent natural hazard and global warming worsening flood predictions for the future, flood risk management and in particular natural flood management is becoming increasingly important. Several studies, including this one, have proven that trees are beneficial when it comes to hydrological and physical soil properties in forest soils, while monoculture systems with herbaceous vegetation promote surface runoff and thus encourage flooding. However, most of the previous studies have been small scale projects and to fully understand the role trees play in flood control, more research needs to be undertaken on a larger catchment scale.

The aim of this research was to establish proof if trees are beneficial for hydrological and physical soil properties and potentially reduce surface runoff and therefore the risk of flooding. This aim was achieved by testing infiltration rate and soil moisture levels in three different land use types with varying tree density. This research represents one of the first detailed assessments of the relationship between vegetation and soil in Southland, New Zealand. All the objectives of this research have been accomplished and key findings coincide with previous research studies. This research has proven that trees are effective as flood mitigating tools by providing crucial ecosystem services such as reducing surface runoff, improving water storing capacity and promoting infiltration rate.

Soil moisture and temperature are two of several important parameters influencing soil hydrological, chemical and biological processes, which in turn can cause detrimental issues for the surrounding environment and ecosystems if they are changed and altered to a different state. It is recommended, that people who wish to change or replace certain land use types or vegetation covers, need to take these issues into consideration and be aware of possible consequences before planning a project. Global warming and increased extreme weather events also need to be acknowledged more during land management planning, as they promote flooding events. Finally, it is suggested to undertake more restoration and planting projects to reap the benefits of trees and woody vegetation transforming the soil and their ecosystems.

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Appendices

Appendix 1: Raw Infiltration Rate Data from the Grassland Paddock

Paddock #1.1		25.06.2020 - 9:45-11:05							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		45				0.0
	1	1	1	45		0	0.00	0.0	0.0
	2	1	2	45		0	0.00	0.0	0.0
	3	1	3	45		0	0.00	0.0	0.0
	4	1	4	44.5		0.5	0.50	30.0	0.5
	5	1	5	44.5		0	0.00	0.0	0.5
	10	5	10	44		0.5	0.10	6.0	1.0
	15	5	15	44		0	0.00	0.0	1.0
	20	5	20	44		0	0.00	0.0	1.0
	25	5	25	44		0	0.00	0.0	1.0
	30	5	30	44		0	0.00	0.0	1.0
	40	10	40	44		0	0.00	0.0	1.0
	45	5	45	44		0	0.00	0.0	1.0
	50	5	50	43		1	0.20	12.0	2.0
1 h	60	10	60	43		0	0.00	0.0	2.0
1 h 10	70	10	70	43		0	0.00	0.0	2.0
1 h 15	75	5	75	43		0	0.00	0.0	2.0

1 h 20	80	5	80	43		0	0.00	0.0	2.0

Average infiltration mm/hr:
1.88

Paddock #1.2 02.07.2020 - 10:15-11:45

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		54				0.0
	1	1	1	54		0	0.00	0.0	0.0
	2	1	2	54		0	0.00	0.0	0.0
	3	1	3	54		0	0.00	0.0	0.0
	4	1	4	54		0	0.00	0.0	0.0
	5	1	5	54		0	0.00	0.0	0.0
	10	5	10	54		0	0.00	0.0	0.0
	15	5	15	54		0	0.00	0.0	0.0
	20	5	20	54		0	0.00	0.0	0.0
	25	5	25	53		1	0.20	12.0	1.0
	30	5	30	53		0	0.00	0.0	1.0
	40	10	40	53		0	0.00	0.0	1.0
	45	5	45	53		0	0.00	0.0	1.0
	50	5	50	53		0	0.00	0.0	1.0
1 h	60	10	60	52		1	0.10	6.0	2.0
1 h 15	75	15	75	51		1	0.07	4.0	3.0
1 h 30	90	15	90	51		0	0.00	0.0	3.0

Average infiltration mm/hr:
0.92

Paddock #1.3		11.07.2020 - 10:05-11:35							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0	▨	39	▨	▨	▨	0.0
	1	1	1	39		0	0.00	0.0	0.0
	2	1	2	39		0	0.00	0.0	0.0
	3	1	3	39		0	0.00	0.0	0.0
	4	1	4	39		0	0.00	0.0	0.0
	5	1	5	39		0	0.00	0.0	0.0
	10	5	10	39		0	0.00	0.0	0.0
	15	5	15	39		0	0.00	0.0	0.0
	20	5	20	39		0	0.00	0.0	0.0
	25	5	25	39		0	0.00	0.0	0.0
	30	5	30	39		0	0.00	0.0	0.0
	40	10	40	39		0	0.00	0.0	0.0
	45	5	45	39		0	0.00	0.0	0.0
	50	5	50	39		0	0.00	0.0	0.0
1 h	60	10	60	39		0	0.00	0.0	0.0
1 h 15	75	15	75	39		0	0.00	0.0	0.0
1 h 30	90	15	90	39		0	0.00	0.0	0.0

Average infiltration mm/hr:
0.00

Paddock #2.1		25.06.2020 - 10:55-1:15							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		47				0.0
	1	1	1	47		0	0.0	0.0	0.0
	2	1	2	47		0	0.0	0.0	0.0
	3	1	3	47		0	0.0	0.0	0.0
	4	1	4	47		0	0.0	0.0	0.0
	5	1	5	47		0	0.0	0.0	0.0
	10	5	10	47		0	0.0	0.0	0.0
	15	5	15	47		0	0.0	0.0	0.0
	20	5	20	47		0	0.0	0.0	0.0
	25	5	25	47		0	0.0	0.0	0.0
	30	5	30	47		0	0.0	0.0	0.0
	40	10	40	46		1	0.1	6.0	1.0
	50	10	50	46		0	0.0	0.0	1.0
1 h	60	10	60	46		0	0.0	0.0	1.0
1 h 10	70	10	70	45		1	0.1	6.0	2.0
1 h 15	75	5	75	45		0	0.0	0.0	2.0
1 h 30	90	15	90	45		0	0.0	0.0	2.0
1 h 40	100	10	100	44		1	0.1	6.0	3.0
1 h 50	110	10	110	44		0	0.0	0.0	3.0

2 h	120	10	120	44		0	0.0	0.0	3.0
2 h 10	130	10	130	43		1	0.1	6.0	4.0
2 h 20	140	10	140	43		0	0.0	0.0	4.0
2 h 30	150	10	150	43		0	0.0	0.0	4.0
2 h 40	160	10	160	43		0	0.0	0.0	4.0
2 h 50	170	10	170	42.5		0.5	0.1	3.0	4.5
3 h	180	10	180	42		0.5	0.1	3.0	5.0
3 h 10	190	10	190	42		0	0.0	0.0	5.0
3 h 20	200	10	200	42		0	0.0	0.0	5.0

Average infiltration mm/hr:
0.74

Paddock #2.2	02.07.2020 - 10:25-11:55

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		4.5				0.0
	1	1	1	4.5		0	0.00	0.0	0.0
	2	1	2	4.5		0	0.00	0.0	0.0
	3	1	3	4.5		0	0.00	0.0	0.0
	4	1	4	4.5		0	0.00	0.0	0.0
	5	1	5	4.5		0	0.00	0.0	0.0
	10	5	10	4.5		0	0.00	0.0	0.0
	15	5	15	4.5		0	0.00	0.0	0.0
	20	5	20	4.4		0.1	0.02	1.2	0.1
	25	5	25	4.4		0	0.00	0.0	0.1

	30	5	30	4.3		0.1	0.02	1.2	0.2
	40	10	40	4.3		0	0.00	0.0	0.2
	50	10	50	4.3		0	0.00	0.0	0.2
1 h	60	10	60	4.2		0.1	0.01	0.6	0.3
1 h 15	75	15	75	4.1		0.1	0.01	0.4	0.4
1 h 30	90	15	90	4		0.1	0.01	0.4	0.5

Average infiltration mm/hr:
0.17

Paddock #2.3	11.07.2020

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		73				0.0
	1	1	1	73		0	0.0	0.0	0.0
	2	1	2	73		0	0.0	0.0	0.0
	3	1	3	73		0	0.0	0.0	0.0
	4	1	4	73		0	0.0	0.0	0.0
	5	1	5	73		0	0.0	0.0	0.0
	10	5	10	72		1	0.2	12.0	1.0
	15	5	15	72		0	0.0	0.0	1.0
	20	5	20	72		0	0.0	0.0	1.0
	25	5	25	72		0	0.0	0.0	1.0
	30	5	30	71		1	0.2	12.0	2.0
	40	10	40	71		0	0.0	0.0	2.0
	50	10	50	71		0	0.0	0.0	2.0

1 h	60	10	60	71		0	0.0	0.0	2.0
1 h 15	75	15	75	71		0	0.0	0.0	2.0
1 h 30	90	15	90	71		0	0.0	0.0	2.0

Average infiltration mm/hr:
1.07

Paddock #3.1	25.06.2020 - 11:15-3:45

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings (WLR)	WLR after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min	min	min	mm	mm	mm	mm/min	mm/hr	mm
	0	0	0		67				0
	1	1	1	67		0	0	0	0
	2	1	2	66		1	1	60	1
	3	1	3	66		0	0	0	1
	4	1	4	66		0	0	0	1
	5	1	5	65		1	1	60	2
	10	5	10	64		1	0.2	12	3
	15	5	15	63		1	0.2	12	4
	20	5	20	63		0	0	0	4
	30	10	30	61		2	0.2	12	6
	40	10	40	59		2	0.2	12	8
	50	10	50	58		1	0.1	6	9
1 h	60	10	60	56		2	0.2	12	11
1 h 10	70	10	70	55		1	0.1	6	12
1 h 20	80	10	80	54		1	0.1	6	13

1 h 30	90	10	90	52		2	0.2	12	15
1 h 40	100	10	100	50		2	0.2	12	17
1 h 50	110	10	110	49		1	0.1	6	18
2 h	120	10	120	47		2	0.2	12	20
2 h 10	130	10	130	44		3	0.3	18	23
2 h 20	140	10	140	41.5		2.5	0.25	15	25.5
2 h 30	150	10	150	40		1.5	0.15	9	27
2 h 40	160	10	160	38		2	0.2	12	29
2 h 50	170	10	170	35		3	0.3	18	32
3 h	180	10	180	33		2	0.2	12	34
3 h 10	190	10	190	29		4	0.4	24	38
3 h 20	200	10	200	25		4	0.4	24	42
3 h 30	210	10	210	21		4	0.4	24	46
3 h 40	220	10	220	14	75	7	0.7	42	53
3 h 50	230	10	230	73		2	0.2	12	55
4 h	240	10	240	70		3	0.3	18	58
4 h 10	250	10	250	68		2	0.2	12	60
4 h 20	260	10	260	66		2	0.2	12	62
4 h 30	270	10	270	64		2	0.2	12	64

Average infiltration mm/hr:
3.39

Paddock #3.2 02.07.2020 - 11:55-1:25

1	2	3	4		5	6	7	8
Reading on stopwatch	Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration

hr	min			mm	mm	mm	mm/min	mm/hr	mm
	0	0	0		49				0
	1	1	1	48		1	1.0	60	1
	2	1	2	48		0	0.0	0	1
	3	1	3	47		1	1.0	60	2
	4	1	4	47		0	0.0	0	2
	5	1	5	46		1	1.0	60	3
	10	5	10	44		2	0.4	24	5
	15	5	15	40		4	0.8	48	9
	20	5	20	37		3	0.6	36	12
	25	5	25	34		3	0.6	36	15
	30	5	30	31	80	3	0.6	36	18
	40	10	40	75		5	0.5	30	23
	50	10	50	69		6	0.6	36	29
	55	5	55	63		6	1.2	72	35
1 h	60	5	60	60		3	0.6	36	38
1 h 15	75	15	75	50		10	0.7	40	48
1 h 30	90	15	90	41		9	0.6	36	57

Average infiltration mm/hr:
25.42

Paddock #3.3		11.07.2020							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm

	0	0	0		73				0
	1	1	1	73		0	0.0	0	0
	2	1	2	72		1	1.0	60	1
	3	1	3	71		1	1.0	60	2
	4	1	4	71		0	0.0	0	2
	5	1	5	70		1	1.0	60	3
	10	5	10	68		2	0.4	24	5
	15	5	15	67		1	0.2	12	6
	20	5	20	65		2	0.4	24	8
	25	5	25	62		3	0.6	36	11
	30	5	30	60		2	0.4	24	13
	40	10	40	58		2	0.2	12	15
	50	10	50	55		3	0.3	18	18
1 h	60	10	60	52		3	0.3	18	21
1 h 15	75	15	75	49		3	0.2	12	24
1 h 30	90	15	90	44		5	0.3	20	29

Average infiltration mm/hr:
16.89

Paddock #4.1	25.06.2020 - 2:45-5:15

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		53				0.0
	1	1	1	53		0	0.00	0.0	0.0
	2	1	2	53		0	0.00	0.0	0.0

	3	1	3	53		0	0.00	0.0	0.0
	4	1	4	53		0	0.00	0.0	0.0
	5	1	5	53		0	0.00	0.0	0.0
	10	5	10	53		0	0.00	0.0	0.0
	15	5	15	53		0	0.00	0.0	0.0
	20	5	20	53		0	0.00	0.0	0.0
	30	10	30	52		1	0.10	6.0	1.0
	40	10	40	52		0	0.00	0.0	1.0
	50	10	50	51		1	0.10	6.0	2.0
1 h	60	10	60	51		0	0.00	0.0	2.0
1 h 10	70	10	70	50		1	0.10	6.0	3.0
1 h 15	75	5	75	50		0	0.00	0.0	3.0
1 h 20	80	5	80	50		0	0.00	0.0	3.0
1 h 30	90	10	90	50		0	0.00	0.0	3.0
1 h 40	100	10	100	50		0	0.00	0.0	3.0
1 h 50	110	10	110	50		0	0.00	0.0	3.0
2 h	120	10	120	50		0	0.00	0.0	3.0
2 h 10	130	10	130	50		0	0.00	0.0	3.0
2 h 20	140	10	140	50		0	0.00	0.0	3.0
2 h 30	150	10	150	50		0	0.00	0.0	3.0

Average infiltration mm/hr:
0.55

Paddock #4.2	02.07.2020 - 11:50-1:20

1	2	3	4		5	6	7	8
Reading on stopwatch	Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration

hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		56				0.0
	1	1	1	56		0	0.00	0.0	0.0
	2	1	2	56		0	0.00	0.0	0.0
	3	1	3	56		0	0.00	0.0	0.0
	4	1	4	56		0	0.00	0.0	0.0
	5	1	5	56		0	0.00	0.0	0.0
	10	5	10	56		0	0.00	0.0	0.0
	15	5	15	56		0	0.00	0.0	0.0
	20	5	20	56		0	0.00	0.0	0.0
	25	5	25	56		0	0.00	0.0	0.0
	30	5	30	55		1	0.20	12.0	1.0
	40	10	40	55		0	0.00	0.0	1.0
	50	10	50	54		1	0.10	6.0	2.0
1 h	60	10	60	54		0	0.00	0.0	2.0
1 h 15	75	15	75	53		1	0.07	4.0	3.0
1 h 30	90	15	90	51		2	0.13	8.0	5.0

Average infiltration mm/hr:
1.33

Paddock #4.3		11.07.2020 - 10:35-12:05							
1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm

	0	0	0		80				0.0
	1	1	1	80		0	0.00	0.0	0.0
	2	1	2	80		0	0.00	0.0	0.0
	3	1	3	80		0	0.00	0.0	0.0
	4	1	4	80		0	0.00	0.0	0.0
	5	1	5	80		0	0.00	0.0	0.0
	10	5	10	80		0	0.00	0.0	0.0
	15	5	15	80		0	0.00	0.0	0.0
	20	5	20	80		0	0.00	0.0	0.0
	25	5	25	80		0	0.00	0.0	0.0
	30	5	30	80		0	0.00	0.0	0.0
	40	10	40	80		0	0.00	0.0	0.0
	50	10	50	80		0	0.00	0.0	0.0
1 h	60	10	60	80		0	0.00	0.0	0.0
1 h 15	75	15	75	79		1	0.07	4.0	1.0
1 h 30	90	15	90	79		0	0.00	0.0	1.0

Average infiltration mm/hr:
0.18

Paddock #5.1 25.06.2020 - 2:45-5:15

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		70				0.0
	1	1	1	67		3	3.00	180.0	3.0
	2	1	2	63		4	4.00	240.0	7.0

	3	1	3	60		3	3.00	180.0	10.0
	4	1	4	57.5		2.5	2.50	150.0	12.5
	5	1	5	55		2.5	2.50	150.0	15.0
	6	1	6	51.5		3.5	3.50	210.0	18.5
	7	1	7	49		2.5	2.50	150.0	21.0
	8	1	8	47		2	2.00	120.0	23.0
	9	1	9	44		3	3.00	180.0	26.0
	10	1	10	41.5		2.5	2.50	150.0	28.5
	11	1	11	38		3.5	3.50	210.0	32.0
	12	1	12	36		2	2.00	120.0	34.0
	13	1	13	33		3	3.00	180.0	37.0
	14	1	14	30		3	3.00	180.0	40.0
	15	1	15	26	85	4	4.00	240.0	44.0
	20	5	20	73		12	2.40	144.0	56.0
	25	5	25	61.5		11.5	2.30	138.0	67.5
	30	5	30	51		10.5	2.10	126.0	78.0
	40	10	40	29	80	22	2.20	132.0	100.0
	50	10	50	65		15	1.50	90.0	115.0
1 h	60	10	60	47		18	1.80	108.0	133.0
1 h 10	70	10	70	32	83	15	1.50	90.0	148.0
1 h 15	75	5	75	77		6	1.20	72.0	154.0
1 h 30	90	15	90	55		22	1.47	88.0	176.0
1 h 40	100	10	100	40		15	1.50	90.0	191.0
1 h 50	110	10	110	18	77	22	2.20	132.0	213.0
2 h	120	10	120	60		17	1.70	102.0	230.0
2 h 10	130	10	130	45		15	1.50	90.0	245.0
2 h 20	140	10	140	31	83	14	1.40	84.0	259.0
2 h 30	150	10	150	71		12	1.20	72.0	271.0

Average infiltration mm/hr:
93.29

Paddock #5.2 | 02.07.2020 - 11:50-1:20

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0	▨	43	▨	▨	▨	0.0
	1	1	1	41		2	2.00	120.0	2.0
	2	1	2	40		1	1.00	60.0	3.0
	3	1	3	39		1	1.00	60.0	4.0
	4	1	4	38		1	1.00	60.0	5.0
	5	1	5	37		1	1.00	60.0	6.0
	10	5	10	31		6	1.20	72.0	12.0
	15	5	15	25	76	6	1.20	72.0	18.0
	20	5	20	74		2	0.40	24.0	20.0
	25	5	25	68		6	1.20	72.0	26.0
	30	5	30	62		6	1.20	72.0	32.0
	40	10	40	50		12	1.20	72.0	44.0
	50	10	50	40		10	1.00	60.0	54.0
1 h	60	10	60	25	74	15	1.50	90.0	69.0
1 h 15	75	15	75	59		15	1.00	60.0	84.0
1 h 30	90	15	90	50		9	0.60	36.0	93.0
1 h 45	105	15	105	38		12	0.80	48.0	105.0
2 h	120	15	120	29		9	0.60	36.0	114.0
2 h 10	130	10	130	20		9	0.90	54.0	123.0

Average infiltration mm/hr:
41.78

Paddock #5.3	11.07.2020 - 10:35-12:05

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		65				0.0
	1	1	1	65		0	0.00	0.0	0.0
	2	1	2	65		0	0.00	0.0	0.0
	3	1	3	65		0	0.00	0.0	0.0
	4	1	4	65		0	0.00	0.0	0.0
	5	1	5	65		0	0.00	0.0	0.0
	10	5	10	63		2	0.40	24.0	2.0
	15	5	15	62		1	0.20	12.0	3.0
	20	5	20	60		2	0.40	24.0	5.0
	25	5	25	59		1	0.20	12.0	6.0
	30	5	30	58		1	0.20	12.0	7.0
	40	10	40	53		5	0.50	30.0	12.0
	50	10	50	53		0	0.00	0.0	12.0
1 h	60	10	60	53		0	0.00	0.0	12.0
1 h 15	75	15	75	50		3	0.20	12.0	15.0
1 h 30	90	15	90	47		3	0.20	12.0	18.0

Average infiltration mm/hr:
6.13

Paddock #6.1	25.06.2020 - 4:15-5:15

1		2	3	4		5	6	7	8
Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		56				0.0
	1	1	1	55.5		0.5	0.50	30.0	0.5
	2	1	2	55		0.5	0.50	30.0	1.0
	3	1	3	55		0	0.00	0.0	1.0
	4	1	4	55		0	0.00	0.0	1.0
	5	1	5	55		0	0.00	0.0	1.0
	10	5	10	55		0	0.00	0.0	1.0
	15	5	15	55		0	0.00	0.0	1.0
	20	5	20	55		0	0.00	0.0	1.0
	25	5	25	55		0	0.00	0.0	1.0
	30	5	30	55		0	0.00	0.0	1.0
	40	10	40	55		0	0.00	0.0	1.0
	50	10	50	55		0	0.00	0.0	1.0
1 h	60	10	60	55		0	0.00	0.0	1.0

Average infiltration mm/hr:
3.08

Paddock #6.2	02.07.2020 - 10:40-12:10						
1	2	3	4	5	6	7	8

Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		54				0.0
	1	1	1	54		0	0.00	0.0	0.0
	2	1	2	54		0	0.00	0.0	0.0
	3	1	3	54		0	0.00	0.0	0.0
	4	1	4	54		0	0.00	0.0	0.0
	5	1	5	54		0	0.00	0.0	0.0
	10	5	10	54		0	0.00	0.0	0.0
	15	5	15	54		0	0.00	0.0	0.0
	20	5	20	54		0	0.00	0.0	0.0
	25	5	25	54		0	0.00	0.0	0.0
	30	5	30	54		0	0.00	0.0	0.0
	40	10	40	54		0	0.00	0.0	0.0
	50	10	50	54		0	0.00	0.0	0.0
1 h	60	10	60	54		0	0.00	0.0	0.0
1 h 15	75	15	75	54		0	0.00	0.0	0.0
1 h 30	90	15	90	54		0	0.00	0.0	0.0

Average infiltration mm/hr:
0.00

Paddock #6.3	11.07.2020

1	2	3	4	5	6	7	8

Reading on stopwatch		Time difference	Cumulative time	Water level readings	Water level readings after 1L refill	Infiltration	Infiltration rate	Infiltration rate	Cumulative infiltration
hr	min			mm		mm	mm/min	mm/hr	mm
	0	0	0		67				0.0
	1	1	1	67		0	0.00	0.0	0.0
	2	1	2	67		0	0.00	0.0	0.0
	3	1	3	67		0	0.00	0.0	0.0
	4	1	4	67		0	0.00	0.0	0.0
	5	1	5	67		0	0.00	0.0	0.0
	10	5	10	67		0	0.00	0.0	0.0
	15	5	15	66		1	0.20	12.0	1.0
	20	5	20	66		0	0.00	0.0	1.0
	25	5	25	66		0	0.00	0.0	1.0
	30	5	30	66		0	0.00	0.0	1.0
	40	10	40	66		0	0.00	0.0	1.0
	50	10	50	66		0	0.00	0.0	1.0
1 h	60	10	60	66		0	0.00	0.0	1.0
1 h 15	75	15	75	66		0	0.00	0.0	1.0
1 h 30	90	15	90	65		1	0.07	4.0	2.0

Average infiltration mm/hr:
0.71

Appendix 2: Raw Soil Moisture Data (in %) for the Paddock

Round 1:
25.06.2020

80	80	83	87	77	79	82	80	86	84	83	83
81	79	83	85	88	87	90	89	80	88	88	87
72	80	81	83	84	85	85	86	87	83	89	88
85	79	82	85	87	86	87	87	79	88	79	85
88	81	85	80	88	88	86	85	82	83	89	84
85	88	90	88	84	80	83	85	83	87	89	86
80	82	84	90	87	85	88	84	87	81	82	84
80	82	84	88	81	74	85	88	86	89	90	88
83	83	89	85	87	83	84	78	87	85	78	86
									Overall SM average:		84.3

Round 2:
03.07.2020

79	79	81	87	76	83	92	86	85	90	84	86
84	82	79	77	85	80	83	79	79	84	82	85
84	73	77	75	84	80	82	83	70	91	81	76
75	70	84	80	84	81	89	87	67	87	83	86
85	81	83	85	83	74	83	79	80	75	85	83
83	76	81	81	78	81	81	82	71	78	75	77
82	86	80	55	80	75	77	72	81	71	79	69
85	78	79	79	80	82	85	81	85	85	87	81
81	78	82	87	83	80	76	75	79	73	80	83
									Overall SM average:		80.4

Round 3:
11.07.2020

85	87	88	92	82	90	91	95	90	93	94	95
89	84	86	89	91	91	93	92	95	94	95	92
84	89	90	94	89	90	93	93	92	97	94	97
84	84	89	89	86	94	97	97	99	95	94	96
88	83	91	87	92	90	93	95	99	96	92	97
82	81	89	95	95	92	96	97	93	95	92	95
85	91	84	89	87	91	92	93	96	97	98	96
90	89	87	96	90	92	97	93	92	95	97	99
88	86	82	90	98	94	91	92	95	103	94	96
									Overall SM average:		91.8

Appendix 3: Raw Soil Moisture Data (in %) for the Restoration Forest

Round 1: 26.06.2020

86	82	71	87	86
81	83	77	87	82
78	89	82	86	85
86	87	81	69	85
89	81	65	82	68
61	92	86	92	81
		Overall SM average :		81.6

Round 2: 02.07.2020

86	79	85	89	85
81	83	83	88	92
87	89	88	91	90
86	76	77	52	93
86	74	80	71	77
89	71	75	84	83
		Overall SM average :		82.3

Round 3: 11.07.2020

90	97	96	99	90
96	95	92	94	95
93	95	99	95	98
96	86	92	97	99
94	92	96	89	88
92	96	89	92	84
		Overall SM average :		93.5

Appendix 4: Raw Soil Moisture Data (in %) for the Kahikatea Forest

Round 1: 27.06.2020

102	94	82	82	86	89
80	84	85	81	83	74
68	85	50	74	85	72
82	63	61	85	88	86
42	68	60	37	39	70
32	73	86	61	61	29
			Overall SM average :		71.6

Round 2: 03.07.2020

96	78	38	78	83	88
80	83	81	81	77	77
82	85	65	74	87	70
75	26	56	78	90	77
44	78	59	23	46	57
48	77	89	27	41	23
			Overall SM average :		67.1

Round 3: 12.07.2020

101	82	35	92	98	95
97	97	78	93	93	89
107	96	57	96	92	96
94	93	58	92	106	97
91	89	68	40	90	87
55	89	107	64	62	45
			Overall SM average :		83.9