Land Degradation & Development Group

A HYDROLOGICAL ASSESSMENT OF THE SPEKBOOM THICKET IN BAVIAANSKLOOF, SOUTH AFRICA



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Date: **July 2011**

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REPUBLIC OF SOUTH AFRICA

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A HYDROLOGICAL ASSESSMENT OF THE SPEKBOOM THICKET IN BAVIAANSKLOOF, SOUTH AFRICA

Master thesis Land Degradation and Development Group submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

Study program:
MSc International Land and Water Management (MIL)

Student registration number:
821226-532-100

Thesis Land Degradation and Development **LDD 80336**

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Date: July 2011

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Wageningen University, Land Degradation and Development Group

Living Lands

Nelson Mandela Metropolitan University

Co-funded and supported by:

Department of Water Affairs – DWA, South Africa

Gamtoos Irrigation Board – GIB, South Africa

Ministery of Agriculture, Nature and Food Quality (LNV), The Netherlands

‘Il planta ainsi cent glands avec un soin extrême.
(...)
Il avait jugé que ce pays mourait par manque d’arbres.
Il ajouta que, n’ayant pas d’occupations très importantes,
il avait résolu de remédier à cet état de choses.
(...)
Quand je réfléchis qu’un homme seul,
réduit à ses simples ressources physiques et morales,
a suffi pour faire surgir du désert ce pays de Canaan,
je trouve que, malgré tout,
la condition humaine est admirable.’

Jean Giono - L’homme qui plantait des arbres (1953)

In this way he planted his one hundred acorns with great care.
(...)
He had concluded that this country was dying for lack of trees.
He added that, having nothing more important to do,
he had resolved to remedy the situation.
(...)
When I consider that a single man,
relying only on his own simple physical and moral resources,
was able to transform a desert into this land of Canaan,
I am convinced that despite everything,
the human condition is truly admirable.

Translated by Peter Doyle

Abstract

Restoration hydrology, Gash model, Mediterranean, Spekboom, Baviaanskloof

Vegetation cover is seen as an important factor in soil and water conservation, especially for dry regions, such as the Mediterranean.Theoretical, vegetation develops a soil and decreases runoff and erosion. Despite the positive stories about environmental restoration, its hydrological effects remain uncertain. Many studies have shown that revegetation does decrease peak flow, but also decrease baseflow. The fall in baseflow result in dry river beds and a significantly decrease of water resources downstream.
The study presented in this report focused on the effects of revegetation in the Baviaanskloof, South Africa, using Spekboom (*Portulacaria afra*). The Baviaanskloof has been used for intensive grazing with goats, that destroyed the original thicket and left the land severely degraded. At the start of the new millenium, a project was started to revegetate with Spekboom to restore the natural environment. Evaluating its ecohydrological effects, measurements were carried out in the summer of 2010/2011 focussing on rainfall dynamics, soil moisture evolution and runoff events. Rainfall and throughfall were measured using six tipping buckets, four interception troughs and a manual rain gauge. Stemflow was measured using a rubber collar. Soil moisture content was measured with six 60 cm soil moisture probes and four individual probes at shallow and deep depth for Spekboom and degraded land. Infiltration measurements were carried out with a minidisc infiltrometer and runoff was monitored with Gerlach troughs. A desktop study was done, predicting interception and infiltration as result from rainfall, using the GaIn3a model, which combines the sparse Gash model with a simple bucket model for runoff.
Results from the monitoring site, showed that around 40% of the gross rainfall is intercepted in Spekboom with a canopy closure of 75%. Minor rainfall events ($<$ 5 mm) intercept significantly more rainfall compared to major rainfall events: 55% versus 35%. The interception rate found in this study is comparable to results from a similar study on Spekboom, but much higher than other Mediterranean shrublan with typical rates between 22% and 33%. Results of stemflow measurements were less clear, showing two significantly different rates (7% versus 1% of gross rainfall). The Gash model predicted rainfall dynamics for the given rainfall dataset good, overestimating interception with 132%.
Spekboom soils showed moisture contents of 30%, while degraded soils showed much lower values of 10%. Typical flushing events can be seen in the soil profile of degraded land, which are absent in soils where Spekboom vegetation is present. Water infiltrates ten times easier and stays longer within the soil. Runoff measurements show a decrease in runoff of around 60% for the Spekboom land compared to degraded land. These values were also predicted using the GaIn3a model and are in line with previous studies on Mediterranean shrublands.
Integration of all fluxes using a water balance approach and the GaIn3a model, show that despite the high interception values for Spekboom, net infiltration under

Spekboom vegetation is similar to degraded land. This is surprising considering previous studies, that show a decrease in baseflow. Furthermore, Spekboom decreases runoff by 30% to 60%, reducing erosive peakflows. Further research is needed to see whether the calculated how much of the infiltration is contributing to baseflow. We suggest Spekboom revegation increases baseflow, due to subsequent soil improvements. However, the role of Spekboom in soil developement as well as its evapotranspiration needs more explanation.

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1 Introduction

Thicket vegetation is of great importance for land and water management in Mediterranean regions. They protect the soil against erosion and major runoff events in a direct and indirect way. Directly, the soil is receiving a more constant and controlled flux of rainfall, due to interception by canopy and litter. Beside that, shrubs also improve the physical and chemical properties of the soil, providing it with nutrients and loosening the earth. This favours the infiltration capacity significantly, decreasing excess water fluxes indirectly (Bochet et al., 1998).
Despite this general knowledge, studies concerning the hydrological implications of shrubs are rare and the few studies done are very cautious and specific; there is a need for further research (Baloutsos et al., 2009). When revegetation is mentioned and land use changes play an important role, the scientific community falls into oposing sites (Cosandey et al., 2005). A loud voice is represented by the positive effects of revegetation on streamflow, creating a stable and reliable source of water (Mander et al., 2010). However, most literature available finds that replantations result in dry river beds down the hill (Scherer and Pike, 2003, Silberstein, 2008, Zhao et al., 2009). Also invading shrubs on cropland are seen as a loss of available water (Maitre et al., 2002, Wilcox et al., 2006). These studies show that vegetation is intercepting and transpiring such amounts of water, that there is no water left for streams to flow. On the other hand, this can also be seen as a positive effect on local hill slope processes, since there will be a decrease in erosive surface water (Garcia-Ruiz et al., 1996).
The present study is trying to give new insights to quantify the positive claims of revegetation projects in respect to degraded land. Focus is on the water balance at catchment scale and as a case study we use the restoration project using Spekboom (*Portulacaria afra*), taking place in the Baviaanskloof (Marais et al., 2009). In this region, overgrazing has caused major soil degradation, destroying large extents of the original vegetation (Lechmere-Oertel, Kerley and Cowling, 2005). A lot of research has been done into the eco-hydrological implications on the large scale, which can be summarized as follows (see also figure 1):

Due to degradation, the soil has less capacity to hold moisture and organic material resulting in the erosion of the vulnerable slopes and an increase in peakflows (Lechmere-Oertel, Cowling and Kerley, 2005). The energy of streamflow which normally gets lost in the vegetation and soil is now focussed in the canalized drainage. In this way the system is losing its water quickly and this eventually lowers the groundwater table. Rivers only flows during times of flooding due to heavy storm events. Thus becoming an unreliable water resource for downstream irrigation areas (e.i. the Gamtoos Valley). Although dams (Kouga Dam) are build to regulate the high peak flows and to ensure water delivery during times of drought for downstream valleys, its capacity is not optimal in degradational conditions (Jansen, 2008).

In the Baviaanskloof, they use Spekboom (*Portulacaria afra*) to mitigate the deto-

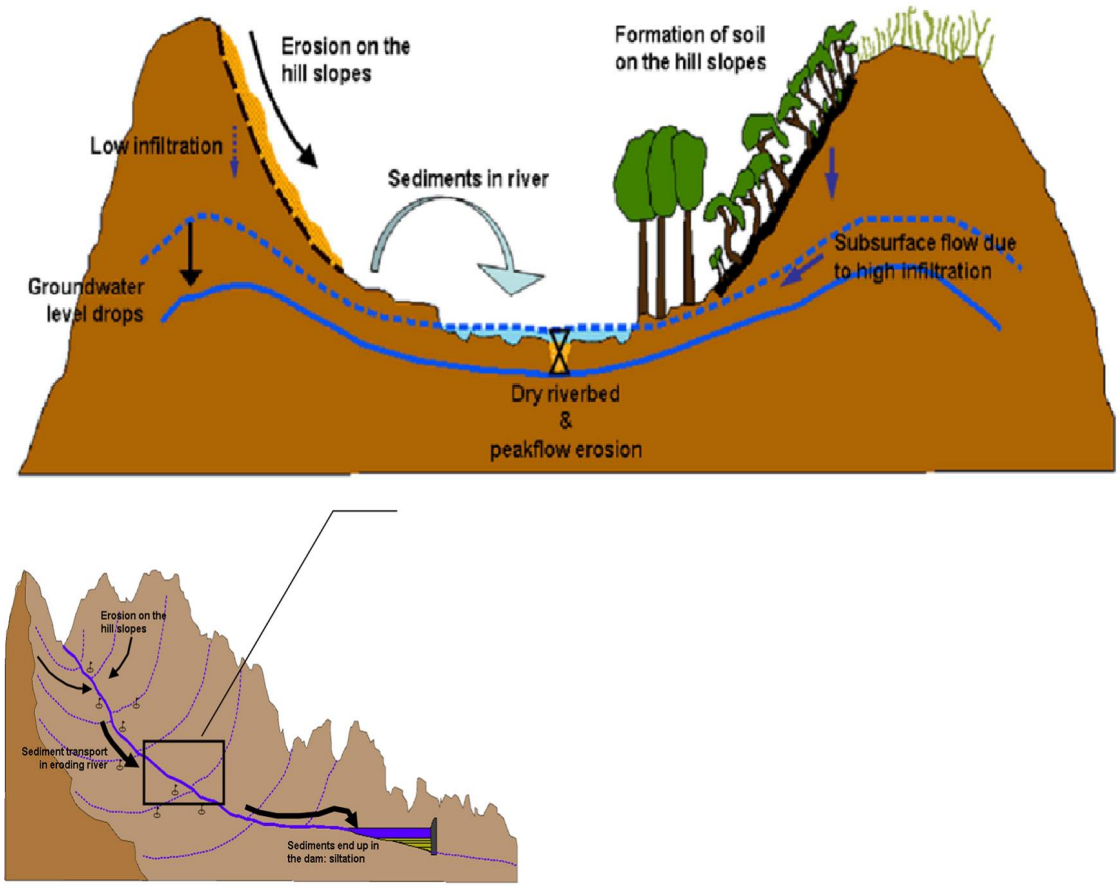


Figure 1: Overview of the hydrology on catchment and hillslope scales in the Baviaanskloof

riation of the landscape. This species is easy to propogate with the use of cuttings, and it grows relatively fast, despite hot and dry conditions. The plant also forms preferred conditions for other subtropical thicket species to evolve. It delivers nutrient-rich litter fall, it provides lots of shade and it improves soil moisture conditions (Powell, 2009). Restoration will both effect the quality of the natural landscape as well as alleviate the river system (Mander et al., 2010).

Replanting of Spekboom will thus protect the soil from further degradation and it results in a healthy streamflow regime by improving the soil water holding capacity.

As already mentioned above, the hydrological effects of revegetation with respect to degraded lands are not so straightforward. Preliminary results concerning rainfall interception by Cowling and Mills (2011) showed that only half of the rain is actually reaching the soil by throughfall, meaning that the other half is lost by direct evaporation. This is considerable when taking into account the limited amount of rainfall falling over a year. From this data it is not evident, that Spekboom replant-

ing will improve streamflow characteristics, such as a lower peakflow and a constant baseflow. The environmental restoration with Spekboom might cause less water to reach the surface and therewith decreasing the peak flow, while at the same time also decreasing the baseflow of the streams. To address the problem of the deteriorated hydrological status in the degraded areas, Spekboom might offer a solution, though the question is in what way.

1.1 Aim of the Study

The general objective of the Baviaanskloof restoration project is to conserve and restorate the natural landscape in a sustainable way by the improvement of the water management. The aim of the here presented study was to investigate the effects of Spekboom thicket restoration on the water balance. There needs to be a better understanding of how the Spekboom thicket is distributing the gross rainfall with respect to evapotranspiration, interception and direct runoff (losses); and stemflow and increased soil moisture (gains). This will ultimately give an indication wether and in what ways these soil and water conservation measures are improving the base flow and peak flow pattern, regulating the excess surface flow.

1.2 Research Question

The main research question regarding the restoration of Spekboom thicket in relation to its hydrological effect can be stated as follows:

Will restoration of vegetation increase the water available for baseflow in respect to peakflow, introducing a healthy water balance into degraded area?

More into detail for the present study, we can ask the following:

Will Spekboom revegetation replenish the moisture content of shallow soils, dispite the apparently high interception rates?

1.2.1 Subquestions

To answer the above research question, many aspects of the water balance have to be taken into consideration. In this study we used direct hydrological measurements to explain (part of) this balance, comparing the present degraded state of the landscape with the intact spekboom thicket. The part of the water balance that is studied in detail concerns interception and soil moisture content and it gives tentative results for stemflow, infiltration and runoff (figure 1). The monitoring site is on the plot to field size. The study answers the following subquestions:

- What are the vegetation specifics for Spekboom?
- How much of the rainfall is intercepted by Spekboom vegetation?

- How much of this interception is transported to the soil by stemflow?
- What kind of model can we use to simulate the rainfall-interception-stemflow interactions?
- What is the effect of the Spekboom vegetation on the soil moisture content?
- How much of the rain results in direct runoff from Spekboom vegetation?
- What will the net effect of the interception dynamics be on the soil moisture content and in general the generation of baseflow and peakflow?

1.3 Structure of the Report

Now the problem and subsequent questions have been presented, the report will first explain some of the main definitions in a theoretical framework. The chapter "Conceptual Framework" will be a short introduction into the water balance and the different physical fluxes.
The report will continue with "Materials and Method". An introduction into the case study area is given, in which the vegetation, soil, meteorology and the historical setting of the Baviaanskloof are described and situated within the scope of the research. Next, the different methods used in the field are shortly described. It discusses vegetation specifics, interception dynamics, soil moisture dynamics and runoff measurements. The interception dynamics include rainfall, throughfall and stemflow measurements. The chapter finalizes with the description of the GaIn model.
In the chapter "Results" all data gathered is presented. A subdivision is made in the different aspects, following the structure of the field methods in the previous chapter. It will first describe the vegetation specifics, followed by rainfall and throughfall dynamics; a short section concerning the stemflow is next, followed by soil moisture dynamics (which includes infiltration measurements) and runoff data. Integrating the data in a water balance approach and the GaIn model approach concludes the chapter "Results".
A "Discusson" chapter will go into depth on three different aspects: 1. equipment used, 2. spatial variability and 3. temporal variability. This is seperately discussed for the interception dynamics, the soil moisture dynamics and the runoff dynamics. At the end we discuss the possibilities for models, such as GaIn and more advanced catchment models. Missing data and knowledge gaps are also recognised.
The report is closed by the chapter "Conclusions", summing up the main findings of the study carried out and giving recommendations for future research and management.

2 Conceptual Framework

This study is concerned with the total water balance, from rainfall to base flow. The most easy way to explain the water balance is with use of a scheme. In figure 2, a representation of the water balance is given. This figure is summing up the total framework of concepts in this research, which is similar to the water balance (Allen et al., 1998):

$$\Delta W/\Delta t = +P - RO + Ir - ETa - DP + CR \quad (1)$$

In which the change in soil water storage ($\Delta W/\Delta t$) is defined by the sum of precipitation (P), irrigation (I) and capillary rise (CR) minus the sum of runoff (RO), deep percolation (DP) and evapotranspiration (ETa). For simplicity, irrigation, capillary rise and deep percolation are often left out, Short discriptions of the different fluxes and its definitions are given below.

The balance starts with the **gross rainfall**, which includes all precipitation: not only rain, but also hail, fog and snow. It is all water that comes from the atmosphere onto the earth cover, either in the form of vegetation, soil, rock or water. Precipitation is extremely variable in space and time and therefore rather difficult to measure.
Part of the gross rainfall is caught by canopy of trees and shrubs and is lost again to the atmosphere by evaporation, this is called the **interception**. Rain that is not caught by the vegetation, but falls onto the soil through vegetation gaps or when driping from the leaves after interception of the canopy, is called **throughfall**. Wa-

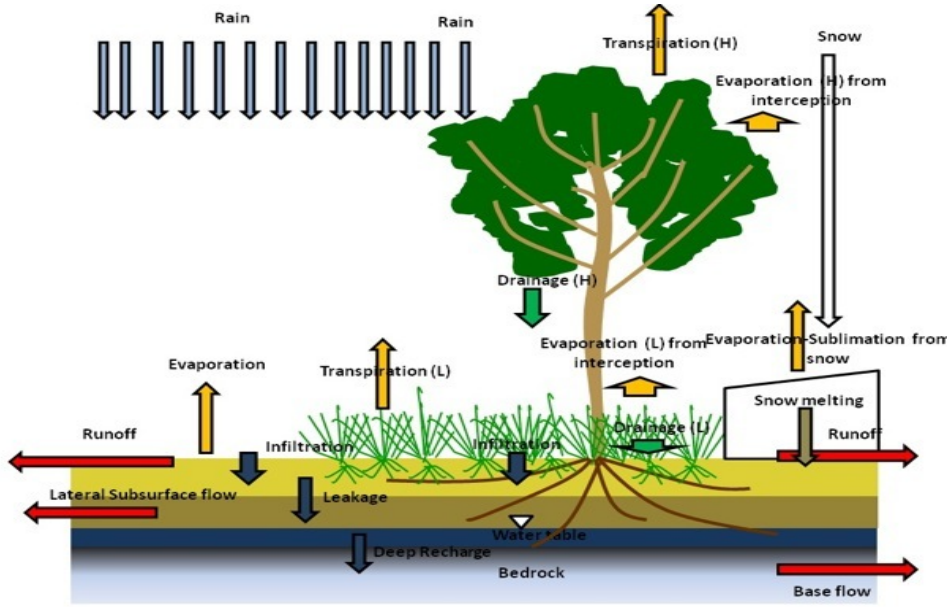


Figure 2: The main fluxes of the water balance according to the Tethys-Chloris model (Caporali et al., 2009).

ter running down the stem into the soil is called **stemflow**. These two fluxes are often taken together, called the **net rainfall**. Before infiltrating in the soil the net rainfall needs to penetrate the litter layer. Water is lost in this level as well, called litter interception. The quantity of the total interception flux is governed by a multitude of factors, such as the rainfall intensity and duration, the canopy storage capacity and the evapotranspiration rate. Compared to temperate climate zones, the amount of interception is relatively low in Mediterranean regions, due to the high intensity and short duration of rainfall events (David and Gash, 2009).
Evaporation of intercepted precipitation makes up to 75 % of the total **evapotranspiration**. This flux is the change of water between the interface with the atmosphere and the surface of either plants (transpiration) or soils (evaporation) (Gash and Dolman, 2009).
The net rainfall that reaches the soil after interception, can soak into the soil by the process of **infiltration**. Together with the soil type, antecedent soil moisture and groundwate level, the net precipitation will increase soil moisture in the vertical and horizontal dimension (Hillel, 2004). This will either flow downstream in the form of lateral subsurface flow or infiltrates deeper into the bedrock in the form of deep recharge. This water is available for baseflow in the streams and rivers.
All the excess of the net precipitation is spilling out of the system by **runoff**, which is either caused by soil saturation excess or soil infiltration excess. This water will form the peak flow in streams and rivers (Martinez-Mena et al., 1998).

The hypothesis for the restoration project in the Baviaanskloof will be that the Spekboom changes the fluxes fundamentally. First of all, it will increase the interception, there with decreasing the net rainfall and thus also decreasing the direct runoff (peak flow). Due to a more constant and a decreased amount of the net rainfall in combination with an increase in soil quality, more water will infiltrate. This will again decrease the direct runoff (peak flow) and at the same time it will also increase infiltration, subsurface flow and deep recharge (fluxes contributing to the base flow). There will thus be more water stored in the soil and more water available for plants, animals and rivers (see also figures 1 and 6).

3 Materials and Method

3.1 Study Area

The Baviaanskloof Mega Reserve is located in the south eastern corner of South Africa behind the fertile plains of the Gamtoos Irrigation Plains around Port Elisabeth (figure 3). Its stunning nature exhibits a multitude of floral and faunal species, which are unique in the world (Turpie et al., 2003). Due to its position at the convergence of three biodiversity spots, the Baviaanskloof is an unique region, comprising seven out of the eight biomes present in South Africa. Therefore this region has been recognized with an UNESCO World Heritage Site award in 2004 (Noirtin, 2008). The deeply incised valley of Baviaanskloof River is around 75 km long and has a river slope of aproximately 8 m/km, which can be characterized as extremely steep; the Amazone river for instance has a slope of around 0.3 to 35 cm/km (Laraque et al., 2009). It is part of the geological Cape system that experienced intense folding during the Alpine orogeny, due to rrifting of Africa from Antartica. The underlying geology comprises the Table Mountain quartzites and Bokkeveld shales. The Table Mountain series forms the typical flat tops of the surrounding mountains, while the Bokkeveld shales are the main source for the nutrient-rich valley bottom soils (Du Toit, 1954).

The Baviaanskloof has a Mediterranean climate, resulting in rainshowers with a short but intense character and a low annual precipitation (300 mm/year). Rainfall is evenly spread over the year, although slightly more rain falls during spring and autumn (Powell, 2009). Temperatures can rise over 40 ℃ during prolonged droughts, while in winter temperatures rarely fall below 0 ℃ (Sigwela et al., 2009). Figure 4 shows the monthly rainfall, evapotranspiration and temperature.

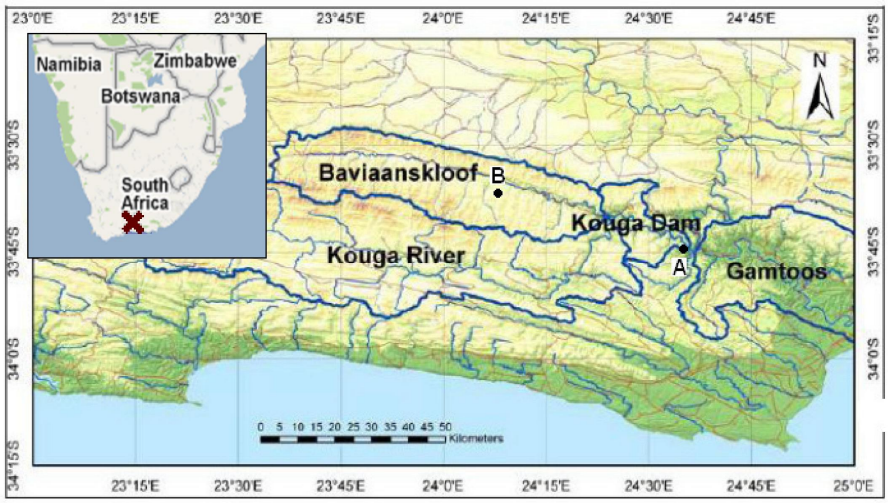


Figure 3: The Baviaanskloof, South Africa: location of the PRESENCE Learning Village (A) and the monitoring plot at Sandvlakte (B), derived from Jansen (2008)

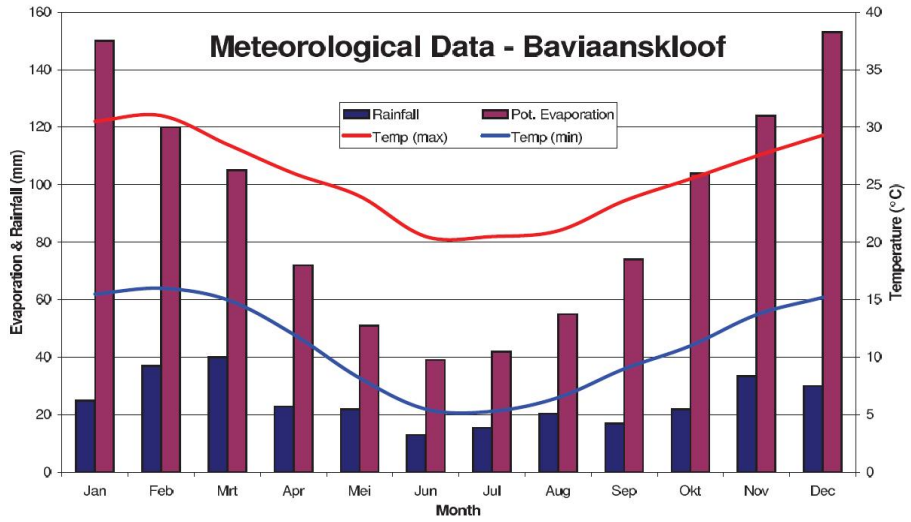


Figure 4: Meteorological data for an average year in the Baviaanskloof region, derived from Jansen (2008)

Due to the combination of low annual rainfall and high temperatures the ecosystem is experiencing great environmentall pressure and water stress (Lechmere-Oertel, Kerley and Cowling, 2005, Commodities, 2009). The climatic configuration makes the landscape prone to extreme fluctuations in runoff and consequently severe land degradation. Especially when adequate management of land and water resources is lacking.
In recent history, extensive browsing by predominantly goats, introduced by Boer settlers, has caused major degradation, destroying large extents of the original subtropical thicket and fynbos vegetation (Lechmere-Oertel, Kerley and Cowling, 2005). The area has nowadays transformed into a pseudosavannah (Sigwela et al., 2009). Although the main land use is pastoral land with goat herding (Mills et al., 2005), agriculture is not seen as a profitable activity anymore (Noirtin, 2008) and focus is changing towards tourism, game hunting farms (Sigwela et al., 2006) and also the carbon trade market using Spekboom replanting (Mills and Cowling, 2009). Besides the deteriorated soil conditions, also the river became ephemeral with occacional flash floods, but mostly exposing its naked riverbed.
To improve management of land and water resources, Spekboom replanting is implemented on many of the degraded hill slopes around the agricultural valley. The present study is carried out in the Western Baviaanskloof close to the farm “Sandvlakte” (see location B on figure 3). At this location a clear fenceline contrast is visible between intact spekboom thicket and degraded pasture.

3.2 Field Methods

The main focus of this study is on rainfall interception of Spekboom vegetation and subsequent soil moisture evolutions. To understand its importance in the hydrological context, further investigation to quantify runoff, soil moisture storage and evaporation was carried out. The monitoring plot, where this research was conducted is located on the farm of Piet Krüger (Sandvlakte), on a north facing hill slope.
Main focus is on individual Spekboom stands, instead of the Spekboom- or subtropical thicket. This approach is chosen, so that an estimate can be given based on Spekboom revegetation. This revegation will mean the introduction of a monoculture in its first phase. Furthermore, Spekboom is the major component in the original thicket vegetation and focussing on this plant alone makes it easier to compare with the degraded situation. A monitoring plot along a fenceline contrast was chosen to install the different measurement devices (see figure 5). A description of all equipment present at the monitoring site is given in Appendix B. At three different levels along a south-facing slope, Spekboom plants are selected to analyse, measuring different aspects of the water balance, as displayed in figure 6. This figure also

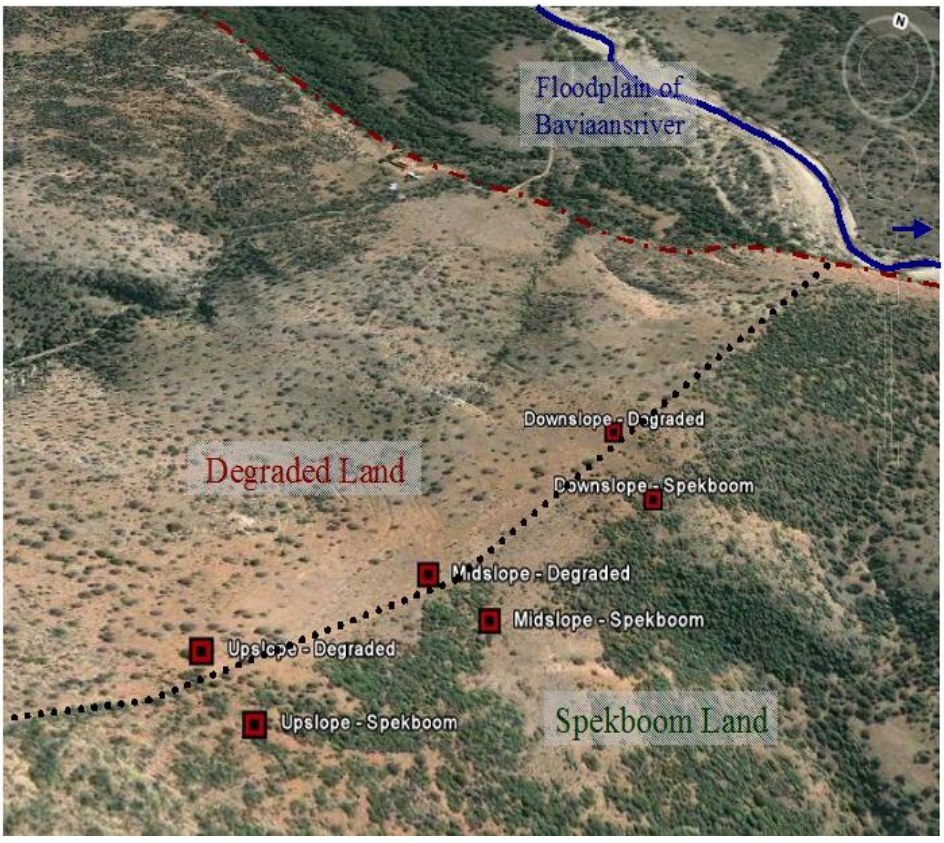


Figure 5: The monitoring plot along a fenceline contrast at the farm "Sandvlakte" in the Baviaanskloof, South Africa (taken from GoogleEarth)

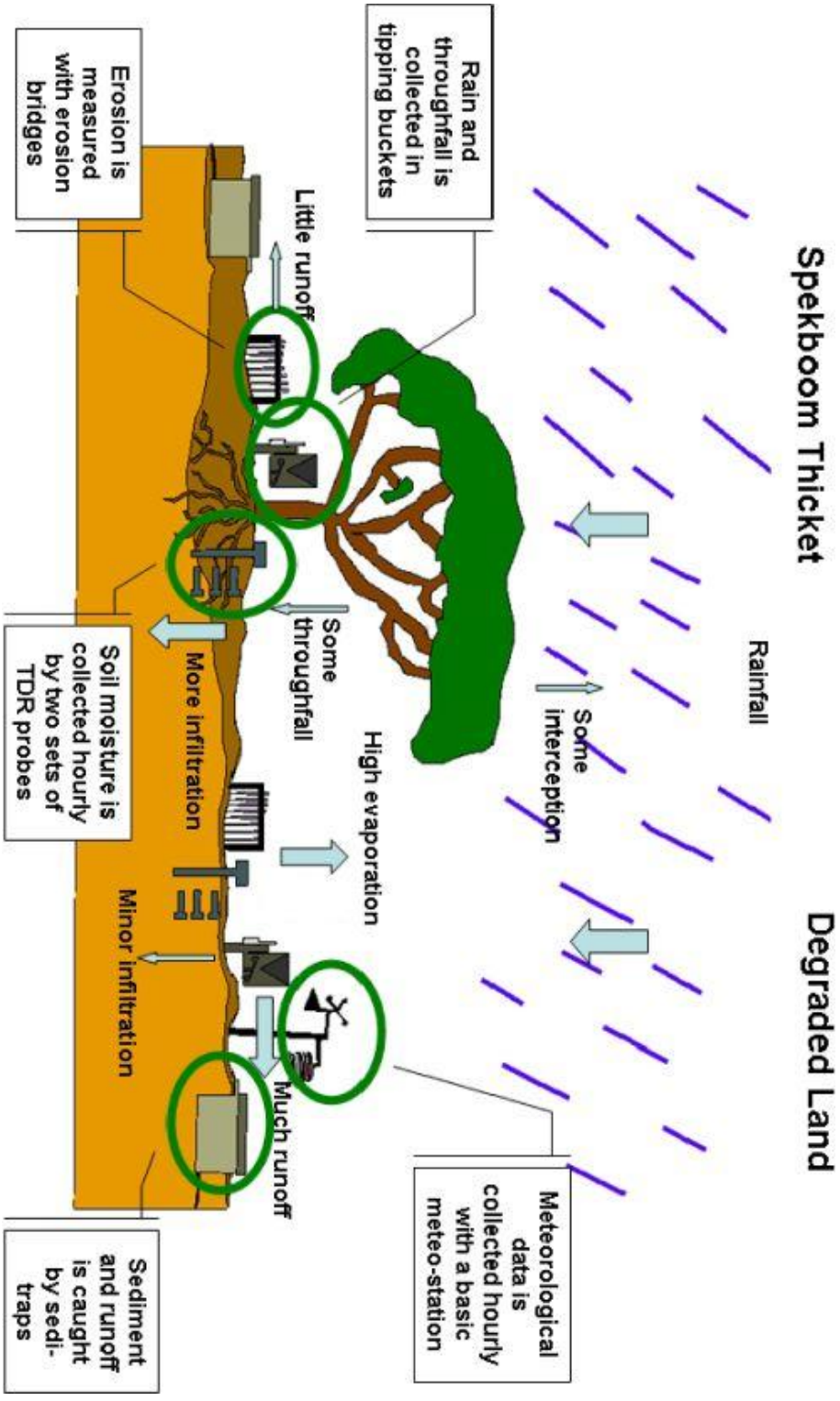


Figure 6: A sketch of the measuring equipment installed at the monitoring plot and the expected hydrological fluxes

gives indications for expected fluxes, as explained in the “Conceptual Framework”. A total of six measuring locations are distinguished:

1. Upslope Thicket
2. Midslope Thicket
3. Downslope Thicket
4. Upslope Degraded
5. Midslope Degraded
6. Downslope Degraded

Vegetation Specifics It is important to specify some different vegetation characteristics for the Spekboom plants used in this research (figure 7), so the data can be more usefull when comparing to other studies. Furthermore, it helps to understand the different hydrological features. Spekboom is a slow growing succulent with a number of large stems, which twist, bend and meander trough each other. At the sides of isolated plants, shoots come up around the main plant, which form a kind of ”skirt”. These shoots are the main mechanism for Spekboom to propagate. We examined shrub height, stem diameter at base level, stem density, and the canopy cover. Canopy cover was measured using the binary image method, which has been used with succes previously, although care needs to be taken with the light within the canopy itself (Avsarm and Ayyildiz, 2010, Korhonen et al., 2006). This methodology only needs a simple digital camera, photographing in an upright position underneath the vegetation in a random grid. These photographs are then translated to a binary picture using Paint Shop Pro; the percentage of black (canopy cover) is measured using Irfan View.

Quantifying Interception To quantify the interception of Spekboom vegetation, three fluxes were measured: the gross rainfall and both the stemflow and throughfall. The stemflow is discussed below as a seperate research item.
The gross rainfall was measured with a tipping bucket (type: DFM) standing in the

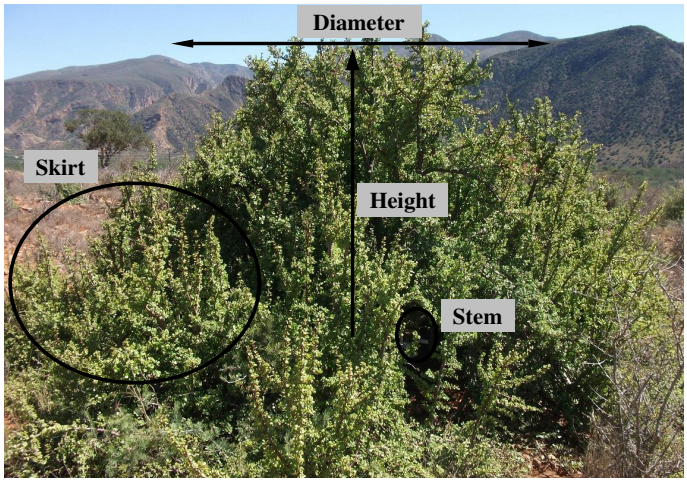


Figure 7: Example of a typical Spekboom plant in the field. The height of this example is over two meters, and the diameter almost four meter. The ”skirt” is indicated as well.

degraded field on one side of the fenceline (figure 8). To measure the throughfall, tipping buckets were placed underneath three individual Spekboom plants. The tipping buckets are logging the number of tips (equivalent to 2 mm of rain) every hour. During the course of the study, the number of tips were counted every ten minutes instead every hour. Thus, a more realistic maximum rain intesity could be determined from the short high intensity rainfall events. However, since this time interval was not set on all the tipping buckets and was only changed halfway the research, only hourly data is used to keep consistency in the data. Rain events have been defined as the time in which rain falls constant, or on a daily basis. Due to the financial value of the tipping buckets and the danger of monkeys playing and destroying it, the individual devices as well as the measured Spekboom plants were fenced in. Beside the tipping bucket, also a normal rain gauge was installed (Návar et al., 1999) as well as troughs, such as suggested by Cowling and Mills (2011). The use of troughs has been carried out and descibed by Cuartas et al. (2007). In this study, we made them from 40 mm thick polyester pipes, cut in half. They had a lenght of 90 cm and were covered with a rather coarse mesh grid. To find any preferred drip or lee side troughs are normally organised in a four-way orientation (David et al., 2006). This four-way orientation has also been applied for the current study (figure 8), although drip and lee sides are not expected to be found, due to its installation underneath dense Spekboom thicket, instead of individual plants. Thicket has been chosen for this method, because of its practicality to install and since it is expected that the troughs will give a more average and reliable value under continuous cover. The three measuring methods (i.e., tipping bucket, manual rain gauge and four-way orientated throughfall troughs) have given variable results and are therefore combined in this study. A statistical appraisal is given for the three different methods using the Nash-Sutcliffe efficiency coefficient, as described below.

Getting an idea of the stemflow Many studies presume a small amount of the interception to reach the soil by stemflow and do not bother to measure this flux. Despite its difficulties, we made an attempt to measure this flux. Stemflow measurements were relatively difficult to implement for the intact Spekboom thicket, due to the entangling nature of its stems. Therefore, we followed Herbst et al. (2008), who measured from representative stems and afterwards scaled up this value using the contributing crown area relative to the total area. A rubber collar was glued on the stem (Valente et al., 1997) from which a small tube was directing the water in a collecting bucket (figure 8). Stemflow was measured on only one stem to get a general idea of its importance within the water balance. Stemflow was normalized for the whole area by the following formula:

$$Sf(mm) = \frac{Sf_{vol}}{\frac{1}{N_s} * \pi * r^2} \tag{2}$$

In which Sf_{vol} is the volume of stemflow, collected in the bucket; N_s is the total number of stems and r is the radius of the plant. This formula assumes that all stems have an equal portion of canopy cover. Since stemflow was measured over



Figure 8: Photographs of the interception troughs (right), the tipping bucket (middle) and the stemflow collar (left) as used in the field

several rain events, individual stemflow values have been calculated using the ratio of the throughflow.

Effects on Soil Moisture A set-up for soil moisture measurements was installed underneath the Spekboom and in the degraded field, using continual TDR measurement in depth (Ledieu et al., 1986, Werner, 2002) of the type DFM Continuous Soil Moisture Probe. Soil moisture was monitored at 10 cm intervals to a depth of 60 cm in the Spekboom thicket and the degraded field on the six locations, as described above. Measurement were taken every hour. We refer to this set as the SM probes. Next to this set, a second set was installed in the field. These TDR devices were of the type LDM e+ SOIL MCT sensor from Eijkelkamp (www.eijkelkamp.com). These were installed at the Spekboom thicket (Midslope, location 2) and at the degraded field (Downslope, location 6). It entails a seperate TDR device for shallow depth (5 cm) and deep depth (50 to 60 cm) and measures the soil moisture every 30 minutes. In the report, we refer to it as the validation probes. The gathered data from both soil moisture probes is analysed using Excell and graphically edited with the Surfer software. Daily soil moisture volume fluxes for the SM probes have been calculated using an average over depth times the depth interval.
Since infiltration rates are difficult to obtain from soil moisture measurements alone, infiltration test were carried out in the field using a handheld minidisc infiltrometer during moist field conditions. To calculate the infiltration rate, the method as described by Zhang (1997) was used.

Indications for Direct Runoff Since runoff dynamics of Spekboom vegetation respective to degraded field situations have already been studied (Sommeijer, 2010), this is not been studied in detail. If implemented in detail, this flux will determine the size of the plots. A closed box, including a Gerlach trap at the lower end (Wischmeier plot), need to be established over plots of approximately 5 to 10 meter length and 1 to 3 meter width, following the methodology presented by Garcia-Ruiz et al. (1996). These dimensions are also familiar to rainfall interception experiments

(Návar et al., 1999). In this study we only take into account measurements taken from Gerlach troughs, without a specified catchment area. These troughs were installed at the six different locations described above. These measurements provide us with relative data and are graphically described using Excell.

3.3 Modelling

In order to find the net effect of the interception parameter on the total hydrological system, a model approach is used. Although it is irrational to think that a model represents THE reality, a model can nevertheless be used to represent a possible reality, explaining it by the use of a limited amount of data (Tunstall, 2004). In this study, models are used to see how reliable the processes on plot scale can be explained and simulated. This information will help in the development of a catchment or even basin scale model (Wilcox et al., 2006). Since an understanding of the interception process is the main focus of this study, an interception model is needed. In 1974, I.J. Jackson called his attempt to model interception in East African highland forest being "in general (..) rather unsatisfactory". He understood the difficulties mainly arose from the variable tropical climate zone, but was also afraid it would "throw doubts on other analyses" (Jackson, 1975).
Since Jackson, not many models have been employed in Africa, but in Europe and America researchers have been developing reliable models, of which the most widely used and acknowledged is the Gash model (Muzylo et al., 2009). This study applied the Gash model, as described by Gash et al. (1995), and improved by Carlyle-Moses and Price (1999), developing the Sparse Gash model. The model uses the linear relation between throughfall and intercedent precipitation in combination with an event-based phases system and is described in Appendix C. It has been used with success on Mediterranean forest stands (Valente et al., 1997), multicultural vegetation covers in a seasonal climate (Herbst et al., 2008), and shrub vegetation in Mexico (Návar et al., 1999), but performed somewhat less in tropical forests (Cuartas et al., 2007).
Statistical analyses is performed to describe the performance of the model by means of the Nash-Sutcliffe goodness of fit comparing the relative variability of the model with that of the observations (Nash and Sutcliffe, 1970):

$$NS = 1 - \frac{\sum_{i=1}^{n}(I_{i,simulated} - I_{i,measured})^2}{\sum_{i=1}^{n}(I_{i,measured} - \overline{I_{i,measured}})^2} \tag{3}$$

In which NS is the Nash-Sutcliffe coefficient, $I_{i,simulated}$ is the value simulated with the model, $I_{i,measured}$ is the value measured in the field and when it has a bar above it, the mean of the total number of values is meant.
A value of one is a perfect fit with the model, however when approaching zero the model is performing as "good" as the variance of the data itself, and it is better to use elementary statistics instead. Values less then zero indicate a very poor performance of the model.
It is interesting to model how much of the rainfall will be available for baseflow

using a simple water balance approach, coupled to the Gash model (Todini, 1996). This is applied in a sequential reservoir assimilation with one reservoir representing the soil moisture storage (Aubert et al., 2003), which is receiving influx, depending on the Hortonian overland flow. This influx is the net infiltration, calculated as the difference between rainfall and the runoff. Runoff occurs whenever the maximum rainfall intensity per hour is more than the tresshold infiltration per hour, as been measured in the field. Runoff is calculated taking the net rainfall times the ratio between the tresshold value and maximum rainfall intensity. Another mechanism is triggered when total rainfall is exceeding a tresshold rainfall of 5 and 10 mm respectively for degraded and Spekboom land. Both the sparse Gash model and the coupled model (GaIn3a model) were relatively easy to implement and graphically illustrated using the statistics program "R" (Venables and Smith, n.d.).

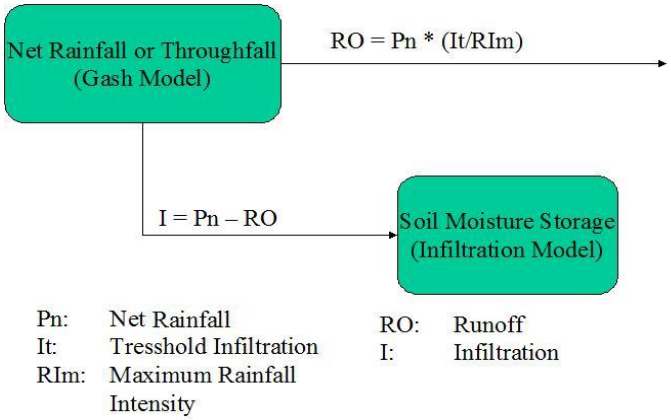


Figure 9: Structure of the bucket infiltration model, linked to the Gash model. The total model I will call the GaIn model 3a.

4 Results

4.1 Description of the Vegetation

When focussing on eco-hydrology, it goes without saying that the vegetation needs sufficient description. According to personal communication with local farmers (e.g. P. Krüger and J. Mason), the vegetation in the Western Baviaanskloof has been severely degraded by goats, that grazed the area from the start of the twentieth century onward. Although goats are still held, many slopes are currently being revegetated, while goats are taken off. At the monitor site, grazing has stopped since twenty years on one side of the fenceline contrast, while on the other side, goats and cattle can still enter. The Spekboom Land has however experienced intensive grazing and this means the Spekboom thicket is been damaged and gaps are still present in the vegetation. Plant specifics are unbearable for future studies to assess the current study correctly. The presence of the Spekboom vegetation also has important effects on the soil.

At three different locations (see figure 5), an average Spekboom plant was selected by visual assessment and used for interception measurements; plant specifics are based on these three individual plants. Additionally, we also included measurements below a thicket of clumped Spekboom plants. An overview of the plant characteristics, such as diameter, height, stem parameter, number of stems and canopy cover is given in table 1.

Diameter (D) and height (H) of the individual Spekboom are around three and two meter respectively. Larger plants cover more area, therefore increasing the total interception per unit area. In the same way, also taller plants will increase the interception, since it will have more interception levels (as observed in the field). The number of stems (N_s) indicates stemflow dynamics; the more stems, the more possibilities for intercepted rainfall to reach the soil via stemflow. On average Spekboom plants have ten stems per plant, excluding the skirt, which are all the small stems that grow around the main plant. This skirt has been observed around the downslope and upslope plant, and is made up of over a sixty individual ten to fifty centimeter high shoots (indicated by an asterisk (*) in the table). The thickness of the stem

Table 1: Characteristics of the monitored Spekboom plants. D is diameter of the canopy bulk, H is the height of the canopy bulk, N_s is the number of indivisual stems, P_s is the perimeter of the individual stems, and CC is the canopy cover.

Spekboom Location	D **(m)**	H **(m)**	N_s **stems**	**Av.** P_s **(cm) [min - max]**	**Av.** CC **(%) [stdev]**
Downslope	4.00	2.35	11*	25.57 [17 - 41]	79.11 [8.25]
Midslope	2.90	1.85	12	24.64 [13 - 42]	69.10 [10.86]
Upslope	2.80	2.20	9*	26.29 [7 - 59]	72.68 [6.73]
Thicket	(-)	(-)	(-)	(-)	75.90 [8.19]
Average	3.23	2.13	10.67	25.50 [13 - 47]	73.63 [9.61]

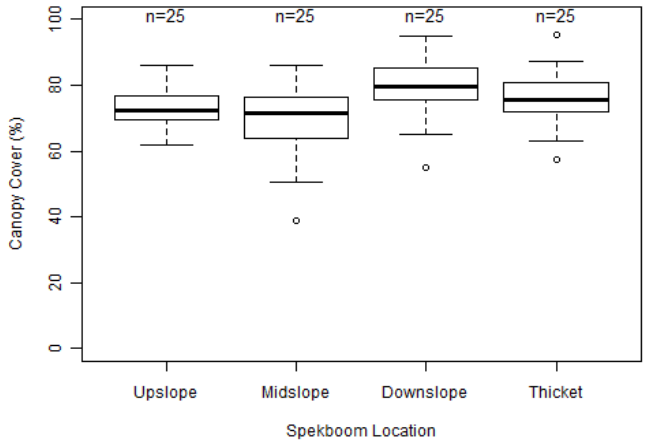


Figure 10: Boxplot of the measured canopy cover data (n is the number of photo shoots under Spekboom plant)

will give an indication of the canopy size; the thicket the stem, the larger the canopy belonging to this stem. On average, we find a stem perimeter (P_s) of 25 cm (from seven stems measured), which is strikingly similar for all locations. However, when taking into account the individual plant, stem diameters vary significantly between 7 cm to almost 60 cm!
Also indicated in table 1 is the canopy cover (CC) as percentage. This is the portion of light obstructed by the plants canopy. Canopy cover ranges from 70% to 80% for the individual plants, while the thicket results in an average density of 75%. Figure 10 shows a boxplot of the measured canopy cover, in which the box is the range between the standard deviation, the line represents the average, the top and bottom stops indicate the 95% and 5% ranges respectively, and the dots indicate possible outliers.

4.2 Rainfall and Throughfall

Rainfall measurements are both dynamic due to different measuring equipment (tipping buckets versus interception troughs and manual rain gauges) and location (general spatial differences). In figure 11, a total of twenty-two rain events measured at the monitoring site from October 2010 untill January 2011 have been included. Extra care has to be taken for the data of January 2011 (events “R” to “W”), since this includes some temporarily malfunctioning equipment. All values are averaged over the three different measuring locations. From these measurements, it can be estimated that less than half of the rainfall is captured by the canopy and lost directly by evaporation. An average value of 60.6% is reaching the soil below the

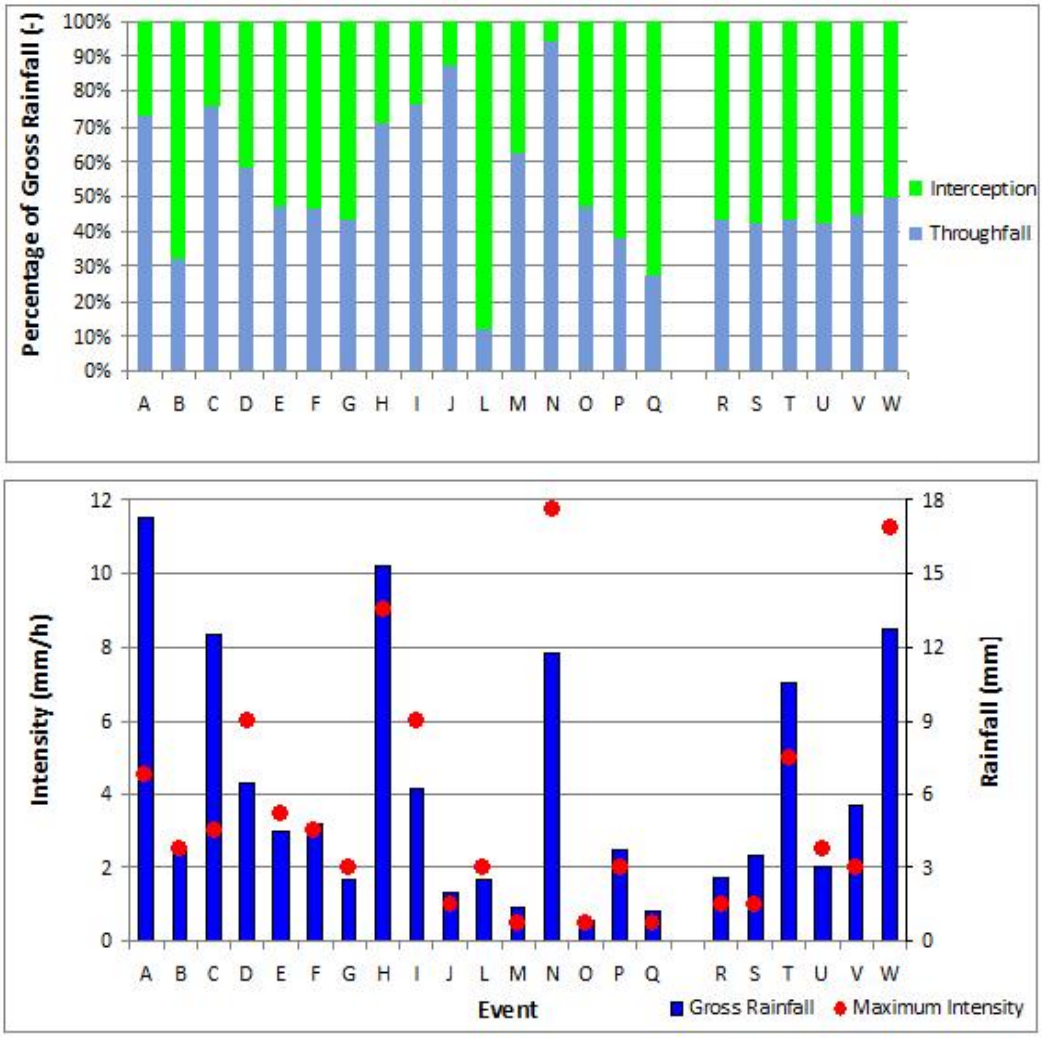


Figure 11: Graph, showing all rainfall event between 1/10/2010 and 15/01/2011. Top graph shows the percentage of throughfall+stemflow and interception. Bottom graph shows the total gross rainfall and maximum intensity.

Spekboom canopy. Relatively more rainfall seems to be intercepted during short rainfalls, while long lasting rainfalls result in more throughfall. It can also be seen that heavy rainfalls generally result in more throughfall, compared to the light rains (e.g., compare event "N" with event "T"). Relative interception (in respect to gross rainfall) increases with both decreasing gross rainfall and decreasing maximum intensity. With a gross rainfall less than 4 mm, we find that 55% is intercepted, while with rainfalls more than 4 mm, 35% is intercepted. When taking individual locations into consideration, similar patterns emerge. However, it may happen that an event yields more throughfall compared to the gross rainfall. The values rainfall intensities per hour average 2.27 mm/h for all events. Also the maximum rainfall intensity is around 2 mm/h, with extremes up to 12 mm/h. These values have all

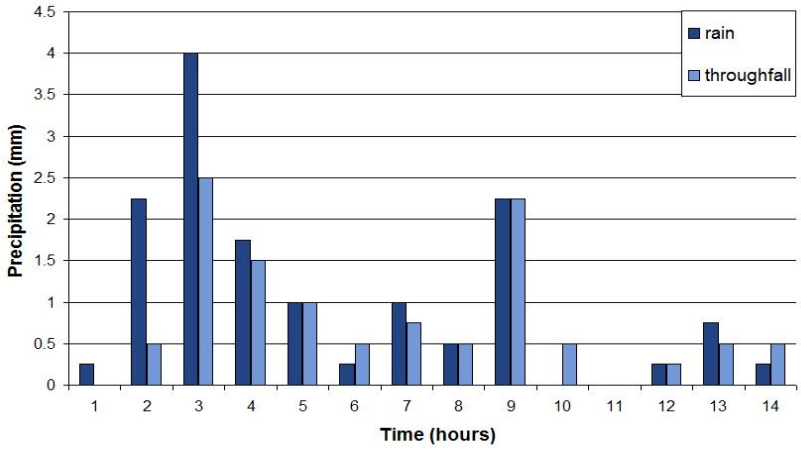


Figure 12: Typical rainfall and throughfall evolution during rainfall. Data is taken from the locations "Downslope Spekboom" and "Downslope Degraded" and occured on 27 October 2010, when almost 15 mm of rain fell and 11 mm of the rain reached the soil trough the canopy

been taken with hourly measurments. When taking quarterly measurements much higher intensities are found up to 31 or even 45 mm/h (22^{nd} of December and 12^{th} of January); on average a rainfall intensity around 3 or 4 mm/h is found. For throughfall these maximum intensities reach up to 14 and 18 mm/h, half the intensity of the actual rain event. These measurements show that a maximum intensity taken from hourly data does not fully represent the force of a rain event. Where hourly data do seldomly show extreme intensities more than 10 mm/h, this value is relatively often

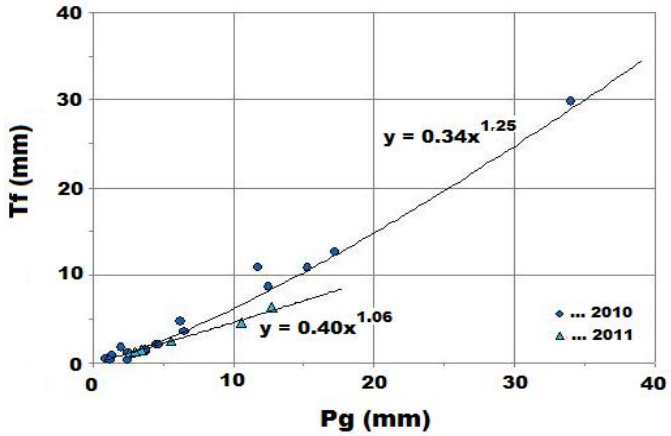


Figure 13: Relation between gross rainfall (P_g) and throughfall (Tf). A trendline indicates a power relation with a Nash-Sutcliffe coefficient of 0.89. The data of 2011 approaches a linear relation.

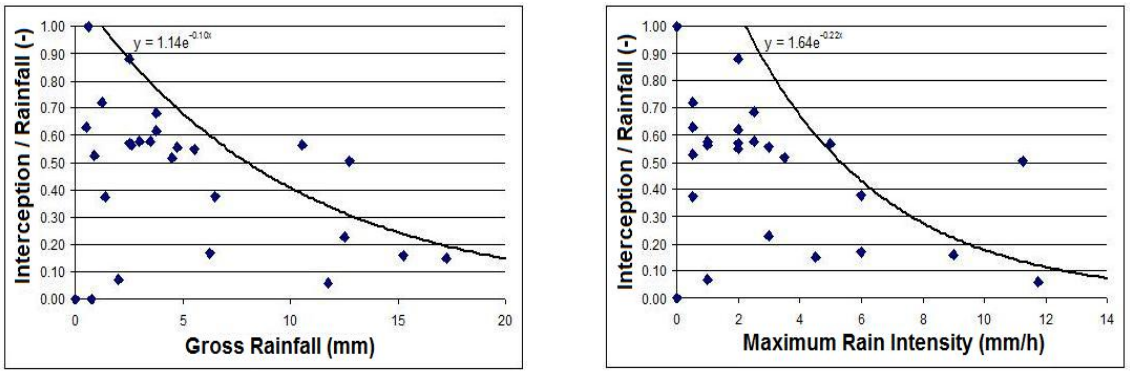


Figure 14: Relative Interception is a function of both gross rainfall (left) and maximum rainfall intensity (right). The exponentional line indicates the limit of data

found using a shorter measuring interval.
A single rainfall event, measured at two similar locations (e.g. "Downslope Spekboom" and "Downslope Degraded") shows the relation between gross rainfall and throughfall. A typical rainfall event is shown in figure 12. The hourly data shows that for the first two hours, the Spekboom is capturing a lot of the gross rainfall into its canopy and releases only a minor amount of it. However, after a few hours the throughfall equals and even exceeds the rainfall data, releasing the rainfall in a more continouos and constant way.
Another way to look at the data is to plot the gross rainfall versus the throughfall, as done in figure 13. A clear power relation between both parameters can be recognised:

$$In = 0.34 * P_g^{1.26} \tag{4}$$

Although it seems this formula is only based on the one extreme point in the high range, it also holds for the data in the low range. The data has been divided in two data sets: one for 2010 and one for 2011, since at the end of 2010, many tipping buckets stopped registrating data. Afterwards, throughfall data is only measured with manual rain gauges and throughfall troughs, as described above. For the data from 2011, a linear relationship is found with a slope of 0.40. The relation between gross rainfall and throughfall can also be proven using relative interception, such as shown in figure 14. An exponential tresshold line indicates that relatively more rain is intercepted in smaller rainfall events. A similar relation is present with the maximum rainfall intensity: the higher the intensity, the less water is intercepted.
The three different methods of measuring throughfall are assessed using the Nash-Suttcliffe method, yielding a good correlation between the three different methods. Data collection from the rain gauge can be seen as most reliable, since it is in good fit with both methods (Nash-suttcliffe coefficients around 0.9). Interception troughs do show some larger variation with respect to the tipping buckets, (Nash-Suttcliffe coefficient of 0.77), especially with larger values (figure 15). All data of rainfall,

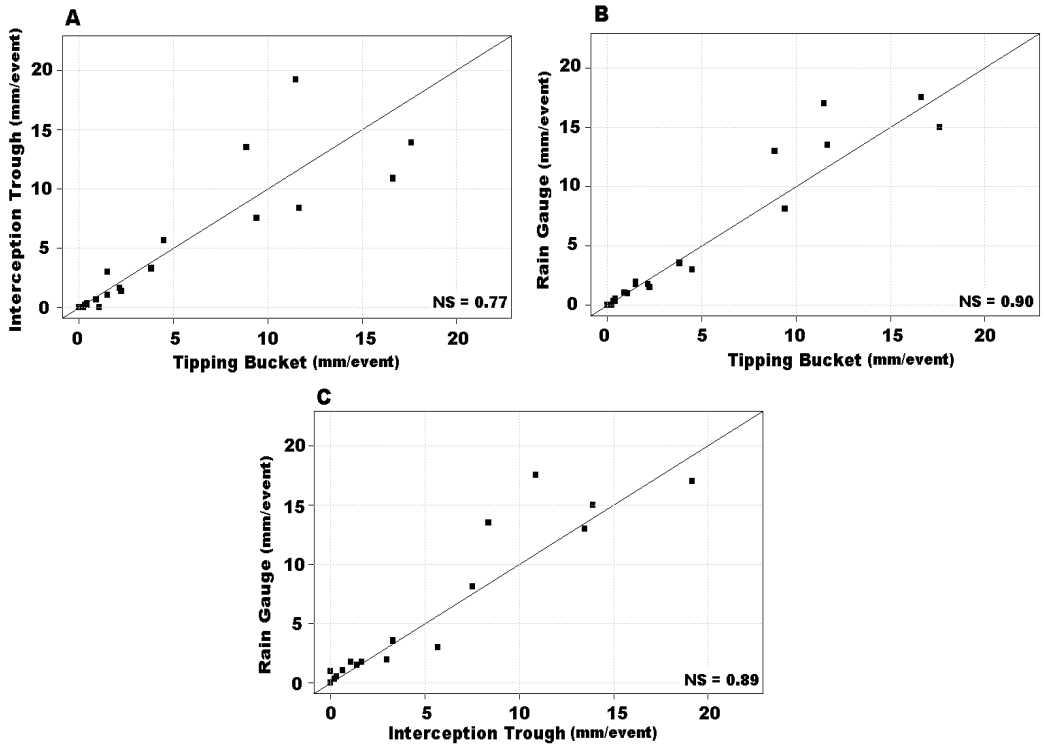


Figure 15: Relations between the three different throughfall measurement methods. Line depicts the 1:1 line and NS values are the corresponding Nash-Suttcliffe coefficients.

throughfall, stemflow and subsequent variables can be found in Appendix E.

Table 2: Stemflow data for selected periods. P_g is gross rainfall, Sf is stemflow, $Sf(\%)$ is the percentage of stemflow relative to the gross rainfall, RI_{av} and RIm are the average and maximum rainfall intensity respectively and In/P_g is the ratio of intercepted over gross rainfall.

$Period(days)$	$P_g(mm)$	$Sf(mm)$	$Sf(\%)$	$RI_{av}(mm/h)$	$RIm(mm/h)$	$In/P_g(-)$
22 - 36	28.3	2.00	7.1	1.3	6	0.41
37 - 72	26.5	2.00	7.5	2.2	9	0.23
74 - 84	21.6	0.26	1.2	3.1	12	0.53
85 - 90	19.7	0.07	0.4	0.8	5	0.57
97 - 99	18.3	0.05	0.3	2.6	11	0.53

4.3 Preliminary Results for Stemflow

It was unfortunate that during the measuring series, the stemflow device was damaged and had to be repaired. This resulted in different results between 7% and 1%, averaging to 3% of stemflow over the whole measuring interval. After recalculations of the colected stemflow over the individual rainfall events, we could calculate a percentage of the stemflow in relation to the total gross rainfall. During the first part of the study, the collecting bucket (content of 1 liter, equal to 2 mm) had overflown, which resulted in a relative stemflow of around 7% of the gross rainfall. When we took the individual events into account (as shown in appendix E) values were as high as 9%! However, since stemflow is collected over multiple rainfall events, we cannot state the exact percentage and its relation to gross rainfall. The measured stemflow was divided proportional over the gross rainfall, using relative throughflow values. After the major rainfall event on the 17^{th} of December, the collecting bucket was found on its side, without water. We did not have any measurements from the 11^{th} of November onwards, while significant rainfall events had happened in between (such as 15 mm on the 26^{th} of November and 6 mm on the 3^{rd} of December). Taking the previous measurements in account, we can assume that the bucket has been fallen due to its weight when overfilling. Since there was no signs of water flowing away from the fallen bucket and since the bucket showed a relatively dry interior, we can assume that the bucket fell some time ago. Probably the last major rainfall of the 17^{th} of December obscured the traces of streaming water. When full, the bucket yields 2 mm of stemflow. This is assumed to have been collected over all former rainfalls except the very last one (summing up a total gross rainfall of 26.5 mm). This results in a relative stemflow of over 7%, with stemflow events up to almost 9%, which is similar to earlier findings. Due to the problem of overfilling and tipping over of the collecting bucket, we changed the sytem. However, after this

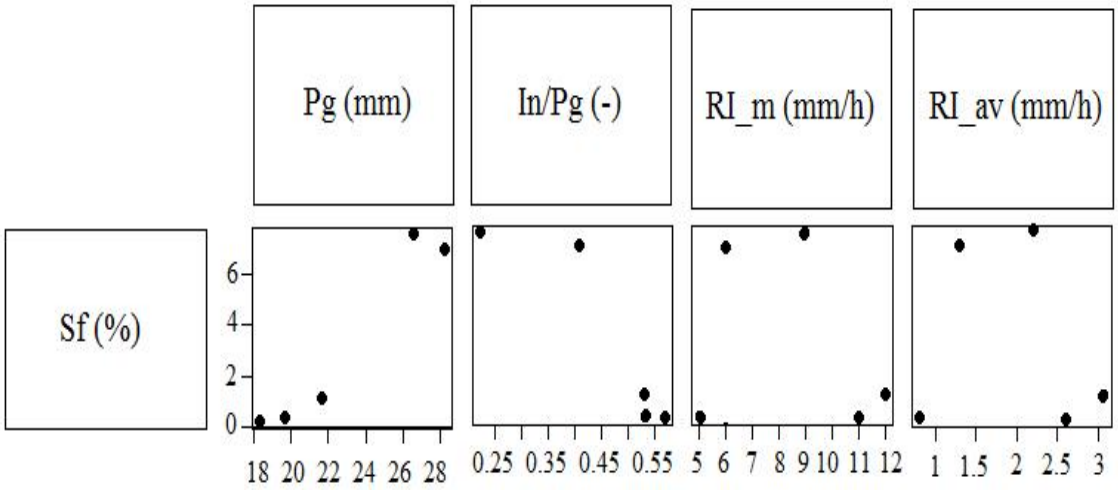


Figure 16: Plots of the different variables affecting the stemflow, data represents multiple events

operation, stemflow measurements were low and resulted in a maximum of 1% of the total gross rainfall (see table 2).
Relations between the stemflow and different interception variables have been studied, although the data set is too small to give decisive relationships (see figure 16). We do see an increased stemflow with large volumes of gross rainfall as well as with a low ratio between P_g and In. This means that whenever a rain event loses a relatively small portion in the canopy, stemflow is high. There is no clear relation with the intensity (both maximal and averaged).

4.4 Effects on Soil Moisture

Soil moisture has been measured with two sets of soil moisture probes. The SM probes were installed in June 2010 at six locations in the Spekboom and degraded lands. The validation probe set was an experimental set, which has been installed in october 2010 at two sites: one in the degraded land (Downslope) and one in the Spekboom land (Midslope).
The data from the SM probes are summarized in figure 17, which represents the data from October 2010 untill mid March 2011 and also in Appendix F. The season started extremely dry in all profiles. A major rain event triggered a first sudden increase in moisture around day 10. Only in Spekboom land this pulse is consistent and seems to keep the topsoil moist untill a next pulse. In degraded land, the moisture profile is quickly getting dry again after the event. This drying process mostly seems to happen from top to bottom, indicating the low capacity of degraded land to protect its soil. After a long period of mostly dry conditions, an extensive wet period is starting at around day 75 (17^{th} of December). The soil becomes moist over the whole profile, both on land vegetated by Spekboom or degraded. Multiple rain events happen between day 75 and day 130. These are especially clear to recognise in the Downslope Spekboom land. Except for the Midslope data, Spekboom land stays relatively wet in this period, while the degraded land is getting dry in between the rainfall events. Also after day 130, the moisture profile remains wet for at least ten days. At the Downslope location this is extended up to at least thirty days! The soil of degraded lands have become dry within five days; only at the Midslope location it remains wet up to twenty days.
We can recognise different soil characteristics in the moisture profiles. At the "Upslope Spekboom" location, moisture intrudes to a depth of 40 cm, while at the "Upslope Degraded" location, water seems to fall out of the profile to deeper depths or stay stuck at the base depth. A concentration of soil moisture can be found at a depth of 20 cm in the Spekboom vegetation, while this concentration level is found at a somewhat deeper level of 40 cm in the degraded land. The characteristic depth of approximately 40 cm in combination with a concentration level around 20 cm can also be found at the downslope locations, while at the "Midslope Degraded" moisture is concentrated at a depth of 40 cm and seems to have a bottom boundary at 60 cm. At the "Midslope Spekboom" location there is no clear concentration level; soil moisture seems to decrease linearly with depth.

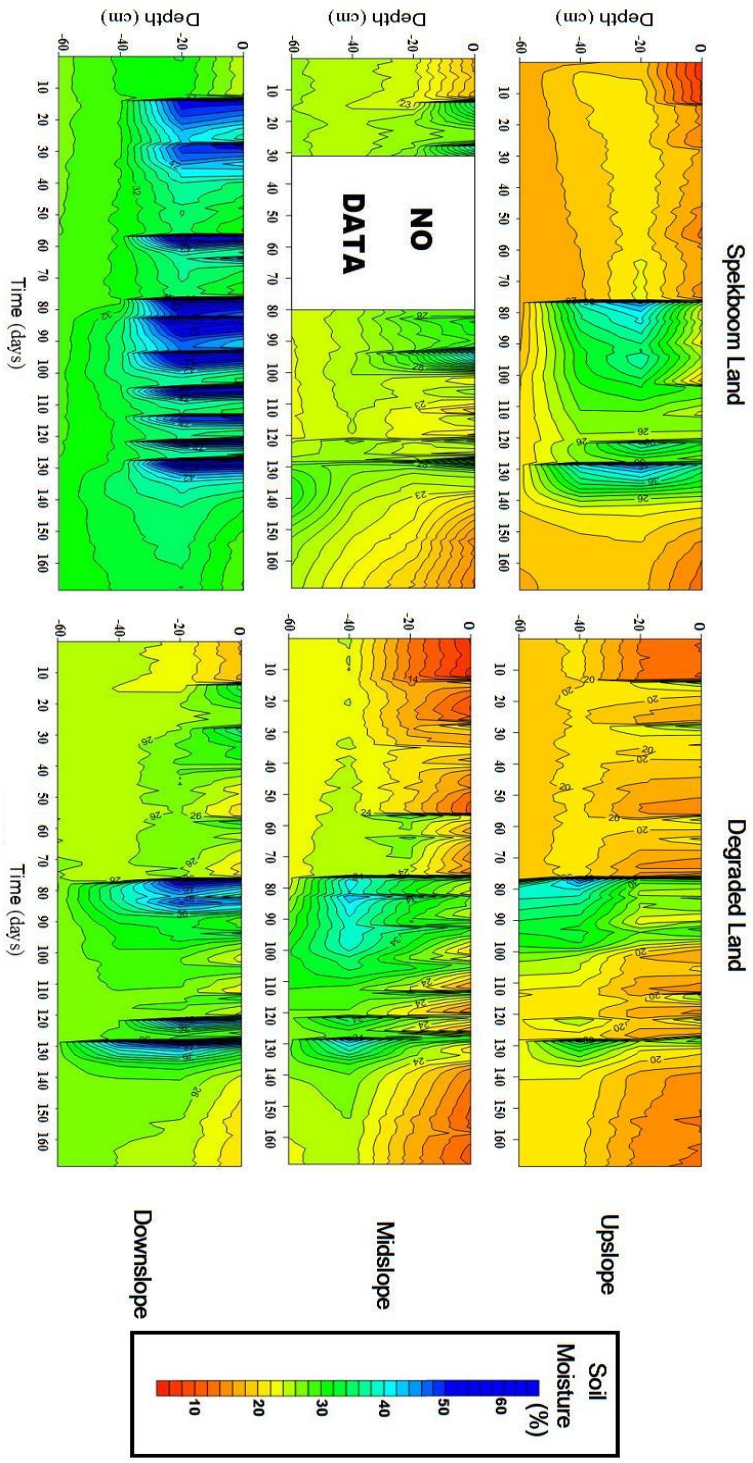


Figure 17: Plots of the soil moisture profile in time and depth. On the y-axis the depth (untill -60 cm) is indicated, and on the x-axis time in days (day 0 = 05/10/2010). Soil moisture profiles have been measured on six locations.

The most obvious differences can be found in the downslope locations. Under Spekboom the topsoil gets extremely moist changing from 25 to at least 60 - 70%. Without Spekboom vegetation the topsoil is rather dry with 17% during dry periods, and increasing to 40% or at maximum 50% during rainfall events. Deeper horizons have a similar soil moisture of around 26% versus 31% for degraded versus Spekboom land. Also during the wet period from day 75 to day 130, it is interesting to see that soil moisture often peaks during rainfalls on the Spekboom land, while the peaks are depressed on the degraded lands (figure 18). Another way to examine the soil moisture dynamics is by plotting daily differences in soil moisture content. In figure 19 the daily change in average soil moisture over 50 cm soil column is given for both degraded and Spekboom land. During rainfall events, soil moisture increases significantly. In most cases the soil moisture under Spekboom becomes more wet and a larger increase in soil moisture content is observed. A few large rain events indicate a greater increase for degraded land though. When no rain is falling, soil moisture is leaving the soil column due to evaporation and negative values are observed. Again, Spekboom land seems to distract more water from the soil, compared to degraded lands. Especially, after a rain event, this decrease can be significantly, depending on the amount of rainfall. In general, there is a constant loss of soil mositure, that is increasing in time, when wet pulses are more frequent and larger. On average there is slightly more gain than loss, due to the magnitude of some individual peaks. When we exclude these, a loss of around 0.8 mm is found for degrade, while only 0.6 mm is found for Spekboom land.

When going upslope the differences between Spekboom vegetation and the degraded land is less obvious. Due to equipment failure, an extended period of data measurements is missing at the Midslope Spekboom location. Soil moisture at a

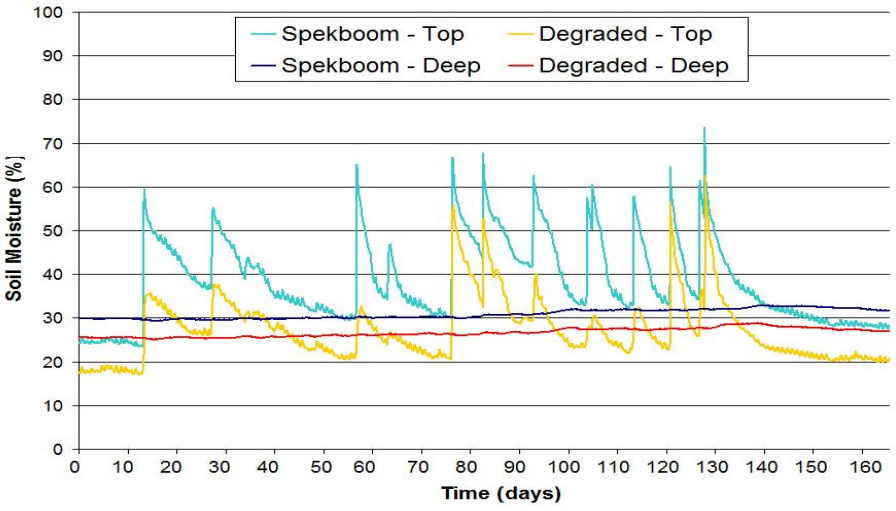


Figure 18: Graph of the shallow and deep soil moisture levels for degraded and Spekboom land in the Downslope location using SM probe

depth of 60 cm is not depending on the precense of Spekboom, having an average soil moisture of 25%. In the topsoil, conditions are somewhat more moist under Spekboom: 20 to 35% versus 5 to 20%. However, during the persisting rains after day 75, soil moisture in the degraded land is increasing to values as high as and even exceeding the values under Spekboom. Especially at a depth of around 40 cm soil moisture is much higher than under Spekboom vegetation (see discussion regarding soil moisture profiles above). At the very end of the data series, soil moisture of Spekboom land finally seems to stay consistently above the values for degraded land.

Where slopes are steepest and soils are thin, we find similar moisture profiles for the degraded and Spekboom land. Soil moisture at depths of 60 cm is found to be a little bit less on Spekboom land (15 to 20% instead of 20 to 25%). This trend is also found in the topsoil, having a average moisture content of around 7 versus 12% in dry periods, increasing to 25 versus 30% during rainfall events for the Spekboom versus the degraded land. The rain events between day 100 and 130 result in somewhat higher moisture levels for Spekboom, up to 50 %. At a depth of 20 to 30 cm, the soil moisture is consistently higher under Spekboom vegetation: around 35 a 40% versus 25 a 30%. From a depth of 30 cm and deeper, soil moisture profiles are similar again and more often higher in the degraded lands (especially at the 50 cm depth level).

The experimental probes can be used for validating the data of the SM probes. Sadly, the probes were not able to gather data over extended time spans, but they did give reliable and clear data on short time scales. Figure 20 shows the evolution of the soil moisture in the topsoil and deep soil. From this data, it can be seen that the soil is in general three times more moist under Spekboom, compared to degraded land. Furthermore, the sudden increase in soil moisture after a rain event is much more pronounced in Spekboom land. An increase from 15 to 45% can be recognised in the topsoil under Spekboom, while the topsoil of degraded land only increased

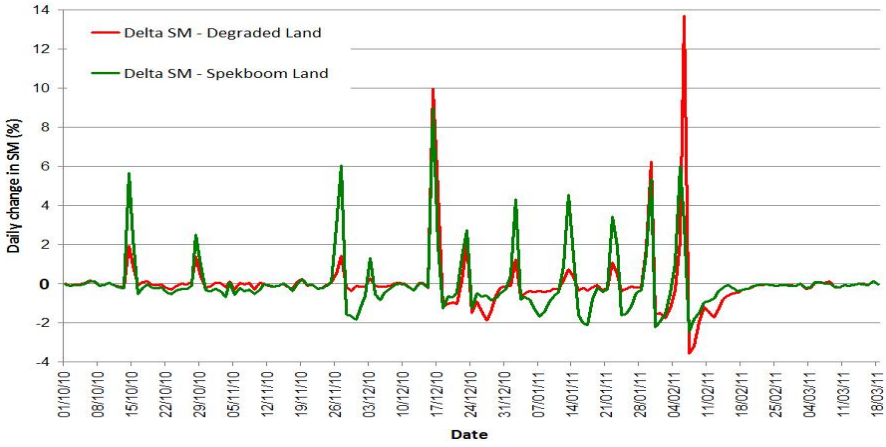


Figure 19: Change in soil moisture content (percentage soil water) from 1/10/2010 to 13/03/2011

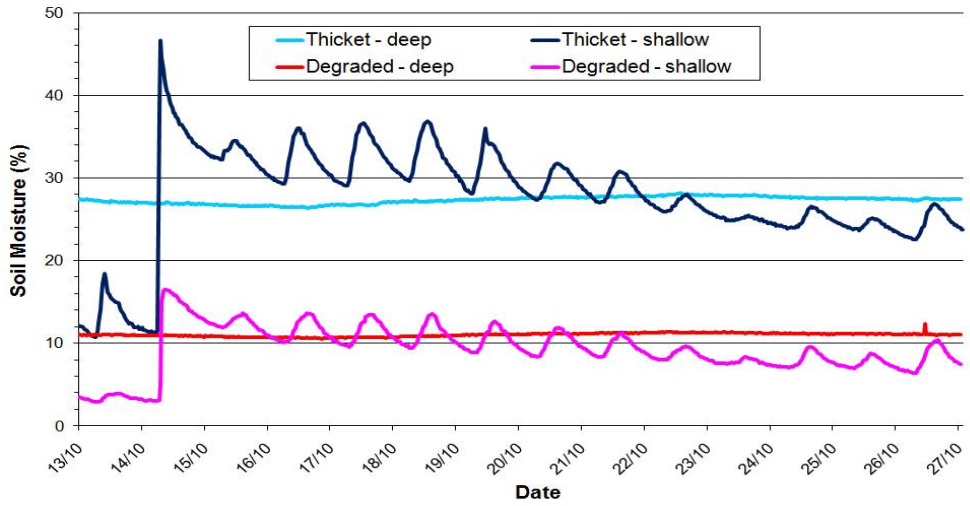


Figure 20: Soil moisture measurements taken by the experimental soil moisture probes between 13 and 19 October 2010, during a rainfall event on 15 October.

from 4 to 16%. After a relaxation period of nine days, soil moisture lowered to 26 versus 8% for Spekboom versus degraded land. At a depth of 50 cm, the probes measure a stable soil moisture of almost 30% under Spekboom vegetation and just over 10% below degraded lands.

4.4.1 Infiltration and Soil Type

For a better interpretation of the soil moisture data, tests on the infiltration capacity have been done. The first couple of tests have been done below Spekboom plants. The soil below the Spekboom has a thick cover of litter (> 5 cm) on top of humid black-grey fine sand, with many rather big rocks in it. An extremely rocky interval marks the difference to brown sand at a depth of 45 cm. Roots extend to a depth of at least 35 cm. The soil profile at the degraded lands is totally different:there is no litter, but a hard crusty topsoil. The soil is a brown chalky loam until a depth of 25 cm, after that it becomes really hard and a more whitish, brown chalky loam, with many rocks. There are less roots, which are also smaller compared to the ones found below the Spekboom. They penetrate to a depth of 30 cm. When applying the minidisc infiltrometer, degraded soil forms an extra crust and only wets the first centimeters, below which the soil stays dry. Temperature fluctuations are moderated under Spekboom vegetation, where the topsoil reached maxima around 30 ℃ and minima around 16 ℃ versus 36 ℃ and 14 ℃ respectively in degraded land. Deep in the soil temperatures are generally a little bit cooler for Spekboom land.
The result from the infiltration tests show a clear difference between Spekboom and degraded lands. Infiltration rates measured under Spekboom vegetation are between 26 to 29 mm/h, averaging 27.5 mm/h. Rates of infiltration are much smaller for degraded lands, where measurements in the same conditions yielded an average rate

of only 0.2 mm/hr! However, a previous trial resulted in a rate of almost 10 mm/h, but this was carried out during dry conditions. The five infiltrations tests can be found back in Appendix H.

4.5 A Bit on Runoff

A series of Gerlach troughs have been installed to give an indication of the runoff at the degraded lands and the Spekboom land. At the six locations, three Gerlach troughs have been installed. These have been measured during a period of three months (from 15 november 2010 untill 15 January 2011). The troughs were ready to measure from the first of November onward and thus the presented data is the first information available. From figure 21, it is clear to see that most runoff has been measured in the downslope troughs, while for midslope and upslope locations values are considerably lower (less than 10% of the downslope location). At all locations the runoff from the degraded land is higher compared to the Spekboom land, especially at the Downslope location. At the Downslope location, one finds a ration of 1 : 2.44 for Spekboom versus degraded land. This ratio is much smaller for the other locations: 1 : 1.45 and 1 : 1.04 for Upslope and Midslope location respectively. Water collected in the Gerlach troughs on the degraded lands is in general much darker and filled with sediment, while runoff from the Spekboom land is relatively clear. All data of the runoff variables can be found in Appendix G.

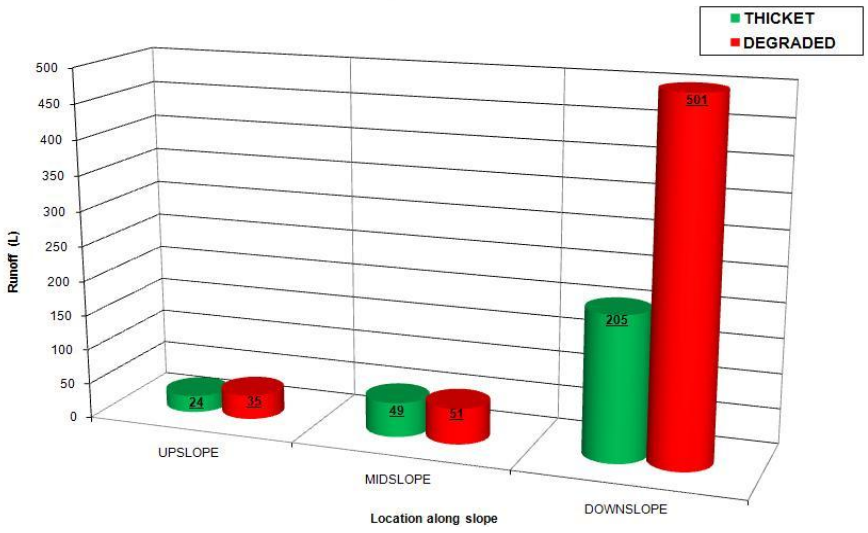


Figure 21: Indications for runoff at upslope and downslope locations, as measured with Gerloch troughs from 15/11/2010 to 15/01/2011

4.6 Integration

Integration of the different hydrological fluxes has been done in two ways. The first approach entails the application of the GaIn3a model, which is based on the Gash model coupled to a simple infiltration method. The information from the measurements and from the GaIn3a model are then used to set up a simple water balance.

4.6.1 Results from the GaIn3a Model

Model runs were done using the total set of data and with two subsets of the same data for verification pruposes. Data for rainfall, throughfall and stemflow dynamics have been adapted from Appendix E, with the exclusion of the rain event on the $17th$ of December, since there is no reliable data on this event, and all data from 2011. In figure 22, the fluxes of throughfall, interception and stemflow are shown. All fluxes together make up the gross rainfall. Using the Sparse Gash model, these hydrological fluxes can be modelled quite reliable. When using the total data set for both the calibration and verification, we use the following parameters as defined by Gash et al. (1995) and for the infiltration part:

Gash part:		
c	Canopy cover	0.742
$\overline{P}$	Average precipitation	5.721 mm
Ec	Average canopy evaporation	1.823 mm
Sc	Canopy storage coefficient	1.480
P'_g	Threshold precipitation for canopy	1.782 mm
Infiltration part:		
SI_{spek}	Threshold rain intensity - Spekboom	27.3 mm/h
SP_{spek}	Threshold rainfall - Spekboom	10 mm
$SI_{deg}r$	Threshold rain intensity - Degraded	3.3 mm/h
SP_{degr}	Threshold rainfall - Degraded	5 mm

The sparse Gash model performed better compared to the original Gash model. The cummulative difference between model and observation for interception adds up to around 132% of the observed value for the sparse Gash model, compared to 159% for the original Gash model (figure 23). Similar values are found for the throughflow with 86% versus 69% of the observed value for sparse and original Gash model respectively (figure 25). When calculating Nash-Sutcliffe coefficients, we find the same results, a better fit is present in the sparse Gash model (NS=0.92 for throughfall), compared to the original Gash model (NS=0.73 for throughfall). This validation is graphically shown in figure 24 and 26, which shows a tendancy of the model to overestimate the interception and underestimate the throughfall.
The coupled infiltration model uses the gross rainfall to calculate overland flow. This results in 17 mm (17%) and 40 mm (41%) of runoff (RO) over 97 mm rainfall for the Spekboom and degraded land respectively. The runoff ratio (RR) is 1 : 2.40 for Spekboom versus degraded land. However, for the Spekboom land the throughfall

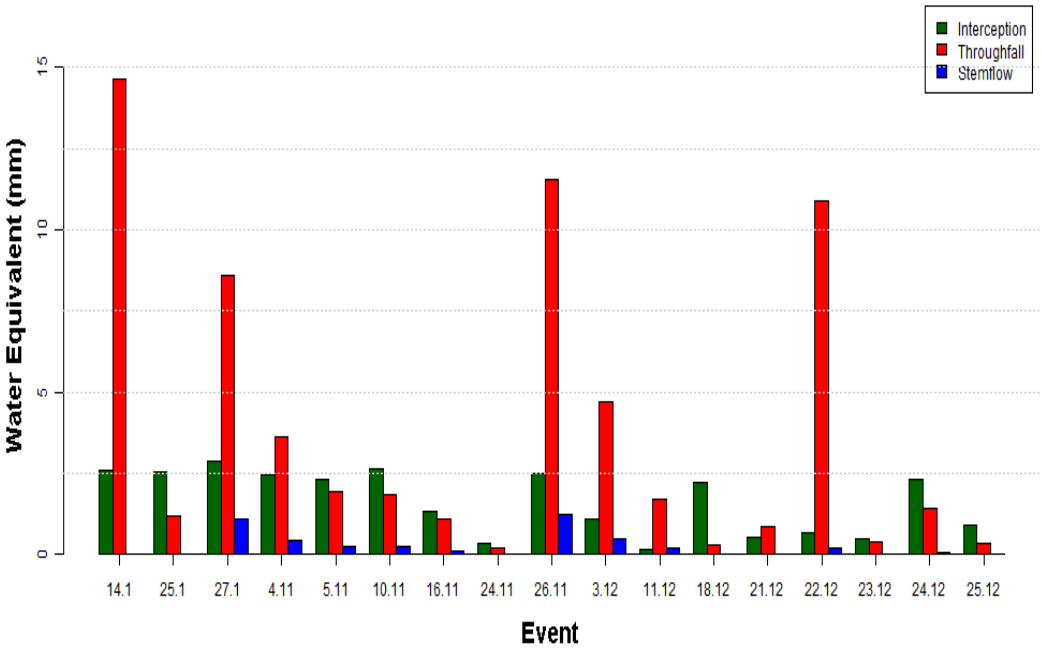


Figure 22: Rainfall, throughflow and stemflow measurements combined

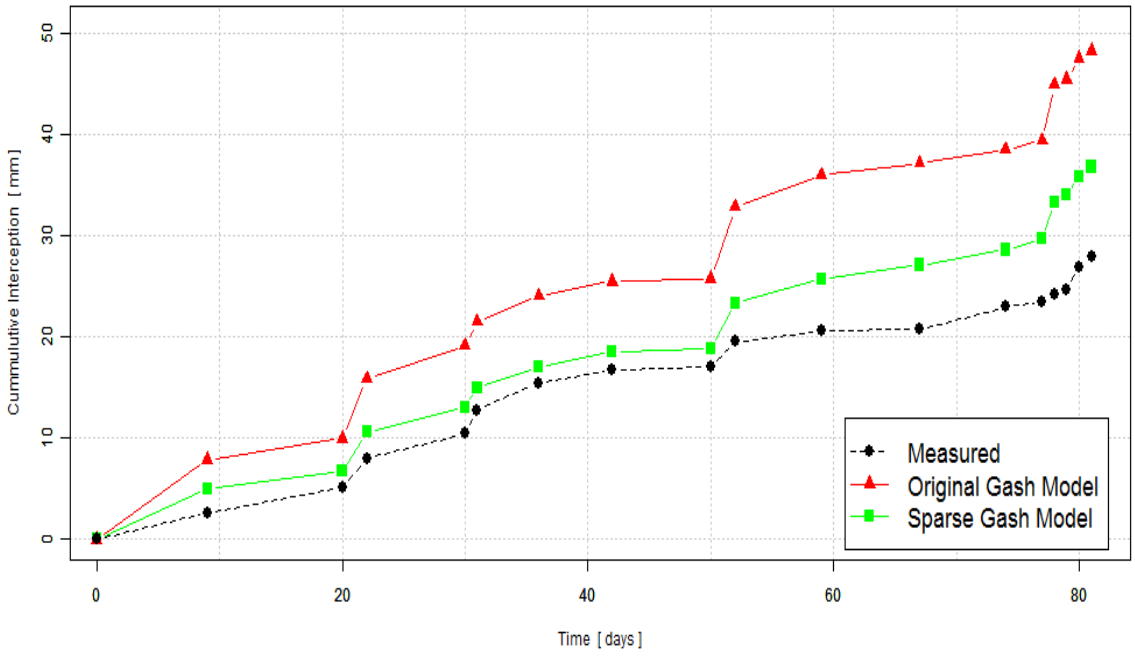


Figure 23: Modelled Interception

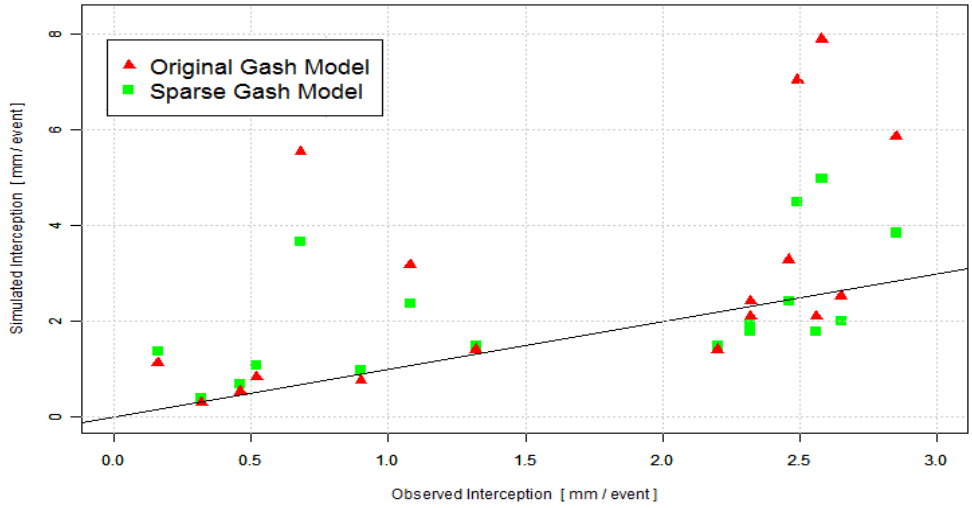


Figure 24: Validated Interception

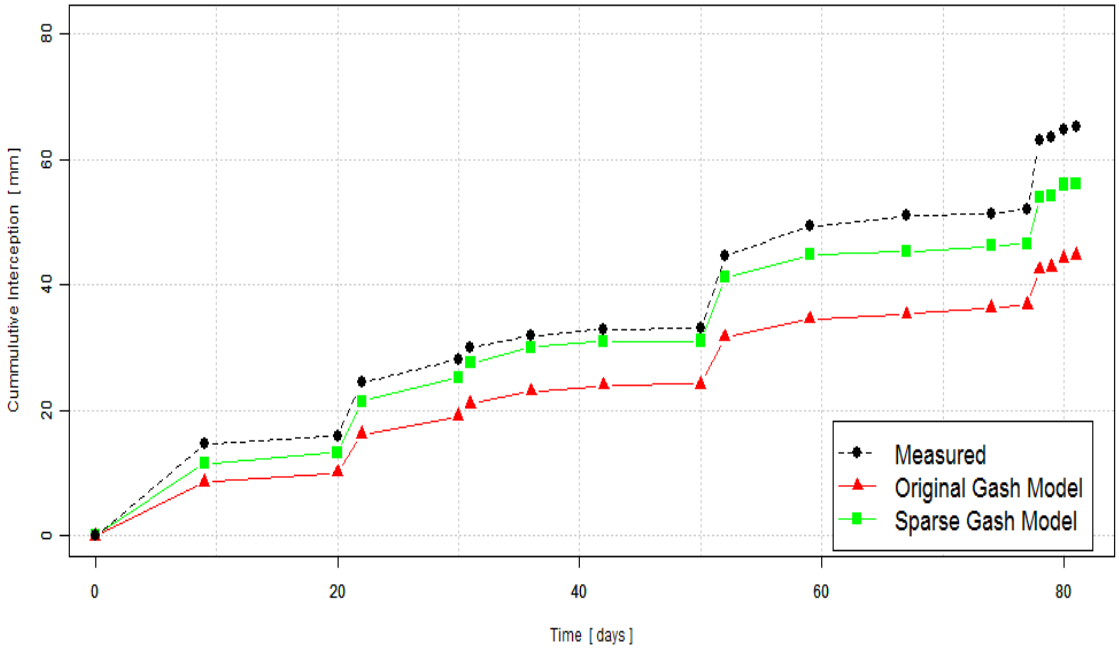


Figure 25: Modelled Throughfall

will be the actual net rainfall, instead of the gross rainfall. When we use this value (65 mm), only 7 mm (11% of P_{eff}) is runoff. Coupling with the Gash model, using its modelled throughfall (56 mm) results in virtually no runoff: less than 2 mm (3% of P_{eff})! Of course the runoff ratio will subsequently increase dramatically (1 : 5.7 and 24.7).

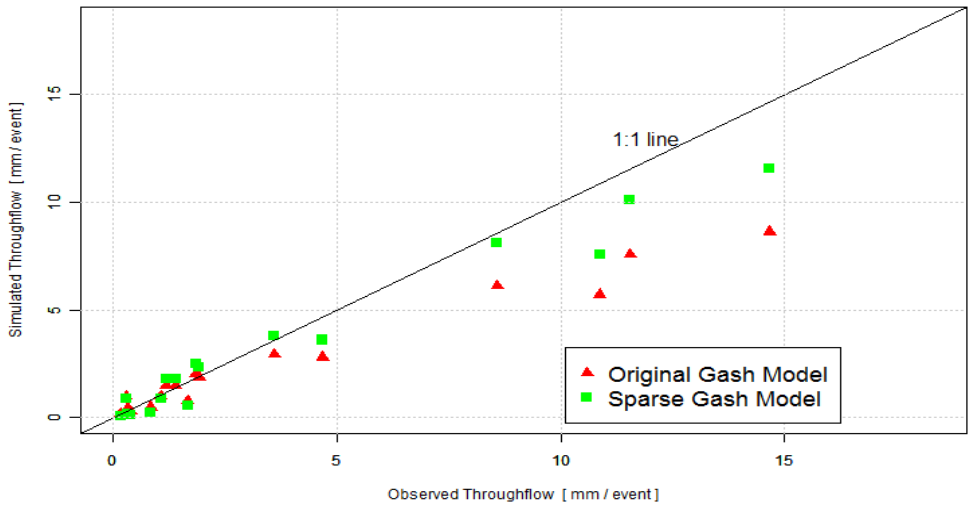


Figure 26: Validated Throughfall

Infiltration is calculated as the left over from the rainfall and the runoff. When not taking into account the interception of the Spekboom, 83% of the rainfall is available for infiltration, compared to 59% for degraded land. When we take the interception into account we find similar percentages of the net rainfall: 89% of the net rainfall is available for infiltration in Spekboom land, while in degraded land this is 56%. Relative to the gross rainfall this results in 60% and 54% for Spekboom versus degraded land. Table 3 gives an overview of these values.

The data set was divided in two equal subsets, selecting similar number of rain

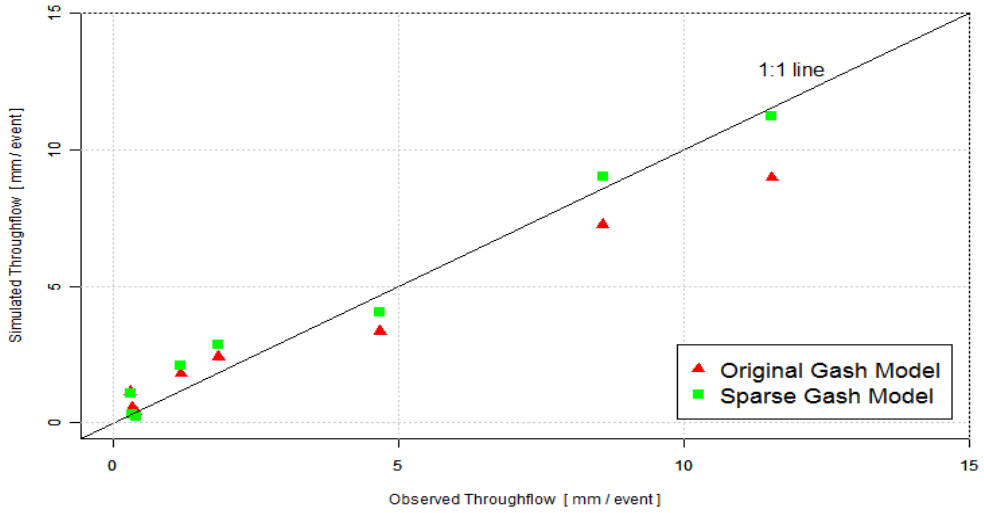


Figure 27: Validated Throughfall for the second subset

Table 3: Main model results. All percentages are relative to gross rainfall and the throughfall in degraded land is calculates being 95% of the gross rainfall.

Variable	P_{eff} (mm)	$(\%)$	RO (mm)	$(\%)$	I (mm)	$(\%)$	RR $(-)$
Degraded P_g	97	100	40	41	57	59	1:2.40
Degraded Tf	92	95	38	39	54	54	1:5.36
Spekboom P_g	97	100	17	17	81	83	1:2.40
Spekboom Tf	65	67	7	7	58	60	1:5.36
Spekboom Tf_{sim}	56	58	2	2	49	50	1:24.7

events with similar magnitudes. One of the sets was used to calculate the model variables, while the other subset was used to validate the model. Figure 27 shows the modeled data versus the observed throughfall. It shows a similar pattern as observed when using the total data set. Nash-Sutcliffe coefficients are in around 0.98 and 0.91 for the sparse and original Gash model respectively. The number of events used was nine.

4.6.2 Water Balance

Before going into the water balance, it is usefull to examine the connection between the different fluxes. Due to the nature of the measurements, runoff data from the

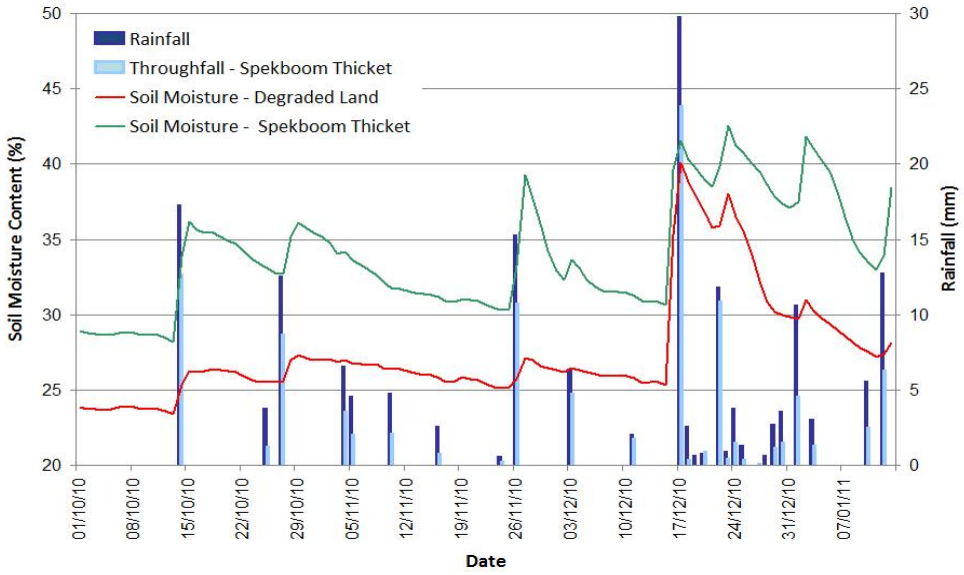


Figure 28: Time series of soil moisture content for both degraded and Spekboom land in relation to the net rainfall on degraded land (= rainfall) and Spekboom land (=throughfall)

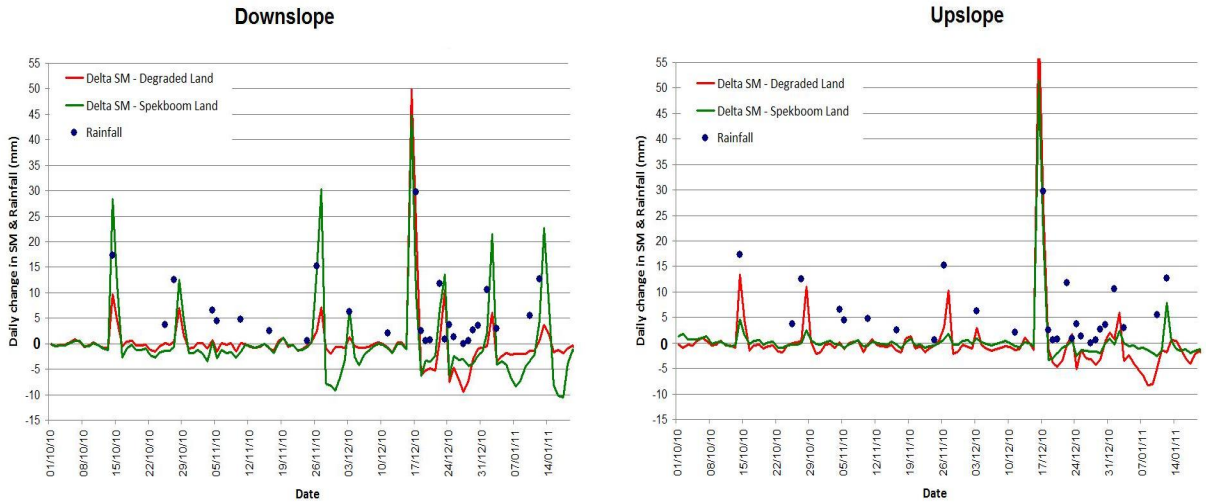


Figure 29: An impression of the effect of rainfall on the change in soil moisture for downslope and upslope locations (rainfall are discrete values, while soil moisture is continue values!)

Gerloch troughs are not applicable in the analysis, since this data is not expressed in unit area and unit volume. Integrating the rainfall data into the soil moisture does give interesting insights. In figure 28, data from the tipping buckets and the SM probe on the downslope location are combined. With significant rain events of at least 10 mm, the soil moisture increases in both Spekboom and degraded land. In general, soil moisture peaks are higher for the Spekboom land, except for the rain event of the 17^{th} of December. After this event, soil moisture is quickly decreasing in the degraded land, while under the Spekboom vegetation it remains stable for at least two more weeks. During this period it remains wet, with some significant rain events. Despite the relatively high interception, more water seems to infiltrate the soil under the Spekboom, compared to the degraded land, which has the total gross rainfall collected.

When we use the daily difference in soil moisture, we find the same story: slightly more water is infiltrating the soil in the Spekboom land compared to the degraded land. Although the change in soil moisture has been calculated in unit lenght, it is still difficult to compare it with the rainfall, which is also measured in unit lenght. There are still quite some situation where rainfall is less than the soil water. Nevertheless, values do not differ with multiple orders of magnitude, but seem to be in the same scale. The negative values for the change in soil moisture are an indication of evapotranspiration. When taking the average there is more evapotranspiration on degraded land compared to Spekboom land (see also results above). This is however mostly caused in the second half of the data series during the wet period, where clear peaks in soil moisture loss are recognised. For the upslope location, there is more water available from rainfall, than there is infiltrating; this means that there

	Pg	In_spek	RO_spek	I_spek	In_degr	RO_degr	I_degr
J	26	6.0	3.5	16.5	1.3	10.5	14.2
F	38	5.9	5.5	26.5	1.9	15.4	20.7
M	40	5.8	5.9	28.3	2.0	16.2	21.8
A	22	5.8	2.8	13.4	1.1	8.9	12.0
M	22	5.8	2.8	13.4	1.1	8.9	12.0
J	12	4.4	1.3	6.3	0.6	4.9	6.5
J	15	5.0	1.7	8.3	0.8	6.1	8.2
A	20	5.6	2.5	11.9	1.0	8.1	10.9
S	18	5.4	2.2	10.4	0.9	7.3	9.8
O	22	5.8	2.8	13.4	1.1	8.9	12.0
N	34	6.1	4.8	23.1	1.7	13.8	18.5
D	30	6.1	4.1	19.7	1.5	12.1	16.4
TOTAL	**299**	**67.8**	**40.0**	**191.2**	**15.0**	**121.0**	**163.0**
Percentage of P		23	13	64	5	40	55

Figure 30: The monthly water balance for Spekboom (...spek) versus degraded (...degr)

is water available for runoff or deep percolation. At this location, it is also striking that water seems to infiltrate the degraded land better than the Spekboom land (figure 29).

Keeping the observations of soil moisture and rainfall in memory, it is now more easy to interpret the data from simple water balance calculations. The first step is to indentify what part of the rainfall is intercepted, runoff or infiltrating. Monthly rainfall data over the last decade (http://www.wunderground.com/history/wmo/68832) is used for this. Interception is taken to be 5% of the rainfall on degraded land and is using equation 4 from fig 13 for Spekboom land. Runoff is taken also taken as a fraction of the rainfall: 0.17 for Spekboom and 0.42 for degraded land (see table 3). The infiltration is the result of the rainfall minus the sum of interception and runoff. Results are shown in figure 30. These indicate that although Spekboom is intercepting a significant portion of the rainfall (23%), there is still more water

	Pg	Etp	Etm_spek	W_spel	ET_spek	Yc_spek	Etm_degr	W_degr	ET_degr	Yc_degr
J	26	150	97.5	9	28	29	82.5	10	25	30
F	38	120	72	26	9	12	60	22	9	15
M	40	106	53	35	20	38	53	27	17	32
A	22	74	29.6	33	15	50	29.6	28	12	39
M	22	55	16.5	39	8	48	16.5	33	7	40
J	12	49	12.25	38	7	56	9.8	35	5	47
J	15	51	10.2	41	6	55	7.65	39	4	50
A	20	57	14.25	45	8	59	11.4	44	6	56
S	18	76	22.8	41	15	64	19	42	12	63
O	22	103	41.2	30	24	58	41.2	29	25	60
N	34	123	61.5	27	26	43	61.5	22	26	42
D	30	134	80.4	16	31	38	67	17	21	32
TOTAL	**299**	**1098**	**511.2**	**32**	**195**	**46**	**459.15**	**29**	**167**	**42**
Percentage of P		**3.67**	**1.71**		**0.65**	range:	**1.54**		**0.56**	range:
						12 -- 64				15 -- 63

Figure 31: The monthly evapotranspiration and vegetation stress for Spekboom (...spek) versus degraded (...degr)

available for infiltration (64% versus 55%). This is mainly due to the high runoff in degraded land (40$ versus 13%).
A second step in the balance is to establish the evapotranspiration for Spekboom and degraded land. This evapotranspiration will use the infiltrated water, calculated in the first step. Evapotranspiration for the Spekboom and degraded land have been calculated using the potential evapotranspiration from Jansen (2008) times a monthly crop or vegetation factor. Potential evapotranspiration is almost four times more compared to the amount of rainfall. When we introduce the monthly vegetation factor the vegetation still needs more water compared to the available rainfall: 1.71 more for Spekboom and 1.54 more for degraded land. The actual evapotranspiraton (ET) is taken as the minimum of antecedent soil moisture (W_{i-1}) plus infiltration (I) and the ratio of antecedent soil moisture over maximum soil moisture (taken to be 70%) times the potential evapotranspiration. The soil moisture is subsequently taken as the minimum of the maximum soilo moisture and the product of antecedent soil moisture plus infiltration minus evapotranspiration. The vegetation yield or stress (Yc) is taken to be the ratio between actual and potentional evapotranspiration. When working out these rules, one obtains the table in figure 31. The main results from this simple approach are a higher soil moisture (32% versus 29%) and a lower vegetation stress (46% yield versus 42% yield) for Spekboom land. Furthermore, actual evapotranspiration for Spekboom is relatively high with 65% versus 56%. These values have been calculated for an average year. However, when doing the same exercise for individual years, we find small differences. A problem came up when using equation 4 for months with extraordinary rainfall amounts.

5 Discussion

Efforts to restore the degraded landscape of the Baviaanskloof involves the large scale planting of Spekboom in valleys and on hill slopes. Revegetation will decrease erosion and direct runoff, but many studies also show that there will be a decrease in baseflow, resulting in dried up streams. These studies are often based on cases of invading vegetation or extensive reforestation. However, it is unclear what effect Spekboom revegetation will have on the Baviaanskloof River Catchment. Knowledge is lacking about interception rates, soil moisture evolution below Spekboom and the amount of decrease in runoff. A monitoring site is set up to measure these major hydrological fluxes. The first results have been presented in this report and are put in the complete framework of other studies during this discussion. Results are discussed comparing to previous research and equipment specifics. First the results from the rainfall-interception system is looked upon, followed by soil moisture data and finally the runoff data is discussed. The chapter will conclude with a little overview on the model results and how to improve the use of models with which data to be measured and collected.

5.1 About Vegetation and Interception

5.1.1 Vegetation Definitions

Spekboom thicket has been described by Powell (2009) as follows: "a dense impenetrable, closed, evergreen, low cover". These characteristics have been observed in intact thicket by the author at several places in the Baviaanskloof, but does apply somewhat less on the monitoring site used in this research. The monitoring site was partly degraded and showed several open patches, exposing the soil surface or a sparse cover of perennial grasses and karroid shrub. This type of landscape is defined to be "transformed succulent thicket" (Lechmere-Oertel, Kerley and Cowling, 2005). Canopy cover is one of the most important factors for plant description and was measured using the binary image method. This method has been approved by Avsarm and Ayyildiz (2010), but is seen as an estimate for canopy closure, instead of canopy cover by both Korhonen et al. (2006) and Paletto and Tosi (2009); the difference however is very subtle. The canopy cover of 75%, measured in this study, can be seen as reliable and compares to dense Eucalyptus stands with a cover of 60% (Valente et al., 1997) and earlier measurements on Spekboom ranging between 70 % (Mills et al., 2005) and 93% (Mills and Cowling, 2006). These results have been estimated on individual plants, which is in comparison to the study by Cowling and Mills (2011), who also used Spekboom clumps, with similar dimensions (see also Mills et al. (2005)). On the landscape scale the value will be much lower (Bochet et al., 1998, Lechmere-Oertel et al., 2008). It can be concluded that the thicket used in this research has been less evolved and more degraded and this has to be taken into account; a lower interception rate and less effects on soil moisture can be expected.

5.1.2 Interception Losses

In this study we found an average value around 39.4% of gross rainfall that does not reach the ground, but is intercepted. This is a substantial loss. With minor rainfall events below 4 mm, this is actually 55%, while more siginificant rainfall yield a interception of 35%. These values are slightly less compared to former study on Spekboom interception, which yield an average of 43.6% (Cowling and Mills, 2011). In this previous study, it has been assumed that stemflow is less than 1% and can therefore be neglected. However, results from the present study suggest stemflow can be as much as 9% and average 3% of the gross rainfall.

When we compare these rainfall dynamics with other studies, it can be concluded that Spekboom has a relatively high interception rate. Despite the many studies on rainfall-runoff systems in Mediterranean shrublands, not much in-depth research has been done concerning its hydrological effect (Luijk, 2010). Some measurements have been done in Mediterranean Maquis and resulted in slightly lower values: interception was between 26% and 40%, while stemflow was measured between 4% and 8% (Baloutsos et al., 2009). Another study done on Mexican shrublands gave interception rates of 22% and stemflow between less than 1% up to 7% (Návar et al., 1999). When we compare these values to interception rates found in forest areas, we find that forests result in a larger throughfall between 73% and 88% (see table 4). This includes both the deciduous Northern hemisphere forests (Herbst et al., 2008, Carlyle-Moses and Price, 1999, Boedt, 2010), tropical forests (Cuartas et al., 2007), Mediterranean pine forests (Valente et al., 1997, Llorens et al., 1997) and Mediterranean deciduous forest (Valente et al., 1997, Gash et al., 1995, Wilcox et al., 2006), although for Mediterranean deciduous forest in Slovenia, Sraj et al. (2008) find somewhat higher values of 28%. Shrub dynamics are totally different to forest dynamics however. Some exceptions are found, but these are difficult to compare to Spekboom and mainly discuss individual trees (Owens et al., 2006, Pereira et al., 2009, Gomez et al., 2002). These examples deal with individual species found in Mediterranean climates, which therefore once again indicates the vegetation adaption to this special environment. The value found for stemflow in this study is similar to other studies, but needs further research, since the data is clearly divided in two data sets of different character.

The relations between interception, throughfall and gross rainfall shown in this study cannot be seen as particularly evident. A Nash-Sutcliffe coefficient was found to be below 0.90, which is still quite close to a one-to-one relationship which results with a result of 1. Nevertheless, it is much less compared to the relations found by Baloutsos et al. (2009), Herbst et al. (2008) and Pereira et al. (2009), who found values close to 0.99. On the other hand, they do compare with Návar et al. (1999). In this study a weak relation was found between the relative interception and the gross rainfall or rain intensity (see figure 14). In this figure, a few outliers can clearly be recognised, that fall above the limit line. These points are however values, based on only a part of the data sources (end of the data logging, when most of the tipping bucket stopped measuring). David et al. (2006) and Llorens et al. (1997) found similar patterns, but more pronounced (figure 32). This could also be due to an

insufficient amount of rainfall data.
Some studies also mention relationships with stemflow. In the present study there is one with the gross rainfall and slightly with the In/P_g, while there is no relation with the rain intensity. Baloutsos et al. (2009) also recognises the gross rainfall as the

Table 4: Rainfall dynamics of the current study compared to previous results from previous studies

Study	Interception (%)		Throughfall (%)		Stemflow (%)	
	mean	range	mean	range	mean	range
This study **- *Spekboom***	**39**	**-**	**61**	**45 - 65**	**3**	**<1 - 9**
Cowling and Mills (2011) - *Spekboom thicket*	44	37 - 51	56	49 - 64	<1	-
Baloutsos et al. (2009) - *Maquis*	-	26 - 40	-	56 - 65	-	4 - 8
Návar et al. (1999) - *Mexican shrub*	22	-	78	-	3	<1 - 7
Pereira et al. (2009) - *Mediterranean oak*	27	-	73	-	-	-
Gash et al. (1995) - *Savannah oak*	12	-	88	-	<1	-
Valente et al. (1997) - *Pine tree*	17	-	83	-	<1	-
Valente et al. (1997) - *Eucalyptus stand*	10	-	88	-	2	-
Carlyle-Moses and Price (1999) - *Canadian hardwood*	19	-	77	-	4	-
Boedt (2010) - *USA hardwood*	-	11 - 12	85	-	-	3 - 4
Owens et al. (2006) - *Arizona Juniper*	40	10 - <100	60	-	-	-
Sraj et al. (2008) - *Mediterranean Deciduous*	27	19 - 40	69	60 - 94	4	2 - 5
Herbst et al. (2008) - *European hardwood*	25	20 - 29	73	70 - 77	2	1 - 4
Cuartas et al. (2007) - *Tropical forest*	-	13 - 22	-	78 - 87	<1	>1?
Gomez et al. (2002) - *Olive tree*	53	29 - 76	47	24 - 71	3	<1 - 10
Dunkerley and Booth (1999) - *Australian Grass*	30	-	70	-	-	-

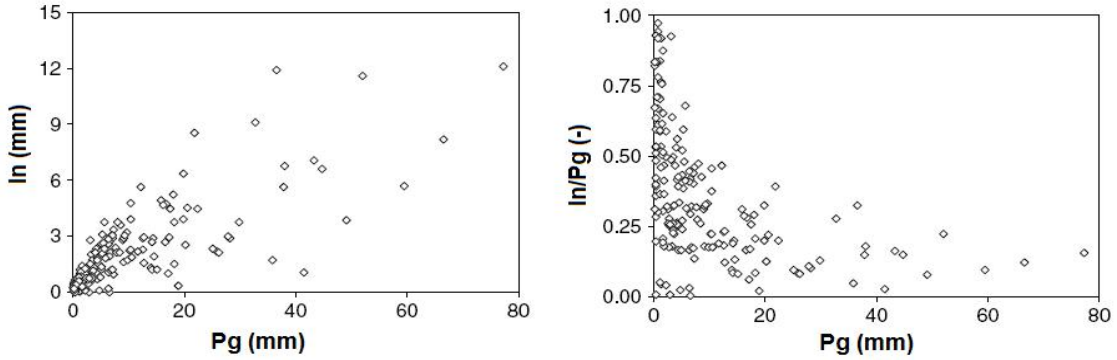


Figure 32: Interception (left) and Relative Interception (right) as a function of gross rainfall according to David et al. (2006)

main factor for stemflow. Together with rain duration, wind speed and maximum rain intesity, an equation is formed to calculate stemflow, which actually results in a Nash-Sutcliffe of 0.96. This is slightly lower compared to throughfall and interception. A similar relation has been found by Herbst et al. (2008), who finds equations for stemflow using only gross rainfall, resulting in a Nash-Sutcliffe coefficient around 0.80 to 0.92 (leafed versus leafless period). Also the stem character (smooth versus rough), canopy architecture, canopy cover, stem diameter and height play an important role for stemflow (Návar et al., 1999), but could not been proven in this study due to a lack of measurements. Concluding, we find that Spekboom has an interception rate of 40%, which is relatively high. Results form stemflow analysis (averaging 3%) are similar to other studies. Interception and stemflow are mainly governed by gross rainfall and in some extend by rain intensit; a limited amount of data makes it difficult to make ultimate conclusions.

5.1.3 The Power of Equipment

The most important problem during the field trips are the precense of baboons. These inquisite animals do not leave equipment alone and like to play with them. Special fencing was needed to keep the equipment save for them, but even this did fail in one location, where baboons broke down one of the receivers of the tipping bucket. The fencing resulted in some disturbances for the equipment: due to top fencing, extra rain is intercepted; the absence of animal activity caused the growth of grass around the buckets. Besides the monkeys, tipping buckets, weather stations, throughfall troughs, manual rain gauges and stem collars disfunctioned sometimes. The problems differed from one type to the other. The tipping buckets stopped measuring whenever the data logger was overloaded. Another problem happened when the Spekboom started flowering and the little hole in the bucket got cemented due to pollen. This was very peculiar, since litter fall was expected to be problematic, due to its high amount; pollen were never thought of posing a problem at a short time interval. Cleaning the buckets every month seemed to be sufficient regarding

the litter fall, but not the pollen. Not only did the site experience many inconveniences and equipment failures, the data gathered is also of such novelity that it may raise questions regarding previous studies. More technical problems concerned the material malfunctioning due to insufficient knowledge, calibration defects and human error. Since results are presented in a series of counts per hour, it is still the user who has to define which counts are from the same rainfall event, or wether we need multiple rainfall events. In combination with the weather station, it appeared that the weather station was always measuring much too little rainfall (often more than 35% less). When trying to calibrate this problem was confirmed, but no further calibration was done. Throughfall troughs and the manual rain gauge suffered similar problems. Since they were not fenced in, animals sometimes moved them around. Nevertheless throughfall troughs are often seen as the most reliable way of measuring (Cuartas et al., 2007). Furthermore, the troughs are positioned underneath uniform Spekboom vegetation, which will represent the real interception best. The interception values given above might thus be slightly more, approaching the data from Cowling and Mills (2011) even closer. The stem collar measurements are clearly divided in two seperate data sets. Was the problem in the start of the measuring period, that the bucket was too small, later on it seemed that there was no bucket needed at all, since the stemflow was so small. The difference appears at the moment, the collar was glued anew and a new bucket was installed. It might have happened that the first bucket was too open and throughfall from the Spekboom filled up the bucket. On the other hand, the tube might have been damaged, filling up with glue, when we tried to repair the collar. New measurements series are needed to solve this issue.

Next to these problems regarding the seperate measuring methods, there are also more general problems, such as the positioning of the collectors. This is not different to other studies and have been discussed thoroughly by e.g. Dunkerley (2000). The collectors might be positioned underneath a dripping branch and therefore collect much more throughfall than in reality falls through. This problem is made minimal by close inspection of the locations and the use of different methods. The different method do not show clear singularities, thus concluding that the average throughfall is a close approximation of the real throughfall. Moreover, it is extremely sporadic that one finds more throughfall compared to rainfall. Also the question wether more collectors are needed is not applicable, due to similar results for all locations. An assessment of the different methods has also be done by other studies. According to Herbst et al. (2008), rainfall troughs connected to tipping buckets show a systematic underestimation of the real throughfall data. Their data however shows a weak correlation with a Nash-Sutcliffe of only 0.34, versus 0.89 for a direct correlation as shown in this study. Also Cuartas et al. (2007) mention a rather large underestimation with the use of troughs (14% versus 18%).

From all the above it is also important that apparent particularities can also be a result of the large heterogeneity of both the rainfall as well as the throughfall (Herbst et al., 2008). It can be concluded that the equipment does present difficulties measuring the real throughfall. However, when sufficient this problem can be

avoided by taking averages. The slight differences in equipment was overruled by the diversity in data.

5.2 The Fate of Soil Water

5.2.1 Soil Moisture Evolutions

In this study, different values for soil moisture were found, depending on location and equipment. The SM probes, which were installed on three different slope levels in both Spekboom and degraded land often showed higher values for soil moisture compared to the soil experimental moisture probes, which were installed on two different slope levels at the Spekboom and degraded land (see table 5). Especially results from the different probes installed in degraded land showed large differences. A possible explanation for this might be the way of installing the SM probes (see below). In general, the data from the experimental SM probes are taken to be more reliable; this counts especially for locations in the degraded land. Soil moisture data from the drylands of Arizona (Paco et al., 2009) and shrubland in SE Spain (Martinez-Mena et al., 1998) both indicate soil moisture around 10%, which is similar to the results of the experimental SM probe. Data from France, where the climate is wet and soils have a good drainage, show a soil moisture content ranging between 25% to 60% (Aubert et al., 2003). These values cannot be expected from the Baviaanskloof, which has a dry climate and soils with poor drainage. However the SM probes do show some typical patterns in soil moisture dynamics. Especially in the downslope location we find differences between Spekboom vegetation and bare soil, regonising daily cycles, root extraction and an impermeable base. This location is most pronounced due to its position: most water will collect from upstream and can be caught by the vegetation.

In our data, a gradual decrease in soil moisture is observed directly after the storm of the 17^{th} of December (day 75) at the location in the degraded land. Where the soil remains relatively wet all through the wet period from day 75 untill day 130 at Spekboom land, the soil becomes consistently dryer in the degraded land, as shown in figures 18, 19 and 28. A possible cause could be the sudden explosion of perennial grass growing all over the hill slope, but wether this has such an impact on soil moisture remains a question (see figure 33). Interception data found by Dunkerley and Booth (1999) does indicate that a high percentage of gross rainfall can be intercepted by grass (see also table 4), and moreover, grass sucks up and transpirates relatively high amounts of soil moisture (Yepez et al., 2005, Paco et al., 2009). An indication of the increase in moisture uptake by the grass is given in figure 34, which plots the different reactions in soil moisture content (loss of soil moisture is positive evapotranspiration) from equal rain events (between 10 and 17 mm), but at different periods from barren soil to grass covered land. In the same figure, data from Yepez et al. (2005) is overlayed that shows a similar pattern in evapotranspiration after applying an irrigation pulse on invasive grass lands. The average number for evapotranspiration (equals the loss in soil water content) resulted in around 0.8 mm/day for grasses and 0.6 mm/day for Spekboom during this study and does resemble the

data given in Paco et al. (2009), who calculates values for grass around 0.25 mm/day, while trees evaporate around 0.5 mm/day.

From figure 17, Spekboom vegetation has an increased soil water content around a depth of 20 cm, while below 40 cm, the profile is considerably dryer and more constant. This phenomenom has also been observed in Vries and Simmers (2002) and here it is explained to be an effect of the root zone. Aguirre and Wrann (1985) also suggested that roots can form a horizon of elevated soil moisture values. This idea is taken over and makes sense since roots have been found untill a depth of 35 cm (figure 35). Another possible explanation is the precense of an interflow layer (Kiely, 2000). However, also in the degraded land we often find a horizon of elevated values. Here it is slightly deeper: around 40 cm. Although there are also roots found untill 30 cm in this profile, cause for the wet horizon is probably the start of a somewhat harder layer at a depth of approximately 45 cm. This could also explain the wet base of the upslope degraded location after the rain event of the 17^{th} of December: due to the hard layer, water might have been ponded in the sandy matrix around the SM probe, making it unrealisticly wet. In other cases the water only flushes trough the profile. Concluding, it can be stated that the soil contains more water below Spekboom vegetation (20 to 30% versus 10 to 20%), especially focussed around the rootzone. Indications from literature are similar. Moreover, after a recharge period, the water will stay in the soil for a more extended time.The change in soil moisture can be used for estimating evapotranspiration. These simple calculations show that perenial grass cover uses more water in a shorter growing period, which can also be deduced from literature. Spekboom seems to be a more sustainable water user.

Table 5: Soil moisture data from this study, compared to Yepez et al. (2005) (D = deep soil and S = shallow soil)

Location	Vegetation	Degraded	Reference
Baviaanskloof			
Topslope	D:23 S:12-30	D:17 S:7-25	SM probe
Midslope	D:25 S:20-30	D:25 S:5-20	SM probe
Midslope	D:30 S:15-45		Experimental SM
Downslope	D:30 S:25-65	D:25 S:15-55	SM probe
Downslope		D:10 S:4-16	Experimental SM
Arizona Grassland			
Evasive	D:3-5 S:1-8		Yepez et al. (2005)
Native	D:3-7 S:1-10		Yepez et al. (2005)
Seine River Basin			
Agriculture	25-60 av:40		Aubert et al. (2003)
Mediterranean			
Shrubs	7-25 av:13		Martinez-Mena et al. (1998)

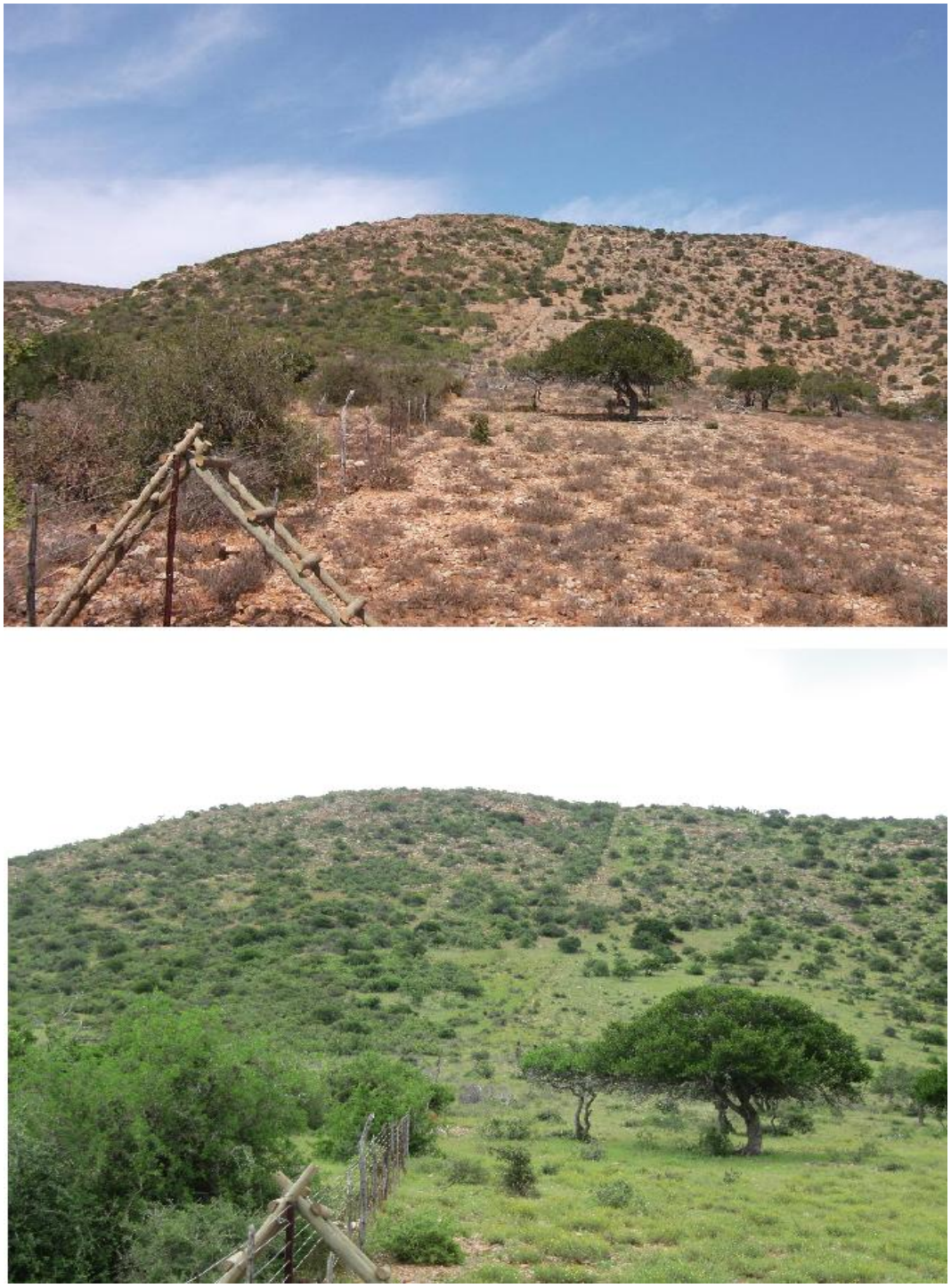


Figure 33: During the monitoring time span, the experimental plot changed in vegetation cover quite drastically. The top picture was taken on 05/10/2010, while the bottom picture was taken on 14/01/2011.

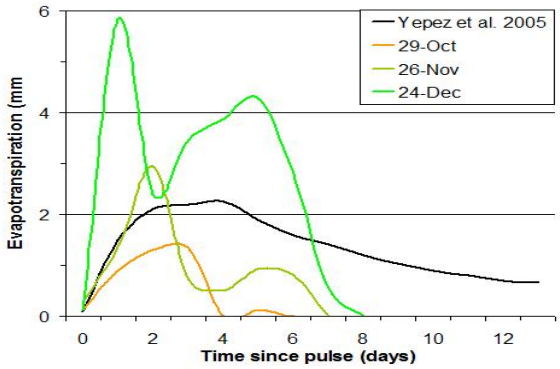


Figure 34: The sudden peaks in evapotranspiration after a rain event or irrigation pulse

5.2.2 Installation Issues

In general, TDR sensors proved to be a succesful way of measuring soil moisture content (Ledieu et al., 1986). Nevertheless, different problems can occur during installing, measuring and data analysis. For a proper functioning of the SM probes, these need to be surrounded with a sandy matrix (personal communication Wouter Vermaak). This will however mean that rain will infiltrate differently along the SM probe compared to the hard soil around it. Especially SM probes located on degraded land will be extra susceptible, since here rain is falling directly on the land. Therefore, the values for the experimental SM probe are taken to be more reliable, since they are in direct contact with the soil. Furthermore the data of the experimental SM probes does much better reflect the difference between Spekboom and degraded land, as well as the daily fluctuations. Finally, the positioning of these probes have been much better thought of, since they were installed in a clearly degraded site and just below a Spekboom plant. The positioning of the SM probes

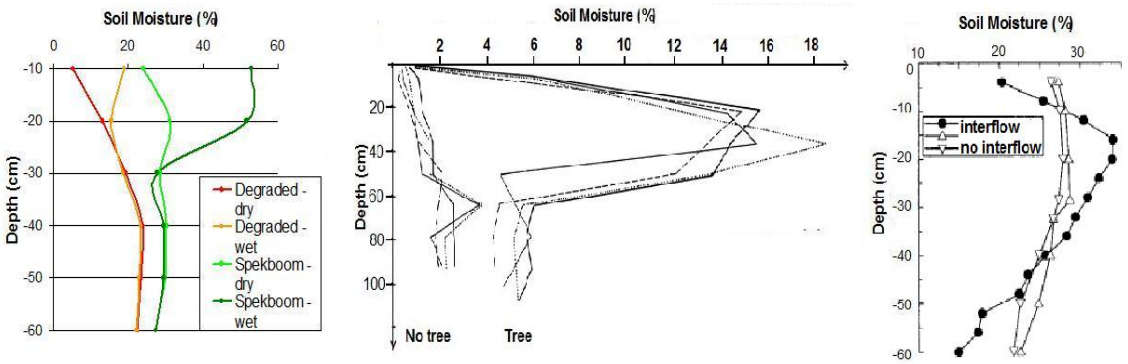


Figure 35: Soil moisture profile in the Baviaanskloof (a) compared to effects by (b) tree roots and (c) an interflow layer

on the other hand was often not well chosen, especially for the Spekboom locations. Only at the midslope location the probe was installed within the Spekboom plants. It was bad luck this sensor broke down and had to reinstalled, needing some time to start up again before returning reliable data. At the topslope location, the SM probe was located under a little tree with some Spekboom around, but in a clear patch; and at the downslope location the SM probe was installed between two Spekboom plants, between which clear signs of concentrated runoff were visible. However since the pattern for the downslope location is consistent with the other locations and the experimental SM probe, we believe that the measurements at this location are still useful.
Despite the better representation of the experimental SM probes, these were subject to more technical problems. The major issue was that they often stopped working after a few weeks or even a few days. A possible cause is the very hard soil, since during insallation, the Baviaanskloof experienced a dry period. This hard soil made the sensors loose and might have disconnected on them selves.
It can also be discussed whether the monitoring plot has been located in the right location within the Baviaanskloof. As already mentioned above, the fenceline contrast is not perfectly clear: Spekboom vegetation has been degraded and is trying to regenerate, but is far from pristine. This will surely effect the soil moisture, since bare soil or vegetation island give rise to a different hydrology, compared to impenetrable thicket. From remote sensing data, analysed by Draaijer (2010), the location seems well chosen. Concluding this subschapter, it can be stated that the use of the SM probe does probably not reflect the real soil moisture at this location, but does give a good indication of the processes going on underneath Spekboom during wet and dry periods.

5.2.3 Some Remarks on Soil and Infiltration

Besides the hydrological aspects of Spekboom vegetation it is also of importance to define some soil characteristics. During this study a description of the soil was made and its temperature and infiltration capacity were measured. More factors still need more research such as particle size, bulk density, porosity (Martinez-Mena et al., 1998), rock fragment content, organic matter, compaction (Bochet et al., 1998), sheer strenght and penetration resistance (Bochet et al., 1999). Few of these aspects (e.g. rock fragment content) have been mentioned by Sommeijer (2010), but are not taken into consideration in this study. Measurements of the temperature below Spekboom have already been carried out and showed that on average temperatures are around 10 ℃ higher and 3 ℃ lower for maximum and minimum values (Lechmere-Oertel et al., 2008). This is in comparison to our values of 6 ℃ cooler and 2 ℃ warmer for minimum and maximum temperature respectively, which was measured at a depth of 5 cm into the soil.
Infiltration rates were measured with a minidisk infiltrometer, which is a reliable and easy method (Zhang, 1997). However, during a first field trip much higher values for infiltration on degraded soil were found compared to a second field trip. Meteorological conditions in combination with the antecedent soil moisture could

have played a role here, since these varied from extremely dry in the first fieldtrip to extremely wet in the second. Deducting total infiltration from the rainfall simulator data of Sommeijer (2010), we could establish that infiltration was two to five times higher in soils underneath Spekboom. On degraded soils, infiltration was around 10 to 50 mm/h, while on soils underneath Spekboom vegetation values reached up from 50 to 150 mm/h. The measurements presented here are in the order of 1 to 10 mm/h for degraded soil and 25 to 30 mm/h for Spekboom soil. These results are much less, but do also result in at least six times higher infiltration rates for Spekboom soils. Other studies mention a tresshold infiltration of 4 to 8 mm for silt to sandy soils (Martinez-Mena et al., 1998), which is more in the line of the infiltration rates of degraded land as found in this study. Overall, little data was found on the subject of infiltration in Mediterranean regions. It can be concluded that soils underneath Spekboom are more developed, have less temperature extremes and have much higher infiltration rates, which has already been proven with previous studies.



Figure 36: Some major field problems with the gerlach troughs: a) shows a flowpath formed around the Spekboom plant inot the trough; b) shows an overfilled oil can, that fills up the drum as well; c) shows flowpaths directing the runoff around the trough; d) shows the danger of checking a trough: scorpions; e) shows a clogged trough.

5.3 Controls on Runoff in Space and Time

A very important factor in a correct runoff measurement is the location of your collectors. Starting from the risk assessment map of Draaijer (2010), we find that the highest erosion risk (and therefore also runoff) is at the downslope area, which is reflected in the data. Questions remains whether this flow is mainly a concentration of upslope infiltration excess runoff, or whether there is a large component of saturation excess runoff created at these locations. A deeper look into remote sensing data shows some kind of pathway in slope lenght factor just over the monitoring plot. It is likely that these components together create the large runoff collected in the downslope locations.

Since the Gerlach troughs are rather small and only comprise a certain area, field observations are very important. At many of the Gerlach trough in downslope locations, flow paths were recognised. When flowpaths are concentrating into the trough, runoff from a very local drainage rill is measured, which is a huge overestimation of the reality. However, when a flowpath is found that deviates from the Gerlach trough and directs the runoff away from it, then there will be too little runoff measured. Both systems have been recognised in the field and can be found in the data.An example is Gerlach trough GT-18, which was located just behind a Spekboom plant and had to measure runoff coming from underneath the Spekboom. Contrarily, the Spekboom functioned as an island, around which a flowpath was recognised, ending straight into GT-18. The flowpath actually continued behind the trough, indicating a possible undercapacity of the Gerlach trough. These flowpaths could carry so much water, that the collecting can of 25 liter was not always sufficient. This caused the can to overflow and the large drum to start filling up. Using the depth and the diameter of the oil drum, estimations were made of the total runoff. These measurements are however less accurate. Other difficulties concerned the tubing, which were sometimes clogged by dead beatles or were simply pulled out by baboons. An overview of different issues concerning the equipment is given in figure 36.

From the above, one can question what the governing factor is to start runoff: is it solely a result of the amount of rainfall? Or is its intensity more important? What is role of the antecedent soil moisture? And what net effect might the flowpaths have on the runoff?

Field observations indicate that all factors are important. Preferred pathways between the vegetated islands were already mentioned above. The formation of gaps in vegetation favours a significant increase in runoff, according to Garcia-Ruiz et al. (1996), Kosmas et al. (1997). From data analysis (see figure 37) runoff has the strongest raltion to rain intensity, having Nash-Sutcliffe coefficients between 0.28 to 0.85, averaging 0.60. It goes without saying that there is also a relation with the gross rainfall, although this is not much stronger compared to e.g. the cummulative gross rainfall, with Nash-Sutcliffe coefficients between 0.16- 0.69 and 0.10-0.62 respectively. No relation is found with the time from the last rain event. Runoff is thus strongly related to rain intensity, followed to the gross rainfall and antecedent rainfall events. This in line with the relations found for other clay soils, as been discussed by Martinez-Mena et al. (1998).

It was unexpected to find most runoff on the downslope location. Upslope a steeper slope in combination with a shallow soil would favour more runoff, compared to downslope where slopes are not so steep and soils are thicker. This effect could also be concluded from figure 29, which shows that changes in soil moisture are relatively small upslope, especially for Spekboom. It suggests that less rainfall is infiltrating and used for evapotranspiration, resulting in more rainfall available for runoff. It has to be noted that this difference is mostly true for the Spekboom land, while degraded lands shows a minor difference between upslope and downslope. For the Spekboom location, one might also explain the difference due to the location of the probe. In the downslope location the sensor seems to be located in the middle of a flowpath, thus resulting in much higher peaks in soil moisture during considerable rain events. These high peaks might just give an indication of water flowing as surface runoff and subsurface flow.
Many studies give estimates for runoff as fraction of the runoff to estimate erodibility and total basin runoff (e.g. Kosmas et al. (1997) with 10% of the gross rainfall). Since this study used Gerlach troughs with unknown catchment areas, the relative runoff between Spekboom and degraded lands was estimated: Spekboom vegetation decreased runoff with 30% to 60% (upslope and downslope values). Model results

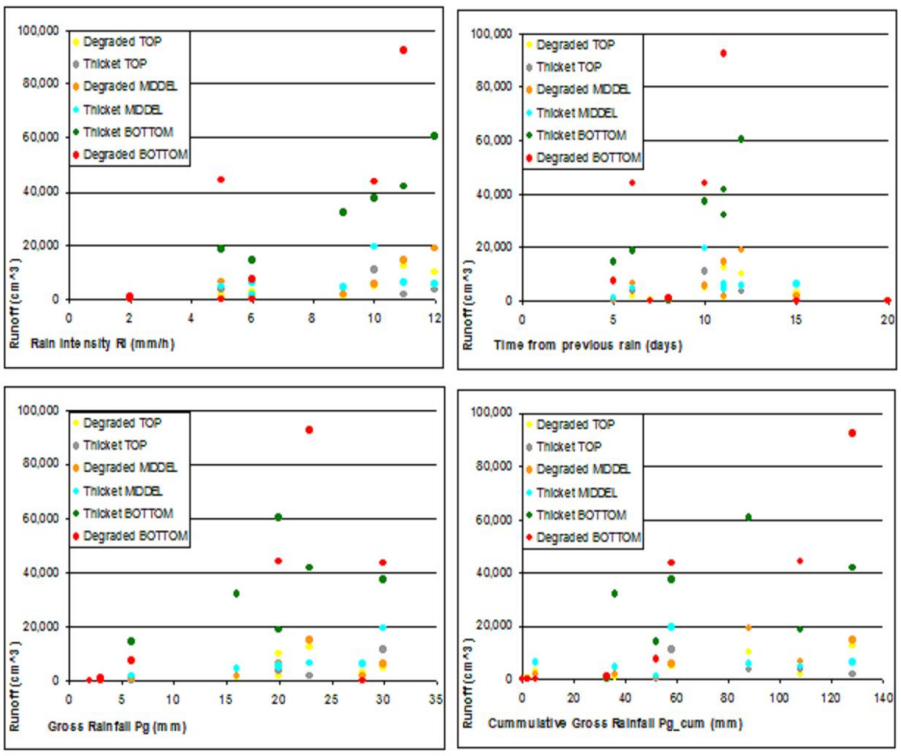


Figure 37: Runoff in relation to different rainfall parameters; starting top left clockwise: rain intensity, time to previous rain event, cummulative rainfall and gross rainfall

show a decrease of 60% or even higher. This is similar to the ratio found by Sommeijer (2010), who found that recently planted Spekboom decreased runoff with 30%, while intact thicket decreases runoff by more than 80%! Similar values of 30 to 60% are also found in literature for different cases in the Mediterranean (Andreu et al., 1998, Bochet et al., 1998, Kosmas et al., 1997). Results from the GaIn3a model, as applied in this study predicted a similar decrease of 60% or even higher. Concluding, one can state that although the Gerlach troughs do not give an exact value over a known area for runoff, they are very useful to estimate the relative decrease in runoff as a result of vegetation. In this study, a decrease of 30% to 60% was found, which is in comparison to previous research.

5.4 Towards a Modelled World

As already found by other authors (Gash et al., 1995, Valente et al., 1997) the sparse Gash model gives much better results compared to the original Gash model. Result during this study are very encouraging for continuation on the modelling path and use more sophisticated models. However, more data is needed: a long data set of at least two years and many different soil parameter as already mentioned above.
Parameters for the Gash model resulted often in relatively high values. The value used for the canopy cover is in comparison to other studies. It is higher compared to Mediterranean forests (Pereira et al., 2009, Valente et al., 1997), but slightly lower than deciduous (Carlyle-Moses and Price, 1999) and much lower compared to tropical forests (Cuartas et al., 2007). Average rainfall R comes out rather high with 5.7, being the double value as compared to many other studies done in Mediterranean regions (Pereira et al., 2009, Valente et al., 1997, Sraj et al., 2008) or milder Nordic climates (Herbst et al., 2008, Carlyle-Moses and Price, 1999). These values correspond more to the average of rainfall intensity on the monitoring site, i.e., 2.2 mm/h. The present value for R as used in the model approaches more the value found by Cuartas et al. (2007) in tropical regions. The same can be stated concerning the canopy storage S value of 1.48 mm. Again this is more in comparison to values from tropical regions, where 1 mm was found for S. It is much higher compared to studies from Mediterranean shrubs and forest, resulting in values between 0.05 and 0.72 mm, only occacionally reaching a maximum of 1.2 mm (Sraj et al., 2008, Valente et al., 1997, Návar et al., 1999). It is interesting to see that the canopy storage is generally higher in Northern hemisphere hardwood forest, that calculate a S value of 1.3 to 1.6 mm, being perfectly comparable to our data. Evaporation from the canopy resulting in almost 2 mm/h for Spekboom. This value is quite extraordinary, for most studies find values well below 1 mm/h (Pereira et al., 2009, Valente et al., 1997, Sraj et al., 2008, Cuartas et al., 2007, Herbst et al., 2008). Nevertheless, also Návar et al. (1999) finds these high evaporation values (between 1.5 and 3.5 mm) for dense shrubland in Mexico. For the treshold precipitation $P'g$, little data is found. This study found a value of 1.8 mm and is more than both Mexican shrubland with values around 0.1 to 1.3 mm (Návar et al., 1999) and hardwood forests, having a treshold precipitation around 1.3 to 1.6 mm (Carlyle-Moses and Price, 1999, Herbst

et al., 2008).
Thus, concluding, we can state that average precipitation R is more alike to tropical regions, the canopy evaporation Ec is in the same order of magnitude as other shrublands; while the canopy storage S is more comparable to hardwood forests. Finally, the treshold precipitation $P'g$ seems to be too high for any system, which might reflect the high interception rate at the start of a rain event (compare with figure 12).
Results from the Infiltration part of the GaIn3a model show that runoff is approximately 40% at degraded land and up to 17% at Spekboom land. This yields a ratio between Spekboom to degraded land of 1 to 2.40. It is interesting that this exact ratio has also been found back in the measurements from the field (1:2.44). This ratio increases quickly though, when we take into account the interception of Spekboom. This means that Spekboom revegetation does decrease the direct flow into the river system, as been stated by many other studies (Martinez-Mena et al., 1998, Kosmas et al., 1997, Andreu et al., 1998). Spekboom interception is calculated to be 33% with the model and of that only 7% of the remaining rainfall is lost to runoff. The modelled interception is comparable to the measured value for substantial rain events (35%), but is not similar to results from the water balance; this approach yields a yearly interception of 23%! However, it has to be taken into account that the interception formula used in the water balance did not suffice. The formula has been based on rainfall events, while here it is used on monthly sums. Another interesting finding form the GaIn3a model is that the amount of water that will infiltrate does not differ much between either Spekboom or degraded land. Under Spekboom vegetation approximately 60% is infiltrating, while at bare soil, 54% infiltratesl. The water balance also gives similar values: up to 64% for Spekboom and 55% for bare soil. This data shows that there is only slightly more water available for infiltration when bare soil is planted with Spekboom. Nevertheless, microclimatic conditions in combination with soil structure and net rainfall characteristics will give infiltrating water a better chance to penetrate the soil and append to the subsurface water reservoir. Water that infiltrates bare soil will have more risk of quick evaporation, formation of saturation excess streamflows and quick subsurface flow patterns. According to the data presented here, no significant increase in baseflow is expected. This result is not in line with either Mander et al. (2010), who states the positive effect of revegatation, nor with many other studies stating a lower flow in streams (Maitre et al., 2002, Wilcox et al., 2006, Scherer and Pike, 2003, Zhao et al., 2009). Sadly, little data has been published regarding the link between effective rainfall and infiltration in combination with the effects of vegetation. The integration of data as carried out in this study shows that the Spekboom system does not yield an increase in baseflow, but does yield a decrease in peak flow. Furthermore, calibrated parameters for the Gash model makes it easier to understand the high interception rates for Spekboom, showing high values for canopy storage, canopy evaporation and treshold precipitation.

5.5 Missing Data

Gaps were recognised, which made it hard to complete the water balance. These gaps are mainly focussed around the soil specifics to estimate a reliable value for the flux of water infiltrating the soil, and around the evapotranspiration to estimate the soil-plant interaction.
To model runoff and infiltration dynamics, many different soil characteristics are needed (Dawes et al., 1998). One of the key aspects is the water retention curve, or the Van Genuchten curve, which quantifies water abstraction and infiltration capabilities, using wilting point and field capacity (Genuchten, 1980). A lot of these variables can also be estimated using data from e.g. Carsel and Parrish (1988). A proper soil water analysis in the lab is however recommended (Dirksen, 2000). Auxiliary data on soil specifics will make it easier to get an understanding of this infiltration versus runoff process of soils. Examples are field measurements on soil particle size, bulk density, total porosity (Martinez-Mena et al., 1998), rock fragment content, organic matter, compaction (Bochet et al., 1998), sheer strenght and penetration resistance (Bochet et al., 1999). Next to these, soil mositure can be locally very variable. A more extensive field campaign to measure soil moisture in a spatial scale is needed, to find preferred stream paths or preferred subsurface flowpaths.
From water balance calculations, evapotranspiration of Spekboom was slightly more compared to degraded land: approximately 510 mm versus 460 mm. Taking into account the water shortage (due to low rainfall rates and interception), Spekboom used 195 mm for actual evapotranspiration, while degraded land used 167 mm. These values have been based on the amount of infiltrating water, which was similar in both Spekboom and degraded land scenario's, both using the water balance method, as well as the GaIn3a model. This results in around 0.5 mm/day for both types of land use. When the negative values of the daily change in soil moisture are taken as evapotranspiration loss from the soil, the same conclusion can be made: both degraded and Spekboom land show similar amounts of evapotranspiration losses. Values are between 0.1 and 6 mm/day. This seems to be counterintuitive when closely examining soil moisture data as shown in figure 20. In this figure, the amplitude of the Spekboom curve is clearly larger compared to the degraded land; from visual interpretation the amplitude of degraded land is around 50% of the amplitude of Spekboom land.
To assess the actual evapotranspiration with a reliable method, this study proposes the use of an evaporation dome, as being described by McJannet et al. (1996) and succesfully used on Saltbush in Western Australia by Luijk (2007). These measurements resulted in a evapotranspiration between 0.5 and 1.0 mm/day for wheatgrass, while saltbush (a shrub up to 2 m high) resulted in evapotranspiration maxima up to 5 mm/day. The wheatgrass data is comparable to the data we find on degraded land (0.5 mm/day from the water balance and 0.5 when using the negative change in soil moisture), while the data found for Saltbush is comparable to the negative daily soil moisture change with values between 1 and 6 mm/day (see figure 34), but not with the data from the water balance, which also calculates 0.5 mm/day

evapotranspiration for Spekboom. When taking the evapotranspiration values for Saltbush (mostly transpiration) versus wheatgrass (mostly evaporation) from Western Asutralia, one can conclude that transpiration makes up between 17 and 50% of the total evapotranspiration. A percentage of 50% has also been found in the amplitude difference as discussed above. Similar numbers are found in literature: Herbst et al. (2008) finds that during leafless periods the evaporation is 5o% of the total evapotranspiration, while this decreases to 25% during leafed periods. David et al. (2006) and Paco et al. (2009) find percentages of 28% and 24% respectively. For Spekboom, data from this study suggest that this percentage is much higher, and that evapotranspiration is similar for degraded and Spekboom land. A possible explanation might be found in the complicated method of Spekboom transpiration, called CAM and described in Powell (2009).
Interception data also needs to be supplemented with a considerable data set to see what happens with extreme rain events and whether seasons play an important role (Herbst et al., 2008). This seasonality has already been seen in the runoff dynamics. Nevertheless, the produced runoff data in this study does not suffice for use in a modelling aproach to close the water balance. Integration of runoff in hydrological modelling needs results with values on a unit scale. A Wischmeier plot can measure runoff in this unit measure, since it measured the runoff from a specific delimited mini catchment Wischmeier and Smith (1978), Garcia-Ruiz et al. (1996).
Finally, research on the stemflow dynamics proofs to be really interesting, since this study resulted in two totally different data sets. Although the most recent data shows stemflow less than 1%, which was expected by Cowling and Mills (2011) and is often measured in Mediterranean vegetation (Gash et al., 1995, Valente et al., 1997), the first data gathered by the stemflow collection yielded approximately 7%. This is much higher than other studies, although Mooney and Dunn (1970) mentions that stemflow in Mediterranean shrub can be as high as 33% of gross rainfall! The average over the complete monitoring period results in 3%, which is a very common number found in many different shrub (Návar et al., 1999) and forest systems (Sraj et al., 2008, Gomez et al., 2002); see also table 4. Concluding from this subchapter, more research is needed into soil characteristics (such as Van Genuchten curve) and evapotranspiration measurments (using an evaporation dome). More detail on the spatial variance in soil moisture will indicate the importance of gaps on (sub-)surface flow and a more extensive data set is needed for both interception as well as stemflow measurements. The results shown in this study do encourage a long lasting monitoring project.

6 Conclusions and Recommendations

The objective of this study was to make a complete picture of the main hydrological fluxes of Spekboom vegetation in respect to degraded land. These fluxes include rainfall dynamics, including gross rainfall, throughfall, interception and stemflow, soil moisture dynamics, including infiltration, and runoff. Simple model approaches are used to answer wether there is more water available for baseflow, instead of peakflow when degraded lands are revegetated with Spekboom.
Spekboom vegetation forms dense shrublands, although at the location this study took place it was partly degraded. Canopy cover measurements showed that 75% of the heavens are obscured by the plant. Clumps of Spekboom have a typical height and diameter of 2 and 3 meter respectively. A clump consists of around ten individual stems ranging in perimeter from 10 up to 50 cm. These values are also found by previous researchers.
On average Spekboom intercepts almost 40% of the gross rainfall. With minor rainfall events (< 5 mm) this is even 55%, while major rainfall events (> 5 mm) this value is 35%. This value is relatively high compared to research done on forests all over the world. Previous measurements on Spekboom vegetation resulted in similar values of around 44%. These high values can be explained due to the high canopy storage coefficient, as deduced from the Gash model. A strong relation can be found between gross rainfall and throughfall. The relative interception can also be resognised as a function of gross rainfall and rain intensity, although in this study this relation is somewhat weak, compared to previous studies. Throughfall is measured with succes by rain gauges and tiping buckets, while the troughs often show a slight underestimation of the throughfall. Nevertheless data from the troughs are more reliable as mentioned in literature and since they are positioned under more uniform Spekboom thicket.
Stemflow data is questionable, since it is divided in two seperate data sets, divided by an operation on the equipment. Nevertheless, data is promising, showing either an extremely high stemflow of 7% or the suspected minor contribution of less than 1%. The average 3% is in accordance with many other studies.The stemflow is in direct relation to gross rainfall, which has also been recognised to be the main forcing in literature.
Data from the soil moisture probes show that soil is more wet under Spekboom vegetation and that rainfall event wet the soil more intense and for a longer subsequent period when Spekboom vegetation is present. Some probes show a three times higher moisture content, resulting in a soil moisture of around 30% in Spekboom vegetation versus 10% under bare soil. Another dataset however is more conservative, estimating a 1.2 to 2 times higher moisture content for Spekboom vegetation, resulting in values from 23 to 30% under Spekboom vegetation and 17 to 25% under bare soil. The first approximation however seems to be more in line with literature and moreover has been recovered from a more reliable soil moisture probe. From the depth profile, it can be concluded that the soil under Spekboom vegetation is more wet and shows a clear root zone around 20 cm, while a hard layer at 40 cm makes

it difficult for water to infiltrate much deeper. Moreover, water stays longer in the soil after a rainfall event, up to 30 days, compared to 5 days for degraded land. The typical flushing events are recognised as pens in the soil-depth-time graphs. The growth of perennial vegetation was clearly noticed on the degraded land and took up a considerable amount of the gross rainfall, preventing it to infiltrate.
Infiltration rates for soil increases significantly for Spekboom vegetation, resulting in almost 30 mm/h versus 3 mm/h for Spekboom versus degraded land respectively. A thick organic litter layer is available and makes the soil texture lighter compared to degraded land. Also, we do not find the clear chalky soil, that occurs from 25 cm onwards in degraded situations. Temperatures are also less extreme when Spekboom vegetation is present: maxima are at least six degrees cooler and minima two degrees warmer.
Data to estimate runoff is somewhat difficult to interpret. In general, the most downslope locations are taken to be most representative, since it collects the cullumative water flow from both Spekboom vegetation or degraded land. From these analysis it is concluded that there will be 2.4 times more runoff when there is no Spekboom vegetation present. This number is in line with the results from the GaIn3a model, presented in this study, and other literature.
The GaIn3a model represents the sparse Gash model in combination with a bucket model for runoff, based on infiltration data. The sparse Gash model results relatively well and provide a good predictive tool for throughfall. In general, the model under-estimates the throughfall and overestimates interception.
Integrating all data shows that there is a undeniable direct link between rainfall and soil moisture. Soil moisture increases directly after a rainfall event, and this peak is often higher underneath Spekboom vegetation, despite the rather great amount of interception. From both the GaIn3a model and a water balance approach, this study shows that similar amounts of water are available for infiltration in both Spekboom and degraded scenario. This means that there is not more water available for baseflow of rivers and streams, but it also does not decrease baseflow, as been stated by many previous studies. Furthermore, it will be more likely that baseflow does increase due to improved soil textures and therewith minimizing the loss of water in subsurface flow. Next to that, most water is lost to direct surface flow in the degraded scenario, instead of interception in the Spekboom scenario. This means that there is a less intense peak of direct flow into the system, decreasing risks on floods and sedimentation.
Nevertheless, it is difficult to interpret these results, due to the absence of crucial data. To complete the water balance, reliable data for evapotranspiration is needed. We also need a better idea of the spatial evolution of soil moisture within the Spekboom vegetation. How important is the mozaic nature of this landscape on soil moisture profiles and subsequent subsurface flow? What will be the effect of overland flow? Due to holes within the vegetation, sometimes overland flow increases dramatically. It will be really interesting when we can use this data into a catchment scale model or use for the interpretation of remote sensing data on soil moisture, vegetation dynamics, surface flow and erosion.

In general it can be concluded that Spekboom vegetation improves soil water content, despite the high interception rate. Also it decreases overland flow substantially. This results in a decrease of peakflow and a more regulated provision of water to rivers and dams. Despite many questions, this study furthermore shows that baseflow is not affected substantially due to revegation. It seems that the increased evapotranspiration (which includes vegetation interception) is cancelled out by a decreased runoff. Nevertheless, it is more likely to result in higher baseflow amounts, due to the improved conditions of the soil specifics, therewith decreasing risks on extra losses in degraded conditions.

Acknowledgements

For the completion of this thesis work, the first people to thanks are the farmers of the Baviaanskloof and with a special thanks to Oom Piet Kruger, who gave all the help needed; the work would have been impossible without his help. Furthermore, I want to mention Chris Lamprecht, who played an essential key role in the installation of the monitorings plot.
For the supervising of this project I want to thank Bart van Eck and Michel Riksen. Richard Cowling helped me in getting a better idea of the problems and unknowns of Spekboom, which advise was indispendable.
Also the mental support needed was offered by a lot of people; I need to mention Bart in this section again, and also Odi (for the sake of mentioning, dude!), my parents, brothers and friends back home, and of course my fellow students who always gave me reason to rave around and do my stuff, cheerio, mates! Special thanks to my girl Lena, who suddenly appeared so clearly in my life when returning from South Africa and who put a lot of believe in my work. Also the brothers at Lilbosch for providing a restfull atmosphere in the days, when finalizing the report. Surely I will never forgive myself when I would forget to mention Dieter and Sylvia and Matt here. These people did definitely challenge a certain ignorance and life style I carry out, but there talks and deeds did definitely encourage me and made me thinking; lots of thanks to you! I hope you will keep going with the good work; the world is in need of more people like you.

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Appendices

A List of Symbols

P	Rainfall (mm)
$\overline{P}$	Average Rainfall (mm)
P_g	Gross Rainfall (mm)
P'_g	Threshold Rainfall for Canopy (mm)
P_n	Net Rainfall (mm)
Tf	Throughfall (mm)
Sf	Stemflow (mm)
Sf_{vol}	Volumetric Stemflow (cm^3)
In	Interception (mm)
RO	Runoff (mm)
I	Infiltration (mm)
It	Tresshold Infiltration (mm)
RI	Rainfall Intensity (mm/h)
RIm	Maximum Rainfall Intensity (mm/h)
RI_{av}	Average Rainfall Intensity (mm/h)
ETa	Actual Evapotranspiration (mm)
ETm	Maximum Crop Evapotranspiration (mm)
W	Water Storage (mm)
$\Delta W/\Delta t$	Soil Water change in time (mm/d)
Ir	Irrigation (mm)
DP	Deep Rercolation (mm)
CR	Capillary Rise (mm)
Yc	Crop Yield (-)
D	Diameter of Canopy (m)
r	Radius of Canopy (cm)
H	Height of Canopy (m)
P_s	Perimeter of Stem (cm)
N_s	Total Number of Stems (-)
CC or c	Canopy Cover (%)
Ec	Average Canopy Evaporation (mm)
Sc	Canopy Storage Coefficient (-)
SI_{spek}	Threshold Rain Intensity - Spekboom (mm/h)
SI_{degr}	Threshold Rain Intensity - Degraded (mm/h)
SP_{spek}	Threshold Rainfall - Spekboom (mm)
SP_{degr}	Threshold Rainfall - Degraded (mm)
NS	Nsh-Sutcliffe coefficient (-)

B Field Euipment on Site

The scheme below shows all the equipment which was installed on the monitoring plot to analyse effects on land and water. Note that during the present study, no use was made of the erosion bridge, since this method needs a long monitoring period and measures the erosion, which is not an integral part of the water budget. Gerlach Troughs are only used to measure runoff, while sediments collected in the troughs have been measured, but are not taken into consideration here, due to its irrelevance for the water budget. The wheather station has only been used for monitoring of rainfall; other climate variables are not taken into consideration.



One weather station is installed to measure rainfall, temperature, humidity, wind and air pressure.





A tipping bucket is used to measure both the rainfall and the throughfall (= rain that falls through the vegetation)





Interception troughs and stem collars measure the interception rate and stemflow under dense thicket, to verify the tipping bucket data





The erosion bridge is a collection of pins, that indicates the microrelief of the soil. Over time this relief changes





Sediment traps (Gerlach troughs) are installed to measure the overland flow and the amount of sediment washed off the slope





Different TDR probes are used to measure the soil moisture. They relate electrical current to moisture content

C Sparse Gash Model

The Sparse Gash model for interception is based on relations between throughfall and stemflow versus precipitation. Interception is seen as the total evaporation during a storm event , which is divided in six stages: when the storm does not saturated the canopy all precipitaton is lost (stage 1); this also holds for the stemflow, when the trunk is not saturated (stage 2); when saturating, canopy interception is divided in the wetting up of the canopy (stage 3), the evaporation of saturated canopy during the storm event (stage 4) and finally evaporation after the storm event ceases (stage 5); for trunk interception, evaporation is static. The equations are as follows (for original Gash model, see Gash et al. (1995)):
Stage 1 - Evaporation for m storms that do not saturate canopy

$$c\sum_{i=1}^{m} P_{g,i} \tag{5}$$

Stage 2 - Trunk evaporation for n-q storms that do not saturate the trunk

$$p_t\sum_{i=1}^{n-q} P_{g,i} \tag{6}$$

Stage 3 - Evaporation for n storms, wetting up the canopy

$$ncP'_g - ncS_c \tag{7}$$

Stage 4 - Evaporation for n from saturation before precipitation ceases

$$(c\overline{E}_c/\overline{R})\sum_{i=1}^{n}(P_{g,i} - P'_g) \tag{8}$$

Stage 5 - Evaporation after rainfall ceases

$$ncS_c \tag{9}$$

Stage 6 - Trunk evaporation for q storms that do saturate the trunk

$$qS_t \tag{10}$$

Including all phases in one model, yields the following formula, in which the second part of equation 7 cancels out against equation 9:

$$\sum_{i=1}^{n+m} I_i = c\sum_{i=1}^{m} P_{g,i} + p_t\sum_{i=1}^{q} P_{g,i} + ncP'_g + (c\overline{E}_c/\overline{R})\sum_{i=1}^{n}(P_{g,i} - P'_g) + ncS_c + qS_t \tag{11}$$

All parameters used in the Sparse Gash model are listed in table 6. The average precipitation is derived from all precipitation events $P_{G,i}$, while the average evaporation $\overline{E_c}$ is derived from the ET calculations using Penmann-Monteith. A more

Table 6: Parameters used in the equations of the Sparse Gash Model

I	Interception	c	Canopy cover
P_g	Precipitation	S_c	Canopy storage coefficient
P'_g	Tresshold precipitation	S_t	Trunk storage coefficient
$\overline{R}$	Average precipitation	m	Number of small storms
$\overline{E}_c$	Average evaporation	n	Number of large storms
p_t	Stemflow partitioning coefficient	q	Number of large storms, saturating the trunk

simple method to find $\overline{E_c}$ is assuming all precipitation is evaporated. This assumption yields a simple equation using the average fraction between interception versus precipitation:

$$E_c = c\overline{R} * \left(\frac{I}{P_g}\right) \tag{12}$$

The stemflow partitioning (or free stemflow) coefficient is derived from the slope of the linear relation between the stemflow and precipitation projected trough the origin. Canopy and trunk storage coefficients are derived from the intercept of respectively the throughfall and the stemflow versus the precipitation.
The interception coefficients that indicate the amount of precipitation needed to saturate the canopy (P'_G) and the trunk (P'_t) can be calculated as follows:

$$P'_g = (-S_c\overline{R}/E_c) * ln[1 - (E_c/\overline{R})] \tag{13}$$

$$P'_t = S_t/p_t \tag{14}$$

From these solutions, Loustau et al. (1992) has shown how to calculate estimates for stemflow and throughfall:

$$SF = p_t \sum_{i=1}^{n} (P_{g,i} - P'_t) \tag{15}$$

$$TF = \sum_{i=1}^{n+m} P_{g,i} - (I_i + SF_i) \tag{16}$$

D R script for Interception - Infiltration model "GaIn" using the Sparse Gash Model

```
# if you want to run the entire script, you can also copy the next line
# into the command window:
# source("Gash_model_Version2.R")

# this statement removes everything from R's memory
rm(list=ls())

# change working directory
setwd("D:\\Thesis_interception\\data\\R")

### READ DATA FILE: R now knows all the variables from this file

 data = read.table("Rain_events1.dat", header=TRUE)

attach(data)

# this file contains: date, Pg, TF, SF, I and I/P (all in mm)
Pg           = Pg
TF           = TF
SF           = SF
In           = I
IP           =I.P
Ev           = Event
day          = Date
Duration     = D

### PLOTTING PICTURES

# make a png file for your picture

png("data.png", width=1000, height=500)

m1=t(data.frame(Stemflow=c(SF),Interception=c(In),Throughfall=c(TF)))

Stemflow=c(SF)
Interception=c(In)
Throughfall=c(TF)
m2= table(Stemflow, Interception, Throughfall)

# some graphical parameters for the picture
```

```
# set y-limits from zero to the largest values of In *1.25
ylim = c(0, 1.25*max(c(TF) ))
xl=length(Ev)
xlim = c(1, xl)


# now the plotting starts: Pg on the bottom with a y-axis on the left
  barplot(m1,
   xlab="Event", ylab="Normalized Water Equivalent  [ mm ]", beside=TRUE,
  col=c("darkgreen","red","blue"),  ylim=ylim, main="Interception Dynamics",
  axis.lty=1, names.arg=Ev, cex.names=1,
  legend.text=TRUE, horiz=FALSE
  )

# add a grey grid
grid(nx=NA, ny = NULL, col="grey80", lty=3)



# add the x-axis
#axis(side=1, at=placexlabel, labels=xlabel)


# close the png file
graphics.off()



### END OF PLOTTING PICTURE

#GET ALL THE VARIABLES FOR THE GASH MODEL!

R=mean(Pg)                      # Mean Rainfall
IPg=mean(IP)                    # Relation between Interception and Rainfall
cc=0.7420                       # DECIDE THE CANOPY COVER
E=IPg*R                         # Estimated Evaporation
Ec=cc*E                         # Estimated Evaporation taking incl. canopy cover

# find some relations
a=5                            # DECIDE THE MINIMUM RAINFALL!
n=length(Pg)
Pgs=array(1:n)
for(i in 1:n)
```

```
{ if(Pg[i]<a)  Pgs[i]=Pg[i]
else Pgs[i]=0}


     fm1=lm(TF~0+Pgs)        # linear model Throughfall versus Rainfall - inter.
     fm2=lm(TF~Pg)           # linear model Throughfall versus Rainfall + inter.
     fm3=lm(SF~Pg)           # linear model Stemflow versus Rainfall with inter.


p1= coef(fm1)[1]              # free throughfall coefficient using slope (fm1)
p2=1-cc
p=p2

S=-1*(coef(fm2)[1])         # Canopy storage capacity using intercept (m2)
Sc=S/cc                     # Canopy storage capacity for sparse model

Sst=coef(fm3)[1]            # Stem or trunk storage capacity using inter. (fm2)
pst=coef(fm3)[2]            # free stem or trunk coefficient using slope (fm3)

#plot(Pg,TF)
#par(new=TRUE)
#abline(fm1)


#FORMULA'S OF GASH CALCULATING INTERCEPTION

PCS=-1*(Sc*(R/Ec))*log(1-(Ec/R))         # Rain that is collected on the canopy
PSS=Sst/pst                              #Rain that is collected on the stem

# INTERCEPTION FORMULA'S:
Ic=array(1:n)
Iw=array(1:n)
Is=array(1:n)
It=array(1:n)
for(i in 1:n)
{ if(Pg[i]<PCS)  Ic[i]=cc*Pg[i]
else Ic[i]=0
  if(Ic[i]==0)
  {Iw[i]=cc*PCS
   Is[i]=((cc*Ec)/R)*(Pg[i]-PCS)
   if(Pg[i]>(PCS+PSS)) It[i]=Sst
   else It[i]=pst*Pg[i]     }  }

#THROUGHFLOW, STEMFLOW AND INTERCEPTION
```

```
In_sim=array(1:n)
SF_sim=array(1:n)
TF_sim=array(1:n)

for(i in 1:n)
{
In_sim[i]=Ic[i]+Iw[i]+Is[i]+It[i]
SF_sim[i]=pst*(Pg[i]-PSS)
TF_sim[i]= Pg[i]-SF_sim[i]-In_sim[i]
}


#Cummulative amounts for Interception, Throughfall and Stemflow
In_cumm=array(1:n+1)
In_cumm[1]=0
In_sim_cumm=array(1:n+1)
In_sim_cumm[1]=0

TF_cumm=array(1:n+1)
TF_cumm[1]=0
TF_sim_cumm=array(1:n+1)
TF_sim_cumm[1]=0

SF_cumm=array(1:n+1)
SF_cumm[1]=0
SF_sim_cumm=array(1:n+1)
SF_sim_cumm[1]=0


days=array(1:n+1)
days[1]=0

for(i in 2:n)
{
In_cumm[i]=In_cumm[i-1] + In[i-1]
In_sim_cumm[i]=In_sim_cumm[i-1] + In_sim[i-1]

TF_cumm[i]=TF_cumm[i-1] + TF[i-1]
TF_sim_cumm[i]=TF_sim_cumm[i-1] + TF_sim[i-1]

SF_cumm[i]=SF_cumm[i-1] + SF[i-1]
SF_sim_cumm[i]=SF_sim_cumm[i-1] + SF_sim[i-1]

days[i]=day[i-1]
```

```
}


In_cumm[n+1]=In_cumm[n]+In[n]
In_sim_cumm[n+1]=In_sim_cumm[n]+In_sim[n]

TF_cumm[n+1]=TF_cumm[n]+TF[n]
TF_sim_cumm[n+1]=TF_sim_cumm[n]+TF_sim[n]

SF_cumm[n+1]=SF_cumm[n]+SF[n]
SF_sim_cumm[n+1]=SF_sim_cumm[n]+SF_sim[n]

days[n+1]=day[n]

#PLOT THE DIFFERENT MODELS FOR INTERCEPTION WITH THE REAL FIGURES

png("ModelIn.png", width=1000, height=500)

ylim = c(0, 1.25*max(c(In_cumm) ))
xlength=max(days)
xlim = c(1, xlength)
labelno=round(xlength/10)
placexlabel=array(1:labelno)
for(i in 1:labelno)
{placexlabel[i]=i*10}

# some graphical parameters for the picture

# add a grey grid
plot(days,In_cumm,ylab="Cummulutive Interception  [ mm ]",ylim=ylim,xlim=xlim,
xlab="Time  [ days ]",main="Comparison of modelled and measured interception
over time",type="n")
grid(nx=NA, ny = NULL, col="grey80", lty=3)
abline(v= placexlabel,col="grey80", lty=3)

#    plot(In_cumm, date)
par(new=TRUE)
plot(days,In_cumm,ylab="",ylim=ylim,xlim=xlim,xlab="",type="b",
pch=16,cex=1.5,lty=2,lwd="1.75",col="black")
par(new = TRUE)
par(new = TRUE)
plot(days,In_sim_cumm,ylab="",ylim=ylim,xlim=xlim,yaxt="n",xaxt="n",type="b",
xlab="",pch=15,cex=1.5,lty=1,lwd="1.75",col="black")
```

```
#add a legend
legend(35,5,legend=c("Measured","Sparse Gash Model"),
pch = c(16,17,15),lty=c(2,1,1),cex=1.5,col = 1, ncol = 1, xjust=0.75, yjust=0.5)

 graphics.off()

 #PLOT THE DIFFERENT MODELS FOR THROUGHFLOW WITH THE REAL FIGURES

png("ModelTf.png", width=1000, height=500)

ylim = c(0, 1.25*max(c(TF_cumm) ))
xlength=max(days)
xlim = c(1, xlength)
labelno=round(xlength/10)
placexlabel=array(1:labelno)
for(i in 1:labelno)
{placexlabel[i]=i*10}

# some graphical parameters for the picture

# add a grey grid
plot(days,TF_cumm,ylab="Cummulutive Interception  [ mm ]",ylim=ylim,xlim=xlim,
xlab="Time  [ days ]",main="Comparison of modelled and measured throughhflow
over time",type="n")
grid(nx=NA, ny = NULL, col="grey80", lty=3)
abline(v= placexlabel,col="grey80", lty=3)

#    plot(In_cumm, date)
par(new=TRUE)
plot(days,TF_cumm,ylab="",ylim=ylim,xlim=xlim,xlab="",type="b",
pch=16,cex=1.5,lty=2,lwd="1.75",col="black")
par(new = TRUE)
plot(days,TF_sim_cumm,ylab="",ylim=ylim,xlim=xlim,yaxt="n",xaxt="n",type="b",
xlab="",pch=15,cex=1.5,lty=1,lwd="1.75",col="black")

#add a legend
legend(35,5,legend=c("Measured","Sparse Gash Model"),
pch = c(16,17,15),lty=c(2,1,1),cex=1.5,col = 1, ncol = 1, xjust=0.75, yjust=0.5)

 graphics.off()


#CALCULATE SOME STATS FOR THE MODELS
```

```
# Goodness of fit: Nash-Sutcliffe efficience
dummy1=array(1:n)
dummy2=array(1:n)
dummy4=array(1:n)
dummy5=array(1:n)
dummy7=array(1:n)
dummy8=array(1:n)

        for (i in 1:n)
{ dummy1[i] = (In[i] - mean(In))^2
  dummy2[i] = (In_sim[i] - In[i])^2
  dummy4[i] = (TF[i] - mean(TF))^2
  dummy5[i] = (TF_sim[i] - TF[i])^2
  dummy7[i] = (SF[i] - mean(SF))^2
  dummy8[i] = (SF_sim[i] - SF[i])^2
  }

var_In = sum(dummy1)
MSD_Insim = sum(dummy2)
var_TF = sum(dummy4)
MSD_TFsim = sum(dummy5)
var_SF = sum(dummy7)
MSD_SFsim = sum(dummy8)

NS_In = 1-(MSD_Insim/var_In)
NS_TF = 1-(MSD_TFsim/var_TF)
NS_SF = 1-(MSD_SFsim/var_SF)

# Error calculations
Err_In=array(1:n)
Err_TF=array(1:n)
Err_SF=array(1:n)

      for (i in 1:n)
{
Err_In[i]=abs(In_sim[i]-In[i])/In[i]
Err_TF[i]=abs(TF_sim[i]-TF[i])/TF[i]
Err_SF[i]=abs(SF_sim[i]-SF[i])/SF[i]
}

Error_In=mean(Err_In)
Error_TF=mean(Err_TF)
Error_SF=mean(Err_SF)
```

```
#Total Error over the Sparse Gash and old Gash model!
ERROR_Gash = (In_cumm[n+1] *(abs(In_cumm[n+1]-In_sim_cumm[n+1])/In_cumm[n+1] )
    +   TF_cumm[n+1]*(abs(TF_cumm[n+1]-TF_sim_cumm[n+1])/TF_cumm[n+1])
    +   SF_cumm[n+1]*(abs(SF_cumm[n+1]-SF_sim_cumm[n+1])/SF_cumm[n+1]))/
    (In_cumm[n+1]+TF_cumm[n+1]+SF_cumm[n+1])


#PLOT THE SIMULATED THROUGHFALL VERSUS THE MEASURED THROUGHFALL

mxsc=1.25*max(TF)
mxsca=c(0,mxsc)
png("ValidationTf.png", width=750, height=500)

plot(TF,TF_sim,xlab="Observed Throughflow  [ mm / event ]",
ylab="Simulated Throughflow  [ mm / event ]",type="p",pch=15,cex=1.5,
ylim=mxsca,xlim=mxsca,main="Model Performance - Throughflow")
text(10,11,"1:1 line",cex=1.3)
abline(a=0,b=1)
grid(nx=NULL, ny = NULL, col="grey80", lty=3)

# close the png file
graphics.off()

#PLOT THE SIMULATED INTERCEPTION VERSUS THE MEASURED INTERCEPTION

mxsc=1.25*max(In)
mxsca=c(0,mxsc)
png("ValidationIn.png", width=750, height=500)

plot(In,In_sim,xlab="Observed Interception  [ mm / event ]",
ylab="Simulated Interception  [ mm / event ]",type="p",pch=15,cex=1.5,
ylim=mxsca,xlim=mxsca,main="Model Performance - Interception")
text(6,6.5,"1:1 line",cex=1.3)
abline(a=0,b=1)
grid(nx=NULL, ny = NULL, col="grey80", lty=3)

# close the png file
graphics.off()


# AND FINALLY WRITE A TABLE OF THE STATS!
labs=t(c("","Error","Nash-Sutcliffe"))
write.table(labs,"Gash_stats.csv",sep=",",row.names=FALSE,col.names=FALSE,
quote=FALSE)
```

```
# write table
table = cbind(rbind("Interception","","Throughfall","","Stemflow"),
rbind(round(Error_In,digits=2),"",round(Error_TF,digits=2),"",
round(Error_SF,digits=2)),rbind(round(NS_In,digits=2),"",round(NS_TF,digits=2),
"",round(NS_SF,digits=2)))
write.table(table, "Gash_stats.csv",quote=FALSE, append=TRUE,sep=",",
row.names=FALSE, col.names=FALSE)
# EXTREMELY SIMPLE INFILTRATION MODEL


RI = Pg/Duration
SI_thick = 27.3                          # Soil infiltration rate for Spekkies
SI_degr = 3.3                           # Soil infiltration rate for Degr. field


RO_thick=array(1:n)
RO_degr=array(1:n)
RO1_thick=array(1:n)
RO2_thick=array(1:n)
RO1_degr=array(1:n)

for(i in 1:n)
{ if(RI_maxi[i]>SI_degr)       RO_degr[i] = Pgi[i]*(SI_degr/RI_maxi[i])
else {if(Pgi[i]>5)             RO_degr[i] = Pgi[i]-5
else RO_degr[i]=0  }
}
for(i in 1:n)
{ if(RI_maxi[i]>SI_degr)       RO1_degr[i] = (0.95*Pgi[i])*(SI_degr/RI_maxi[i])
else {if((0.95*Pgi[i])>5)      RO1_degr[i] = (0.95*Pgi[i])-5
else RO1_degr[i]=0  }
}


for(i in 1:n)
  {if(RI_maxi[i]>SI_thick)    RO_thick[i] = Pgi[i]*(SI_thick/RI_maxi[i])
else {if(Pgi[i]>10)           RO_thick[i] = Pgi[i]-10
else RO_thick[i]=0}
}

for(i in 1:n)
  {if(RI_maxi[i]>SI_thick)    RO1_thick[i] = TFi[i]*(SI_thick/RI_maxi[i])
else {if(TFi[i]>10)           RO1_thick[i] = TFi[i]-10
else RO1_thick[i]=0}
}
```

```
for(i in 1:n)
  {if(RI_maxi[i]>SI_thick)    RO2_thick[i] = TF_sim[i]*(SI_thick/RI_maxi[i])
else {if(TF_sim[i]>10)       RO2_thick[i] = TF_sim[i]-10
else RO2_thick[i]=0}
}

Inf_degr = Pgi - RO_degr
Inf_thick = Pgi - RO_thick
Infs_thick = TFi - RO2_thick


# EASY TO MAKE A TABLE OF IT ALL!
labsi=t(c("","Rain","Effective Rainfall","Runoff","(%)","Effective Runoff",
"Simulated","Infiltration", "(%)","Simulated","","Spekboom/Degrade",""))
write.table(labsi,"RO_data.csv",sep=",",row.names=FALSE,col.names=FALSE,
quote=FALSE)
# write table
table1 = cbind(rbind("Spekboom","Degraded"),
rbind(round(sum(Pgi),digits=2),round(sum(Pgi),digits=2)),
rbind(round(sum(TFi),digits=2),round(sum(0.95*Pgi),digits=2)),
rbind(round(sum(RO_thick),digits=2),round(sum(RO_degr),digits=2)),
rbind(round(sum(RO_thick)/sum(Pgi),digits=2),round(sum(RO_degr)/sum(Pgi),
digits=2)),rbind(round(sum(RO1_thick),digits=2),round(sum(RO1_degr),digits=2)),
rbind(round(sum(RO2_thick),digits=2),""),rbind(round(sum(Inf_thick),digits=2),
round(sum(Inf_degr),digits=2)),rbind(round(sum(Inf_thick)/sum(Pgi),digits=2),
round(sum(Inf_degr)/sum(Pgi),digits=2)),rbind(round(sum(Infs_thick),
digits=2),""), rbind("",""),rbind(round(sum(RO_degr)/sum(RO_thick),digits=2),
round(sum(Inf_degr)/sum(Inf_thick),digits=2)),rbind("Runoff","Infiltration"))
write.table(table1, "RO_data.csv",quote=FALSE, append=TRUE,sep=",",
row.names=FALSE, col.names=FALSE)


# REMOVE DATA from memory
detach(data)
```

E Datasheet for Interception Dynamics

Date	Downslope		Midslope		Upslope		4-way Interception Troughs			Gauge	Stemcollar	Pg_av	Tf_av	In_av	I/P	D	Rlm
	Pg	Tf	Pg	Tf	Pg	Tf	Tf - Left	Tf - Right	Tf - Median	Tf	Sf						
14-Oct	17.5	18.75	ERROR	15.75	17	9.5	ERROR	ERROR	ERROR	ERROR	ERROR	17.3	14.7	2.6	0.15	9	4.5
25-Oct	4.25	1.5	ERROR	1.75	3.25	1.5	0.5	0.7	0.6	ERROR	ERROR	3.8	1.2	2.6	0.68	3	2.5
Measure							0.5	0.7									
27-Oct	14.5	11.3	ERROR	9.0	10.5	8.0	8.0	7.1	7.5	8.1	1.07	12.5	8.6	2.9	0.23	11	3.0
04-Nov	6.5	3.8	ERROR	4.3	ERROR	3.5	3.5	3.1	3.3	3.6	0.43	6.5	3.6	2.5	0.38	4	6.0
05-Nov	4.5	1.3	ERROR	3.5	ERROR	1.8	1.7	1.6	1.6	1.8	0.25	4.5	1.9	2.3	0.52	3	3.5
10-Nov	4.8	1.5	ERROR	3.8	ERROR	1.5	1.5	1.3	1.4	1.5	0.25	4.8	1.9	2.6	0.56	4	3.0
Measure							14.7	13.1		15.0	2.00						
16-Nov	2.5	0.5	ERROR	1.8	ERROR	1.0	0.0	0.0	0.0	1.0	0.11	2.5	1.1	1.3	0.57	3	2.0
24-Nov	0.5	0.5	ERROR	ERROR	ERROR	0.0	0.0	0.0	0.0	0.0	0.01	0.5	0.2	0.3	0.63	0	0.5
26-Nov	15.3	11.5	ERROR	ERROR	ERROR	6.3	14.7	12.2	13.5	13.0	1.21	15.3	11.6	2.5	0.16	4	9.0
03-Dec	6.3	4.8	ERROR	ERROR	ERROR	4.3	5.1	6.3	5.7	3.0	0.49	6.3	4.7	1.1	0.17	2	6.0
Measure							19.8	18.5*		17.0							
11-Dec	2.0	1.5	ERROR	ERROR	ERROR	1.5	3.5	2.5	3.0	2.0	0.17	2.0	1.7	0.2	0.07	3	1.0
17-Dec	141.3	21.0	ERROR	ERROR	ERROR	20.8	48.5	33.0	40.8	26.0	ERROR	141.3	29.9	111.4	0.79	16	10.0
Measure		38.75**					52.0	35.5		28.0	2.00						
18-Dec	3.5	0.0	1.5	1.0	ERROR	0.0	0.3	0.1	0.2	0.4	0.00	2.5	0.3	2.2	0.88	2	2.0
19-Dec	0.8	0.0	0.5	0.0	ERROR	0.0	0.0	0.0	0.0	0.0	0.00	0.6	0.0	0.6	1.00	1	0.0
20-Dec	0.8	1.0	0.8	1.3	ERROR	0.5	0.9	0.4	0.7	1.1	0.01	0.8	0.9	-0.1	0.00	1	0.0
20-Dec	1.5	1.0	1.3	1.3	ERROR	0.5	0.9	0.4	0.7	1.1	0.01	1.4	0.9	0.5	0.37	1	0.5
22-Dec	14.3	11.8	9.3	16.5	ERROR	6.8	11.6	5.2	8.4	13.5	0.20	11.8	10.9	0.7	0.06	1	11.8
23-Dec	1.3	1.0	0.5	0.3	ERROR	0.0	0.5	0.2	0.3	0.5	0.01	0.9	0.4	0.5	0.53	1	0.5
24-Dec	4.0	0.3	3.5	2.5	ERROR	1.8	1.5	0.7	1.1	1.8	0.03	3.8	1.4	2.3	0.62	1	2.0
25-Dec	1.5	0.3	1.0	0.5	ERROR	0.5	0.3	0.1	0.2	0.4	0.01	1.3	0.3	0.9	0.72	1	0.5
27-Dec	0.0	0.5	0.0	0.0	ERROR	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.1	-0.1	0.00	0	0.0
28-Dec	0.5	0.0	0.8	0.0	ERROR	0.0	0.0	0.0	0.0	0.0	0.00	0.6	0.0	0.6	1.00	0	0.0
Measure							15.0	6.8		17.5	0.26						
29-Dec	ERROR	ERROR	2.0	ERROR	3.3	ERROR	1.1	1.5	1.3	0.8	0.01	2.6	1.1	1.5	0.56	6	1.0
30-Dec	ERROR	ERROR	2.5	ERROR	4.5	ERROR	1.4	1.9	1.7	1.1	0.01	3.5	1.5	2.0	0.58	7	1.0
01-Jan	ERROR	ERROR	8.1	ERROR	13.0	ERROR	4.4	6.0	5.2	3.2	0.04	10.6	4.5	6.0	0.57	10	5.0
03-Jan	ERROR	ERROR	2.5	ERROR	3.5	ERROR	1.2	1.7	1.4	0.9	0.01	3.0	1.3	1.7	0.58	2	2.5
Measure							8.1	11.1		6.0	0.07						
10-Jan	ERROR	ERROR	4.6	ERROR	6.5	ERROR	3.2	1.8	2.5	ERROR	0.01	5.6	2.5	3.1	0.55	4	2.0
12-Jan	ERROR	ERROR	9.2	ERROR	16.3	ERROR	7.9	4.6	6.3	ERROR	0.04	12.7	6.3	6.4	0.50	3	11.3
Measure							11.1	6.4			0.05	137.2	83.2	49.6			
TOTAL											4.38 (3%)	137.2	83.2	49.6	0.36	Tf=61%	

* One of the two troughs fell, so data has been multiplied by two

** Total value of throughfall from 26-Nov untill 17-Dec

F Datasheet for Soil Moisture Dynamics

Due to the large amount of data, this appendix can only be provided in excell format. Please contact author or LivingLands for acquiring more information regarding the soil moisture measurements.

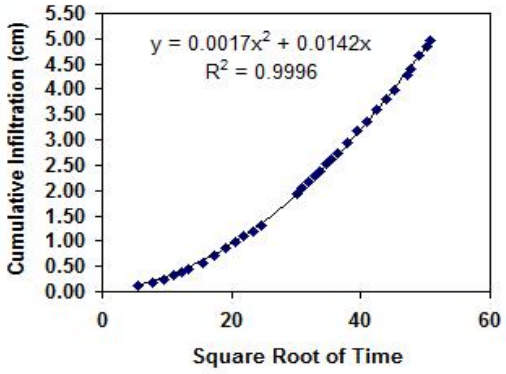
G Datasheet for Runoff Dynamics

Date	21-Oct	27-Oct	12-Nov	20-Nov	1-Dec	6-Dec	17-Dec	28-Dec	3-Jan	14-Jan	TOTAL (Liter)
Pg	4	3	28	3	16	6	30	20	20	18	
Rlm	2	5	6	2	9	6	10	12	5	11	
Remarks?	No	No	Yes	No	No	Yes	No	No	No	No	
Degraded TOP	* Numbers count from the fence outward										
GT-1	0	78	2,402	0	995	186	4,400	7,500	1,100	8,100	
GT-2	0	0	0	0	53	119	100	475	150	600	
GT-3	0	199	849	0	66	133	450	2,350	710	3,700	
Total_Degr_Top	0	277	3,252	0	1,115	438	4,950	10,325	1,960	12,400	**34,717**
Thicket TOP	* Numbers count towards the fence										
GT-4	0	139	0	13	451	0	2,250	1,900	1,400	700	
GT-5	0	0	650	27	425	199	1,500	940	780	500	
GT-6	0	28	995	40	770	133	7,500	710	1,300	650	
Total_Thick_Top	0	167	1,646	80	1,646	332	11,250	3,550	3,480	1,850	**24,000**
Degraded MIDDEL	* Numbers count from the fence outward										
GT-7	40	0	53	0	119	0	700	1,000	1,200	1,500	
GT-8	170	0	0	0	1,088	796	2,750	13,100	3,300	9,800	
GT-9	5	0	1,633	146	531	199	2,500	5,000	2,000	3,500	
Total_Degr_Mid	215	0	1,686	146	1,739	995	5,950	19,100	6,500	14,800	**51,131**
Thicket MIDDEL	* Numbers count towards the fence										
GT-10	0	0	730	0	3,451	1,394	11,400	4,150	750	4,200	
GT-11	0	0	1,062	0	929	27	5,750	1,250	2,000	1,500	
GT-12	0	70	4,526	0	239	133	2,300	500	2,200	700	
Total_Thick_Mid	0	70	6,318	0	4,619	1,553	19,450	5,900	4,950	6,400	**49,260**
Degraded BOTTOM	* Numbers count from the fence outward										
GT-13	2	0	0	0	8,097	0	2,800	75,000	20,000	19,400	
GT-14	200	0	0	1,022	16,857	557	6,250	25,000	10,900	19,200	
GT-15	0	0	0	0	86,760	7,008	34,750	100,000	13,300	54,000	
Total_Degr_Bot	202	0	0	1,022	111,713	7,566	43,800	200,000	44,200	92,600	**501,103**
Thicket BOTTOM	* Numbers count towards the fence										
GT-16	0	0	0	66	0	0	0	1	0	0	
GT-17	0	0	0	0	14,866	12,676	6,000	25,500	2,800	7,800	
GT-18	0	0	0	0	17,255	1,832	31,500	35,000	16,000	34,100	
Total_Thick_Bot	0	0	0	66	32,121	14,508	37,500	60,501	18,800	41,900	**205,396**
*** All values in cm^3**											

H Datasheet for Infiltration Tests

Infiltration test at degraded land @ 17.12.2010

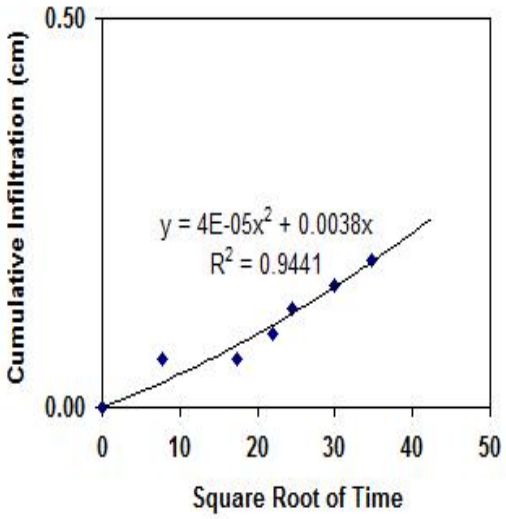
Time (s)	sqrt (Time)	Volume (mL)	Infiltration (cm)
0		79	0.00
30	5.48	77	0.13
60	7.75	76	0.19
90	9.49	75	0.25
120	10.95	74	0.31
150	12.25	73	0.38
180	13.42	72	0.44
240	15.49	70	0.57
300	17.32	67.5	0.72
360	18.97	65.5	0.85
420	20.49	63.5	0.97
480	21.91	61.5	1.10
540	23.24	60	1.19
600	24.49	58	1.32
900	30.00	48.5	1.92
960	30.98	46.5	2.04
1020	31.94	44.5	2.17
1080	32.86	42.5	2.30
1140	33.76	41	2.39
1200	34.64	39	2.52
1260	35.50	37.5	2.61
1320	36.33	35.5	2.74
1440	37.95	32	2.96
1560	39.50	28.5	3.18
1680	40.99	25.5	3.36
1800	42.43	22	3.58
1920	43.82	18.5	3.81
2040	45.17	15.5	3.99
2220	47.12	11	4.28
2280	47.75	9	4.40
2400	48.99	5	4.65
2520	50.20	2	4.84
2580	50.79	0	4.97



A	6.12	*clay loam*	C1	2.E-03	*Slope of chart*
k = C1/A	0.00027	cm/s	**Infiltration:**	**9.71**	**mm/hr**

Infiltration test at degraded land @ 29.12.2010 - I

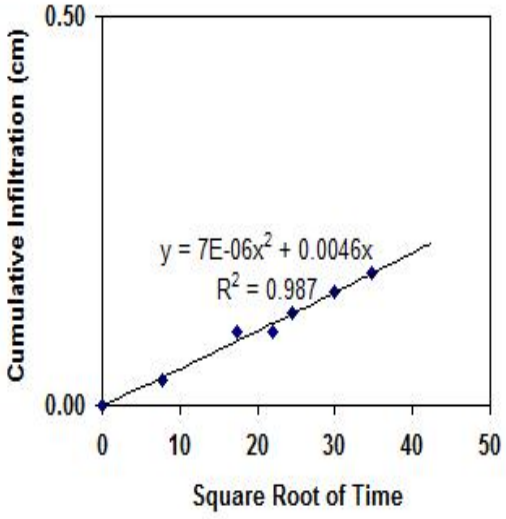
Time (s)	sqrt (Time)	Volume (mL)	Infiltration (cm)
0	0.00	80	0.00
60	7.75	79	0.06
300	17.32	79	0.06
480	21.91	78.5	0.09
600	24.49	78	0.13
900	30.00	77.5	0.16
1200	34.64	77	0.19
1500	38.73		
1800	42.43		



A	5.86	*clay loam*	C1	4.E-05	*Slope of chart*
k = C1/A	6.83E-06	cm/s	**Infiltration:**	**0.25**	**mm/hr**

Infiltration test at degraded land @ 29.12.2010 - II

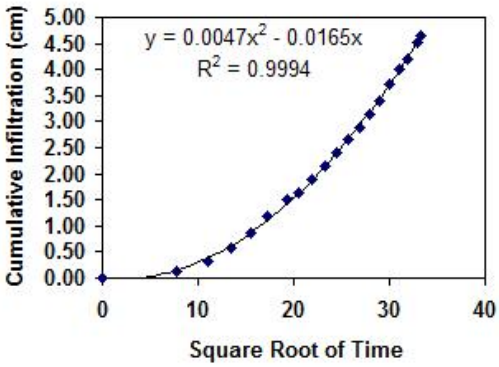
Time (s)	sqrt (Time)	Volume (mL)	Infiltration (cm)
0	0.00	75.5	0.00
60	7.75	75	0.03
300	17.32	74	0.09
480	21.91	74	0.09
600	24.49	73.6	0.12
900	30.00	73.2	0.14
1200	34.64	72.8	0.17
1500	38.73		
1800	42.43		



A	5.86	*clay loam*	C1	7.E-06	*Slope of chart*
k = C1/A	1.19E-06	cm/s	**Infiltration:**	**0.04**	**mm/hr**

Infiltration test at Spekboom land @ 29.12.2010 - I

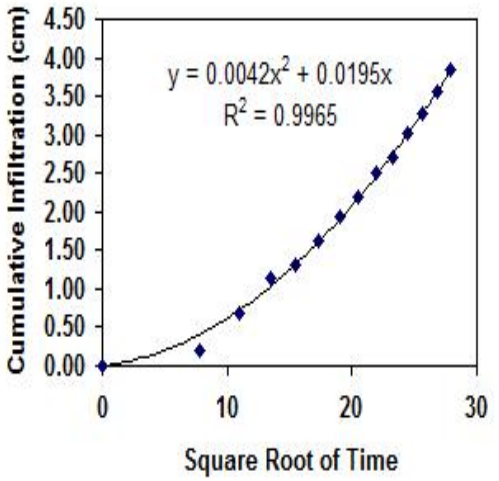
Time (s)	sqrt (Time)	Volume (mL)	Infiltration (cm)
0	0.00	78	0.00
60	7.75	76	0.13
120	10.95	73	0.31
180	13.42	69	0.57
240	15.49	64	0.88
300	17.32	59	1.19
375	19.36	54	1.51
420	20.49	52	1.64
480	21.91	48	1.89
540	23.24	44	2.14
600	24.49	40	2.39
660	25.69	35.5	2.67
720	26.83	32	2.89
780	27.93	28	3.14
840	28.98	24	3.40
900	30.00	19	3.71
960	30.98	14.5	3.99
1020	31.94	11	4.21
1080	32.86	6	4.53
1110	33.32	4	4.65



A	5.86	*clay loam*	C1	5.E-03	*Slope of chart*
k = C1/A	0.000797	cm/s	**Infiltratior**	**28.69**	**mm/hr**

Infiltration test at Spekboom land @ 29.12.2010 - II

Time (s)	sqrt (Time)	Volume (mL)	Infiltration (cm)
0	0.00	61	0.00
60	7.75	58	0.19
120	10.95	50	0.69
180	13.42	43	1.13
240	15.49	40	1.32
300	17.32	35	1.64
360	18.97	30	1.95
420	20.49	26	2.20
480	21.91	21	2.52
540	23.24	18	2.70
600	24.49	13	3.02
660	25.69	9	3.27
720	26.83	4.5	3.55
780	27.93	0	3.84



A	5.86	*clay loam*	C1	4.E-03	*Slope of chart*
k = C1/A	0.000724	cm/s	**Infiltratior**	**26.05**	**mm/hr**