The effect of different ground cover vegetation on water infiltration in different soil types.

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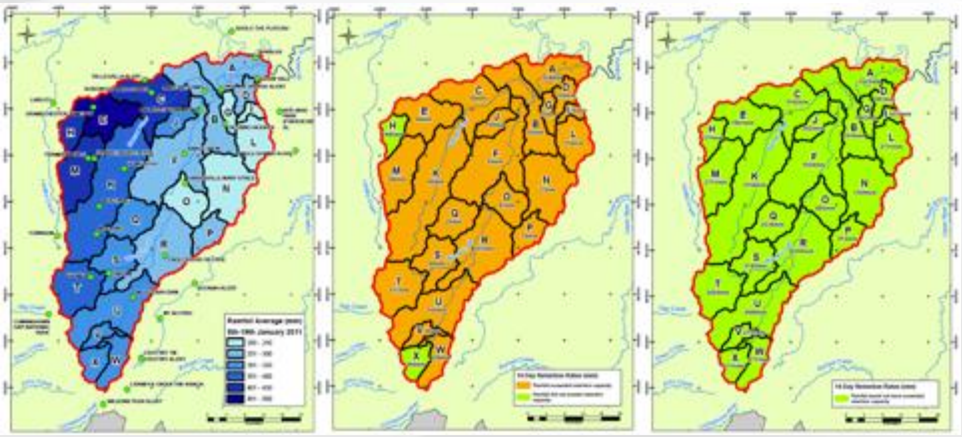

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Thank you all!!

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I. LITERATURE REVIEW

The effect of different ground cover vegetation on water infiltration in different soil types.

Urban Water - Flood mitigation
(Literature Review; Applied field research; Mathematical modelling)

Problem Characterisation and Project Goal

Over the past century, land use has changed dramatically in the South-east Queensland region and in addition to climate change will increase the magnitude of flooding events. The literature highlights that better management of vegetation cover on corridors, floodplains and riparian zones along the catchments can contribute to a reduction in flooding impacts downstream. Therefore, this study will examine the effects of varying types of vegetation and water infiltration rates in different soil types on intercepting rainfall to manage runoff and erosion around the Bremer catchment within the Ipswich region. The main objective of this project is to provide a more robust way of identifying how the relationship between plant canopy structure and soil infiltration rates can be targeted to dramatically decrease runoff and hence provide effective flood mitigation from the International Water Management (IWM) perspective or context and its social, economic, political technological, legal and environmental implications.

Proposed Research Questions:

- How does vegetation intercept rainfall and hence affect flooding downstream?
- How does soil type and its distribution in a catchment affect runoff?
- How can the above information be used to mitigate flooding?

Objectives:

- To characterise different combinations of soil-vegetation along the Bremer catchment to assess rainfall infiltration.
- To calculate the infiltration rates within different soils under different vegetation, to define the best relationship for flood mitigation.
- To analyse the effect of rain and its changes in the soil water infiltration under different canopy vegetation, to contribute to flood reduction downstream.
- To document the findings of this assessment and publish in an article.

1. Introduction

Globally and indeed Australia massive land use modification including sprawling, densified urban development and agricultural modification to land have caused an imbalance in the catchment hydrological regime, leading to the intensification of reported floods in large areas Zhang et al., (2001). Disasters (such as flood events) whilst triggered by natural process of rainfall are vastly magnified because of the change to landform, poor floodplain management planning and are man-made catastrophes Rana, (2013).

In addition to this, areas like Queensland in Australia are encountering climate change effects in the form of higher temperatures, increased rainfall intensity, increased bushfires and more frequent extreme events, such as floods and more severe prolonged droughts Keogh et al., (2011). According to Giupponi and Gain, (2017) climate change is one of the significant threats to society. Because water is the principal medium through which climate change affects the Earth's ecosystems and consequently people's livelihoods and well-being.

Therefore, the purpose of this document is to present from the IWM's context one increasingly significant aspect for this concept, the adaptation to climate change related risks, with a focus on floodplain management Benson and Lorenzoni, (2017). The fundamental intent of this study is derived from the need to understand and quantify the relationship between the different types of vegetation and soil water infiltration rates, to restore catchment vegetation in order to reduce the amount of rainfall that forms runoff, and to achieve a flood mitigation effect.

Figure 1. Queensland Flooding during 2011-2012, the source from: Berry and Smith, (2017)

The Brisbane River with a catchment of approximately 13,570 km^2 is the longest river in the state of Queensland. This river has a long history of flooding with written evidence dating back almost 200 years, and it experienced its second largest flood since the twentieth century in January 2011 Liu and Lim, (2018). According to the Department of the Environment and Science, the flooding and cyclones of the 2010–11 rainy season saw most of Queensland declared a disaster area. This flooding event caused severe injuries and loss of life, disrupted the social fabric of the community, impacted economic activity and caused damage and destruction to the natural and built environment Healthy Waters, (2012) as shown in Figure 1.

Whilst flood events can be naturally occurring phenomena that can benefit an ecosystem's health; Schuch et al., (2017). Serra-Llobet et al., (2018) Noted that "*Floodplains are a vital component of a healthy river system which maintains the diversity of species and a dynamic mosaic of habitats including open water, submersed/emergent aquatic vegetation, wet meadows/prairies, and bottomland hardwood forests*". However, in the case of the Brisbane River catchment and its sub-catchments' floodplains, where the human activity has impacted and reduced the ability of ecosystems to recover soils in order to absorb additional water and mitigate floods, generating an ecological disruption and flood footprints Schuch et al., (2017). Regionally based scientific studies undertaken throughout South East Queensland have shown that excess urban stormwater runoff into urban streams has significant adverse impacts on the quality and ecological functioning of those receiving waters. The Brisbane river and subsequently Moreton a wetland of international importance under the Ramsar convention are two such receiving environments Rahman and Weber, (2003).

2. Flood Mitigation Approach

In response to the challenges mentioned above, Australian water professionals, such as government bodies, industrial sectors, and independent researchers are looking beyond basic approaches to flood mitigation. For instance, the implementation of EBA (Ecosystem Base Approach) and IWM (Integrated Water Management) [1].

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[1] As quoted by BISWAS, A. K. 2008. Integrated Water Resources Management: Is It Working? *International Journal of Water Resources Development,* 24**,** 5-22. the most usual definition for IWM is "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*" from the GWP 2013.

Where, the EBA (Ecosystem-based approaches) recognise the role of well managed natural assets, such as wetlands, forest and coastal systems, in preventing and mitigating negative impacts of natural hazards, such as earthquakes, flooding, landslides, cyclones, wildfires, and drought Healthy Waters, (2012). Moreover, the inclusion of the IWM strategy is a holistic, long-term planning approach, which considers all water services (potable water, stormwater, backwater, etc.), sources, stakeholders, and impacts in order to create the optimal outcomes for society Closas et al., (2012).

In contrast, the literature describes an inadequate approach to traditional flood management methodology; due to the fact that these methods were "locally" reviewing and restricting developments within floodplains using a series of lines along the waterways, well-known as waterway corridors. However, the lack of specific planning and regulators from the economic, political and environmental perspective were unable to manage development pressure into the hydraulic system. Moreover, these flood mitigation approach and mechanisms were also reactive rather than proactive and can do little to maintain a problem at its source. In some areas they may also have exacerbated these risks of flooding, and other water quality concerns Rahman and Weber, (2003).

2.1 Ecosystem-based approaches

According to the EBA study, the majority of Queensland settlements established in or near floodplains have catchments and wetlands which are significantly modified and could not be forcefully returned to natural function. This results in a long history of flooding within the Queensland community Healthy Waters, (2017). Consequently, the role of carefully planned networks of green open spaces in contributing to flood management has been recommended, which along with policy-driven indicators will holistically assess how ecosystem features can be managed to reduce vulnerability to floods Schuch et al., (2017).

Based in the EBA, Berry and Smith, (2017), who are co-directors on this document have presented two possible main mitigation methodologies for the upstream of the river basin in order to reduce the impact of flooding down the stream. The first one consists of floodplain land use change, which aims to choose proper sustainable practices for hill slopes, introducing, hedgerows along contours, contour ploughing, zero till and arable reversion. The second one looks at the upland intervention modification to drainage systems, as well as restoring wetlands and floodplains. It also looks at the strategic slowing /storage in drainage systems through 'naturalistic intervention,' e.g., introducing woody debris in streams and smaller tributaries. Furthermore, it looks at replacing/reintroducing meanders and reconnecting and re-engaging floodplains. These methodologies provide options to improving the whole-system, by restoring the pre-development stream flow by bringing back natural hydrological (infiltration, storage, evapotranspiration) and geomorphic processes (sediment supply, channel planform migration) within the catchment environment Lim and Lu, (2016).

2.2 IWM approaches and climate change adaptation

The IWM approaches are essential for the sustainable development of water resources globally and, it is a fundamental part of the water planning philosophies for all the Australian water authorities in each state. This is enacted in coordination with the National Water Initiative (NWI) agreed in 2004, Cooper et al., (2017). In contrast and according to Serra-Llobet et al., (2016); the IWM has since been widely accepted by the water management community worldwide. However, for some water professionals this is a relatively broad concept that is difficult to implement across the whole catchment and consequently, the implementation of IWM can be a challenge.

An increasingly essential aspect of IWM is the Climate Change Adaptation (CCA) concept and its related risks from flooding which affects social, economic, political, technological, legal and environmental aspects Benson and Lorenzoni, (2017). The continuing efforts to integrate "*the climate change in water management provide a unique opportunity for lessons drawing and knowledge exchange on IWM and CCA, in particular how they may contribute to, or undermine, each other*" Giupponi and Gain, (2017).

Furthermore, the recent approval of Agenda 2030 by the United Nations (UN 2015) has provided a new framework in which IWM and CCA were components of the planetary efforts towards sustainable development. In particular it looks at elements contributing respectively to sustainable development goal (SDG) 6 ("*Ensure availability and sustainable management of water and sanitation for all*") and 13 ("*Take urgent action to combat climate change and its impacts*"). Within goal 6 of SDGs, the target (6.5) is focused on the implementation of 'integrated water resources management [IWRM] at all levels, including through transboundary cooperation as appropriate', to be achieved by 2030 Giupponi and Gain, (2017).

3. The effects of vegetation in flood management from the IWM perspective

This document aims to examine the effects of vegetation changes on water retention which contributes to the reduction of runoff. It also aims to model the catchments mathematically based on their diverse vegetation and soil types. The findings of this will provide useful information about the hydrological function of vegetation in catchment's water balance Zhang et al., (2001).

The literature highlights the importance of the vegetation within ecosystem and how its benefits water retention and in turn flood mitigation. According to Schuch et al., (2017), the vegetation along the catchment improves and increases the soil retention properties which reduce the runoff. Consequently, the importance of an adequate variety and management of vegetation along the catchments is essential for flood mitigation efforts. These "green spaces" are also important areas within urban areas to provide storage for floodwater and also to reduce the erosion and the movement of sediments into the rivers and estuaries. Suitable vegetation within the riparian areas of a water system can also moderate runoff from low intensity and short length rains. Nevertheless, *"variations to vegetation cover caused directly or indirectly by climate change could lead to impacts on hydrological and erosion processes, through changes to rainfall capture and flood resistance"* Nunes et al., (2009).

According to Croke et al., (2017), there is a lack of information, and inadequate knowledge that primarily results in the ineffectiveness of proper catchment vegetation management in the regions of the world categorised by extreme floods events and extended droughts. This author also mentions the challenges within the management of the revegetation along the catchments and the establishment of green spaces along this. Seeing that the main constraints are: the difficulty of identifying the most suitable type of vegetation, where these could contribute most to the enhancing flood problems and also identifying the active channel bank and bank top. Therefore, the complex connections between these parameters make an impact valuation uncertain Nunes et al., (2009).

Noting this, it is important to mention that the use of vegetation to manage inundations along the catchment is fundamental and directly connected to the concepts of water sensitive planning and integrated urban water management Schuch et al., (2017). As an example, in the key principals and framework for WSUD (Water Sensitive Urban Design) as shown in Figure 2, to protect the natural system, restore water balance and create landscape amenities are directly related with the adequate management of vegetation in the catchment's urban areas.

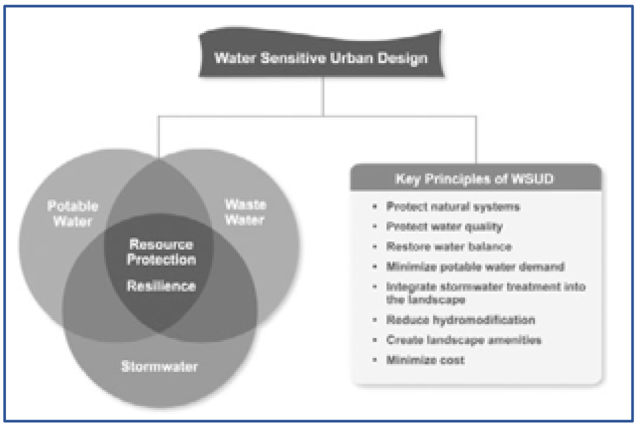

Figure 2. key Principals and Framework of water sensitive urban design (WSUD), source: Donofrio et al., (2009).

Dadson et al., (2017) agrees that in the process of reducing flood hazards through the adequate management of vegetations vegetation programs, such as; green spaces, riparian zones, green corridors, development floodplains, etc. There are significant advantages: "*including enhanced ecosystem services (aquatic, riparian and terrestrial) such as greater biodiversity, improved soil and water quality, carbon sequestration, reduced soil erosion, greater agricultural productivity and improved public health and well-being*". Although, these practices are implemented internationally, the methodologies are quite experimental and in most cases are not replicable due to the number of variables involved. This in turn makes it difficult to implement as an environmental policy due to the complex nature of the varying catchments across a legislative area Schuch et al., (2017).

4. The effects of different soil's types in flood management from the IWM perspective

Roub et al., (2013) concedes that there is a vital importance of soils to maintain the water retention capacity of the catchment and contributing to an ecosystem and catchment health. A disturbance in the catchment soil and land's uses will be reflected in the increase of runoff, erosion, the increase of nutrients loads and sediment in the catchments, as well as, the reduction of supply to the phreatic level.

Hümann et al., (2011) states that soils under natural catchment conditions or undisturbed ecosystems tend to be relatively more porous with high retention capacities, consequently this lowers surface runoff rates. In areas with more vegetation, the effect of the roots loosens the soil and reduces the compaction phenomenon which in turn increases the water storage capacity. This action can reduce the chance of floods being generated by large rainfall events. Therefore, and according to Esteban Suárez et al., (2013) founding on his study; the infiltration rates under undisturbed ecosystem are higher. However, the variations in infiltration capacity seem to be predominantly explained by soil type.

The urbanisation process along the catchments has disturbed the soil and natural water cycle; reducing the porous surfaces and the artificial channelisation of runoff, increasing the risks of flooding and transporting sediments into the riverbanks and estuaries Renouf et al., (2016). The water professionals to improve the efficiency of water management in the catchment, and to contemplate the urbanisation effects, are assessing the initial conditions of the soil and water's cycle and comparing this after the development, using the urban metabolism conceptual framework. By undertaking this approach it allows them to take a better decision regarding "*greenspace and the connectivity it provides to support water resources and water sensitive cities*" Kenway et al., (2011).

5. Summary

According to this literature review; the role of the vegetation in improving soil water infiltration rates to reduce runoff in the catchments is a new and continuously evolving discipline, and it has been evaluated in several locations around the world. The implementation of these findings into the IWMR holistic' approach will be vital for the water cycle protection and is the responsibility of the water professionals, governments, and the catchment's stakeholder. This applied concept can improve the ecosystems and human well-being, sustainably, including food production, climatic regulation, environmental risk mitigation, sociocultural – economic needs, community amenities, among other advantages.

Other benefits of adequate vegetation and soil relation, it can include reducing stream power (and thus erosion), increasing water quality, groundwater recharge and ecology through habitat, improving economic and social welfare without compromising the sustainability of the ecosystems. Which links well to the Integrated Water Management concept and the Integrate Water Management objectives.

It was found through this literature review that there is a lack of water governance and policies on this subject. The literature also highlights the importance of the vegetation and soil in flood management mitigation, but there are not any numerical values or guidelines for implementation of this because the majority of the case studies are area specific and cannot be statistically replicated or scalable[Σ].

[Σ] 2676 words – Literature Review

II. Publishable Manuscript

The effect of different ground cover vegetation on water infiltration in different the soil types.

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Abstract

Historical development of agricultural land and the following intensification of urban development areas has drastically effected catchment's ability to naturally mitigate flood events. Coupled with generally poor floodplain management planning and the addition of the climate change, this is resulting in more severe flooding and hence larger scale disasters. Therefore, water professionals need more robust and sustainable approaches to flood mitigation events with an emphasis on less reactive and more proactive solutions including in the area of broader land and catchment management. This study has found a correlation between vegetation and soil type and identifies the best water retention conditions through a series of soil physical analysis's connections and a deep statistic's study. In an ideal scenario of landscape management in catchments we found that the use of Long grass with some shrubs and trees can reduce stream power. We analysed infiltration results from different vegetations along with rainfall information on the Bremer catchment for the January 2011 flood event. We also modelled infiltration effects against both the existing and ideal vegetation's conditions. These results were then mapped via GIS with the findings and conclusions cited at the end of this document.

1. Introduction

The effect and importance of different ground cover vegetation on improving the infiltration and retention capacity of water in soils, across and throughout catchments has long been mentioned in various studies. However, the lack of appropriate field measurements and a reduced statistical approach has limited the use of vegetation cover as part of any flood risk mitigation programs. Consequently, the City of Ipswich through the Works Parks and Recreation department in conjunction with Synergy Solutions, IWC and the University of Queensland has undertaken this study. The study aims to provide a more robust way of identifying the relationship between plant canopy structure and soil infiltration rates in order to reduce rainfall runoff dramatically and hence provide effective flood mitigation baselines.

Human derived land use modifications have caused negative effects on the hydraulic balance along catchments within both rural and urban areas which has in turn increased the risk of floods and droughts along with climate change Gajic et al., (2008). Consequently, the IWM evolved approaches into this area of research which included work from the CCA to provide analysis on the impacts on social, economic, political, technological, legal and environmental aspects Benson and Lorenzoni, (2017). This new approach provides information and adaptation tools for mitigation programs to reduce flood risk events at the catchment scale, by involving the water decision makers such as planners, governments, and stakeholders Smith and McAlpine, (2014).

Hümann et al., (2011) states that "the interactions between forests and soils remain a particularly 'grey' area in the hydrological knowledge." Nevertheless, the IWM approach and other approaches such as WSUD encourage conserving water in landscapes and soil profiles in order to reduce the runoff during rain events while protecting our natural resources Schuch et al., (2017). Responding to these challenges involves a fundamental change in the way we design and build our cities and administer our water resources Donofrio et al., (2009).

1.1 Ipswich Council and Brisbane River Catchment flow study

At the Brisbane's various catchment and sub-catchment levels of the Brisbane, local flood studies have been undertaken since the 2011 flood event. The Queensland government, its local councils and other stakeholders are working on a long-term plan for the Brisbane River Catchment calling it the Brisbane River Flood Study" its aim to be able to inform improvements to community safety and resilience along the catchment. This study is based on the flood management risk cycle framework, shown in Figure 3. This is the first study at the local scale with the Councils of Brisbane, Ipswich, Lockyer Valley and Somerset regional council cooperating together in this task Queensland Government, (2017).

Figure 3. Flood Risk Management Cycle Framework, source from Queensland Reconstruction Authority, (2017).

The Brisbane River catchment Flood Study was released in May 2017; however, the Flood Management Plan is scheduled to be complete by the end of 2018. Consequently, this document will provide a reference data to help to achieve the land management Actions ID-LM4 and later on LM2, which includes: prioritisations locations for landscape management, as well as, relationships between broad-scale revegetation. It is however noted, that the Flood Management Plan is not a holistic integrated water catchment plan and further supplementary works are required in this space. A focus on the integrated benefits of flooding, waterway health, ecology and water supply are required.

2. Materials and Methods

2.1 Study site

This study focused on the Bremer catchment, which also forms part of the Brisbane River catchment in South-East Queensland. The Bremer River catchment has an area of approximately 202,195 ha. Within this catchment there are a diverse range of land uses including; agriculture, mining, industry, commerce, natural areas and urban development including the City of Ipswich City of Ipswich, (2018b). According to the hydraulic study from MAUNSELL-AECOM, (2008), *"the flow in Bremer River during a 100-year ARI (Average Recurrence Interval) design event exceeds the capacity of the main channel of the waterway, and substantial overbank inundation occurs within the preferred alignment"*. It is evident that this sub-catchment has the issues of the urban development, including, salinity problems and is impacted heavily by industry, past and present. Furthermore, the areas within the catchment are currently undergoing some of the most rapid residential and commercial development rates in Australia including Springfield and Ripley Valley City of Ipswich, (2018a).

Berry and Smith, (2017) takes the view that the extent of remnant vegetation in the Bremer catchment pre-European vs today can be represented as shown in Figure 4.

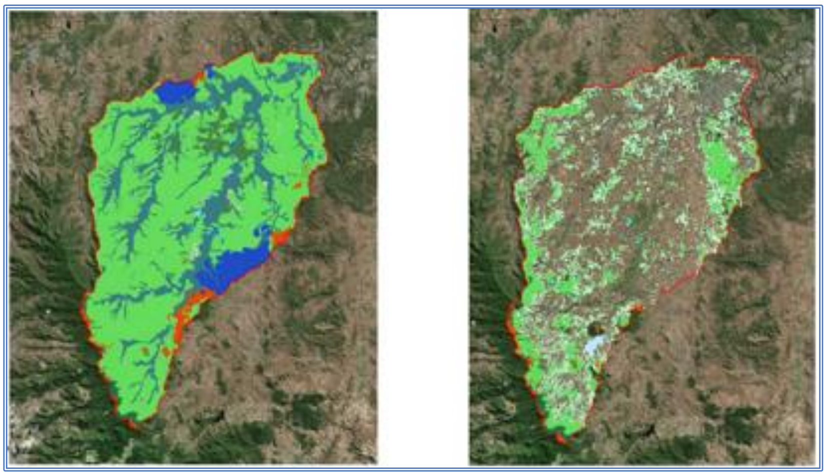


Figure 4. Extent of remnant vegetation in the Bremer Catchment pre-European vs today, source: Berry and Smith, (2017).

2.2 Sampling design

In order to identify the effect of different ground cover vegetation on water infiltration in different the soil types, the proposed project design has classified three groups of vegetation (V1, V2 and V3) against two soil groups (S1 and S2), as shown in the below Table 1.

Vegetations			Soils	
V1	Pasture, partially compacted		S1	heavy Soil
V2	Long grass with some shrubs and trees		S2	light soil
V3	Heavy canopy with a mix of shrubs and large foliage trees			

Table 1. Proposed project design- By the author- 2018.

The soil samples and field measurements were carried out during March and April of 2018 within the Bremer catchment area. The six selected plots included the combinations between variables V (canopy Type) and S (soil type), where the soil samples were deliberately taken under the three-differing vegetation (V1, V2, V3) conditions. As shown in Figure 5. These samples included six infiltration rates (mm/hr) on site by the disc permeameter method by two repetitions and a 24 core soil samples for further analyzed in the soil science laboratory at the University of Queensland.

Assessments	Monitoring sites	Repetitions	Total
Infiltration rates	6	2	12
Bulk Density, etc	6	2 (10 – 20 cm)	24

Figure 5. Sampling design and Monitoring plots - By the author -2018.

2.3 Soil analysis methodology

Throughout this study, the response variables to the hypothesis were defined in principle as each of the 21 independent variables, these variables describe the experiment delivered, and the explanatory variables defined as the type of soil (S) and vegetation (V), which were established at the start of this document. The methods of analysis include a direct method of analysis and calculative methods, as shown in Table 2.

Response variables of the hypothesis		Direct methods of analysis	Calculative methods
Infiltration Rate, mm/h		Disc permeameter	
k_sat (0-10cm), mm/h	k_sat (10-20cm), mm/h	Falling head method	
Bd (0-10cm), g/cm3	Bd (10-20cm), g/cm3	Tanner sampler for Bulk density	
FC (0-10), g/g	FC (10-20), g/g	Pressure plates for soil water release curve	
PWP (0-10 cm), g/g	PWP (10-20 cm), g/g	Pressure plates for soil water release curve	
PAW (0-10cm), g/g	PAW (10-20cm), g/g		Using phase relationships
PoreVolume 0-10cm, %	PoreVolume 10-20cm, %		Using phase relationships
AirFilled PV 0-10cm, %	AirFilled PV 10-20cm, %		Using phase relationships
FC (0-10),%	FC (10-20),%		Using phase relationships
PWP (0-10 cm),%	PWP (10-20 cm),%		Using phase relationships
PAW (0-10cm), %	PAW (10-20cm), %		Using phase relationships

Table 2. response variables methodology - By the author – 2018.

2.3.1 *Direct methods description*

2.3.1.1 Disc permeameter:

According to Clothier and White, (1981), Sorptivity needs to be measured on site to eliminate the effect of macro-pores and obtain the matrix Sorptivity. It was achieved using the Disc permeameter; the data was measured in mm/second and capture to calculated infiltration rate in mm/h, this assessment was conducted in the six plots with a minimum of two repetitions in each, as shown in **Appendix I.**

2.3.1.2 Falling head method:

The falling head method (FHM) is based on Lefranc's test with falling heads from 1986, which has been used to measure the saturated hydraulic conductivity, under the equation below, Pedescoll et al., (2011).

Calculate by the equation (a): $Ks = {}^{\ln\frac{h1}{h2} * L}\Big/_{\Delta t}$

Where: K -Sat (mm/h); h1-h2 (initial distance- final distance (mm)); L (Height of water (mm)); Δt (time difference(s)). This was calculated to the 24 samples taken from the 6 plots with 4 repetitions at 2 deeps from soil surface (0-10 cm and 10-20 cm) as shown in **Appendix I.**

2.3.1.3 Tanner Sampler for Bulk Density:

Using the methodology proposed by McIntyre and Barrow, (1972), the 24 core samples were taken on site during March – April 2018. The samples were extracted at the same place as the disc permeameter testing site, at two different depths (0-10 cm and 10-20cm). the dimensions of each core sample are 12.5 cm diameter and 8.5 cm tall. The samples were transported to the lab of Soil science at UQ where the bulk density among other physical properties were measured. The Bulk density was measured by the dry oven method in gr/cm^3.

2.3.1.4 Pressure Membrane extraction to calculate PWP and FC

The PWP (permanent wilting Point in g/g) and FC (Field Capacity g/g) were calculated in the UQ- Soil science Lab using the method of pressure membrane extraction at 0.1Bar and 15Bar respectively, this method was replicated from Richards, (1941).

2.3.2 Calculative methods descriptions

Using the soil physical calculation- soil phase relationships; proposed by Kirkham, (2014), the following equations below were used:

2.3.2.1 PAW (g/g):

Calculate by equation (b): $PAW = FC - PWP$

2.3.2.2 Pore volume (%):

Calculate by equation (c): $PoreVolum = 1 - {}^{Bd}/_{2.65}$

2.3.2.3 Air filled (%):

Calculate by equation (d): $AirFilled = FC(\%) - PoreVolume(\%)$

2.4 statistical analysis

The Statistical analyses were conducted in R version 3.4.2 (2017-09-28) / R- Studio / R-Commander - version 3.4.2, R Core Team, (2017). This analysis was undertaken in four different steps:

i) Step one focused on analyses of the two explanatory variables (Soil – vegetation) for each of the twenty-one independent response variables and was represented through several scatter charts.

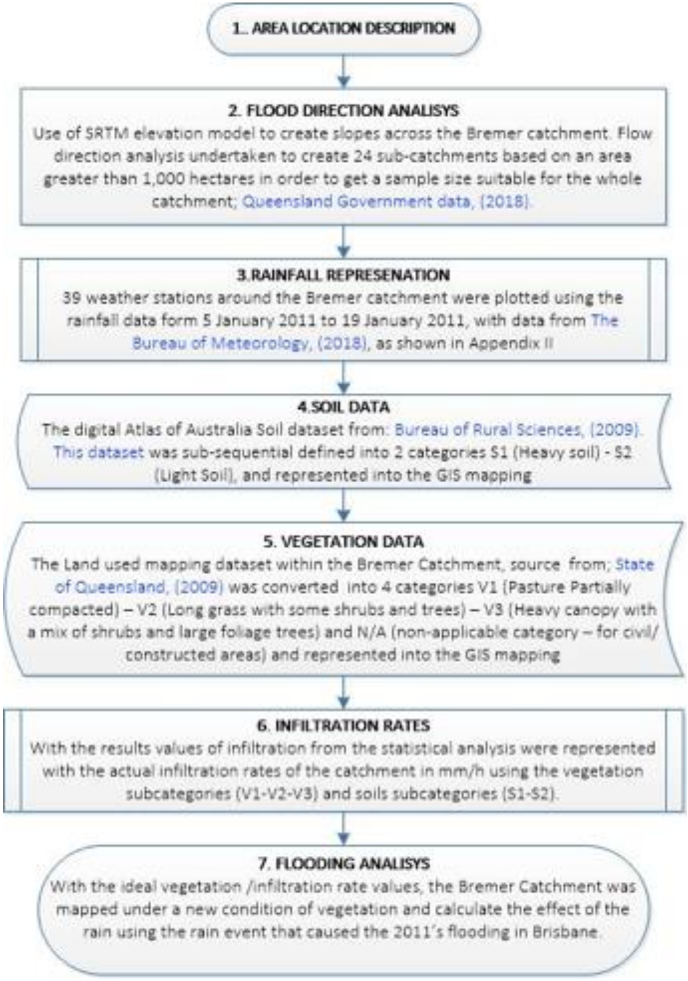
ii) In step two, the measures of central tendency and dispersion of each of the 21 response variables, within the three types of vegetation and the two types of soil were calculated, in order to select the less variable " groups/response variables". This was those where there was less variability in the mean and standard deviation, the less variability, the better it will be for the Hypothesis model to be presented.

iii) Due to the results obtained from the step two, where the data set was spread, it was essential to proceed with the Principal Component Analysis (PCA) which is a method that emphasize variation and bring out strong patterns in dataset Powell and Lehe, (2018).

iv) In the final step (step 4) the implementation of analysis of variance (ANOVA) was used to establish the connection between the two principle variables of soil type and vegetation type and the response variables Naik, (2018).

2.5 Uses of field data in a GIS Study

In order to accomplish the third objective of the initial proposal "To analyse the effect of rain and its changes in the soil water infiltration under different canopy vegetation, to contribute to flood reduction downstream."; Historic rainfall events in the Bremer catchment were analysed. A fourteen-day period including and either side of the January 12th, 2011 Brisbane flooding event was analysed. Soil and vegetation data within the Bremer catchment was also gathered and statistically analysed within a GIS and presented via several maps. All data used for this analysis was sourced or adapted from a recognised state, federal or industry recognised datasets. The procedure of this study is shown in the following flowchart, Figure 6.



1. AREA LOCATION DESCRIPTION

2. FLOOD DIRECTION ANALISYS

Use of SRTM elevation model to create slopes across the Bremer catchment. Flow direction analysis undertaken to create 24 sub-catchments based on an area greater than 1,000 hectares in order to get a sample size suitable for the whole catchment; Queensland Government data, (2018).

3.RAINFALL REPRESENATION

39 weather stations around the Bremer catchment were plotted using the rainfall data form 5 January 2011 to 19 January 2011, with data from The Bureau of Meteorology, (2018), as shown in Appendix II

4.SOIL DATA

The digital Atlas of Australia Soil dataset from: Bureau of Rural Sciences, (2009). This dataset was sub-sequential defined into 2 categories S1 (Heavy soil) - S2 (Light Soil), and represented into the GIS mapping

5. VEGETATION DATA

The Land used mapping dataset within the Bremer Catchment, source from; State of Queensland, (2009) was converted into 4 categories V1 (Pasture Partially compacted) – V2 (Long grass with some shrubs and trees) – V3 (Heavy canopy with a mix of shrubs and large foliage trees) and N/A (non-applicable category – for civil/ constructed areas) and represented into the GIS mapping

6. INFILTRATION RATES

With the results values of infiltration from the statistical analysis were represented with the actual infiltration rates of the catchment in mm/h using the vegetation subcategories (V1-V2-V3) and soils subcategories (S1-S2).

7. FLOODING ANALISYS

With the ideal vegetation /infiltration rate values, the Bremer Catchment was mapped under a new condition of vegetation and calculate the effect of the rain using the rain event that caused the 2011's flooding in Brisbane.

Figure 6. Flow Chart uses of filed and Lab data in GIS study - By the author -2018

3. Results

3.1 Soil physical properties results

3.1.1 Infiltration Rate – disc permeameter results

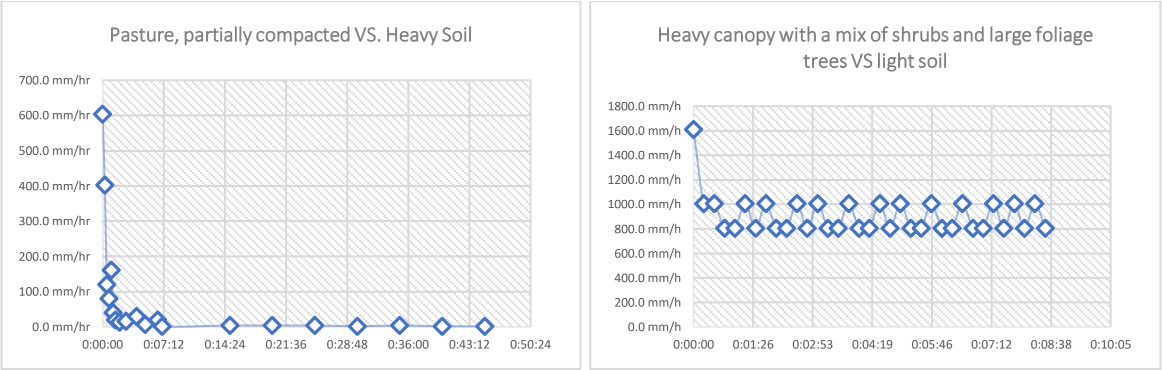


Figure 7. Infiltration rates chart - By the author - 2018

As mentioned in the methodology, the sorptivity was used as the method to measure the field hydraulic property of the soil to indicate treatment-induced changes in the ability of the soil to absorb water , under undisturbed conditions Materechera et al., (1993).Figure 7, illustrates the results under two different treatments (V1, S1 and V3, S2), consequently, the results under the six treatments by two repetitions are represented in Table 3. And the chart for each of the treatment can be find in **Appendix I.**

Vegetation Type	Soil Type	Infiltration Rate, mm/h
V1	S1	3.2
V1	S1	36.8
V2	S1	1207.5
V2	S1	411.7
V3	S1	257.2
V3	S1	914.8
V1	S2	25.7
V1	S2	52.4
V2	S2	632.3
V2	S2	1288.0
V3	S2	908.5
V3	S2	603.8

Table 3. Disc permeameter - infiltration rates results - - By the author – 2018.

3.1.2 K-Sat - Falling head method results

Vegetation Type	Soil Type	Ksat (0-10cm), mm/h	Ksat (10-20cm), mm/h
V1	S1	205.5	1.9
V1	S1	5.3	48.1
V2	S1	728.5	14.6
V2	S1	42.6	83.8
V3	S1	3.2	164.9
V3	S1	8.5	242.8
V1	S2	4.4	2.0
V1	S2	13.7	6.4
V2	S2	129.7	1137.2
V2	S2	151.8	476.7
V3	S2	585.8	374.5
V3	S2	131.5	149.3

Table 4. K- sat result by the Falling head Method – - By the author – 2018.

A notable difference between the results of K-sat of the two different levels (0-10; 10-20 cm) was observed. This could be due to the different boundary conditions for both measurements.

3.1.3 Bulk density results

Vegetation Type	**Soil Type**	**Bd (0-10cm), g/cm3**	**Bd (10-20cm), g/cm3**
V1	S1	1.532	1.565
V1	S1	1.564	1.493
V2	S1	1.313	1.652
V2	S1	1.327	1.454
V3	S1	1.423	1.219
V3	S1	1.280	1.462
V1	S2	1.290	1.546
V1	S2	1.226	1.456
V2	S2	1.104	1.231
V2	S2	1.312	1.665
V3	S2	1.503	1.264
V3	S2	1.117	1.438

Table 5. Bulk density Results – - By the author – 2018.

The values of bulk density vary between 1.1 to 1.5 g/cm^3, the variability could be caused by soil profile conditions under each different treatment. According to USDA-NRCS, (2018), these range of values are consider ideal Bulk density for plant growth under any soil texture

3.1.4 Pressure membrane extraction – results

Vegetation Type	Soil Type	FC (0-10), g/g	FC (10-20), g/g	PWP (0-10 cm), g/g	PWP (10-20 cm), g/g	PAW (0-10cm), g/g	PAW (10-20cm), g/g
V1	S1	0.297	0.270	0.142	0.147	0.155	0.123
V1	S1	0.271	0.232	0.126	0.163	0.145	0.069
V2	S1	0.303	0.378	0.154	0.244	0.149	0.134
V2	S1	0.398	0.375	0.205	0.222	0.193	0.153
V3	S1	0.347	0.360	0.156	0.189	0.191	0.171
V3	S1	0.626	0.331	0.250	0.215	0.376	0.116
V1	S2	0.443	0.312	0.194	0.181	0.249	0.131
V1	S2	0.521	0.396	0.279	0.222	0.241	0.175
V2	S2	0.472	0.316	0.253	0.205	0.219	0.112
V2	S2	0.396	0.235	0.213	0.138	0.182	0.097
V3	S2	0.298	0.219	0.187	0.105	0.111	0.113
V3	S2	0.636	0.188	0.331	0.128	0.305	0.060

Table 6. Pressure Membrane extraction Results – - By the author – 2018.

According to Keller and Karmeli, (1974) Values greater than 0.6 g/g can be consider error in the data, as the maximum possible values for all soil textures are 0.54 g/g corresponding to clay soil.

3.1.5 *Soil Phases Relation – results*

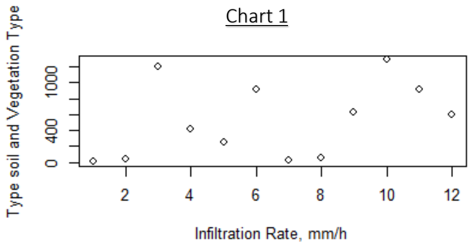
Vegetation Type	Soil Type	PoreVolume 0-10cm, %	PoreVolume 10-20cm, %	AirFilled PV 0-10cm, %	FC (0-10),%	AirFilled PV 10-20cm, %	FC (10-20),%	PWP (0-10 cm),%	PWP (10-20 cm),%	PAW (0-10cm), %	PAW (10-20cm), %
V1	S1	42%	41%	-3%	45.5%	-1%	42.2%	21.8%	22.9%	23.7%	19.3%
V1	S1	41%	44%	-1%	42.4%	9%	34.7%	19.8%	24.4%	22.7%	10.4%
V2	S1	50%	38%	11%	39.8%	-25%	62.5%	20.3%	40.3%	19.6%	22.1%
V2	S1	50%	45%	-3%	52.9%	-9%	54.5%	27.2%	32.3%	25.6%	22.2%
V3	S1	46%	54%	-3%	49.4%	10%	43.8%	22.2%	23.0%	27.2%	20.9%
V3	S1	52%	45%	-28%	80.1%	-4%	48.3%	32.0%	31.4%	48.1%	16.9%
V1	S2	51%	42%	-6%	57.2%	-7%	48.2%	25.1%	28.0%	32.1%	20.2%
V1	S2	54%	45%	-10%	63.8%	-13%	57.6%	34.2%	32.2%	29.6%	25.4%
V2	S2	58%	54%	6%	52.1%	15%	39.0%	27.9%	25.2%	24.2%	13.8%
V2	S2	50%	37%	-1%	51.9%	-2%	39.2%	28.0%	23.0%	23.9%	16.2%
V3	S2	43%	52%	-1%	44.7%	25%	27.6%	28.1%	13.3%	16.6%	14.3%
V3	S2	58%	46%	-13%	71.0%	19%	27.0%	37.0%	18.4%	34.1%	8.6%

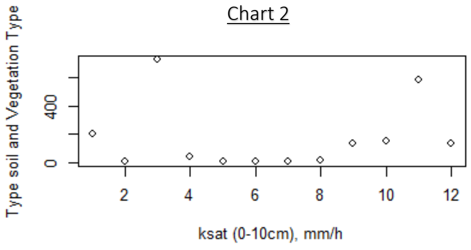
Table 7. Soil Phases Relations Results – - By the author – 2018.

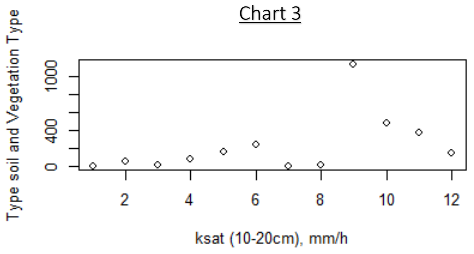
3.2 Statistical analysis results

3.2.1 The dispersion analysis

The typicality of the two variables (Soil – vegetation) for the independent response variables, was represented by scatter charts below. This analysis identifies the twenty-one variables and response of the hypothesis under the three vegetations and two soil types, previously mentioned. These charts were generated via R Core Team, (2017), the code in **Appendix III**.







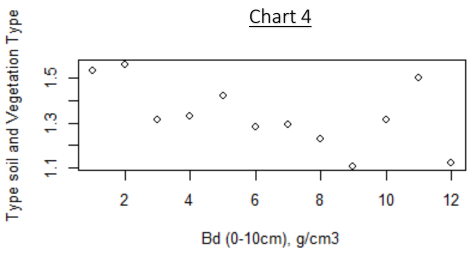


Chart 5

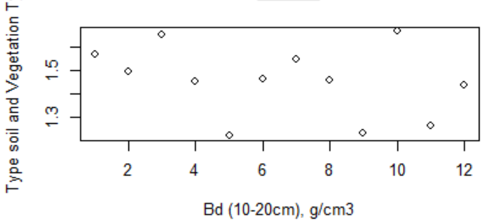


Chart 6

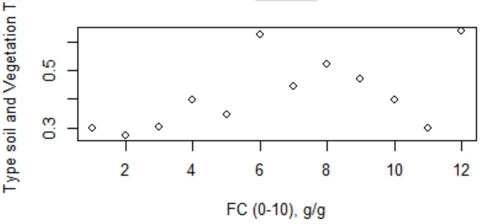


Chart 7

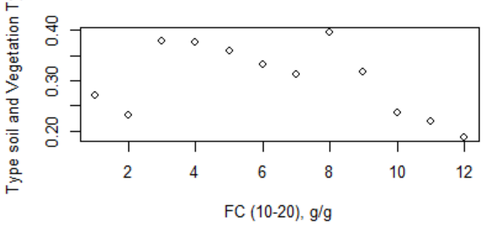


Chart 8

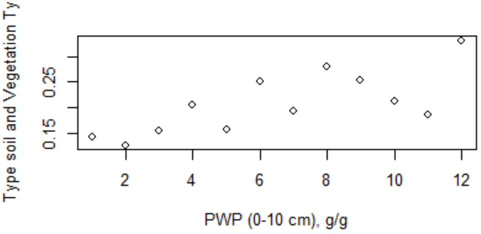


Chart 9

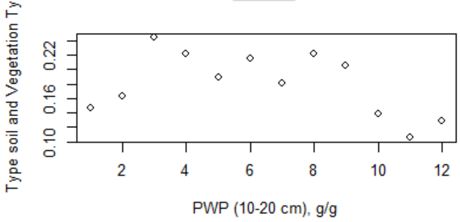


Chart 10

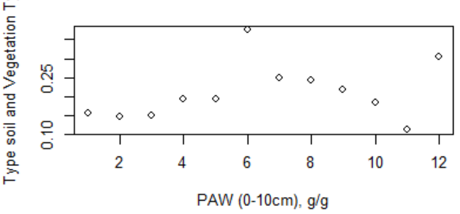
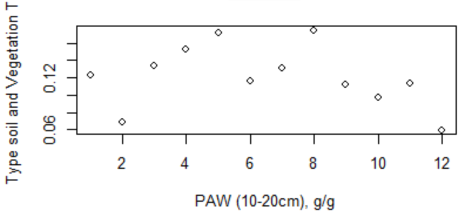


Chart 11



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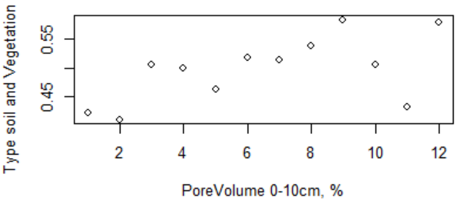


Chart 13

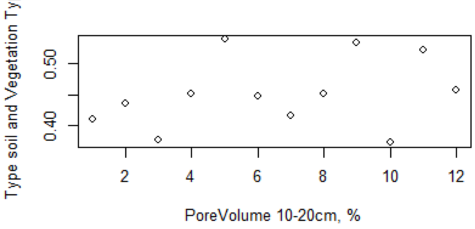


Chart 14

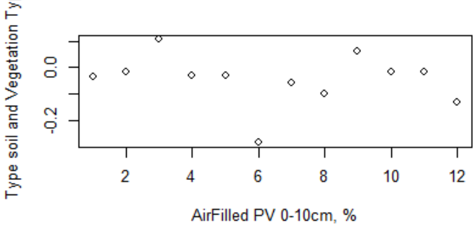


Chart 15

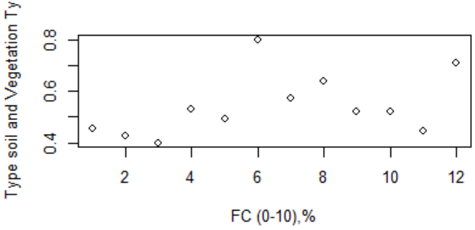
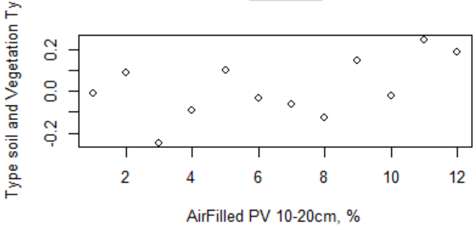


Chart 16



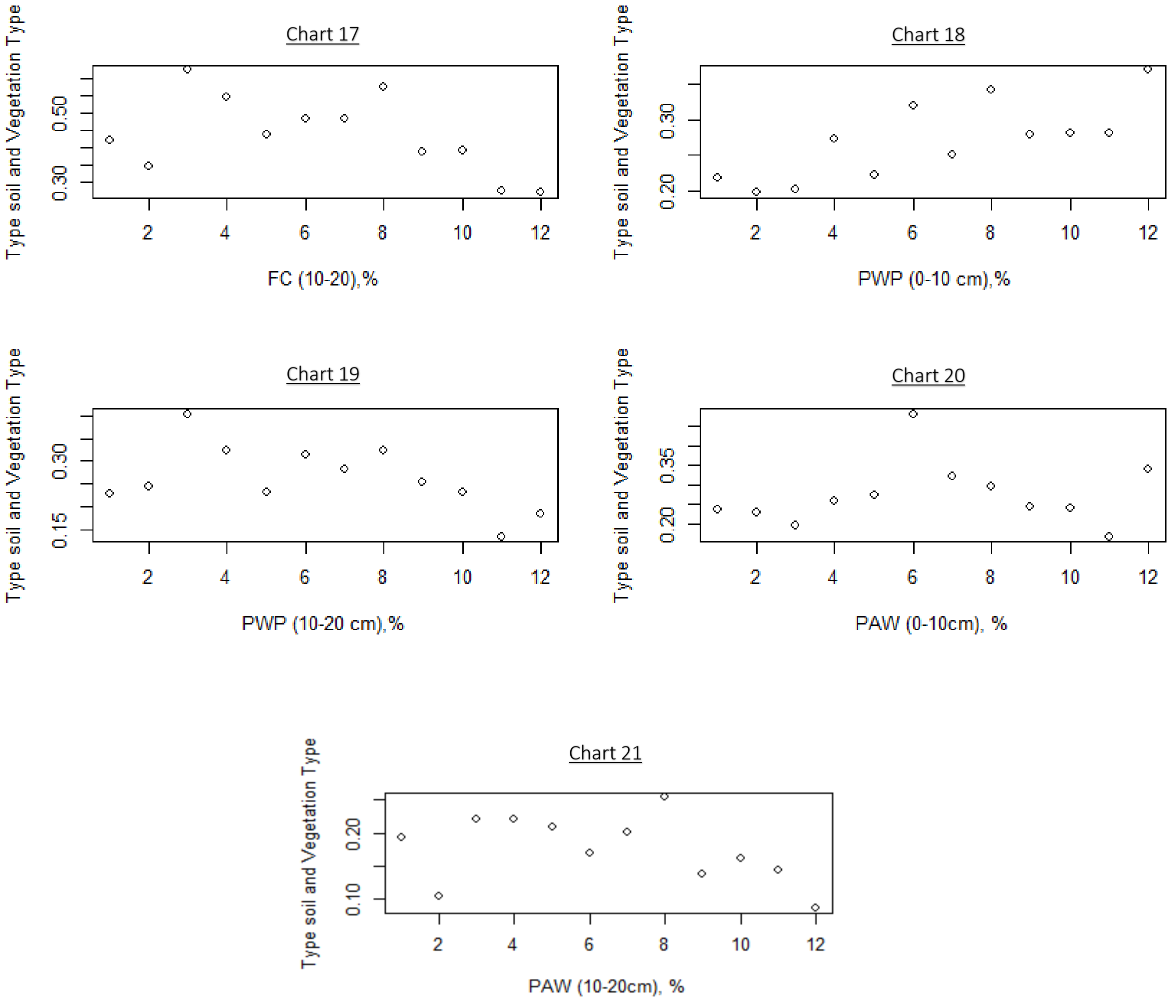


Figure 8. Distribution Charts of the response's variables - By the author – 2018 - R Core Team, (2017)

From the analysis and through the generated dispersion scatter charts of the twenty-one qualitative variables, it shows that there is a great variability in the data results. This could be due to the measurements not being recorded under randomization or that the number of samples selected for the correlation to the hypothesis wasn't adequate. Consequently, we cannot have a great reliability on the behaviour of these variables, along with the fact that the results of the study may not be useful at this stage.

It should be noted that this illustration of the variables allows us to see behaviours and draw certain types of "conclusions" under the intuition since until now no kind of estimation or inference has been made. It was surmised that it is not convenient to perform a normal low analysis since due to the great variability it is convenient to look at the variables from a different method.

3.2.2 Measures of central tendency and Dispersion for the response variables:

Once the dispersion graphs were analysed, the decision was made to calculate the measures of centralisation and dispersion of each of the twenty-one variables within the three types of vegetation and the two types of soil, to determine the "groups that presented less variability. This analysis focused in the study of the mean and standard deviation, since they are measures that allow us to see how large or small the average value of the variables is, and how much variability they have, since the less variability the variable has, the better it will be for the model to be presented.

This code was simulated by naming the tables that contained each of the variables, in the different types of vegetation and soils through R-Commander R Core Team, (2017), as shown in **Appendix III**. Subsequently a summary was made which calculated measures of centralization and dispersion. In this analysis the mean, the standard deviations, the standard error of the mean, the interquartile range were considered along with quantiles of 0, 20, 5, 75 and 1. As the objectives aims to correlate rainfall values mm/h, the three response variables study were:

3.2.2.1 Infiltration rate mm/hr

	mean	sd	se(mean)	IQR	0%	25%	50%	75%	100%	n
Heavy soil; pasture, partially compacted	20.0	23.8	16.8	16.8	3.2	11.6	20.0	28.4	36.8	2.0
Heavy soil; Long grass with some shrubs and trees	809.6	562.8	397.9	397.9	411.7	610.6	809.6	1008.5	1207.5	2.0
Heavy soil; Heavy canopy with a mix of shrubs and large foliage trees	586.0	465.0	328.8	328.8	257.2	421.6	586.0	750.4	914.8	2.0
Light soil; Pasture, partially compacted	39.1	18.9	13.3	13.3	25.7	32.4	39.1	45.8	52.4	2.0
Light soil; Long grass with some shrubs and trees	960.2	463.6	327.8	327.8	632.3	796.2	960.2	1124.1	1288.0	2.0
Light soil; Heavy canopy with a mix of shrubs and large foliage trees	756.1	215.5	152.4	152.4	603.8	679.9	756.1	832.3	908.5	2.0

Table 8. Infiltration Rates statistics analysis - By the author – 2018.

The variable Infiltration Rate, mm/h presents very different average values to each other, with respect to the types of soil, for both: the soil Heavy and for the light soil in the three types of vegetation, thus, were very small values (20.0 and 39.1, respectively) with respect to the largest ones (809.6 and 960.2, respectively). As shown in Table 8.

Through the analysis of the standard deviation (Sd); the lowest values for each of the observations correspond to the vegetation type "Pasture, partially compacted" to each one of the soils treatments. As the (Sd) for this type of vegetation in the soil light soil is 18.9, and in the soil heavy soil is 23.8. It could be concluded that the infiltration is lower in the type of vegetation "Pasture, partially compacted", for the type of soil heavy soil.

3.2.2.2 K-sat (0-10cm), mm/h

	mean	sd	se(mean)	IQR	0%	25%	50%	75%	100%	n
Heavy soil; pasture, partially compacted	**105.4**	**141.6**	100.1	100.1	5.3	55.3	105.4	155.4	205.5	2.0
Heavy soil; Long grass with some shrubs and trees	**385.6**	**485.0**	342.9	342.9	42.6	214.1	385.6	557.0	728.5	2.0
Heavy soil; Heavy canopy with a mix of shrubs and large foliage trees	**5.9**	**3.7**	2.6	2.6	3.2	4.5	5.9	7.2	8.5	2.0
Light soil; Pasture, partially compacted	**9.1**	**6.6**	4.6	4.6	4.4	6.8	9.1	11.4	13.7	2.0
Light soil; Long grass with some shrubs and trees	**140.8**	**15.6**	11.0	11.0	129.7	135.3	140.8	146.3	151.8	2.0
Light soil; Heavy canopy with a mix of shrubs and large foliage trees	**358.7**	**321.2**	227.1	227.1	131.5	245.1	358.7	472.3	585.8	2.0

Table 9. K-Sat (0-10cm) statistics analysis - By the author – 2018.

The variable k-sat (0-10cm), mm/h, where the smallest mean value in the soil type heavy soil is 5.9 corresponding to the vegetation type; “Heavy canopy with a mix of shrubs and large foliage trees” while in the type of soil light soil, the smallest average value is 9.1.

Concerning the standard deviation (Sd), it can be observed that the standard deviation in the type of soil heavy soil, the smallest register was 3.7, corresponding to the type of vegetation Heavy canopy with a mix of shrubs and large foliage trees. In the light soil type, the lowest variability is recorded in the Pasture vegetation type, partially compacted, with a value of 6.6. It should be clarified that the variability and mean values are very broadly with respect to the values of the observations since very high values are remitted concerning small values and have concluded that this variable's data is not reliable.

3.2.2.3 K-sat (10-20cm), mm/h

	mean	sd	se(mean)	IQR	0%	25%	50%	75%	100%	n
Heavy soil; pasture, partially compacted	**25.0**	**32.7**	23.1	23.1	1.9	13.4	25.0	36.5	48.1	2.0
Heavy soil; Long grass with some shrubs and trees	**49.2**	**48.9**	34.6	34.6	14.6	31.9	49.2	66.5	83.8	2.0
Heavy soil; Heavy canopy with a mix of shrubs and large foliage trees	**203.9**	**55.1**	38.9	38.9	164.9	184.4	203.9	223.3	242.8	2.0
Light soil; Pasture, partially compacted	**4.2**	**3.1**	2.2	2.2	2.0	3.1	4.2	5.3	6.4	2.0
Light soil; Long grass with some shrubs and trees	**806.9**	**467.0**	330.2	330.2	476.7	641.8	806.9	972.0	1137.2	2.0
Light soil; Heavy canopy with a mix of shrubs and large foliage trees	**261.9**	**159.3**	112.6	112.6	149.3	205.6	261.9	318.2	374.5	2.0

Table 10. K-Sat (10-20cm) statistics analysis - By the author – 2018.

In the variable k-Sat (10-20cm), mm/h, the smallest mean value in the soil type heavy soil is 25.0 for the type of vegetation, pasture, partially compacted. In the soil type light soil, the smallest average value is 4.2, corresponding to the vegetation type Pasture, partially compacted.

With respect to the variance, it can be observed that the standard deviation in the type of soil heavy soil, smallest registered is 32.7, consistent to the type of vegetation Pasture, partially compacted. It should be noted that the variability in this type of soil concerning vegetation types is not as great as was seen in the previous variables. In the light soil type, the lowest standard deviation (Sd) is recorded in the Pasture vegetation type, partially compacted, with a value of 3.1.

Once the analysis of tendency and dispersion measures was carried out, it could be observed that the 21 variables taken in this study show very different behaviours within themselves. With respect to the types of soil, and in relation to the other variables, due to the dispersion or variability as shown in **Appendix III**, which include the summary of the 21 response variables tendency and dispersion measurements.

From the measurements of central tendency and dispersion for the variables response between the two types of soil with respect to the three types of vegetation "the hypothesis", we can conclude that there is not a certain degree of reliability in the measurements, as the data are not under the normal, that could be due to the fact, the experiment from the beginning could have been poorly planned, thus not using relevant measures in the measurement of each of the variables, and randomness at the time of data collection.

3.2.3 The Principal Component Analysis (PCA)

A decision was made to carry out an analysis of principal components (PCA), in order to identify the most suitable model for the established problem, between the response variables. Analysis was undertaken to see if some of the 21 response variables are correlated by the use of the function-cor code (data) - RStudio R Core Team, (2017).

From the orthogonal transformations of PCA, establishing 12, of which the first four components have a variance greater than 1, so it is necessary to see what the variance is explained, applied by each of the 12 components:

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
Standard deviation	**2.68**	**2.49**	**1.63**	**1.57**	0.97	0.90	0.64	0.40	0.33	0.05	0.0124	2.79E-16
Proportion of Variance (%)	**0.34**	**0.29**	**0.12**	**0.11**	0.04	0.04	0.02	0.01	0.01	0.00	1E-05	0.00E+00
Cumulative Proportion	0.34	0.64	0.77	0.88	0.93	0.97	0.99	0.99	1.00	1.00	1E-05	1.00E+00

Table 11. Principal Component Analysis - By the author – 2018.

This analysis focuses on the proportion of variance explained, applied by each of the twelve main components, from which it can be deduced, that the first 4 main components are those that explain the total variability in 34.2%, 29.6%, 12.7 % and 11.8% respectively, that is, they are the highest variability percentages that best explain the total variability with respect to the other components, since they have an accumulated variance of 88.3%.

From this analysis and reviewing our main components, it is determined that the variable k-sat (10-20cm), mm/h is the variable that the four main components give greater value, please refer to **Appendix III** for the complete PCA. It is necessary to clarify that in the first main component, this variable is not given greater value, but if the variable Ksat (0-10cm), mm / h, unlike the other three components, which give a great value to the same variable but at different levels.

3.2.4 ANOVA – k-sat (10-20cm), mm/h.

According to the previous statistical analysis, the variable Ksat (10-20cm), mm/h, is determined as a variable independent of the remaining 20 response variables. This is why an ANOVA analysis is allowed to this variable, which serves to determine if the two conditions explain well the variable Ksat (10-20cm), mm/h.

The ANOVA to the Ksat variable was done by R-Commander R Core Team, (2017), and the stats output is shown in Figure 9.

```
> RegModel.1 <- lm(ksat..10.20cm...mm.h~Soil.Type+Vegetation.Type, data=Dataset)
> summary(RegModel.1) Call: lm(formula = ksat..10.20cm...mm.h ~ Soil.Type + Vegetation.Type,
data = Dataset)

Residuals:
   Min      1Q  Median      3Q     Max
-317.53 -129.77  -22.89   46.87  779.49
Coefficients:
            Estimate Std. Error t value Pr(>|t|)

(Intercept)      -390.6     357.8 -1.092    0.303
Soil.Type         265.0     178.9  1.481    0.173
Vegetation.Type   109.1     109.6  0.996    0.345

Residual standard error: 309.9 on 9 degrees of freedom
Multiple R-squared:  0.2615,     Adjusted R-squared:  0.09736
                    F-statistic: 1.593 on 2 and 9 DF, p-value: 0.2557
```

Figure 9. ANOVA K-sat (10-20) – R – Outputs, - By the author – 2018 R Core Team, (2017)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-390.6	357.8	-1.092	0.303
Soil.Type	265	178.9	1.481	0.173
Vegetation.Type	109.1	109.6	0.996	0.345

Table 12. ANOVA – p-value analysis by the author.

In order to determinate if our k -sat (10-20) is statistically significant, we use the p-value from the ANOVA analysis, under the standard of p-value of <0.05 (5%) is significant, then, it is evident that soil type has a P-value of 0.173 (=17.3%), vegetation 0.345 (=34.5%) which means neither is significant! However, the level of confidence is 5%, consequently, it can be said that the variable Ksat (10-20cm), mm/h., can be explained by the two types of soil and the three types of vegetation quite well.

VEGETATION TYPE	HEAVY SOIL (mean)	LIGHT SOIL (mean)	HEAVY SOIL (Sd)	LIGHT SOIL (Sd)
pasture, partially compacted	25.0	4.2	32.7	3.1
Long grass with some shrubs and trees	49.2	806.9	48.9	467.0
Heavy canopy with a mix of shrubs and large foliage trees	203.9	261.9	55.1	159.3

Table 13. K-Sat (10-20cm) statistics analysis Results - By the author – 2018.

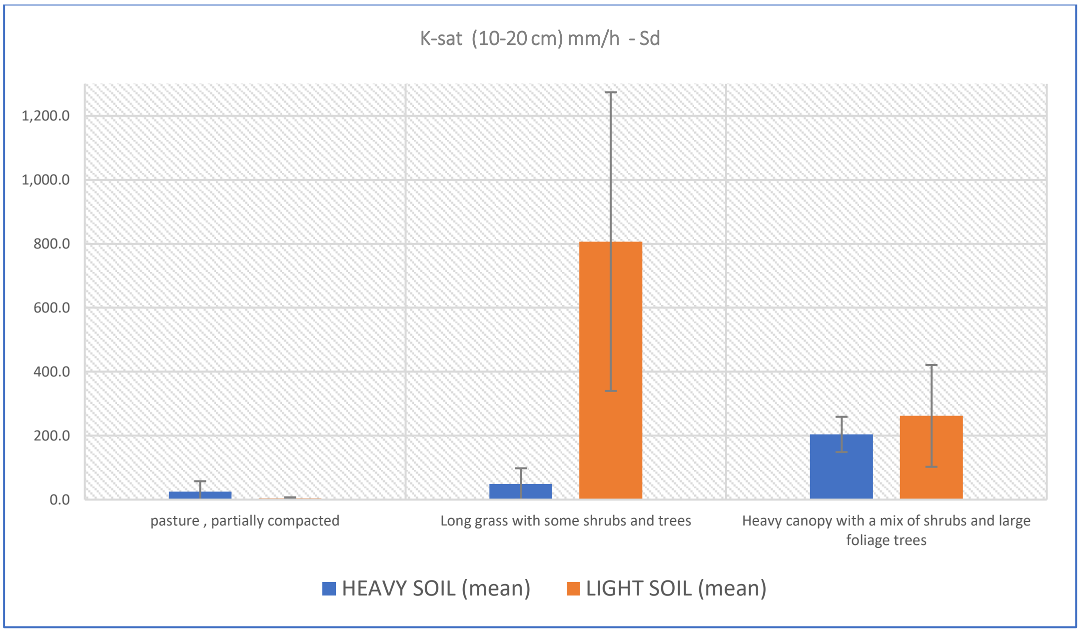


Figure 10. K-Sat (0-10cm) statistics analysis representations - By the author – 2018.

From this statistical analysis and in order to support the study's objectives, the light soil under long grass with some shrubs and trees have the best infiltration conditions (807 mm/h), followed by light soil/heavy soil under heavy canopy with a mix of shrubs and large foliage trees (262 – 204 mm/h). Consequently, no effect of soil on Ksat on compacted and heavy canopy veg, but huge effect on grass.

These results are consistent with the study from Fatichi et al., (2014), where was mentioned that grassland are also important in flood mitigation management. Due to the fact that long grasses are typically subjected to management practices that can change the biophysical structure of the canopy through defoliation and can alter soil hydraulic properties, including Ksat.

The long grasses with some shrubs and trees under light soil conditions reduce the water flow velocity and depth of water flow, more common know as hydraulic roughness change, this is due to the vegetation density Rak et al., (2016). In contrast, the pasture partially compacted resistance of waterflow velocity is higher and wouldn't be consider ideal in flood mitigation management. Next charter will simulate and ideal scenario using our findings from this charter.

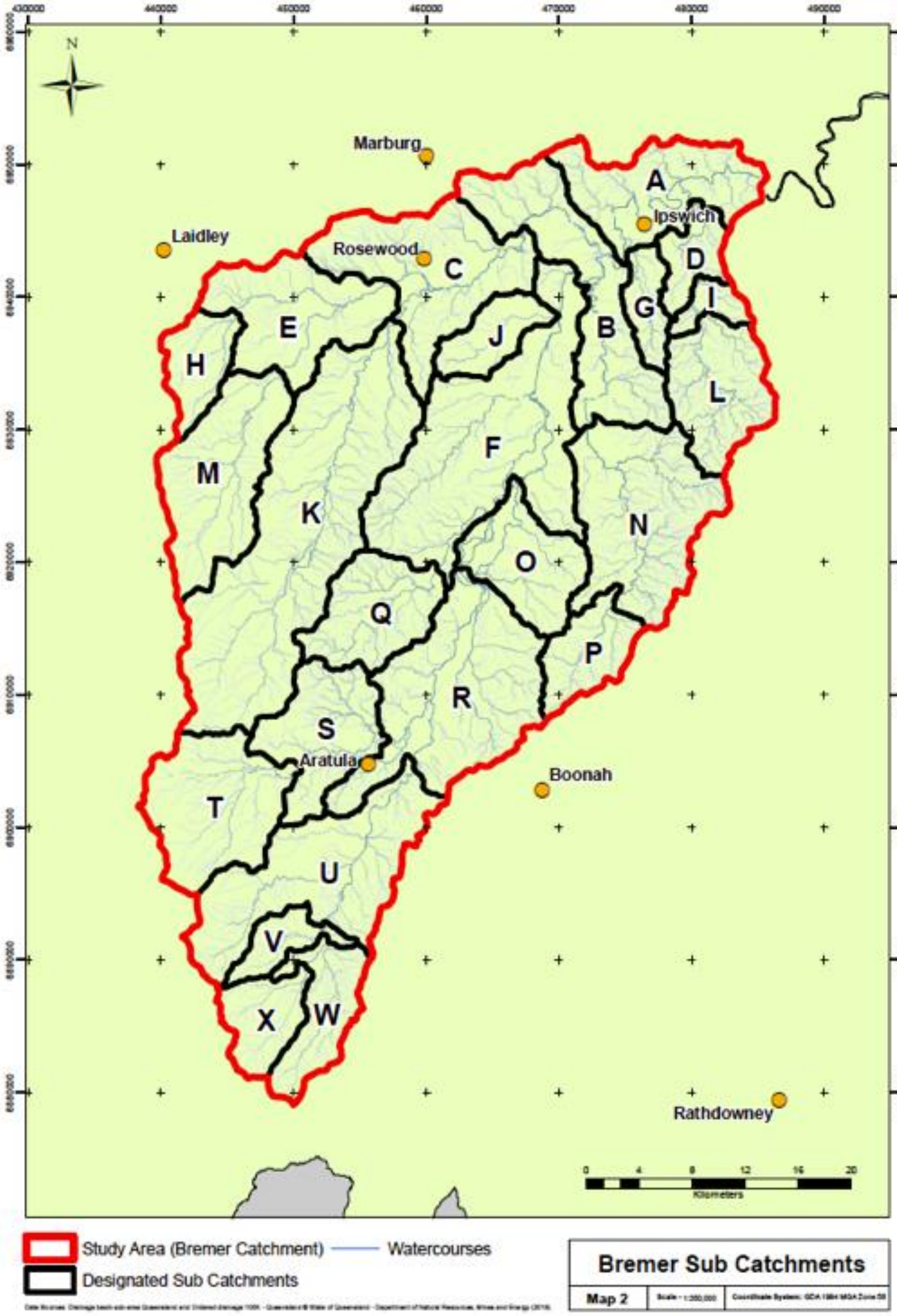
3.3 GIS Study Results

3.3.1 Area Location Description

Map 1. Study area location - By the Author and Studiospatial – source: Queensland Government data, (2018)

3.3.2 Flood Direction Analysis

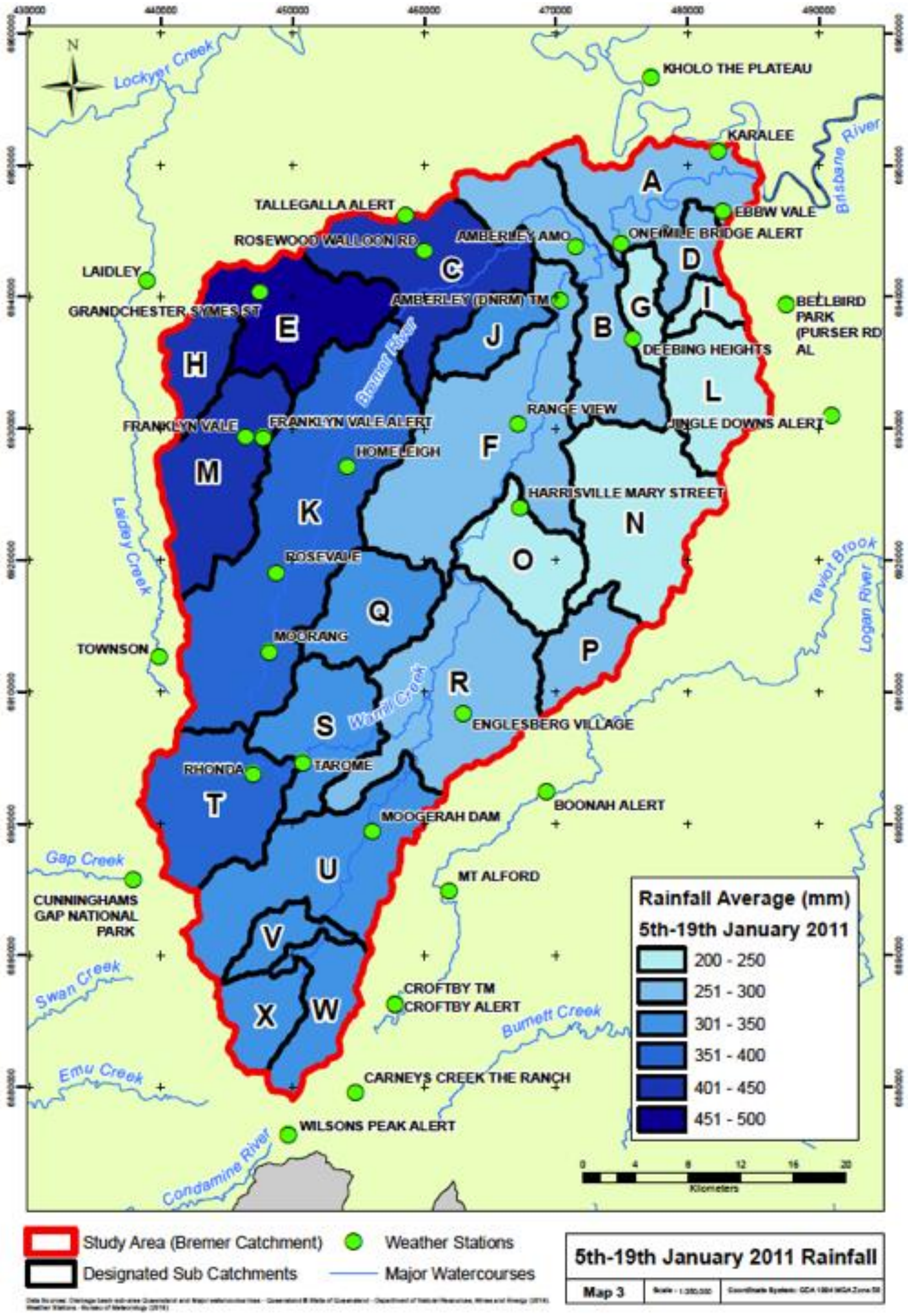
Plotted by the Use of SRTM elevation model to create slopes across the Bremer catchment. Flow direction analysis undertaken to create 24 sub-catchments based on an area greater than 1,000 hectares in order to get a sample size suitable for the whole catchment; Queensland Government data, (2018)



Map 2. Bremer sub-catchments analysis - By the Author and Studiospatial – source: Queensland Government data, (2018)

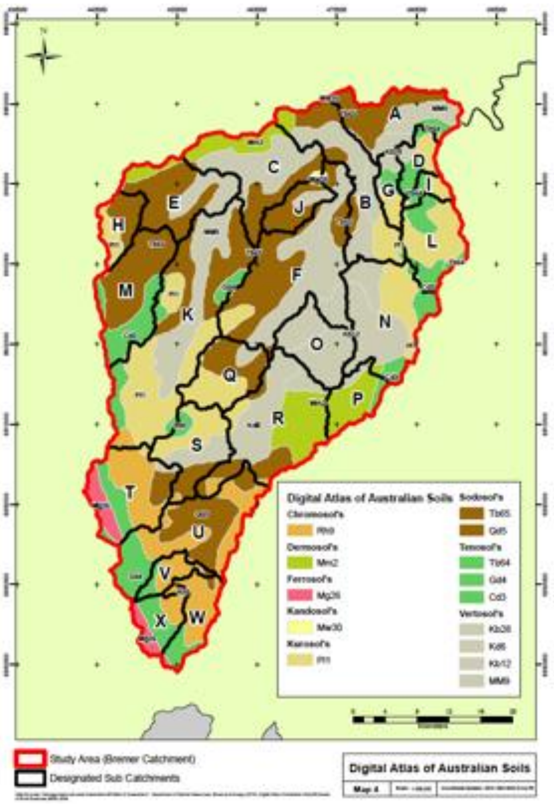
3.3.3 Rainfall Event representation

Plotted with 39 weather stations around the Bremer catchment, and using the rainfall data form 5 January 2011 to 19 January 2011, with data from The Bureau of Meteorology, (2018), as shown in **Appendix II**.



Map 3. Bremer Catchment – rainfall data 5th -19th January 2011; By the Author and Studiospatial, source: The Bureau of Meteorology, (2018), Appendix II.

3.3.4 Soil Type Results



According to McKenzie et al., (2000), the Digital Atlas of Australia for the soil categories in the Bremer catchment are summarised in the below table:

Soil Type	PPF1	Texture	Type
Cd3	Uc2.12	1	S2
Gd4	Um6.21	3	S2
Kb12	Ug5.12	5	S1
Kb28	Ug5.1	5	S1
Kd6	Ug5.1	5	S1
MM9	Ug5.3	4	S1
Mg26	Gn4.11	3	S2
Mm2	Ug5.37	5	S1
Mw30	Gn2.14	1	S2
Pl2	Dr3.41	1	S2
Qd5	Dr2.42	2	S2
Rh9	Db3.12	1	S2
Tb64	Dy3.41	1	S2
Tb65	Dy3.41	1	S2

Map 4. Bremer Catchment soil type, By the author and Studiospatial, source: Bureau of Rural Sciences, (2009).

In order to classify the soil into the hypothesis categories the texture group numbers 1 to 6 from McKenzie et al., (2000) , were divided into the two subgroups (S1 – S2), as shown in the figure 7

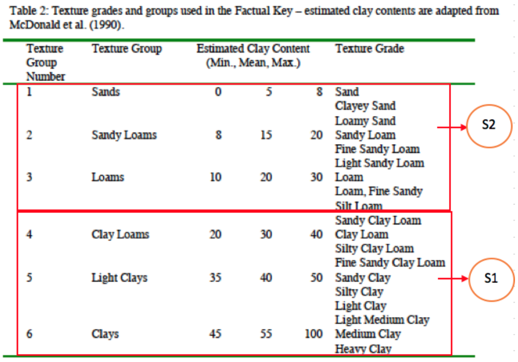
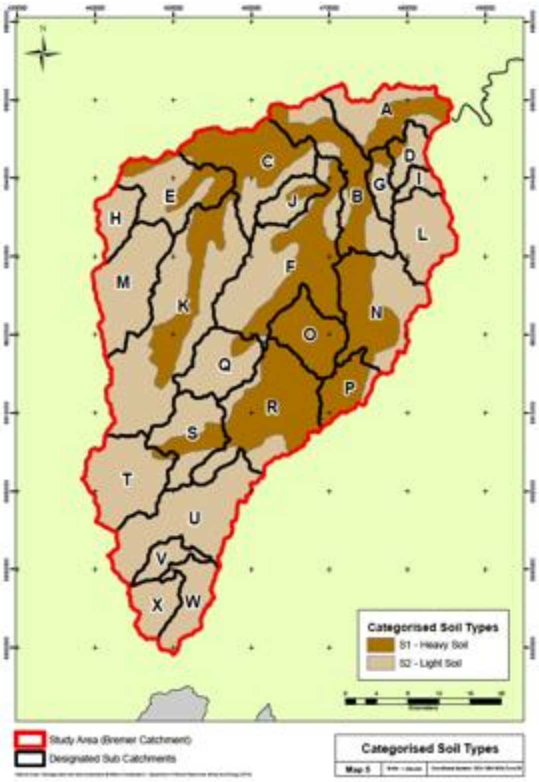


Table 2: Texture grades and groups used in the Factual Key – estimated clay contents are adapted from McDonald et al. (1990).

Texture Group Number	Texture Group	Estimated Clay Content (Min., Mean, Max.)			Texture Grade
1	Sands	0	5	8	Sand Clayey Sand Loamy Sand
2	Sandy Loams	8	15	20	Sandy Loam Fine Sandy Loam Light Sandy Loam
3	Loams	10	20	30	Loam Loam, Fine Sandy Silt Loam
4	Clay Loams	20	30	40	Sandy Clay Loam Clay Loam Silty Clay Loam Fine Sandy Clay Loam
5	Light Clays	35	40	50	Sandy Clay Silty Clay Light Clay Light Medium Clay
6	Clays	45	55	100	Medium Clay Heavy Clay

Figure 11. texture Grades by McKenzie et al., (2000)

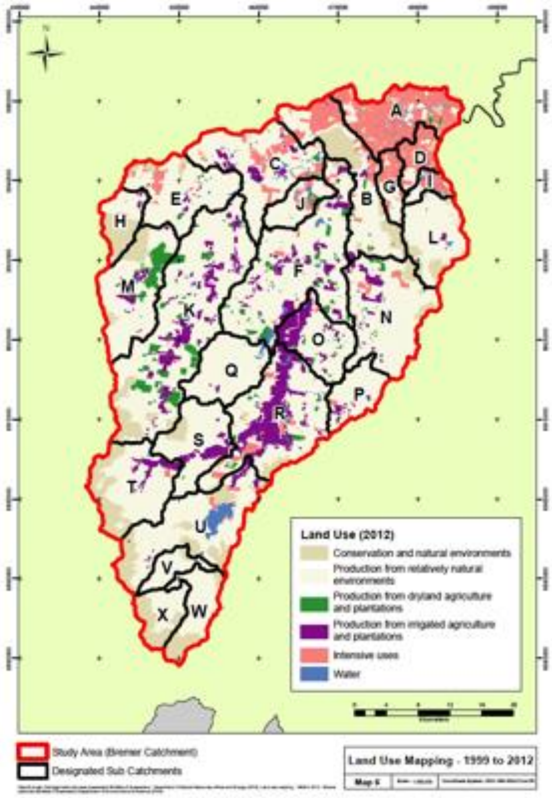


Map 5. Bremer Catchment soil type, By the author and Studiospatial, source: Bureau of Rural Sciences, (2009).

3.3.5 Vegetation Data Results

The vegetation data was gathered from Land use mapping - 1999 to 2012 - Bremer catchment, state of Queensland dataset, where this is divided into 6 major categories and 191 subcategories, as shown in the below table:

Number	Land Use Categories (2012)
1	Conservation and natural environments
2	Production from relatively natural environments
3	Production from dryland agriculture and plantations
4	Production from irrigated agriculture and plantations
5	Intensive uses
6	Water

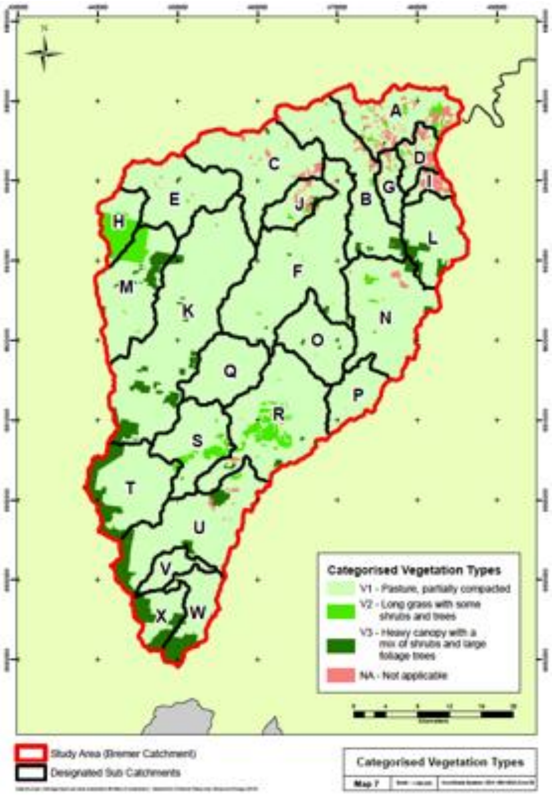


Map 6. Land use Mapping 1999-2012 By the author and Studiospatial; Source: State of Queensland, (2009).

In order to classify the vegetation into the hypothesis values the 191 subcategories were thoroughly reviewed and categorised, into the four subgroups – vegetation types (V1, V2, V3 and NA), as shown in vegetation type table

Table 14 Vegetation Type by the author

	Vegetations Type
V1	pasture, partially compacted
V2	Long grass with some shrubs and trees
V3	Heavy canopy with a mix of shrubs and large foliage trees
NA	Not applicable



Map 7. Categorize vegetation types - By the author and Studiospatial; Source State of Queensland, (2009).

3.3.6 Infiltration Bremer catchment results

Using the K-Sat (10-20 cm) gathered from the statistical analysis shown in the below table:

VEGETATION TYPE	HEAVY SOIL, mm/h (mean)	LIGHT SOIL, mm/h (mean)
pasture, partially compacted	25.0	4.2
Long grass with some shrubs and trees	49.2	806.9
Heavy canopy with a mix of shrubs and large foliage trees	203.9	261.9

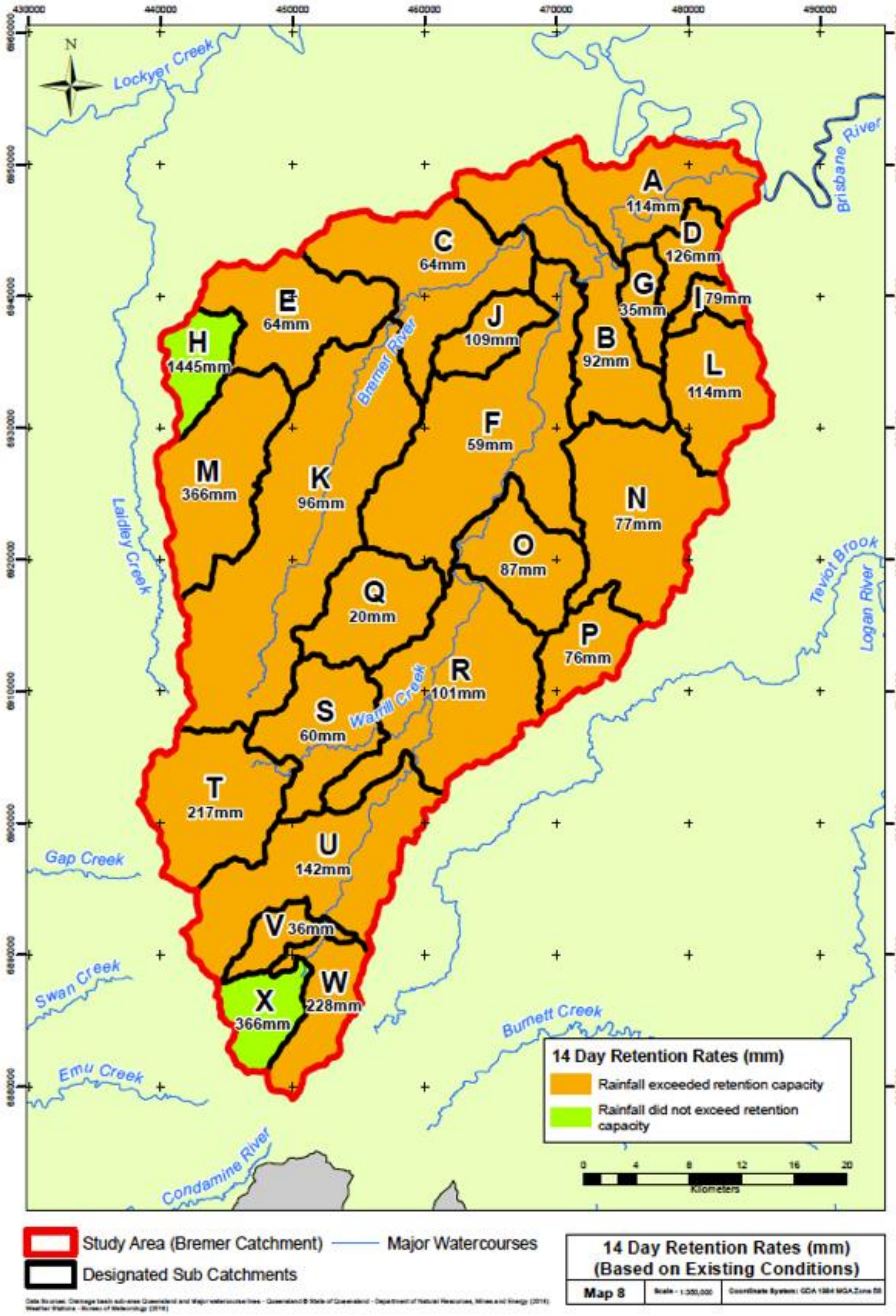
Table 15. Bremer Catchment Infiltration rates results- By the author - 2018.

These values were applied to the initial condition of the catchment regarding vegetation (V1, V2, V3) and soil type (S1, S2) and correlated the rain event that generates the flooding in January 2011. As a result, the retention of water on the soil was exceeded in the majority of sub-catchments by the rainfall during the 14-day period, which has contributed to flooding downstream of the catchment. As shown in Table 16 and Map 8.

Sub-areas of the catchment	Total Area (m²)	Total Retention (l/m2*h)	mm/hr	14 Day Existing Soil/Veg Combination Retention Rates (mm)	14 Day Average Rainfall Total (mm)
A	85,697,561	2,900,788,014	0.34	114	274
B	113,093,407	3,083,021,275	0.27	92	291
C	117,140,661	2,227,644,414	0.19	64	408
D	27,657,332	1,037,822,038	0.38	126	254
E	90,665,088	1,732,615,319	0.19	64	459
F	196,025,095	3,438,188,385	0.18	59	269
G	24,224,103	253,835,355	0.10	35	250
H	34,682,528	14,912,397,928	4.30	1,445	412
I	14,720,426	348,061,261	0.24	79	243
J	32,392,073	1,048,169,609	0.32	109	317
K	256,323,675	7,321,433,408	0.29	96	367
L	69,069,211	2,345,971,673	0.34	114	236
M	100,837,552	10,982,562,603	1.09	366	401
N	126,067,791	2,874,679,729	0.23	77	233
O	63,241,945	1,644,718,917	0.26	87	229
P	41,424,866	937,221,183	0.23	76	255
Q	66,136,267	398,156,165	0.06	20	322
R	152,592,486	4,596,074,913	0.30	101	275
S	72,752,224	1,290,170,633	0.18	60	325
T	96,153,021	6,220,781,034	0.65	217	352
U	131,603,875	5,566,859,823	0.42	142	313
V	23,555,318	255,597,669	0.11	36	318
W	47,741,323	3,243,562,031	0.68	228	308
X	38,150,611	4,153,234,769	1.09	366	320
Bremer Catchment	**2,021,948,439**	**82,813,568,148**	41	137.62	

Table 16. Bremer Sub-catchment Infiltration rates at initial conditions vs rainfall results - By the author - 2018.

From this data analysis we can also estimate the approximate volume of water that contributed from the Bremer catchment into the of Brisbane 2011 flooding during the 14 days of the study. In total 135 mm in average that under a catchment area of 202195ha is equal to 274.479 ML in 14 days.



Map 8. Bremer catchment - 14 day retention rates under initial vegetation conditions - By the author and Studiospatial; Source State of Queensland, (2009)

To support the objectives of this document a scenario was generated where the soil is constant, and the catchment is a combination of grass with some shrubs and trees and Heavy canopy with a mix of shrubs and large foliage trees. The values from the statistical study within the table below were used:

VEGETATION TYPE	HEAVY SOIL, mm/h (mean)	LIGHT SOIL, mm/h (mean)
Long grass with some shrubs and trees	----	806.9
Heavy canopy with a mix of shrubs and large foliage trees	203.9	---

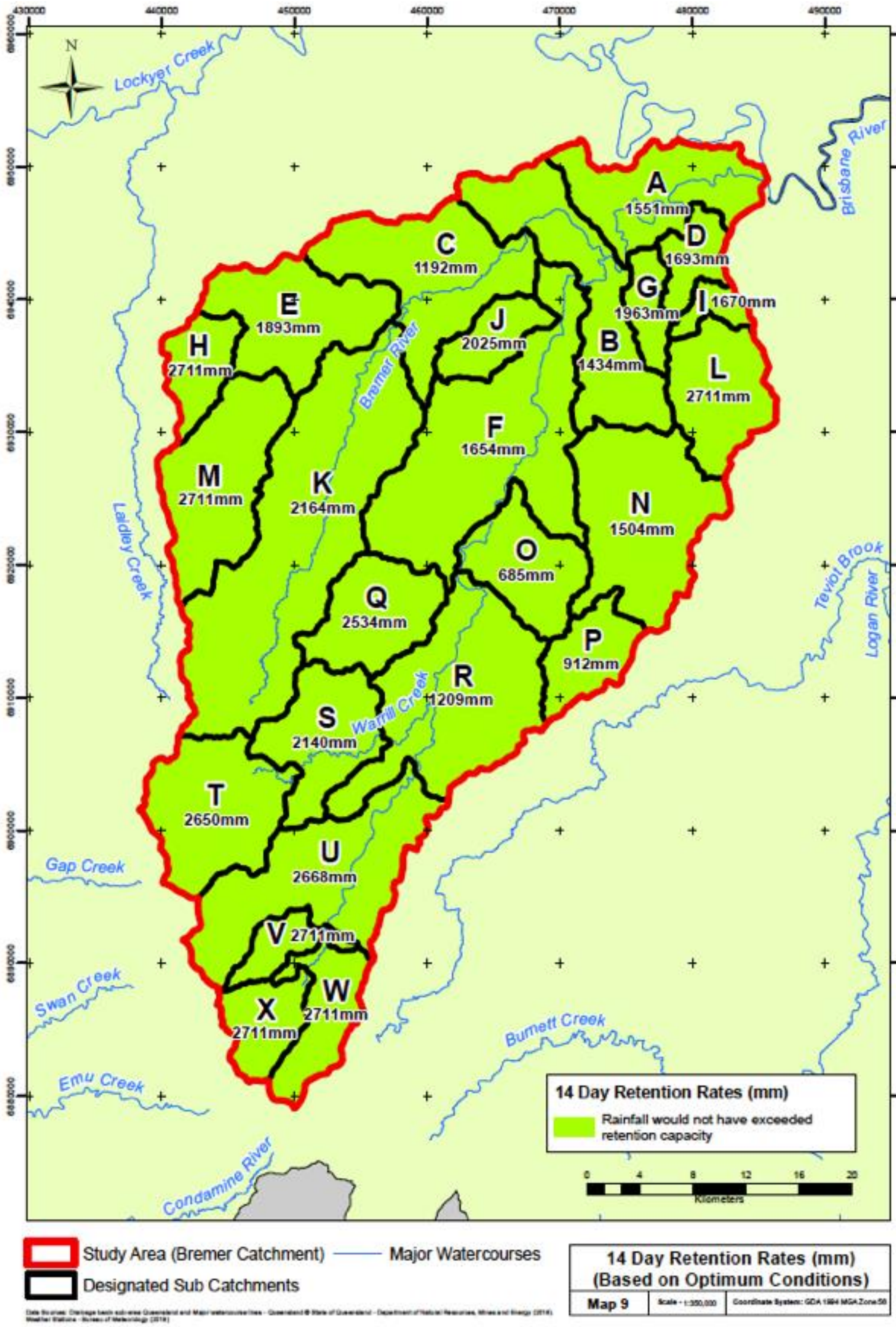
Table 17. Bremer Catchment Infiltration rates Ideal results- By the author - 2018.

These values were applied to the initial soil conditions of the catchment (S1, S2) and correlated to the rain event that generated the flooding in January 2011. As a result, the retention of water on the soil would not exceed the retention capacity in any of the catchments by the rainfall during the 14-day period, As shown in Table 17 and Map 9.

Catchment	Total Area (m^2)	Total Retention (l/m2*h)	mm/hr	14 Day Optimum Soil/Veg Combination Retention Rates (mm)	14 Day Average Rainfall Total (mm)
A	85,697,561	36,666,247,000	4.6	1551.3	274
B	113,093,407	45,179,109,759	4.3	1433.9	291
C	117,140,661	39,337,672,327	3.5	1192.2	408
D	27,657,332	12,898,256,553	5.0	1693.0	254
E	90,665,088	49,348,967,784	5.6	1893.1	459
F	196,025,095	93,043,112,110	4.9	1653.8	269
G	24,224,103	13,897,873,178	5.8	1962.9	250
H	34,682,528	13,072,933,914	8.1	2711.2	412
I	14,720,426	6,968,769,130	5.0	1670.1	243
J	32,392,073	18,470,366,974	6.0	2024.6	317
K	256,323,675	157,731,262,872	6.4	2163.6	367
L	69,069,211	53,385,974,954	8.1	2711.2	236
M	100,837,552	70,383,258,433	8.1	2711.2	401
N	126,067,791	53,548,305,032	4.5	1503.8	233
O	63,241,945	11,251,966,736	2.0	685.2	229
P	41,424,866	10,312,352,829	2.7	912.5	255
Q	66,136,267	49,477,223,749	7.5	2533.9	322
R	152,592,486	50,302,537,022	3.6	1208.8	275
S	72,752,224	45,041,381,979	6.4	2139.8	325
T	96,153,021	69,613,596,292	7.9	2650.0	352
U	131,603,875	98,949,904,666	7.9	2668.4	313
V	23,555,318	18,751,188,257	8.1	2711.2	318
W	47,741,323	35,278,911,230	8.1	2711.2	308
X	38,150,611	26,630,493,512	8.1	2711.2	320
	2,021,948,439	1,079,541,666,293			

Table 18. Bremer Sub-catchment Infiltration rates under ideal vegetation condition vs rainfall results- By the author.

In this "ideal scenario" the rain from 2011, which caused the second biggest flooding event in the Brisbane city did not exceed the total retention capacity of the Bremer catchment. In contrast, the water table would be recharged as part of the natural process of infiltration.



Map 9. Bremer catchment - 14 day retention rates under IDEAL vegetation conditions - By the author and Studiospatial; Source State of Queensland, (2009)

4. Discussions

The main problem we were trying to deal during the execution of this multidisciplinary project, is that actually water professionals are unable to accurately quantify the effects of vegetation and land management on flood modelling and if indeed increase in the vegetation of the upper catchments could be a legitimate method of flood mitigation. This links comprehensively with IWM approach as it moves consideration away from the discrete ambit of a development site in terms of hydrological thinking and towards a whole of catchment function approach. To understand this better we were able through this study to determinate and quantified how vegetation and soil types impact rainfall losses in general, in this case specifically infiltration rates (Ksat 10-20 cm).

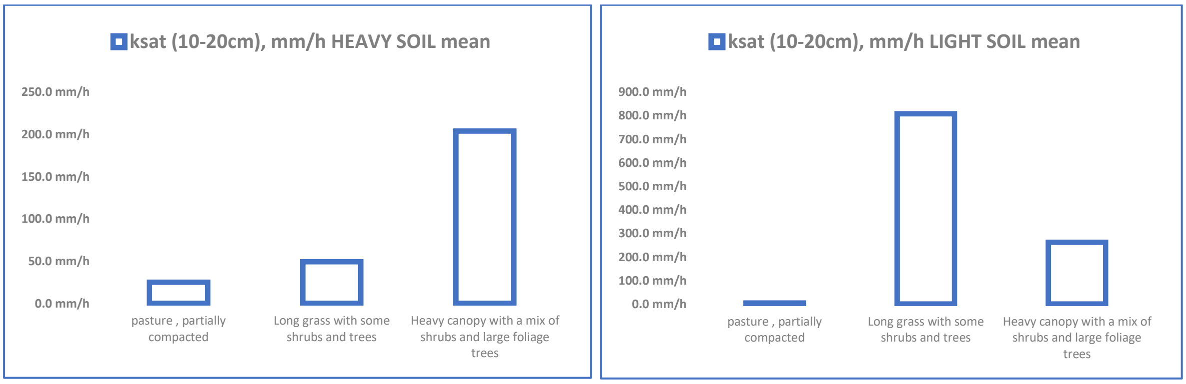


Figure 12. Quantitative analysis of vegetation and soil type for flood modelling in mitigation - By the Author – 2018 .

4.1 Vegetation intercept rainfall and hence affect flooding downstream

Gageler et al., (2014), contents that reforestation of riparian areas along the catchments can be motivated by a variety of purposes including growing landscape connectivity for wildlife movements and biogeochemical functions such as trapping nutrients, sediment, pesticides, bank stabilisation, improved water quality and for recreational proposes. Therefore, our study was focused in revegetation as part of the flood mitigation programs. We were able to demonstrate that the reintroduction of vegetation with a variety of Long grass with some shrubs and trees in the long term can reduce runoff, improving the soil infiltration (K-sat) properties in levels between 49 – 806 mm/h approximately for heavy and light soils. In contrast, we found that the use of more homogenic vegetation such us, pasture, partially compacted can reduce the soil (K-sat) properties in levels between 5 – 25 mm/h approximately, as shown in Figure 12. What is more, we found that adequate vegetation in reforestation processes, it can include reducing stream power increasing water quality improvement, groundwater recharge and ecology through habitat etc. Which links well to the Integrated Water Management concept and the Integrate Water Management objectives.

4.2 Soil type and its distribution in the catchment affect runoff.

The physical soil properties including Ksat (mm/h) changed considerably under the three study vegetation's conditions, as shown in Figure 12. The observed trend for Ksat (mm/h) under light soil presented a more abroad range between 4 – 807 mm/h, whereas the pattern for Ksat (mm/h) under heavy soil filed a smaller rang with considerable low values in the same scale which oscillate between 25 – 204 mm/hr. Thus, these values are consistent with previous soil studies. In addition and according to Rose et al., (2014), the effect of the vegetation in each soil type can dramatically change the porosity; where more homogeneous vegetation and pastures can reduce the porosity in the soil due to compaction issues, whereas soil under more diverse vegetation can find more soil pores, due to the effect of roots and organic matter Beven and Germann, (1982).

4.3 The effect of rain and its changes in the soil water infiltration under different canopy vegetation.

As part of the climate change challenges the flood risk approach was introduced formally in the 'Policy Document on Water Safety', which was published in 2009 Jong and Brink, (2017). This study's findings were used to model the second largest flood since the twentieth century in the Brisbane in January 2011. The mathematical modelling was implemented in a sub-catchment of the Brisbane river, the Bremer catchment. Where was compared the actual soil and vegetation conditions against to an ideal scenario where the vegetation is replaced by vegetation with a high infiltration rate, as shown in Figure 13. As a result, in the actual condition model the rainfall exceeded the retention capacity of the Bremer catchment, whereas, in the ideal scenario rainfall did not exceeded the Bremer's retention capacity.

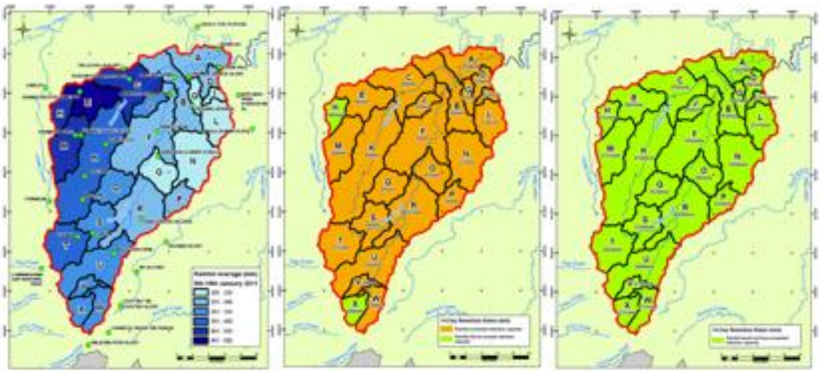


Figure 13. GIS study summary - By the Author – 2018.

It is noteworthy that this sort of data modelling can help water practitioners to make better decisions, which includes: prioritisations locations for landscape management, as well as, relationships between broad-scale revegetation. And in our case contribute to the Brisbane River Flood Study.

4.4 Recommendations

"The uncertainty of climate change should not be an obstacle to action" Katherine, (2014), Through this study based on the challenges of climate change and landscape modifications as a result of development, we would recommend to water decision makers to consider more holistic approaches, such as the IWM, to confront these challenges; as well as, reviewing the natural processes of bionetworks, and how they can provide us with patterns and clues for better ecosystems manage and flood mitigation solutions.

This study and report has provided the high level understanding and potential for flood reductions as a result of increasing vegetation cover in catchments. However in order to provide further evidence and practical application of this, the following recommendations should be understaken

- More detailed soil profiles and a wider sample across the catchment will provide more reliable results
- Deeper soil profiles should be undertaken
- More samples undertaken in the one area to confirm any variability around areas with heavy tree cover etc.
- Investigation of the impact of root zones and how this affects infiltration

With this additional data, a flood model should be developed to accurately model changes to hydrology and also the potential impact of increased roughness through the hydraulic models to affect velocity and hence downstream flood levels. Additionally, physical modelling of these types of processes may also aid in understanding

4.5 Limitations

During this study of the effect of different ground cover vegetation on water infiltration in different the soil types; we found various limitations that can be grouped as: conceptual and technical limitations: First, the conceptual limitations which included: lack of legislation support, lack of integrate approach across professions and a poor literature review from the holistic IWM approach. Second, technical limitations such us not understanding soil storage in lower profiles or groundwater, modelling complexity and parameters and the variability in the data results.

During this study of the effect of different ground cover vegetation on water infiltration in different the soil types there were a number of limitations of the study which should be noted for future reference. These included:

- Only testing the data from the first 20cm of soil profile and assuming equivalent infiltration in the whole soil profile
- Not accounting for groundwater
- ?>??
- ???
- Gunnar might be able to help you with more limitations of the study

5. Conclusion

This research has attempted to study the effect of different ground cover vegetation on water infiltration in different the soil types, in order to quantify the effects of vegetation in land management for flood modelling purposes. Also, to provide water decision makers with values of infiltration (Ksat) to determinate, which types of vegetations will benefice the flood mitigation along catchments. Our methodology demonstrates to some degree that the already established vegetation with a variety of Long grass with some shrubs and trees can reduce runoff increasing soil water retention capacity at much gather rate than already established consistent vegetation of pastures. These finding has contributed to shifting the traditional hydrological catchment approach to a more holistic catchment function approach, based in the principals of IWM perspective or context and its social, economic, political technological, legal and environmental effects*.

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* 7196 words – Publishable Manuscript

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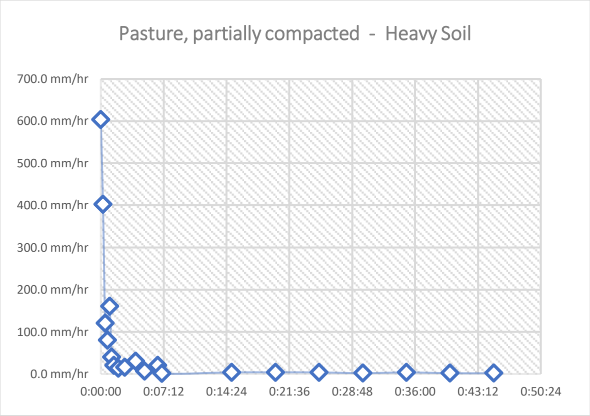
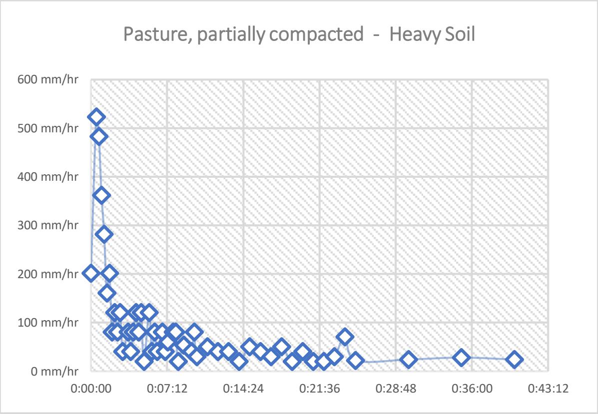
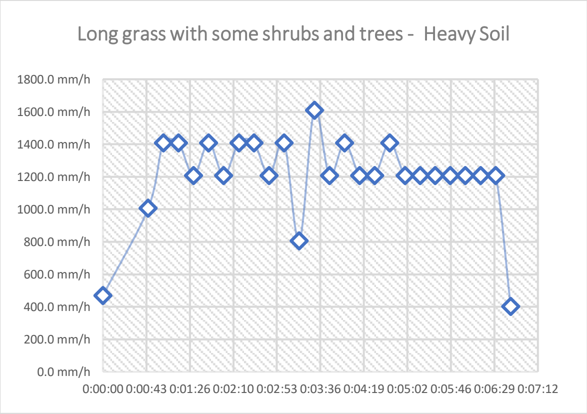
7. Appendix

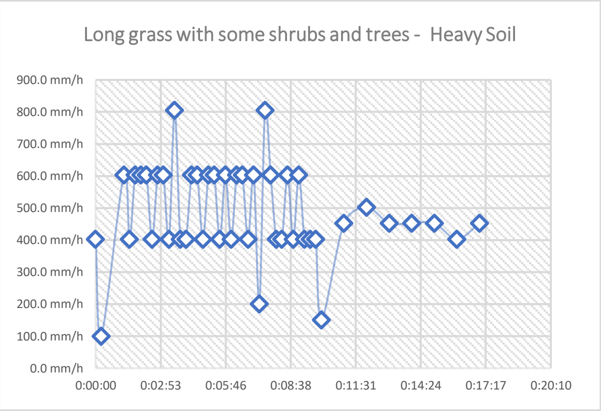
APPENDIX I. Soil Analysis

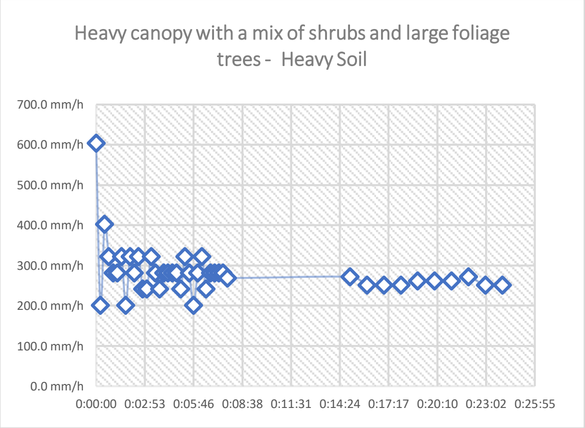
a) Disc permeameter charts

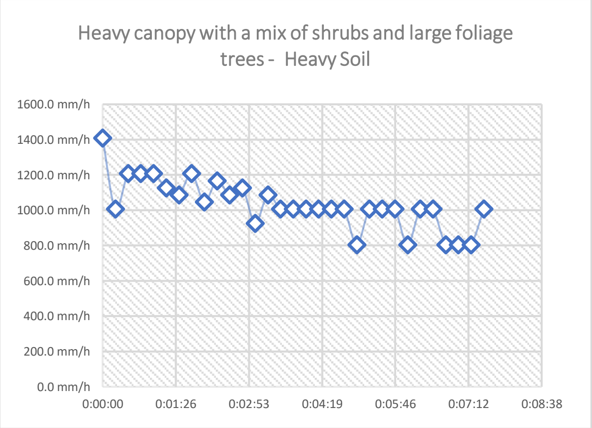

Pasture, partially compacted - Heavy Soil

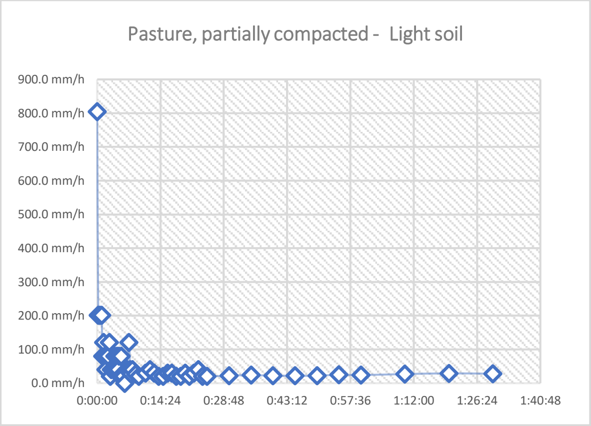

Pasture, partially compacted - Heavy Soil

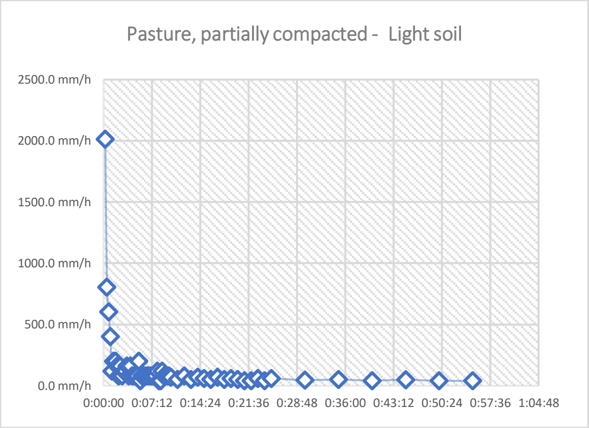

Long grass with some shrubs and trees - Heavy Soil

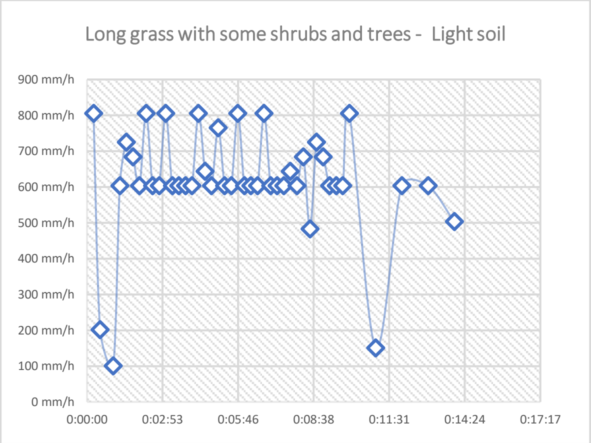

Long grass with some shrubs and trees - Heavy Soil

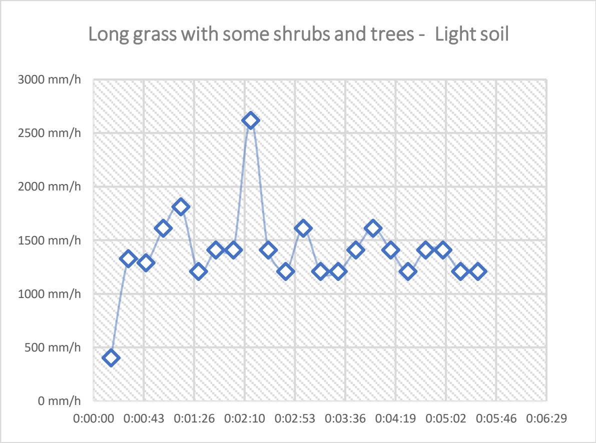

Heavy canopy with a mix of shrubs and large foliage trees - Heavy Soil

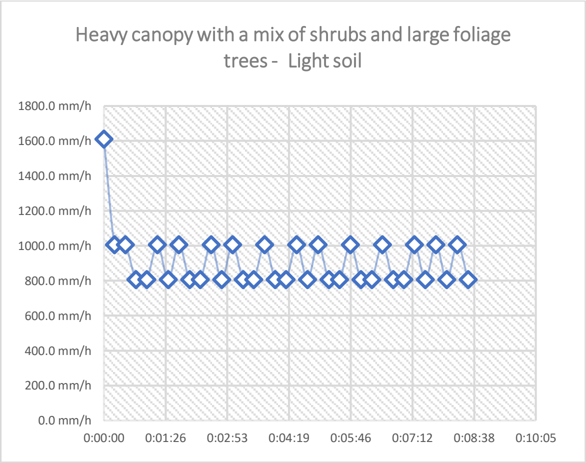

Heavy canopy with a mix of shrubs and large foliage trees - Heavy Soil

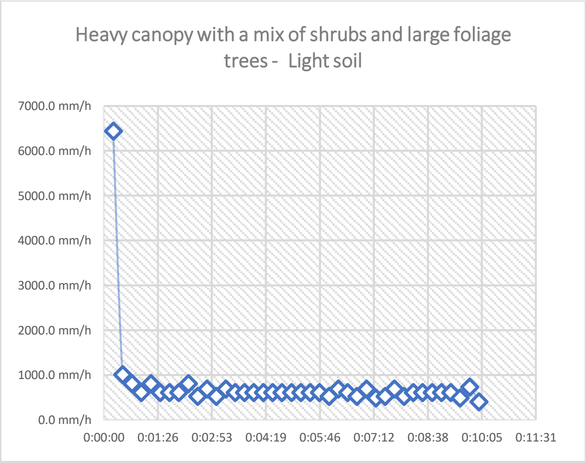

Pasture, partially compacted - Light soil
900.0 mm/h
800.0 mm/h
700.0 mm/h
600.0 mm/h
500.0 mm/h
400.0 mm/h
300.0 mm/h
200.0 mm/h
100.0 mm/h
0.0 mm/h
0:00:00
0:14:24
0:28:48
0:43:12
0:57:36
1:12:00
1:26:24
1:40:48


Pasture, partially compacted - Light soil
2500.0 mm/h
2000.0 mm/h
1500.0 mm/h
1000.0 mm/h
500.0 mm/h
0.0 mm/h
0:00:00
0:07:12
0:14:24
0:21:36
0:28:48
0:36:00
0:43:12
0:50:24
0:57:36
1:04:48


Long grass with some shrubs and trees - Light soil
900 mm/h
800 mm/h
700 mm/h
600 mm/h
500 mm/h
400 mm/h
300 mm/h
200 mm/h
100 mm/h
0 mm/h
0:00:00
0:02:53
0:05:46
0:08:38
0:11:31
0:14:24
0:17:17


Long grass with some shrubs and trees - Light soil
3000 mm/h
2500 mm/h
2000 mm/h
1500 mm/h
1000 mm/h
500 mm/h
0 mm/h
0:00:00
0:00:43
0:01:26
0:02:10
0:02:53
0:03:36
0:04:19
0:05:02
0:05:46
0:06:29


Heavy canopy with a mix of shrubs and large foliage trees - Light soil
1800.0 mm/h
1600.0 mm/h
1400.0 mm/h
1200.0 mm/h
1000.0 mm/h
800.0 mm/h
600.0 mm/h
400.0 mm/h
200.0 mm/h
0.0 mm/h
0:00:00
0:01:26
0:02:53
0:04:19
0:05:46
0:07:12
0:08:38
0:10:05


Heavy canopy with a mix of shrubs and large foliage trees - Light soil
7000.0 mm/h
6000.0 mm/h
5000.0 mm/h
4000.0 mm/h
3000.0 mm/h
2000.0 mm/h
1000.0 mm/h
0.0 mm/h
0:00:00
0:01:26
0:02:53
0:04:19
0:05:46
0:07:12
0:08:38
0:10:05
0:11:31

APPENDIX II. GIS Study

a) Rainfall Information

1. Bremen catchment Rainfall data from 5-1-11 to 19-1-11, source;

Site	Name	Lat	Long	Rainfall (mm/h)
40004	AMBERLEY AMO	-27.6297	152.7111	306.0
40091	GRANDCHESTER SYMES ST	-27.6597	152.4675	546.0
40094	HARRISVILLE MARY STREET	-27.8086	152.6675	187.2
40104	ENGLESBERG VILLAGE	-27.949	152.6235	254.5
40135	MOOGERAH DAM	-28.0302	152.5529	295.6
40139	MT ALFORD	-28.0708	152.6119	239.2
40142	MT CROSBY	-27.5364	152.7992	320.2
40183	ROSEVALE	-27.8522	152.4797	329.2
40184	ROSEWOOD WALLOON RD	-27.6322	152.5944	406.0
40198	TAROME	-27.9826	152.4996	317.6
40317	RANGE VIEW	-27.7508	152.6664	215.2
40374	FRANKLYN VALE	-27.7594	152.4564	420.5
40400	MOORANG	-27.9065	152.4736	352.0
40447	RHONDA	-27.9902	152.461	336.2
40490	CARNEYS CREEK THE RANCH	-28.2086	152.5389	329.0
40493	HOMELEIGH	-27.78	152.5346	336.5
40503	TALLEGALLA ALERT	-27.6075	152.58	571.0
40675	TOWNSON	-27.9097	152.3886	524.8
40716	LAIDLEY	-27.6514	152.3808	273.0
40786	JINGLE DOWNS ALERT	-27.7456	152.9081	179.0
40792	RIPLEY ALERT	-27.7106	152.8072	320.2
40793	LYONS ALERT	-27.7633	152.8367	320.2
40816	AMBERLEY (DNRM) TM	-27.6658	152.6989	306.0
40835	MULGOWIE TM	-27.7317	152.3633	N/A
40836	ONE MILE BRIDGE ALERT	-27.6272	152.7461	230.0
40841	CROFTBY TM	-28.1481	152.57	277.0
40867	KALBAR TM	-27.9406	152.6236	320.2
40876	WILSONS PEAK ALERT	-28.2372	152.4867	327.0
40912	FRANKLYN VALE ALERT	-27.7597	152.47	420.5
40928	KARALEE	-27.5639	152.8208	295.1
40947	CROFTBY ALERT	-28.1481	152.57	277.0
40949	BOONAH ALERT	-28.0033	152.6875	265.0
40962	EBBW VALE	-27.6053	152.8244	245.1
40985	BELLBIRD PARK (PURSER RD) AL	-27.6692	152.8731	211.0
40990	KHOLO THE PLATEAU	-27.5131	152.7692	328.6
40992	DEEBING HEIGHTS	-27.6931	152.7547	240.0

APPENDIX III. Statistical Analysis Results

A. Dispersion scatter charts CODE - RStudio

```
plot(`Infiltration Rate, mm/h`, data = graficas, xlab = "Infiltration Rate, mm/h", ylab = "Type soil and Vegetation Type", main="Gráfico 1")
plot(`ksat (0-10cm), mm/h`, data = graficas, xlab = "ksat (0-10cm), mm/h", ylab = "Type soil and Vegetation Type", main="Gráfico 2")
plot(`ksat (10-20cm), mm/h`, data = graficas, xlab = "ksat (10-20cm), mm/h", ylab = "Type soil and Vegetation Type", main="Gráfico 3")
plot(`Bd (0-10cm), g/cm3`, data = graficas, xlab = "Bd (0-10cm), g/cm3", ylab = "Type soil and Vegetation Type", main="Gráfico 4")
plot(`Bd (10-20cm), g/cm3`, data = graficas, xlab = "Bd (10-20cm), g/cm3", ylab = "Type soil and Vegetation Type", main="Gráfico 5")
plot(`FC (0-10), g/g`, data = graficas, xlab = "FC (0-10), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 6")
plot(`FC (10-20), g/g`, data = graficas, xlab = "FC (10-20), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 7")
plot(`PWP (0-10 cm), g/g`, data = graficas, xlab = "PWP (0-10 cm), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 8")
plot(`PWP (10-20 cm), g/g`, data = graficas, xlab = "PWP (10-20 cm), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 9")
plot(`PAW (0-10cm), g/g`, data = graficas, xlab = "PAW (0-10cm), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 10")
plot(`PAW (10-20cm), g/g`, data = graficas, xlab = "PAW (10-20cm), g/g", ylab = "Type soil and Vegetation Type", main="Gráfico 11")
plot(`PoreVolume 0-10cm, %`, data = graficas, xlab = "PoreVolume 0-10cm, %", ylab = "Type soil and Vegetation Type", main="Gráfico 12")
plot(`PoreVolume 10-20cm, %`, data = graficas, xlab = "PoreVolume 10-20cm, %", ylab = "Type soil and Vegetation Type", main="Gráfico 13")
plot(`AirFilled PV 0-10cm, %`, data = graficas, xlab = "AirFilled PV 0-10cm, %", ylab = "Type soil and Vegetation Type", main="Gráfico 14")
plot(`FC (0-10),%`, data = graficas, xlab = "FC (0-10),%", ylab = "Type soil and Vegetation Type", main="Gráfico 15")
plot(`AirFilled PV 10-20cm, %`, data = graficas, xlab = "AirFilled PV 10-20cm, %", ylab = "Type soil and Vegetation Type", main="Gráfico 16")
plot(`FC (10-20),%`, data = graficas, xlab = "FC (10-20),%", ylab = "Type soil and Vegetation Type", main="Gráfico 17")
plot(`PWP (0-10 cm),%`, data = graficas, xlab = " PWP (0-10 cm),%", ylab = "Type soil and Vegetation Type", main="Gráfico 18")
plot(`PWP (10-20 cm),%`, data = graficas, xlab = "PWP (10-20 cm),%", ylab = "Type soil and Vegetation Type", main="Gráfico 19")
plot(`PAW (0-10cm), %`, data = graficas, xlab = "PAW (0-10cm), %", ylab = "Type soil and Vegetation Type", main="Gráfico 20")
plot(`PAW (10-20cm), %`, data = graficas, xlab = "PAW (10-20cm), %", ylab = "Type soil and Vegetation Type", main="Gráfico 21")
```

B. Tendency and Dispersion - CODE - RStudio

```
> Dataset1 <- readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/heavy soil,pasture.xls",
+   rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> library(abind, pos=16)
> library(e1071, pos=17)
> numSummary(Dataset1[,"Infiltration.Rate..mm.h", drop=FALSE], statistics=c("mean", "sd",
+   "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
 > Dataset2 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/heavy soil, long grass.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> numSummary(Dataset2[,"Infiltration.Rate..mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
      > Dataset3 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/heavy soil, heavy canopy.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> numSummary(Dataset3[,"Infiltration.Rate..mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> Dataset4 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/light soil, pature.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> numSummary(Dataset4[,"Infiltration.Rate..mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> Dataset5 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/light soil, long grass.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> Dataset6 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/light soil, long grass.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> numSummary(Dataset6[,"Infiltration.Rate..mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> Dataset7 <-
+   readXL("C:/Users/KELLY/Desktop/Patricia/semestre 2018-2/australia/light soil, heavy canopy.xls",
+    rownames=FALSE, header=TRUE, na="", sheet="Hoja1", stringsAsFactors=TRUE)
> numSummary(Dataset7[,"Infiltration.Rate..mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset1[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset2[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset3[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset4[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset6[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset7[,"ksat..0.10cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset1[,"ksat..10.20cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset2[,"ksat..10.20cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset3[,"ksat..10.20cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+   .25,.5,.75,1))
> numSummary(Dataset4[,"ksat..10.20cm...mm.h", drop=FALSE],
+   statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
```

```
+  .25,.5,.75,1))
> numSummary(Dataset6[,"ksat..10.20cm...mm.h", drop=FALSE],
+  statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+  .25,.5,.75,1))
> numSummary(Dataset7[,"ksat..10.20cm...mm.h", drop=FALSE],
+  statistics=c("mean", "sd", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
   > numSummary(Dataset1[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset2[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset3[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset4[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset6[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset7[,"Bd..0.10cm...g.cm3", drop=FALSE], statistics=c("mean",
+   "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset1[,"Bd..10.20cm...g.cm3", drop=FALSE],
+  statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+  .25,.5,.75,1))
> numSummary(Dataset2[,"Bd..10.20cm...g.cm3", drop=FALSE],
+  statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+  .25,.5,.75,1))
> numSummary(Dataset3[,"Bd..10.20cm...g.cm3", drop=FALSE],
+  statistics=c("mean", "sd", "se(mean)", "IQR", "quantiles"), quantiles=c(0,
+  .25,.5,.75,1))
> numSummary(Dataset4[,"Bd..10.20cm...g.cm3", drop=FALSE],
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+  .25,.5,.75,1))
> numSummary(Dataset1[,"FC..0.10...", drop=FALSE], statistics=c("mean", "sd",
+  "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset2[,"FC..0.10...", drop=FALSE], statistics=c("mean", "sd",
+  "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
> numSummary(Dataset3[,"FC..0.10...", drop=FALSE], statistics=c("mean", "sd",
+  "se(mean)", "IQR", "quantiles"), quantiles=c(0,.25,.5,.75,1))
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```

C. The Principal Component analysis (PCA)

PC1	PC2	PC3
7.186540e+00	6.218487e+00	2.669540e+00
PC4	PC5	PC6
2.478232e+00	9.419250e-01	8.157980e-01
PC7	PC8	PC9
4.146132e-01	1.639332e-01	1.078461e-01
PC10	PC11	PC12
2.930138e-03	1.554066e-04	7.795962e-32

a) Component principal 1:

In main component 1, the variables are given greater value: Bd (0-10cm), g/cm3, PAW (0-10cm), g/g, AirFilled PV 0-10cm, %, PWP (0-10 cm), g/g, PoreVolume 0-10cm, %, FC (0-10), g/g.

Infiltration Rate, mm/h	ksat (0-10cm), mm/h	ksat (10-20cm), mm/h
-0.02723961	0.179114803	-0.075202733
Bd (0-10cm), g/cm3	Bd (10-20cm), g/cm3	FC (0-10), g/g
0.290739271	0.056886882	-0.37131404
FC (10-20), g/g	PWP (0-10 cm), g/g	PWP (10-20 cm), g/g
-0.009881196	-0.337062893	-0.051379941
PAW (0-10cm), g/g	PAW (10-20cm), g/g	PoreVolume 0-10cm, %
-0.349691608	0.043545282	-0.290739271
PoreVolume 10-20cm, %	AirFilled PV 0-10cm, %	FC (0-10),%
-0.056886882	0.272181056	-0.357420292
AirFilled PV 10-20cm, %	FC (10-20),%	PWP (0-10 cm),%
-0.036832465	0.018428999	-0.32354946
PWP (10-20 cm),%	PAW (0-10cm), %	PAW (10-20cm), %
-0.013913502	-0.309158155	0.060012041

b) Component principal 2:

In main component 2, the variables are given greater value: FC (10-20), g/g, PoreVolume 10-20cm, %, AirFilled PV 10-20cm, %, PWP (10-20 cm),%, Bd (10-20cm), g/cm3, PAW (10-20cm), g/g, FC (10-20),%, PAW (10-20cm), %, PWP (10-20 cm), g/g,ksat (10-20cm), mm/h.

Infiltration Rate, mm/h	ksat (0-10cm), mm/h	ksat (10-20cm), mm/h
0.02804559	0.013181677	0.161780685
Bd (0-10cm), g/cm3	Bd (10-20cm), g/cm3	FC (0-10), g/g
0.063295156	-0.168434267	-0.014698846
FC (10-20), g/g	PWP (0-10 cm), g/g	PWP (10-20 cm), g/g
-0.357785218	0.044868064	-0.350871112
PAW (0-10cm), g/g	PAW (10-20cm), g/g	PoreVolume 0-10cm, %
-0.061527594	-0.280093591	-0.063295156
PoreVolume 10-20cm, %	AirFilled PV 0-10cm, %	FC (0-10),%
0.168434267	-0.008450205	-0.022766257
AirFilled PV 10-20cm, %	FC (10-20),%	PWP (0-10 cm),%
0.377294531	-0.398832096	0.066189494
PWP (10-20 cm),%	PAW (0-10cm), %	PAW (10-20cm), %
-0.375062691	-0.077810551	-0.345558115

C) Component principal 3:

In main component 3, the variables are given greater value: Bd (0-10cm), g/cm3, FC (10-20), g/g, PoreVolume 10-20cm, %, AirFilled PV 10-20cm, %, ksat (10-20cm), mm/h, Bd (10-20cm), g/cm3, AirFilled PV 0-10cm, % , PWP (10-20 cm), g/g, PoreVolume 0-10cm, %.

Infiltration Rate, mm/h	ksat (0-10cm), mm/h	ksat (10-20cm), mm/h
-0.04102795	0.01189177	0.34590089
Bd (0-10cm), g/cm3	Bd (10-20cm), g/cm3	FC (0-10), g/g
-0.15579274	-0.49707558	-0.02892163
FC (10-20), g/g	PWP (0-10 cm), g/g	PWP (10-20 cm), g/g
0.26152900	0.05674367	0.17108754
PAW (0-10cm), g/g	PAW (10-20cm), g/g	PoreVolume 0-10cm, %
-0.09522643	0.30977072	0.15579274
PoreVolume 10-20cm, %	AirFilled PV 0-10cm, %	FC (0-10),%
0.49707558	0.21522027	-0.10203212
AirFilled PV 10-20cm, %	FC (10-20),%	PWP (0-10 cm),%
0.16675145	0.03801485	0.01186852
PWP (10-20 cm),%	PAW (0-10cm), %	PAW (10-20cm), %
-0.03303381	-0.15804619	0.12990001

d) Component principal 4:

In main component 4, the variables are given greater value: Infiltration Rate, mm/h, ksat (0-10cm), mm/h, ksat (10-20cm), mm/h, Bd (10-20cm), g/cm3, PWP (0-10 cm), g/g, PAW (10-20cm), g/g, PoreVolume 0-10cm, %, AirFilled PV 0-10cm, %, PoreVolume 10-20cm, %.

Infiltration Rate, mm/h	ksat (0-10cm), mm/h	ksat (10-20cm), mm/h
0.49561881	0.39929896	0.28365694
Bd (0-10cm), g/cm3	Bd (10-20cm), g/cm3	FC (0-10), g/g
-0.29938233	0.19545362	0.02465873
FC (10-20), g/g	PWP (0-10 cm), g/g	PWP (10-20 cm), g/g
-0.07257264	0.15050438	0.04027220
PAW (0-10cm), g/g	PAW (10-20cm), g/g	PoreVolume 0-10cm, %
-0.08172937	-0.19389457	0.29938233
PoreVolume 10-20cm, %	AirFilled PV 0-10cm, %	FC (0-10),%
-0.19545362	0.30222802	-0.10553877
AirFilled PV 10-20cm, %	FC (10-20),%	PWP (0-10 cm),%
-0.10049967	0.02988495	0.06822703
PWP (10-20 cm),%	PAW (0-10cm), %	PAW (10-20cm), %
0.12135118	-0.20094133	-0.10555698

e) R-Commander Commander (PCA)

```
## Export of Excel data to R-Commander
library(readxl)
datos<- read_excel("C:/Users/Esneider/Desktop/Esneider/semester 2018-2/Australia/variables explicativas.xlsx")
View(datos)
### recognition of variables and renaming
a<-datos$`Infiltration Rate, mm/h`
b<-datos$`ksat (0-10cm), mm/h`
c<-datos$`ksat (10-20cm), mm/h`
d<-datos$`Bd (0-10cm), g/cm3`
e<-datos$`Bd (10-20cm), g/cm3`
f<-datos$`FC (0-10), g/g`
g<-datos$`FC (10-20), g/g`
h<-datos$`PWP (0-10 cm), g/g`
i<-datos$`PWP (10-20 cm), g/g`
j<-datos$`PAW (0-10cm), g/g`
k<-datos$`PAW (10-20cm), g/g`
l<-datos$`PoreVolume 0-10cm, %`
m<-datos$`PoreVolume 10-20cm, %`
n<-datos$`AirFilled PV 0-10cm, %`
o<-datos$`FC (0-10),%`
p<-datos$`AirFilled PV 10-20cm, %`

## we look at the correlation between the explanatory variables:
q<-cor(datos) q
##ACP: R provee dos funciones para llevar este
#analisis (princomp() y prcomp(nombre de datos escalados))
##prcomp arroja resultados más precisos, por lo que se emplea este
acp<-prcomp(scale)
acp
## LET'S SEE WHAT IS THE EXPLAINED VARIANCE APPLIED BY EACH ONE OF THE COMPONENTS
## SEE WITH MANY COMPONENTS WE'LL BE ABLE TO STAY FOR THE ANALYSIS
summary (acp)
## we see the standard deviation of each of the components
desv <-acp [[1]]
trap
## We are interested in the variance
variance <-desv ^ {2}
variance
## we are left with the first four main components
## We keep the first four main components in a variablecp1<-acp[[2]][,1]
cp1
cp2<-acp[[2]][,2]
cp2
cp3<-acp[[2]][,3]
cp3
cp4<-acp[[2]][,4]
cp4
## we keep the three main components
comp<-cbind(cp1,cp2,cp3,cp4)
```