

The Relationship Between Soil Water Regime and Soil Profile Morphology: A Proposal for Continued Research

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Report to the Water Research Commission

by the

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SYMBOLS USED

Θ_v volumetric soil water content (mm)

 $AD_{s>0.7}$ annual duration of water saturation above 0.7 of porosity (days year⁻¹) Av Avalon soil form (orthic A – yellow-brown apedal B – soft plinthic B)

Bd Bloemdal soil form (orthic A – red apedal B – unspecified material with signs of wetness) $D_{s>0.7}$ duration of degree of water saturation above 0.7 of porosity in a particular year (days event⁻¹)

 $F_{s>0.7}$ frequency of water saturation above 0.7 of porosity (events year⁻¹)

gh G horizon gs E horizon

Hu Hutton soil form (orthic A – red apedal B – unspecified)

Ka Katspruit soil form (orthic A – G)
Kd Kroonstad soil form (orthic A – E – G)

Lo Longlands soil form (orthic A - E - soft plinthic B)

ne neocutanic B horizon

on unspecified material with signs of wetness

ot orthic A horizon P precipitation

Pn Pinedene soil form (orthic A – yellow-brown apedal B – unspecified material with signs of

wetness)

re red apedal B horizon

ro rock

s degree of saturation (volume of water per volume of pores)

s>0.7 degree of water saturation above 0.7 of porosity

so saprolite

sp soft plinthic B horizon

Tu Tukulu soil form (orthic A – neocutanic B – unspecified material with signs of wetness)

ud unconsolidated material without signs of wetness We Westleigh soil form (orthic A – soft plinthic B)

ye yellow-brown apedal B horizon

1. INTRODUCTION

Knowledge of the hydrology of South African soils becomes more important as the demand for water approaches the supply. This is especially true for determining catchment water yield. It seems likely that the relationship between soil water regime and soil profile morphology could contribute towards improving these procedures. The underlying rationale is that there are large differences between the hydrological characteristics of different soils in a catchment, which are expressed in their morphology, and which influence lateral downslope water movement (interflow), and therefore the shape of the hydrograph. This aspect of hydrology has, however, only recently received attention in South Africa. Initial indications are that diagnostic soil forms and horizons, defined in Soil Classification - A Taxonomic System for South Africa (Soil Classification Working Group, 1991), can be evaluated in terms of duration of water saturation due to their narrow morphological definitions (Van Huyssteen, 2004). The South African soil classification system is structured with soil forms as taxons at the highest level. Each soil form is defined by a specific sequence of diagnostic horizons, defined in terms of soil morphology. The pioneers of soil classification in South Africa were consciously and unconsciously influenced by the largely arid and semi-arid nature of the country when selecting differentiating criteria, paying special attention to soil morphological features resulting from water. The hydrology of diagnostic subsoil horizons can therefore be inferred from their fairly specific definitions. This is important as interflow in the solum occurs in these horizons, making soil classification an important input in any hydrological pedotransfer function.

All the water that reaches a stream has, therefore, to either pass over the soil surface (runoff) or pass through the soil (deep drainage and lateral flow). It can therefore be said that the soil influences the flow rate, amount and quality of water that reaches the stream. Soil further impacts on the above through its influence on the rate of evapotranspiration.

Our studies over the past few years in "The relationship between soil water regime and soil profile morphology in the Weatherley catchment, an afforestation area in the North Eastern Cape" (WRC Project K5/1317), have led us deeper and deeper into hydropedology. This process has made us aware of the need to obtain experience in catchments and related measurement sites with characteristics different from those at Weatherley. This procedure seemed to be the logical way forward to build capacity in hydropedology, our capacity, and that of our students and co-workers. In so doing we should be able to improve the support we can offer to hydrologists.

Apart from continuing data collection and interpretation at Weatherley, the main objective of this project was, therefore, to carefully select a few new study sites. We have decided that, to obtain optimum benefit from future studies at these sites, they should include a wide range in terms of soil, parent material, topography, climate and vegetation. The amount of data that has already been collected by other researchers and is appropriate in relation to our focus, is also an important criterion. That information will serve to facilitate the interpretation of the results of our studies.

1.1. Motivation

Reliable hydrological and geohydrological models are important tools for the successful management of water resources. All water that flows from a catchment, or into the groundwater, must first pass over or through the soil. It therefore follows that modelling of soil hydrology must be reliable for a hydrological or geohydrological model to be reliable. Correct interpretation of soil profile morphology provides an excellent long-term index of soil hydrology. A detailed soil survey of any experimental catchment, or geohydrological survey area, together with other essential soil qualities (texture, bulk density, final infiltration rate, matric suction curve, saturated hydraulic conductivity, etc.), for the main

diagnostic horizons, can therefore make a valuable contribution to improving hydrological and geohydrological models.

The definition of a few soil series, with characteristic pedo-hydrological properties ($AD_{s>0.7}$, saturated hydraulic conductivity, bulk density, *etc.*) per horizon and profile would be a major advancement in the provision of input parameters for the above-mentioned models. A large scale map (*e.g.* 1:2 500 to 1:10 000 scale) on which such soil series are delineated should be of great value to hydrologists and geohydrologists.

1.2. Objective

To aid in the prediction of catchment water yield (the hydrograph) by interpretation of soil characteristics and climate data.

1.3. Aims

- a. To do a literature review, listing catchments where soil water and runoff data is available, to define their data deficiencies and to suggest augmentation.
- b. To conduct workshops in Gauteng, Pietermaritzburg and Stellenbosch, with the aim of improving the list compiled in the above aim.
- c. Continue data collection and interpretation in the Weatherley catchment.

1.4. Technology transfer

Two refereed articles (Van Huyssteen *et al.*, 2006a; Van Huyssteen *et al.*, 2006b) were published and nine conference contributions (Jennings, 2006; Joseph *et al.*, 2005; Le Roux, *et al.*, 2005; Le Roux *et al.*, 2006; Van Huyssteen *et al.*, 2005a; Van Huyssteen *et al.*, 2005b; Van Huyssteen *et al.*, 2006c; Zere *et al.*, 2005; Zere *et al.*, 2006) were made during the course of this project.

1.5. Capacity building

Ms K. Jennings and Mr T.B. Zere were appointed as research assistants on this project. Mr T.B. Zere will obtain his Ph.D. degree during the April 2006 graduation ceremony, while Ms K. Jennings should qualify for her B.Sc. Hons. degree during June 2006.

2. LITERATURE REVIEW

2.1. Introduction

Due to the shortage of water in South Africa, many studies in catchment hydrology and soil hydrology have been undertaken over a wide range of environments. Most of the intensive studies seem to have been funded by the WRC, resulting in excellent advances in all the related fields of science. The focus of this review of literature has therefore been mainly on WRC reports. Relevant ones were selected from a comprehensive list provided by the WRC. These were studied with two objectives. The first one was to identify a wide range of research catchments in South Africa which qualify in terms of our selection criteria. In addition, experienced hydrologists and those in related fields have been asked for guidance in the provisional selection process. The second objective was to identify deficiencies and ways in which we could possibly contribute towards overcoming these.

2.2. Results

2.2.1. Provisional list of catchments

The compiled provisional list of catchments is presented in Table 1. Columns were provided for all the information about the catchments which we considered would be useful when making the final choice.

The information already available to us has also been included. Information which is still outstanding will be collected as far as possible from the contact persons recorded in the last column, or from their publications. Although it is too soon to draw detailed conclusions about the information in Table 1, there is one prominent deficiency. It is the absence of soil survey maps for most of the catchments. Where no soil survey has been undertaken, it is unlikely that the detailed information about the soils needed for reliable hydrological modelling is available. Even if some data in this connection has been collected, without a soil map it will not be known to what portions of the catchment it is applicable. Schulze (2004) accentuates the importance of information about soils and their distribution for effective hydrological modelling (Figure 2).

The catchment size (Figure 2) that will be best for our purposes is an important question during the catchment selection process. In this regard Royappen *et al.* (2002) make the following relevant statement: "Many past ACRU simulations on both large and small catchments have highlighted a general problem of correctly simulating flows from small catchments. Over large catchments, spatial variations in geological and soil characteristics tend to average out, allowing easier simulations of the combined flows from the many smaller sub-catchments. At the smaller scale, however, individual characteristics express themselves strongly through the hydrograph, and highlight our incomplete understanding in the link between rainfall and stream flow". The phrase "easier simulations" in the second sentence probably means "more accurate simulations". Schulze (2004) also presents his views on the relative importance of different catchment features and anthropogenic influences on hydrological responses in the form of the diagram reproduced here as Figure 2. Only the top portion of the diagram is relevant here. Soil and local topography are considered to dominate the "hydrological response" on catchments with areas less than about 500 ha.

The implication of these statements is that we will learn most about the influence of different kinds of soil on the hydrograph from studies in small catchments of less than about 500 ha. This is borne out by the comparison presented by Van Huyssteen et al. (2005) between hydrographs of the 160 ha Weatherley and 67 ha Cathedral Peak VI catchments. The rainfall in the two catchments is similar. The portions of the hydrographs which were compared represented rain free periods in autumn after a wet summer, i.e. the catchments were both well filled with water. The relatively quickly released interflow water, represented by the lower curved portion of the hydrograph down to the base flow level, amounted to 2.7 and 7.7 mm ha⁻¹ in the two catchments respectively (Figure 1). The far larger amount from Cathedral Peak VI is doubtlessly due to the large storage capacity of both the very deep, humus rich soils and deep lower vadose zone; and in addition the absence of a large riparian zone to impair movement of the interflow water to the stream. In contrast the soils in the Weatherley catchment are dominated by relatively shallow hydromorphic soils with a relatively low storage capacity. In addition the large portion of these hydromorphic soils in the riparian zone tends to absorb and dissipate the interflow water before it reaches the stream. This feature confirms the importance of local topography at this scale as indicated in Figure 2. Another reason for the preference for small research catchments is that those are the sites at which data collection would probably have been conducted at maximum intensity in the past, and is possibly still being undertaken.

In his discussion of Figure 2, Schulze (2004) identifies texture, depth and drainage as the important soil characteristics; and slope, aspect, and altitude gradient influences on microclimate, as the important topographic characteristics. This conclusion accentuates the need to give preference in our selection process, where possible, to catchments on which the topography has already been mapped in detail.

Provisional list of catchments from which a selection can be made for a proposed WRC project aimed at improving our understanding of the relationship between soil water regime, soil profile morphology and hydrology Table 1

Name	Location	Area	느	L	1:50000		Climate	te	Ö	Geology	Hydro	Soil	Soil	Soil	Contour	Bore	Veg. 3	Soil	Risk 4	Dev. 5	Contact Person
	Region / Co-ord 1	(ha)	map		map	니	MAR	ETo	Е			water survey	urvey	anal.	map ²	holes		physical			
						zone	(mm)	or Eo				meas.				and		prop.			
								(mm)								(number)					
Cath. Peak VI	Cathedral	89			2929AB		1200	yes	yes	yes	yes	yes	on O	some	yes	yes	б	some	_	ď	C Everson
	Peak														(20m)						
2 Streams	Greytown	22			2930BA		840	yes	yes		yes	yes	9	some	yes	yes (8)	gct	yes	_	ပ	C Everson
	(30°40", 29°11")																				
Ntuze WIHO 17	Empangeni	20					1300	yes		yes	yes	some	yes	yes	yes	yes	gc	some		_	B Kelbe
Mphogodiba	Haenertsburg	±225			2329DD						yes		91	ou	probable	yes (7)		ou		_	Tunka/S Lorentz
SSI	KZN Emmans										yes	some							ч	_	GPW Jewitt
Thabamhlope	Drakensberg										yes										R Schulze
	(29°58", 30°20")																				
De Hoek VIH015	Drakensberg	103					1115	1658			yes			some			D				R Schulze
Cedara	KZN										yes								ᅩ	4	
Upper Moder	Moder ThabaNchu	94000		Dc17		42S	540	±2000		yes	yes	ou	9	ou	yes	ou	gc	ou	ح		L Pretorius
River (C52A)															(20m)						
Weatherley	Maclear	160			3128AB					yes	yes	yes	yes	yes	yes (2m)	yes	ğ	yes	Ε	p-d	CW van Huyssteer
Goedertrou	Riebeeckwes									yes	yes		yes								MV Fey
Lambrechtsbos	Stellenbosch	99					1145			yes	yes		on O				÷		_	-	Royappen
	(33°57", 18°57")																				
Witklip V	White River	108					1100			yes	yes	some	no				gţ	some	_	Ţ	Royappen
	(25°14", 30°54")																				
Westfalia B	Duiwelskloof	33					1253			yes	yes		9				÷		_	p-f	Royappen
	(23°43", 30°04")																				

¹ Southern latitude and eastern longitude (degrees, minutes)

 $^{^{2}% \}left(-1\right) =0$ Contour map and contour intervals (m)

³ Vegetation types: g = grassveld; f = forestry; gc = mixed grassveld and crops; gt = mixed grassveld and trees; gct = mixed grassveld, crops and trees

 $^{^4}$ Refers to risk of instrument vandalization: h = high; m = medium; l = low

 $^{^5}$ Development: p = pristine; c = commercial; r = rural development; f = forestry

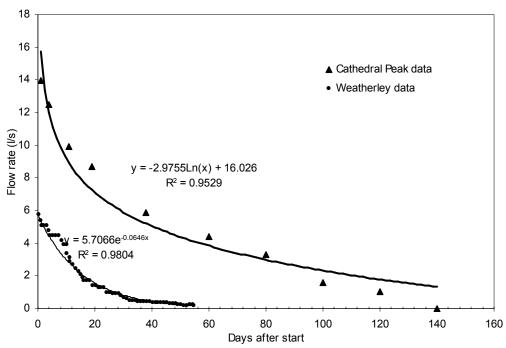


Figure 1 Typical hydrographs for the Weatherley and Cathedral Peak (VI) catchments during a rainfree period at the end of the rain season, approximately up to the stage when base flow starts.

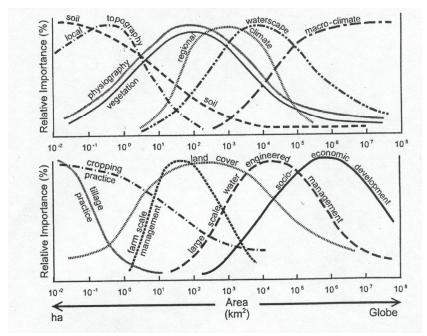


Figure 2 Natural heterogeneities (top) and anthropogenic influences (bottom) occur across a range of spatial scales, but dominate hydrological responses over a narrower spectrum (Schulze, 2004).

In Figure 2 the relative importance of soil and local topography is shown to be small on catchments larger than about 10 000 ha. This can be misleading. It needs to be remembered that the diagram is dealing with "hydrological responses", and not with "hydrological processes". The diagram is in agreement with the statement of Royappen *et al.* (2002) quoted above. Simulations measure the hydrological responses of catchments. Shortcomings due to incomplete understanding of the complex processes involved result in inaccuracies for particular sub-catchments. In larger catchments, with many sub-catchments, it seems that these inaccuracies tend to balance out, resulting in satisfactory

results – referred to by Royappen *et al.* (2002) as "easier simulations". It should not, however, be concluded from Figure 2 that soil and topography become relatively unimportant with regard to hydrological process in large catchments. Soil and local topography must inevitably be of dominating importance in all catchments since all the water that reaches the stream must either pass over or through the soil at some stage.

Soil water regime studies not associated with catchment studies can also provide valuable information regarding the relationship between soil water regime and soil profile morphology. That is the reason for the provisional list of such studies presented in Table 2.

2.2.2. Augmentation of available data

In the process of compiling this literature review it has become clear that there are a number of valuable contributions which soil scientists can make. It seems that these contributions have been minimal in the past. The current growing importance of integrated water resources management and stream flow reduction activities accentuates the need for these contributions (Kahinda *et al.*, 2005; Woyessa *et al.*, 2005). In the long-term a most valuable contribution will be the elucidation of the relationship between soil water regime and soil profile morphology. Some useful direct, short-term contributions are listed below.

Detailed soil surveys

These provide valuable information for hydrological models. Such surveys are currently rather expensive. The wise implementation of new technologies such as GIS, digital terrain mapping, computerized soil survey programmes, and improved equipment for field investigations, could possibly improve the efficiency and reduce the cost of these surveys. Research in this regard is needed. "Soil classification: A taxonomic system for South Africa" (Soil Classification Working Group, 1991) has not yet been expanded to include soil series. Expansion in this regard would be useful to hydrologists, especially differentiation at series level of soils with specific hydrological characteristics.

Bulk density

This is a basic soil characteristic of great importance to hydrologists, because it measures to porosity (pore volume) and therefore potential water storage capacity of soils (Lorentz *et al.*, 2001; Lorentz *et al.*, 2004). Procedures need to be developed to provide Db values for specific kinds of horizons.

Drainage curves and the drained upper limit

The characteristic way in which a soil drains from close to saturation to the point at which drainage becomes negligible is important in hydrology (Schulze, 2004). This process delivers the interflow and low flow water of the hydrograph. Drained upper limit (DUL), where water drainage from a soil stops after saturation, is an important parameter. It is encouraging to see that this term, instead of field water capacity, is being used by Schulze (2004). A procedure needs to be developed to predict drainage curves for different kinds of soils - in view of the fact that the field determination is so laborious and expensive. The amount of water which different kinds of vegetation can extract, through transpiration above DUL, while the soil is draining, also needs to be determined. A field-determined drainage curve provides basic information needed for the determination of DUL (Hattingh, 1993).

Table 2 List of non-catchment soil water regime studies that could provide useful information

Site / ecotope Soil water Climate Soils	Soil water	Climate	Soils	=	Topography	Geology	Drainage	Reference
	measured	1	Pedology	Physical		}	curve	
				prop				
Kenilworth/Bainsvlei	many years	detailed	yes	yes	yes	yes	yes	Bennie <i>et al.</i> , 1994
Tweespruit/Westleigh	± 3 yrs	detailed	yes	yes	yes	yes	yes	Bennie <i>et al.</i> , 1994
Hoopstad/Clovelly	± 3 yrs	detailed	yes	yes	yes	yes	yes	Bennie <i>et al.</i> , 1994
Petrusburg/Hutton	± 3 yrs	detailed	yes	yes	yes	yes	yes	Bennie <i>et al.</i> , 1994
Bethlehem/Avalon	٠.	detailed	yes	yes	yes	yes	yes	Hoffmann & Kotzé
Rooipoort/Hutton-Clansthal	± 1 yrs	detailed	yes	yes	yes	yes	yes	Haarhoff, 1989
Cedara/Doveton (?)	<i>د</i> .	detailed	yes	yes	yes	yes	<i>د</i> .	Berry <i>et al.,</i> 1987
Setlagole/Clovelly	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Wolmaransstad/Hutton	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Kroonstad/Avalon	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Bethal/Hutton	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Bethal/Avalon	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Ermelo/Longlands	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Bultfontein/Clovelly	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Petrusburg/Bloemdal	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Glen/Swartland	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 2000
Glen/Bonheim	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Khumo/Swartland	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
Vlakspruit/Arcadia	3 seasons	detailed	yes	yes	yes	yes	yes	Hensley <i>et al.</i> , 1997
La Mercy/Swartland	2 seasons	detailed	yes	yes	yes	yes	<i>د</i> .	Van Antwerpen 1998
Nooitgedacht	3 seasons	detailed	yes	yes	yes	yes	OU	Hensley <i>et al.</i> , 1997
Seven Oaks	7 years	detailed	۷.	<i>د</i> .	<i>ر</i> .	<i>ر</i> .	<i>ر</i> .	Roberts, 1994
Kruger Park (5 sites)	yes	probably	<i>ر</i> .	<i>د</i> .	<i>د</i> .	<i>ر</i> .	<i>ر</i> .	Lorentz, UKZN
Kruger Park (2 sites)	yes	ر.	<i>ر</i> .	<i>د</i> .	<i>ر</i> .	<i>ر</i> .	<i>ر</i> .	Archibald, CSIR
Kokstad	yes	detailed	some	<i>د</i> .	<i>د</i> .	yes	<i>ر</i>	Van Zyl & Lorentz, 2003
Grabouw	yes	detailed	yes	yes	yes	yes	ن	Van Huyssteen, 1995

Final infiltration rates of different soils

Final infiltration rate (If) of a soil as an important soil property, because it determines the amount of runoff from that soil. Determination thereof should therefore be valuable to hydrologists. It should be determined on undisturbed sites with an apparatus that simulates rainfall. The simple, easy to use apparatus designed by the Institute for Agricultural Engineering of the ARC (Reinders & Louw, 1984) could be used for this determination.

2.3. Conclusions

Hydrology has many facets, each one with specific complexities and problems to solve. This is a complex subject and requires inputs from a wide range of disciplines. The contribution of soil has been neglected in the past. There is therefore a need to identify the niche areas where Soil Scientists can contribute their unique skills to aid in hydrology and hydrological modelling.

One of the most obvious deficiencies of most current catchment-based hydrological studies is the absence of a detailed soil survey and combined with detailed information on the hydrological properties of the soils. Some of these determinations are laborious and expensive, but are nevertheless important for reliable hydrological modelling. Research aimed at developing methods to simplify the acquisition of this information will therefore be useful.

In the long term, improving our understanding of the relationship between soil water regime and soil profile morphology should inevitably yield valuable results by improving the reliability of hydrological models through the provision of sufficient soil information.

3. RESULTS OF WORKSHOPS AND CATCHMENT VISITS

3.1. Introduction

The interaction between soil and hydrology is a field of research neglected to the point where it has become an essential research niche for both Soil Science and Hydrology. The result is the emergence of hydropedology (Lin *et al.*, 2005) as a science in the last decade. Hydropedology covers the following interrelated areas:

- a. soil horizons (layers) as indicators of flow and transport characteristics in soils,
- b. soil morphology as signatures of soil hydrology,
- c. water movement over the landscape in relation to soil cover,
- d. hydrology as a factor of soil formation and a driving force of a dynamic soil system (Lin *et al.*, 2005).

In spite of the obvious overlap in the disciplines of hydrology and soil science, relatively little research has been done in hydropedology. Most of the work done in Africa was done by soil scientists (Donkin & Fey, 1991; Van Huyssteen, 1995; Le Roux, 1996; Blavet *et al.*, 2000; Blavet *et al.*, 2002). Some valuable pioneering collateral applications have been made by Schulze (1989).

In South Africa hydropedological research may generate important information needed in hydrology and catchment management. Hydropedological research on the relationship between soil water regime and soil profile morphology (Van Huyssteen *et al.*, 2005), revealed useful information about the duration of free water in the soils of the Weatherley catchment.

Soil vary in wetness because due to a spatial variation of water in the soilscape. There is also a temporal variation in wetness, differing between seasons and from year to year. These variations are complicated by the impact of parent material on the occurrence of soils. Simple interpretations using soil data normally available is insufficient for the comprehensive interpretation of soil water regimes.

This is further complicated by uncertainty regarding the relative importance of event driven soil forming processes, and continuing soil forming processes.

The degree to which information collected at Weatherley represent diverse conditions is uncertain. Calibration of the information on other catchments is therefore necessary. The first motive for the workshops was therefore to select catchments with suitable data to verify the results obtained at Weatherley.

The second motive for the workshops was to find common ground between the disciplines of hydrology and soil science that can contribute to the understanding and prediction of the behaviour of water in the landscape.

3.2. Procedure

Workshops were held at centres where research, deemed to be related, has been done. The first workshop was held in Pietermaritzburg. Profs. Roland Schulze and Simon Lorentz of the University of KwaZulu-Natal and Dr Colin Everson of the CSIR participated. Several catchments were visited: Emhaus, Wartburg, Two Streams, and Thabamhlope. Rain and mist kept the group from visiting Cathedral Peak VI. The second visit was to Stellenbosch. Mr Jan Bosch and Dr David le Maitre of the CSIR and Dr Freddie Ellis and Mr Jan Lambrechts of the University of Stellenbosch participated. The Jonkershoek catchments with its various sub-catchments were visited. The third visit was to Prof. Denis Hughes of the University of Rhodes. The Bedford catchment was included in the visit. The forth visit was to Empangeni where Prof. Bruce Kelbe and Mr G. Mulder of the University of Zululand participated and the Ntuze catchment and sub-catchments were visited. The last visit was to Pietermaritzburg to synthesize the information accumulated during the workshops and discuss new concepts with Prof Simon Lorentz.

3.3. Results and discussion

3.3.1. Finding common ground

The workshops were introduced with a presentation to initiate discussions. The participants generally agreed that the subject of the presentation was of common interest to both disciplines.

The role of soil

Soil plays a major role in hydrology as it influences the infiltration/runoff relationship, water storage, lateral flow in the soil body, and release of water to the underlying weathered and cracked rock. This behaviour of soil influences peak flow and interflow, both of which influence the form of the hydrograph. Extremes in the spectrum of infiltration rates are presented by coarse sandy soils and gravel with high infiltration rates and low runoff on the one hand, and a rock outcrop with no infiltration on the other hand. Clay soils, rich in smectites, and crust forming soils also have low infiltration rates and high runoff rates.

Soils vary in their water holding capacity. The main soil properties controlling this property are soil depth, texture and bulk density. Shallow sandy soils hold little water and can become saturated by small rainfall events. In contrast deep clay soils can hold large amounts of water. The size of the soil water reservoir plays an important role in the total amount of water lost by evapotranspiration, thus influencing hydrology. Soils with hydromorphic horizons can store water that is lost by vertical and lateral drainage and through evapotranspiration.

After infiltration the permeability of the soil horizons, saprolite and underlying rock controls the behaviour of water in the landscape (Kelbe personal communication, 2005). The permeability of the

subsoil horizons and materials control the degree and permanence of subsoil saturation. Periodic to permanent saturation of soil horizons impacts on the flow through of water to the lower vadose zone and the availability of water for evapotranspiration. The interaction between the solum and lower vadose zone is very important as water moves both from the soil to the rock and back (Lorentz personal communication, 2005).

The combined impact of these soil properties on hydrology is uncertain. Although experienced soil scientists can predict the occurrence of a soil in the landscape quite well after a thorough field survey, taking into account amongst other things the size of the micro catchment, slope, slope shape and length and position in the landscape, they cannot quantify its contribution to the hydrology of the catchment (Ellis & Lambrechts personal communication, 2005). This "soft knowledge" available to soil scientists is valuable in characterising hillslope response. Up to now the role of soft knowledge in defining hillslope sequential behaviour has been neglected. The challenge is to digest soil or land survey data in relation to hillslope hydrological behaviour (Lorentz personal communication, 2005). This challenge is currently met to some extent by research tools with which the impact of soil qualities on hydrological modelling can be manipulated to improve the accuracy of predictions (Mulder personal communication, 2005).

Similarities in soil and hydrological concepts

Catchment hydrology is studied in various ways, generally without much soil information. Yet the workshop participants agreed that soils have a marked influence catchment hydrology. The interrelationship between soil and hydrology results in some useful relationships being found between the distribution of soil in the landscape and its hydrological behaviour. These interrelationships occur over a wide range of scales.

The soil pedon serves as the object of observation for soil water and physical measurements for hydrological purposes (Figure 3). Pedons and observation points are therefore the smallest measurable entities and are usually indicated on maps as points and therefore have no area.

The ecotope represents the smallest agricultural unit of land with homogeneous soil, slope, climate and production practice (MacVicar *et al.*, 1974). It correlates well with the hydrological response unit and is typically presented as map units on detail soil maps (scale 1:10 000, or larger). In soil science, toposequences which describe the distribution of soils on a hill slope, correlate well with hillslope transects as used by hydrologists. Toposequences are called hydrosequences when the wetness of the soils are related to terrain characteristics.

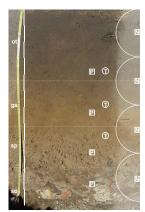


Figure 3 A profile of a pedon of the Longlands form in the Weatherley catchment, showing from left to right the diagnostic soil horizons and the positions of the bottoms of pipes used for water extraction, tensiometers cups and neutron water meter measurement spheres (Van Huyssteen *et al.*, 2005).

A three dimensional toposequence is termed a soilscape (Figure 4). Soilscapes are subdivisions of land types (Land Type Survey Staff, 2000) with less variation in soil pattern. Various ecotopes occur in a soilscape. Soilscapes can be mapped on a scale of 1:50 000. The concept of a soilscape coincides quite well with that of a hillslope, or half the physiographic unit of a quaternary catchment. However, if the other half of a hill has a similar soil pattern the two hillslopes can be considered as a single soilscape.

Land types (Land Type Survey Staff, 2000), mapped on a scale of 1:250 000, often overlie large parts of catchments. For example land type Dc17 constitutes approximately 80 % of the upper Modder River catchment near Thaba Nchu, east of Bloemfontein. The association of soil distribution and hydrology at small scale is probably currently not well understood and therefore seldom used. It is envisaged that the detailed information contained in the description of land types could make a valuable contribution to hydrological modelling if wisely employed.

There is a need for soil-landscape modelling to improve soil data collection at a reasonable price (Lin et al., 2005). Hydrological studies on large areas rarely apply soil information for the following reasons: Firstly, detailed soil surveys are very laborious and therefore expensive. For large catchments the cost of a reconnaissance soil survey may double the budget of the research project. The cost of a detail soil survey can be 25 times more expensive than a reconnaissance survey (Table 3). Secondly, in large catchments the impact of soil variation on hydrological responses tends to average out (Figure 2). According to Schulze (Personal communication, 2005) the role of soil information is less important for hydrological modelling in large catchments. Thirdly, the interpretation and application of soil data in hydrological research on large catchments may also be problematic as soil data generated through soil surveys may be difficult to apply in hydrological models (Bosch & Le Maitre personal communication, 2005).

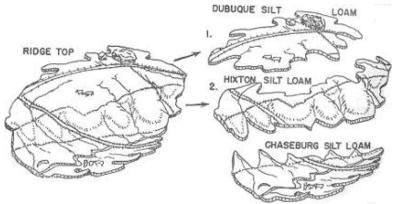


Figure 4 A schematic presentation of a soilscape / hillslope with three ecotopes/hydrological response

Table 3 Rate and relative cost of soil surveys at different scales (Adapted from Le Roux et al., 1999)

Intensity	Scale	Intensity	Relative cost per	Relative cost per ha
onony	Coalo		observation (Detail = 1)	(Detail = 1)
Intensive	1:500	0.04	2	20
Detail	1:10 000	1	1	1
Detail reconnaissance	1:50 000	4	0.4	0.1
Reconnaissance	1:250 000	25	0.16	0.04
Rapid reconnaissance	1:1 000 000	625	0.08	0.01

3.3.2. Catchments suitable for further studies

Cathedral Peak VI (Everson *et al.*, 1998), Two Streams (Everson *et al.*, 2004), Jonkershoek (Royappen *et al.*, 2002), Bedford (Hughes & Sami, 1992), Ntuzi (Van Zyl & Lorentz, 2003) and Wartburg (Loretz & Berry, 2005) were evaluated to determine its suitability for future hydropedological research (Table 4).

Only two catchments with data satisfactorily matching Weatherley in terms of intensive soil water measurements were found, namely Cathedral Peak VI and Two Streams (Everson personal communication, 2005). The reasons seem to be that the soil water measurements were essential for the type of research done and the nature of the catchments. The catchments were obviously selected to suit the intended research. The soilscapes of these catchments play an important role in catchment hydrology and provide the opportunity to test and add value to the Weatherley results.

Environmental conditions at Cathedral Peak VI and Two Streams differ significantly from those at Weatherley. The parent material of the soils of Cathedral Peak VI is Drakensberg lava and the average annual rainfall is 1 200 mm. At Two Streams the parent material is Beaufort sandstone and shale and the average annual rainfall is 840 mm. This variation in environmental conditions provides the opportunity for making meaningful comparisons with the hydropedological information acquired at Weatherley.

3.3.3. Serving the two way interaction

Needs of hydrologists

Through the process of finding common ground it was realised that South African hydrologists are familiar with soil science and the use soil information to varying degrees. The hydrological information available in the field of soil science is currently not user friendly (Lin *et al.*, 2005). This is also true for South Africa. Hydropedology, still new to both hydrologists and soil scientists defines common ground between the two disciplines. Exploring it from both sides promises to yield precious rewards.

Application of soil information in hydrological studies is complicated by *scale*. With scale there is a variation in detail resulting in the statement by Lin *et al.* (2005) that computer models are either too good to be real or too real to be good. Hydrologists work from very small to very large catchments. In all cases the challenge is to apply useful soil information in appropriate ways. Soil data is presented in soil survey reports as a description of the soils and their distribution in the landscape by means of a map. It includes spatial, morphological, chemical and physical data. This is too much data, and normally not sufficiently refined to be used meaningfully in hydrological research (Bosch & Le Maitre personal communication, 2005). What is necessary is that the soil survey data be interpreted and reduced to a few categories of useful information determined by the needs of the specific hydrological project (Hughes personal communication, 2005).

Hydrologists are aware of the fact that local soil variation is a result of the interaction between water and parent material, as influenced by topography, and that soil is an important component in the hydrological system (Everson, Lorentz & Schulze personal communication, 2005). However, the strong relationships developed by the two way interaction still need to be elucidated. Some useful information about these relationships exists in the field of pedology (Van Huyssteen, 1995; Van Huyssteen *et al.*, 2005). It is currently available as concepts and hypotheses or "soft" information (Lorentz personal communication, 2005). This information needs to be identified, interpreted and quantified. During the development of ACRU an attempt was made to characterise the hydrological properties of the soils of South Africa with the knowledge and understanding of the soil types existing at that time. Current knowledge and information could improve this (Schulze personal communication, 2005).

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Information	Cathedral Peak VI	Two Streams	Jonkershoek	Bedford	Ntuzi (W17)	Wartburg
	(Everson <i>et al.</i> ,	(Everson <i>et al.</i> ,	(Royappen <i>et al.</i> ,	(Hughes & Sami,	(Van Zyl &	(Loretz & Berry,
	1998)	2004)	2002)	1992)	Lorentz, 2003).	2005)
Continuous, intensive NWM measurements	4 years	5 years	×	×	×	Start 2006
ET data	Detail for 3 years	Detail for 5 years	Detail	Detail	Detail	Detail
Geology	Drakensberg	Mudstone and	Table Mountain	Sandstone and	Drakensberg	Ecca shales,
	Basalt	shale of the	Sandstone	mudstone of the	basalt	Natal Group
		Beaufort formation,		Middleton		Sandstone
		Karoo system		formation and		
				dolerite intrusions		
Climate data	Detail	Detail	Detail	Detail	Detail	Detail
Annual rainfall (mm)	1 200	840	540	435 - 670	1321	<i>~</i>
Soil survey	×	×	×	×	×	×
Size (ha)	89	75	777	$670 \mathrm{km}^2$	20	1200
Hydrograph	Yes	Yes	Yes	Yes	Yes	Yes
Land use during	Grassland	Forestry and	Forestry	Grassland	Mixed	Mixed
measurements		grassland				
No of NWM observation	16	25	×	10	×	ڼ
sites						
No of NWM	9	9	×	7-10	×	4
observations per site						

Development and transfer of "soft" knowledge

The behaviour of soils is the result of four interacting factors: parent material of the soil, position in the landscape, climate, and biology (Jenny, 1941). Current soil information is usually mainly about what soils are and not what soils do. Interpretation and elucidation of this information is needed to explain the hydrological behaviour of soils. In an effort to make appropriate information available to hydrologists soil scientists will have to identify their needs (Lambrechts personal communication, 2005). Some of this information is available through soil scientists, but needs to be communicated to hydrologists.

The interpretation of soil data (soil types, morphological and chemical data) used to be very limited and normally land use specific. Soils used to be classified, described and stored. Very little of this interpretation is available to land users including hydrologists as the survey reports are data rich and information poor (Lin *et al.*, 2005). Only recently has the focus moved to unlock the interpretative value of soil data. Previously only vague, dubious statements were often made about the behaviour of soil types. This has been a world wide trend. The focus has, however, now moved to relationships between co-variables and soil properties, thus opening up the ability to interpret soil behaviour in relation to different land uses. Increased knowledge on the properties of soils has improved the ability of soil scientists to characterise soils. Typical ranges of common soil properties of specific soil types are also becoming available. What is needed to serve hydrology is information about characteristic responses of specific soil types and soilscapes. With regard to some common and important soil properties, like their characteristic seasonal soil water regimes, extensive measurements and interpretations still need to be made to provide in the soil information requirement of hydrologists.

The quantification of soil properties important to hydrology has increased with the realisation of the importance of pedotransfer functions (PTF's) in hydropedology. Pedotransfer functions relate simple soil characteristics often found in soil surveys to more complex parameters that are needed in modelling and that are relatively difficult to measure (Bouma, 1989). Soil classification makes the following pedo-information available about particular soils: soil form, family and phase. This provides information about the "structure" of the soil of a map unit. Classification defines the presence and arrangement of specific soil horizons (soil form level), generally important soil properties (soil families), and locally dominant soil properties not incorporated in the soil form or family (series or phase level).

The distribution of soil types in the landscape varies drastically in different localities. The soil map makes the transfer of the following soil information possible: soil distribution, map unit purity and map unit variation. Although map units and map legends create the idea that the map units are pure they always contain a portion of other soils. Map units with the same name also vary in composition. Contrary to general belief pixel data is not in demand by hydrologists (Lorentz, Everson & Schulze personal communication, 2005). Pedotransfer functions of soil physical properties can be the vehicle making information about soil map units available for hydrological modelling. These properties include infiltration rate, permeability and bulk density of soil horizons, drainage curves, soil water retention curves and plant available water of the soil profile.

3.4. Conclusions

The emergence of the discipline of hydropedology requires new approaches from soil scientists. It seems certain that the synergistic interaction between soil scientists and hydrologists will optimise research in hydropedology, producing valuable results for hydrologists. A clear distinction needs to be made between the following three categories of soil science knowledge of use to hydrologists:

- a. currently available but "user unfriendly" knowledge
- b. available "soft" knowledge that needs to be captured and quantified and

c. generation of new data needed to improve the contribution of soil science to hydrology and hydropedology.

The assistance that soil scientists can provide to hydrologists lies in two fields. Firstly to quantitatively characterise the annual and seasonal soil water regimes (of which duration of different degrees of wetness is the foundation, etc.) of hydrologically important soils of South Africa and the correlation with soil morphology. An example in this regard is the parameter $AD_{s>0.7}$ (mean annual duration of degree of saturation (s) above 0.7 of porosity) developed for soils of the Weatherley catchment. The importance of this parameter lies in its value for pedotransfer purposes. As soon as reliable quantitative data is available on the soil water regime and its range of specific diagnostic horizons, this information can be used by hydrologists in other catchments where these horizons occur without requiring further laborious measurements.

The Cathedral Peak VI and Two Streams catchments should be used to verify existing soil hydrological information and to acquire more information in this regard. Secondly, appropriate soil survey procedures and the interpretation of the data to make it suitable for hydrologists at all scales – intensive to extensive – need to be developed.

4. DATA FROM THE WEATHERLEY CATCHMENT

4.1. Introduction

Neutron soil water measurements continued at Weatherly during the course of this project. The main aim was to ensure continuity in the dataset. Final infiltration rates of selected soils were also measured. This serves to elucidate the already vast dataset for the Weatherley catchment. Only limited interpretations were made from these data.

4.2. Soil water contents

Fifty neutron water meter measurements have been made at the 29 measuring sites in the Weatherley catchment. When using the data it should be borne in mind that *Eucalyptus nitens, Pinus patula* and *Pinus eliottii* trees were planted in the catchment during September 2002. It was expected that this would have a marked impact on the soil water regime. Water saturation graphs for the 29 measuring sites are presented in Appendix A. Soil morphological data, which should be used in the interpretation of this data, were reported by Van Huyssteen *et al.*, 2005. No significant drying was observed from the graphs for any of the 29 measuring sites.

Annual duration of water saturation above 0.7 of porosity ($AD_{s>0.7}$) was calculated to augment the data reported by Van Huyssteen *et al.*, 2005. Summary data are reported in Appendix B. Annual values are reported in Tables 1, 2 and 3 of Appendix C. A summary graph is presented in Figure 5. The values confirm, but were generally slightly lower than those reported by Van Huyssteen *et al.*, 2005. This was most probably due to the inclusion for data from 1997 as well as a possible increase in transpiration from the trees. The standard error decreased due to an increase in the number of observations.

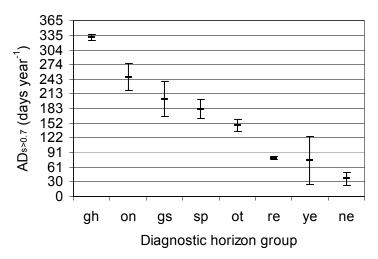


Figure 5 Mean and standard error of mean the AD_{s>0.7} values per diagnostic horizon group.

4.3. Final infiltration rate

Runoff from a soil surface occurs when the rainfall intensity (P_i) exceeds the final infiltration rate (I_f) of the soil. Runoff from a particular area of land will, however, only occur when the surface storage and detention (SD) of the land surface is also exceeded. Storage and detention are influenced by a number of factors, including slope, surface roughness, and vegetative cover. For hydrological models to predict runoff from different parts of a catchment all these and other relevant factors need to be taken into account in addition to I_f . Final infiltration rate (I_f) nevertheless remains an important parameter in hydropedology, but seems to be seldom measured. It was therefore decided to make some I_f measurements on selected ecotopes in Weatherley catchment.

The apparatus (Figure 6) described by Reinders & Louw (1984) was used for the I_f measurements. The top or distribution bucket has one vertical open slot through which water is sprinkled in a single direction by a rotating sprinkle nozzle mounted inside the bucket and fed with water under a constant 65 kPa pressure. The apparatus provides a range of application rates depending on the distance from the apparatus. The actual application rate at each point was measured by means of a stopwatch and the amount of water collected in small cans placed at different distances from the apparatus. Water collection for each of the cans was terminated and the time recorded when runoff commences around each of the cans. The results provided three points on the infiltration curve. The detailed procedure for calculating I_f from these results is presented by Reinders & Louw (1984).

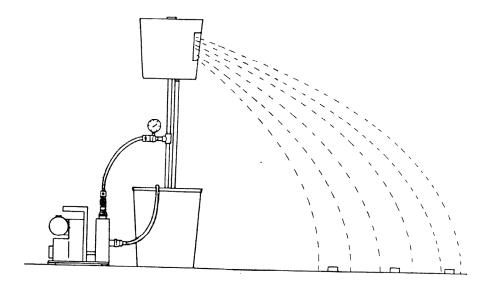


Figure 6 Diagrammatic representation of the sprinkle infiltrometer (Reinders & Louw, 1984).

Nine sites in the Weatherley catchment, representing six important ecotopes, were selected for the measurements. The sites were located close to the soil profiles described by Van Huyssteen *et al.* (2005), and bear the same numbers. Six replicate measurements were made at each site. Two sprinkler infiltrometers were used. The measurements were made on 16 and 17 February 2006. Because of the high rainfall in this area, especially during this time of the year, the water in the local stream has a very low salt content. This water was therefore considered suitable and was used for the I_f measurements. The grass was cut and removed from each site before measurement started. Observations were made in the relatively small core areas between grass tufts. It is expected that these conditions increased the variation between replicate measurements, as compared to measurements made on a uncovered surface.

Detailed results are presented in Appendix D. Some of these are clearly extraneous; e.g. run No. 2 at 234, run No. 4 at 240, run No. 3 at 212. There are also cases where, because the coefficient is negative, it is not possible to calculate I_f , e.g. run No, 5 at 201; run No. 4 at 220; run No. 1 at 240; run No. 6 at 212; runs 2 and 5 at 235. Results which were considered to be meaningful are presented in Table 5, together with relevant information on the ecotopes. Measurements could not be made at two additional sites originally selected (profile 218 - Kd form & profile 204 - Lo form) where the soil surface was saturated and therefore prevented the determination of I_f .

There was considerable variation in the I_f values. Coefficients of variation (CV) vary from 11 to 28 % (Table 5), after extraneous values have been excluded. It was concluded that the relatively small areas available for measurement between tufts contributed to the wide variation in results. The I_f values are low considering the generally coarse textures, where high I_f values were expected. This was probably due to crusting, a common phenomenon in topsoils with a clay contents between about 10 and 20 %.

A factor which promotes crusting is a particular ratio of fine to coarse particles which promotes dense packing of the particles at the surface. The ratio of fine particles (fiSa+vfiSa+coSi +fiSi) to coarse particles (meSa+coSa) was calculated and compared to I_f . No meaningful correlation was found. Another factor which promotes crusting is a high exchangeable sodium percentage (ESP). The only supporting evidence in this regard in Table 5 is for profile 235 with the relatively high ESP of 9.8 % and low I_f value of 4.8 mm h^{-1} . The other topsoils have low ESP values which clearly did not correlate with I_f . Correlations of I_f with organic carbon and CEC_{soil} were considered, but without success.

Table 5 Final infiltration rates (If) and selected soil data for selected ecotopes in the Weatherley catchment

Profile	Slope	Soil		Texture	Gravel ³	Partic	cle size dis	tribution o	f the fine e	arth in the	Particle size distribution of the fine earth in the 0-100mm layer	layer
o N	(%)	form	(Mg-m ⁻³)	(0 - 100mm)	(%)	coSa	meSa	fiSa	vfiSa	coSi	ĮSĮ	Ö
201	10	P	1.22	coSaLm	8,0	20.4	30.6	14.3	8.5	6.7	8.8	9.5
212	13	Tu	1.47	coSaLm	2.5	20.7	15.6	17.9	17.9	11.2	10.0	9.0
220	13	Bd	1.41	coSaLm	0.2	15.7	21.2	15.9	11.9	10.2	10.1	15.2
221	10	머	1.31	Lm	0.1	12.3	13.1	6.6	10.9	16.1	16.8	17.7
234	11	۸۸	1.58	coSaLm	0.1	31.0	22.0	8.6	2.5	7.8	14.5	6.3
235	3	Ka	1.39	coSaLm	1.3	13.6	14.8	20.0	14.3	15.8	11.6	10.2
240	10	H	1.45	Lm	I	9.5	9.7	6.6	15.8	21.4	15.0	21.9

cV ₈	(%)	27	20	28	22	11	13	13	
SE,	(mm h ⁻¹⁾	1.4	2.3	2.2	1.2	1.2	2.0	1.0	
Mean I _f ⁶	(mm h ⁻¹)	5.2	11.3	7.8	5.4	10.5	4.8	8.0	
္၁၀	(%)	1.1	1.0	1.0	1.2	1.5	1.2	1.6	
ESP^4	(%)	2.3	8.9	3.7	4.4	5.5	8.6	I	
CECsoil	(cmol _c kg ⁻¹)	4.8	3.6	5.0	0.9	6.1	4.3	ı	
Profile	O	201	212	220	221	234	235	240	

Longlands; Av = Avalon; Bd = Bloemdal; Hu = Hutton; Tu = Tukulu; Ka = Katspruit

Bulk density values are for the 0 – 50 mm layer (Le Roux et al., 2005) for all the profiles except for profile 234 where it is for the 0 – 300 mm layer (Van Huyssteen et al., 2005) 1 Lo = 2 Db =

³ Results obtained after the gravel determination was improved ⁴ ESP = Exchangeable sodium percentage

⁵ Organic carbon values are for the 0 – 50mm layer (Le Roux et al., 2005) for all the profiles except 234 where it is for the 0 – 100 mm layer (Van Huyssteen et

al., 2005)

⁶ Mean final infiltration rates after exclusion of extraneous values
⁷ SE = Standard errors with extraneous values excluded
⁸ CV defined here as SE as a percentage of the mean

4.4. Conclusions

Data collection continued in the Weatherley catchment during the course of this project. Neutron water meter measurements were made weekly and added one year's worth of soil water content data to the already vast dataset. Addition of the soil water data confirmed previous conclusions, although $AD_{s>0.7}$ values were slightly lower for the diagnostic horizons. Final infiltration rate measurements were made at seven sites in the Weatherley catchment. Results were lower than expected, given the sandy nature of the topsoil. The lower infiltration rate was probably due to crusting, although no meaningful correlations could be drawn.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

5.1. Title

Hydrological interpretation of soils in the Cathedral Peak VI, Two Streams and Weatherley catchments

5.2. Focus

The focus of ongoing research must be to improve the contribution of soil science to hydrological research in South Africa. Significant contributions can be made in several aspects.

5.3. Rationale

The interaction between soil and hydrology is a field of research neglected to the point where it has become an essential research niche for both soil science and the science of hydrology. Because the soil is the 3D membrane covering the earth, research in hydropedology is exposing the interaction between soil and water in:

- a. wetlands and non-wetland ecosystems and catchment water supply
- b. food security, change in land use and catchment water supply
- c. carbon sequestration, effective water use and catchment water supply

Because hydropedology supports hydrology with knowledge of soil horizons serving as indicators of flow and transport characteristics in soils, soil morphology as signatures of soil hydrology, water movement over the landscape is in relation to properties of the soil surface and hydrology as a factor of soil formation and a driving force of a dynamic soil system the relationship establishes itself well.

The nature of the throbbing, pulsating soil water in the landscape received relatively little research attention. Interaction with prominent hydrologists revealed that, after quantification of soil water regime parameters, common ground needs to be found and concepts generated before quantitative contributions to prediction of hillslope behaviour can be made.

Application of soil information in hydrological studies is complicated by scale and it can be quantified and optimised. The absolute dominance of soil properties on hydrological behaviour at any point in a catchment contrasted to the forgiving nature of small scale hydrology averaging out soil variation asks for research on the variation in impact on different scales.

The emergence of the discipline of hydropedology requires new approaches from soil scientists. It seems certain that synergistic interaction between soil scientists and hydrologists will optimise research in hydropedology, producing valuable results for hydrologists. A clear distinction needs to be made between the following three categories of soil science knowledge of use to hydrologists:

- a. currently available but "user unfriendly" knowledge
- b. available "soft" knowledge that needs to be quantified, and

c. generation of new data needed to improve the contribution of soil science to hydrology and hydropedology.

The service that soil scientists can provide for hydrology lies in two fields. Firstly the quantitative characterisation of the annual and seasonal soil water regimes (of which duration of different degrees of wetness is the foundation, etc.) of hydrologically important soils of South Africa and the correlation with soil morphology. Secondly, appropriate soil survey procedures and the interpretation of the data to make it suitable for hydrologists at all scales – intensive to extensive – need to be developed.

The aim is to enhance the application of soil survey information by improved interpretation of existing data and low cost, effective soil surveys. Existing data includes land type data, other custom made survey data and expert knowledge. Low cost effective surveys implies predictive mapping on all scales of work. A small impact is expected with intensive surveys and a large impact is expected with reconnaissance. A range of soil survey requirements and procedures for different scales of hydrological research must emerge. With the aid of current data on soil survey information, the impact of predictive mapping on different scales of soil survey will be determined. Afterwards the research catchments involved will all have soil maps with survey reports.

Levels of soil survey information can be defined as:

- a. An informative presentation of land type data (scale 1:250 000). This is probably suitable for hydrology research on primary catchments where many land types are involved, secondary catchments where a few land types are involved and tertiary catchments covered by one land type or a major part of it. The interpretation of the land type data to define PTF's characterising hillslopes and predicting hillslope response is the challenge to make it worth its while. A brief visit to the area and observations on each land type can significantly improve the quality of the product.
- b. Soilscape survey (1:50 000): The subdivision of land types into soilscapes reduces soil variation further. The extent to which it affects hydrology has to be tested. A soilscape survey exposes characteristic hillslopes and improves the interpretation of hillslope behaviour.

5.4. Objective

- a. To improve guidelines for the hydrological interpretation of selected South African soils. That is calibrating and validating the Weatherley results in other environments.
- b. To improve prediction of hillslope and catchment behaviour using soil data. Conceptualising the soil qualities important in hydrology needs to be attended to before it can be quantified.
- c. To generate soil survey information using advanced soil survey techniques and to improve interpretation of soil survey information to make it more accessible for hydrological purposes.

5.5. Aims

- a. To conduct a literature study on the advances in hydropedology, the relation with the hydrological interpretation of South African soils, and the application to catchment hydrology.
 - I. Hydropedology of South African soils
 - i. Soil water regime
 - AD.
 - 2. Wetting and drying patterns
 - 3. Classes of soil water regimes
 - ii. Water losses from a pedon and polipedon of South African soils
 - 1. ET
 - 2. Lower vadose zone
 - 3. Lateral drainage.

- II. Application of soil data in hydrological and pedological research and models
 - Spatial variation
 - ii. Infiltration rates
 - iii. Internal drainage rates
 - iv. Subsoil accumulation of water
 - v. Deep drainage and water loss to lower vadose zone
 - vi. Lateral drainage and the impact on lower lying soils i.e. a study of hydrotoposequences
- III. Advancement in soil survey techniques
 - i. Land type survey
 - ii. Soilscape survey
 - iii. Detail survey
- b. Improved correlation of soil morphology with the soil water regime of South African soils.
 - I. To continue neutron soil water measurements in the Weatherley catchment.
 - II. To collate and augment relevant data for Two Streams catchment.
 - i. Soil water measurements (soil water measurements should commence in the first year)
 - ii. Geology
 - iii. Soil characterization (description, analysis).
 - iv. Characterization of the topography.
 - III. To collate and augment relevant data for the Cathedral Peak VI catchment.
 - i. Soil water measurements (soil water measurements should commence in the first year)
 - ii. Geology
 - iii. Soil characterization (description, analysis).
 - iv. Characterization of the topography.
 - IV. To collate data recorded in catchments without hydrographs.
 - V. To quantify the soil water regimes in the three catchments and other ecotopes.
 - VI. To determine the relationship between soil water regime and soil profile and diagnostic horizon morphology in the catchments.
- c. To support hydrologists in improving models predicting hydrological hillslope behaviour.
 - An improved understanding of the common ground between soil science and catchment hydrology: Conceptualization of soil qualities controlling hydrology and how these are accommodated in South African soil forms, soil families and their distribution. Develop and define "soft knowledge".
 - II. To develop pedotransfer functions for the soils of South Africa to transform soil data into hydrologically useful information. Quantify "soft knowledge" to serve as user friendly soil qualities.
 - III. To develop improved soil survey techniques to generate survey data for characterizing hillslopes on the common range of scales.
- d. To identify further research needs, gaps and opportunities.

5.6. Deliverables

- 1. Year one: Reports on literature study of
 - a. The science of hydropedology.
 - b. Advanced soil survey techniques and the application of soil survey information in catchment hydrological research.
- 2. Year two: Reports on
 - a. Collation and augmentation of data for the Two Streams catchment.
 - b. A soil survey report (soil map and survey report) of 6 paired catchments (quaternary) using improved intensive soil survey techniques.
 - c. The impact of different levels of soil information on hydrological predictions of these catchments.
- 3. Year three: Report on
 - a. Collation and augmentation of data for the Cathedral Peak VI catchment.
 - b. A soil survey report of Two Streams and Cathedral Peak VI catchments using improved detail soil survey techniques.
 - c. The impact different levels of soil information on hydrological predictions in these catchments.

- 4. Year four: Report on
 - a. The quantification of the soil water regimes and the relationships with soil profile and diagnostic horizon morphology for the three catchments and other ecotopes.
 - b. A soil survey report of primary catchments (Bedford and Mtuze) using improved reconnaissance/rapid reconnaissance soil survey techniques.
 - c. The impact on hydrological predictions on these catchments.
- 5. Year five: Report on improved hydropedological applications for Two Streams, Cathedral Peak VI and Weatherley incorporating the latest soil water regime interpretations of these catchments.

5.7. Proposed budget

Year	Deliverable	Budget
1	a. Report on literature study of advanced soil survey techniques and the application of soil survey information in catchment hydrology research.	R250 000
	b. Report on results of the literature study on the science of hydropedology	R500 000
2	a. Report on a soil survey of a quaternary catchment using improved soil survey techniques and the impact on hydrological predictions.	R450 000
	b. Report on the collation and augmentation of data for the Two Steams catchment	R450 000
3	a. Report on a soil survey of a tertiary catchment using improved techniques and the impact on hydrological predictions.	R400 000
	 Report on the collation and augmentation of data for the Cathedral Peak VI catchment 	R400 000
4	a. Report on a soil survey of a primary catchment using improved soil survey techniques and the impact on hydrological predictions.	R450 000
	 Report on the quantification of the soil water regimes and the relationships with soil profile and diagnostic horizon morphology for the Two Streams, Cathedral Peak VI and Weatherley catchments 	R450 000
5	Report on the incorporation of upgraded information on Two Streams, Cathedral Peak VI and Weatherley and the rerun hydrological models with different levels of SSI.	R450 000
	TOTAL	R3 800 000

6. CONCLUSIONS

Neutron water meter measurements in soils of catchments with hydrographs are available for Two Streams and Cathedral Peak VI. However, these measurements are also available for several ecotopes in catchments without hydrographs. These data are representative of a wide variety of environmental conditions including climate, soils and land use.

The impact of different soil types on the hydrographs of Weatherley and Cathedral Peak VI not only emphasizes the role of soil properties on hydrological behaviour, but also the role of accessible soil information in hydrology. In spite of the role soil survey information plays in agriculture it has not been applied extensively in the field of hydrology.

Soil water data collected during this project confirmed previous conclusions, although $AD_{s<0.7}$ values were slightly lower for the diagnostic horizons. Final infiltration rates were lower than expected and poorly correlated with the main factors controlling infiltration.

It is proposed that future hydropedological studies focus on the Weatherley, Two Streams and Cathedral Peak VI catchments. Data need to be collected and augmented for these catchments. It seems that soil data is the major dataset lacking from the latter two catchments. Soil water measurements should also be reinstated in the latter two catchments to augment the available water dataset. It is proposed that the project runs over five years, with a estimated budget of R3 800 000.

Two refereed articles were published and nine conference contributions were made during the course of this project. Ms K. Jennings was appointed as research assistant and should qualify for her B.Sc. Hons. degree during June 2006.

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Appendix A

Degree of water saturation and daily rainfall for P201 to P237 over 7 years from 1 January 1997 until 31 December 2005

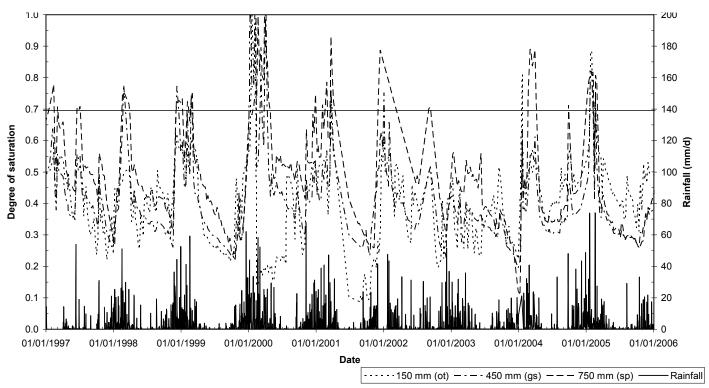


Figure 1 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 201.

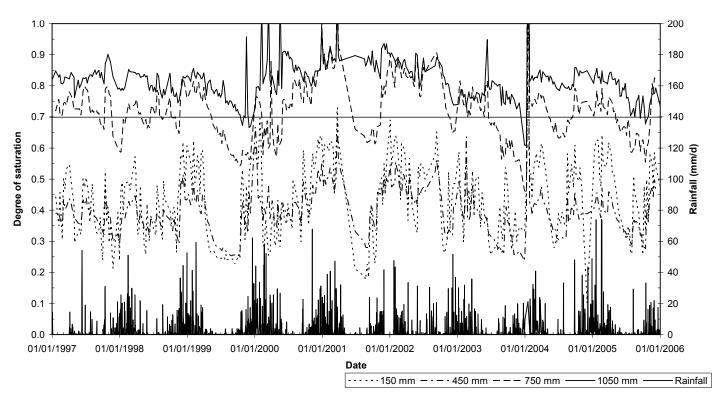


Figure 2 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 202.

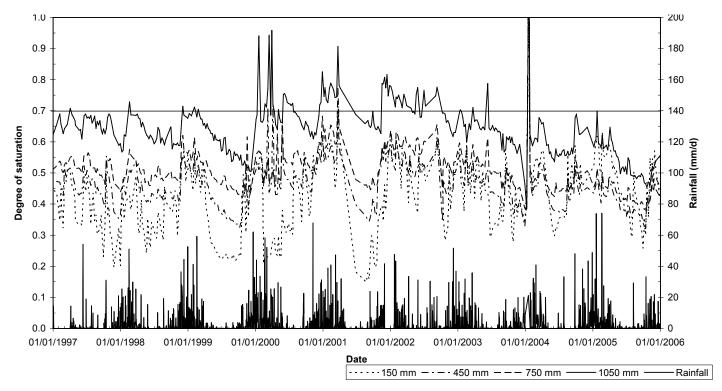


Figure 3 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 203.

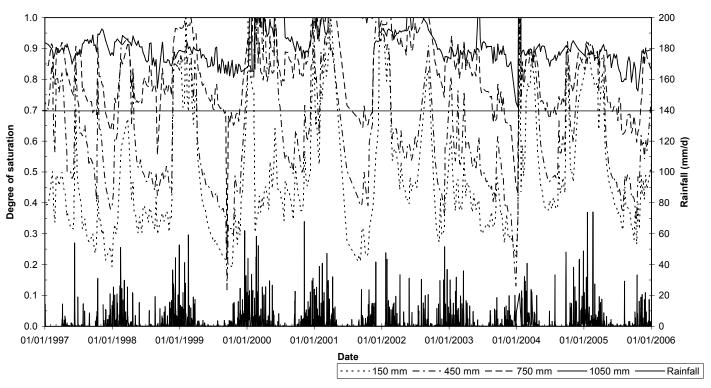


Figure 4 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 204.

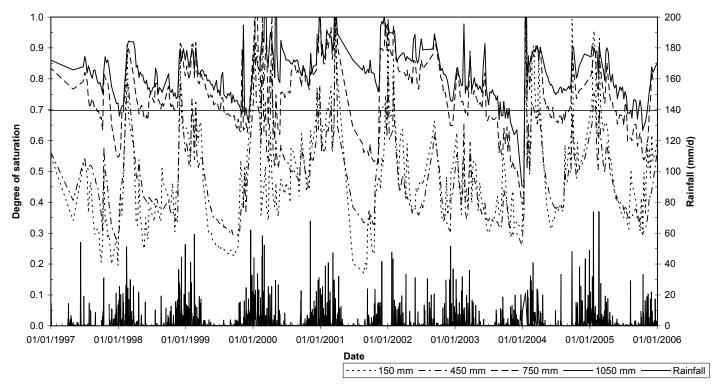


Figure 5 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 205.

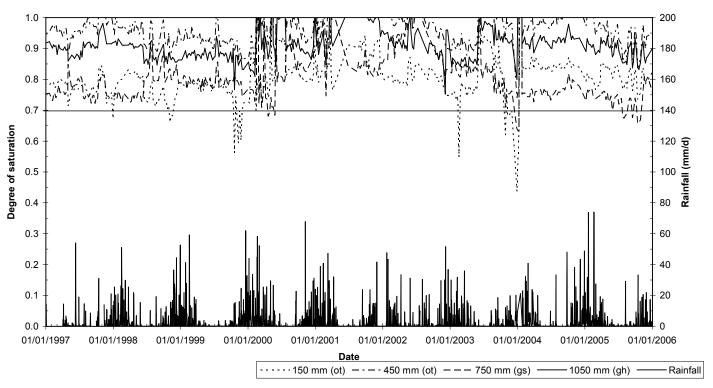


Figure 6 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 206.

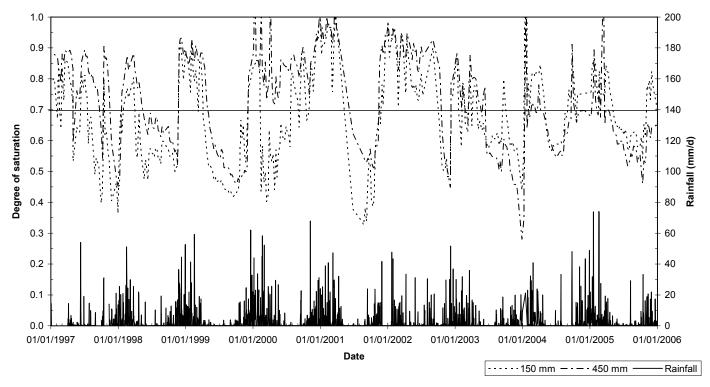


Figure 7 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 207.

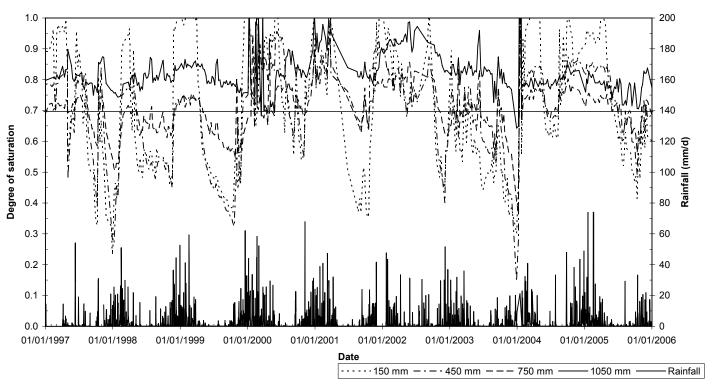


Figure 8 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 208.

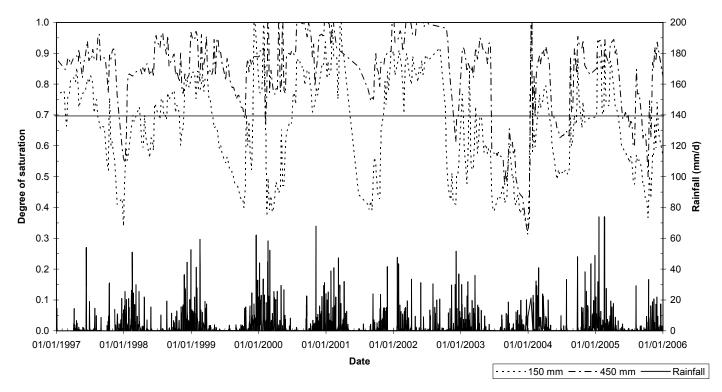


Figure 9 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 209.

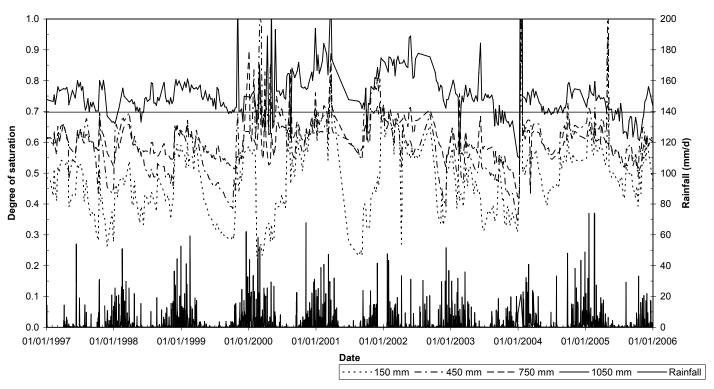


Figure 10 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 210.

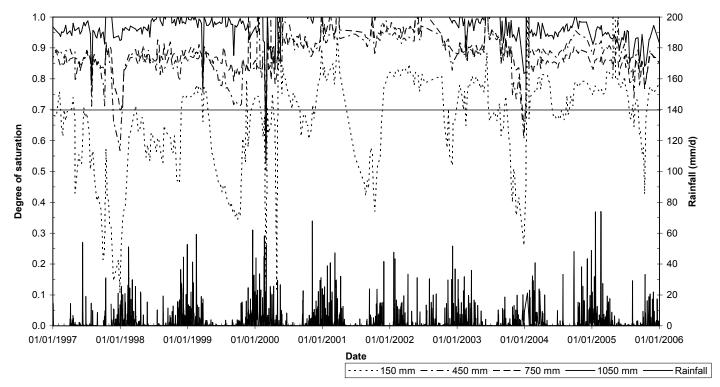


Figure 11 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 211 (Katspruit 1000).

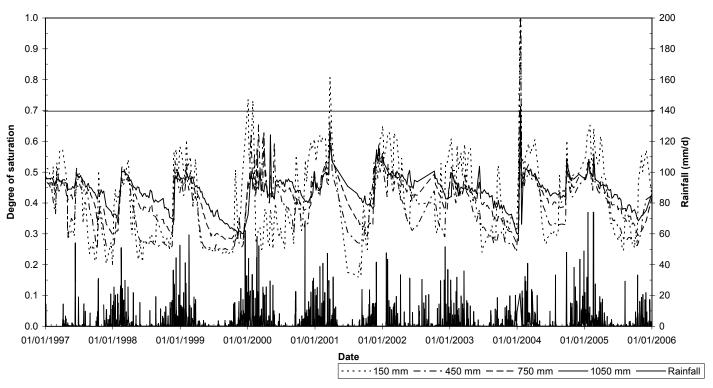


Figure 12 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 212 (Tukulu 1110).

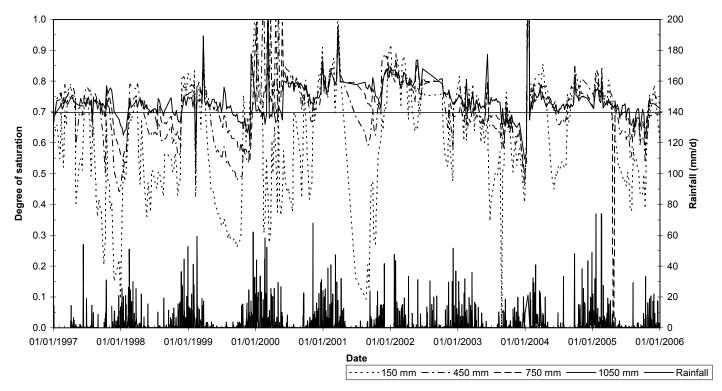


Figure 13 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 213 (Katspruit 1000).

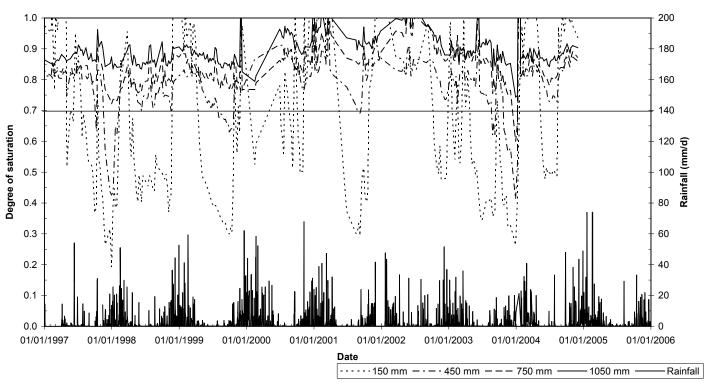


Figure 14 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 218 (Katspruit 1000).

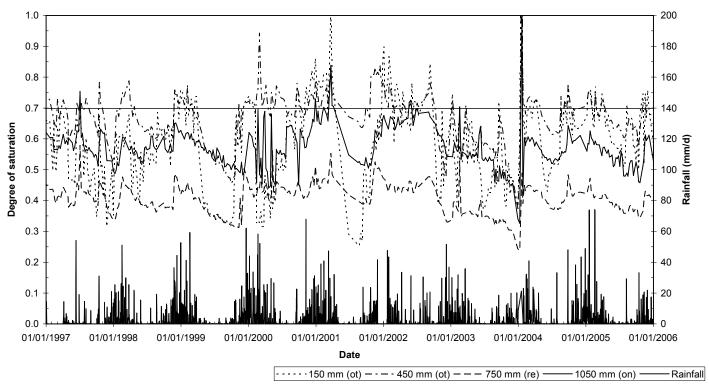


Figure 15 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 220 (Bloemdal 2100).

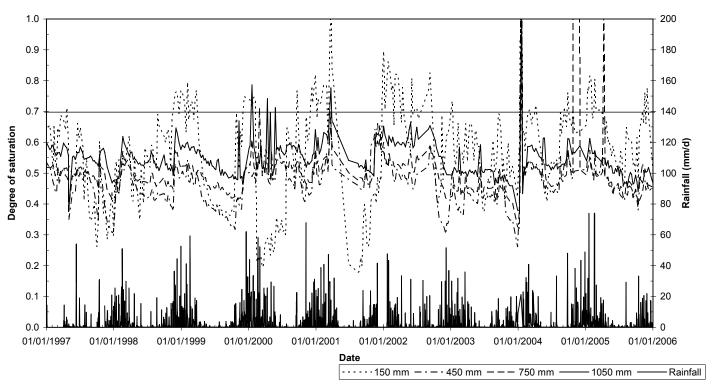


Figure 16 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 221 (Hutton 2100).

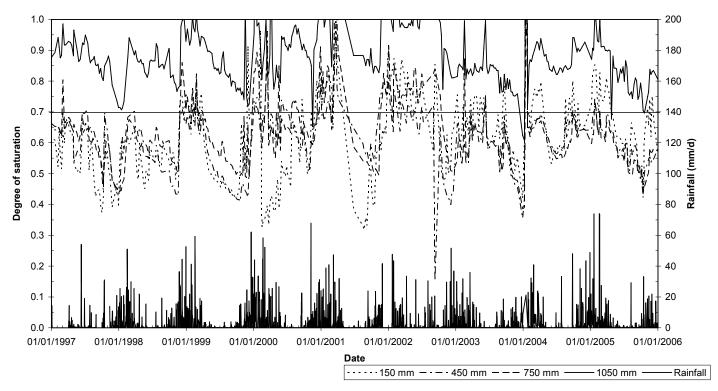


Figure 17 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 222 (Oakleaf 1210).

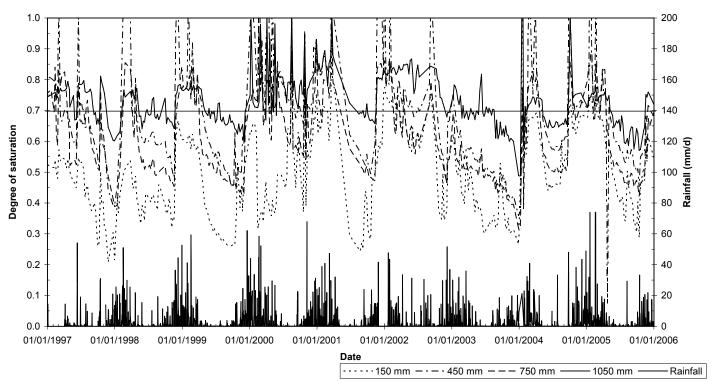


Figure 18 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 225 (Longlands 2000).

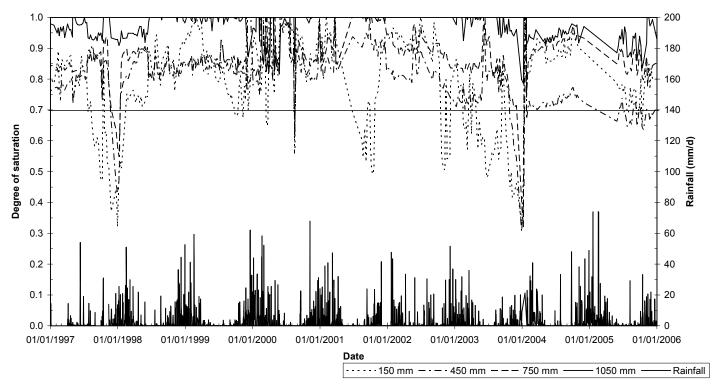


Figure 19 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 226 (Kroonstad 1000).

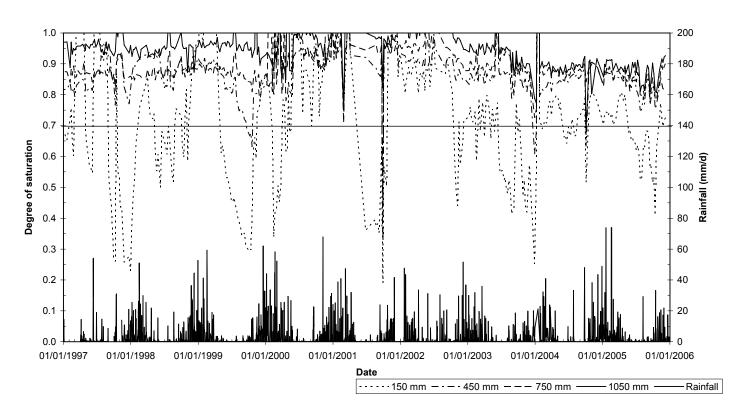


Figure 20 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 229 (Kroonstad 1000).

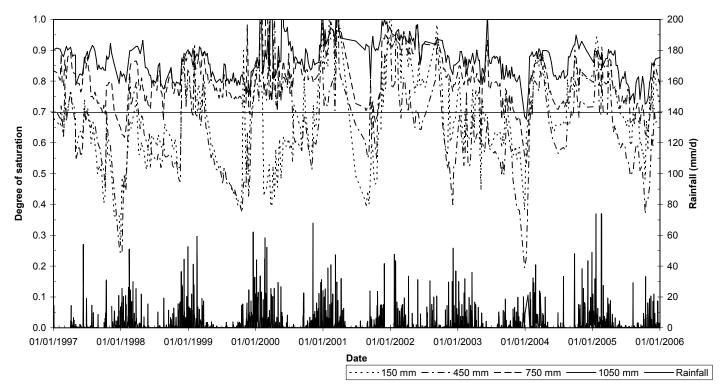


Figure 21 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 230 (Westleigh 1000).

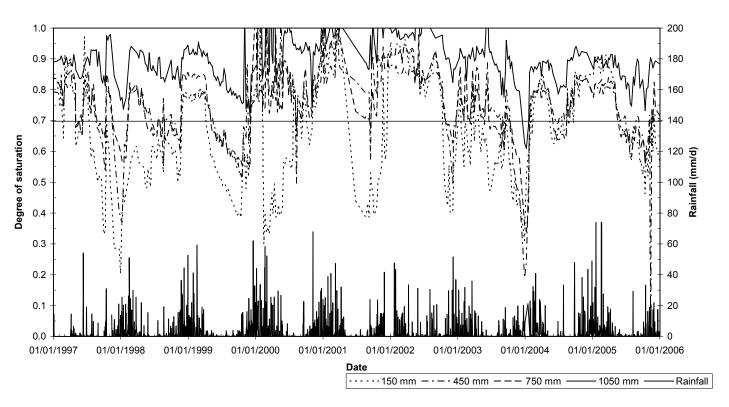


Figure 22 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 231 (Westleigh 2000).

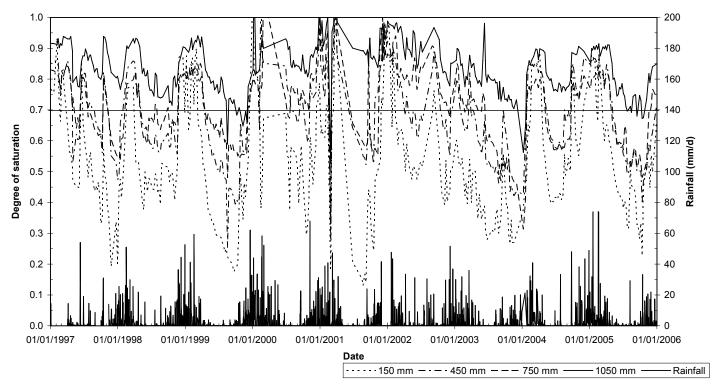


Figure 23 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 232 (Katspruit 1000).

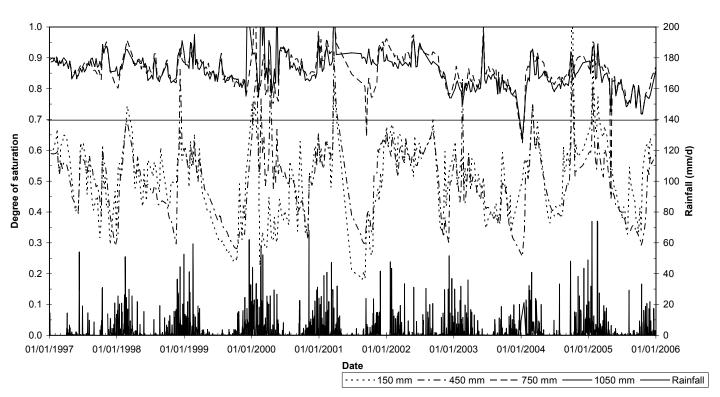


Figure 24 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 233 (Pinedene 2100).

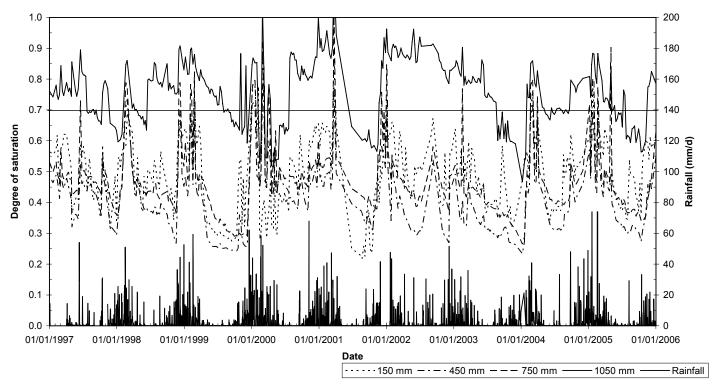


Figure 25 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 234 (Avalon 2100).

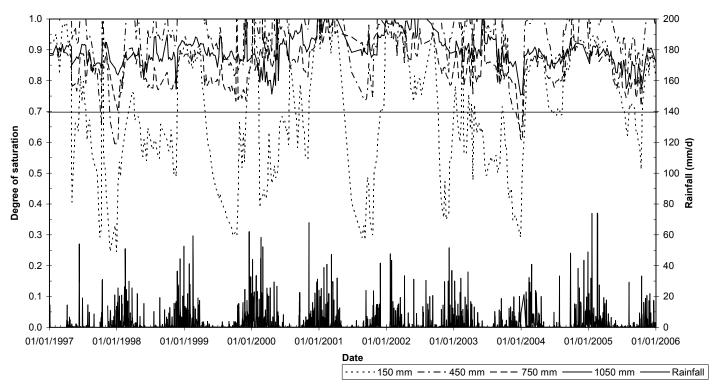


Figure 26 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 235 (Katspruit 1000).

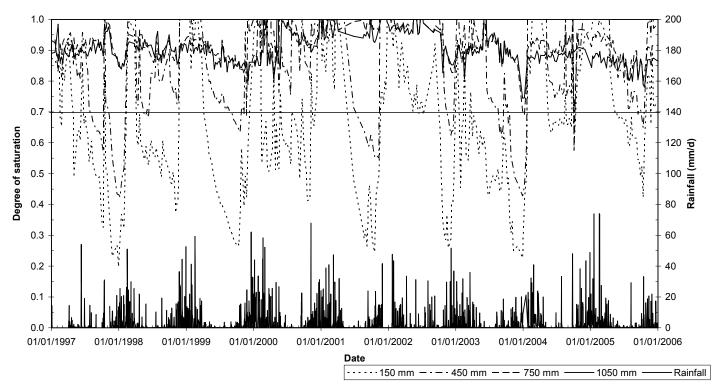


Figure 27 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 236 (Katspruit 1000).

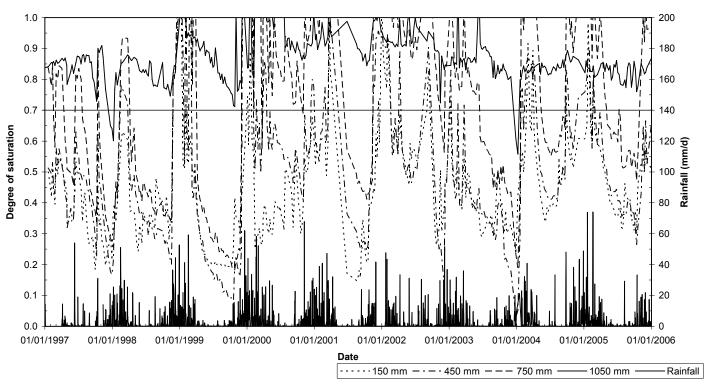


Figure 28 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2005 for profile 237 (Westleigh 1000).

Appendix B

Mean annual duration, mean frequency and mean duration of s>0.7 events for P201 to P237, calculated over 7 years from 1 January 1997 until 31 December 2005

Table 1 Mean annual duration of s>0.7 (AD $_{s>0.7}$), mean frequency of s>0.7 (F $_{s>0.7}$) and mean duration of s>0.7 events (D $_{s>0.7}$) for profiles 201 to 237, based on weekly soil water content measurements from 01/01/1996 until 31/12/2005

Profile No.	Depth (mm)	Diagnostic horizon	AD _{s>0.7} days year ⁻¹	F _{s>0.7} events year ⁻¹	D _{s>0.7} * days event ⁻¹
201	160	ot	6	0	5
201	460	gs	11	1	6
	760	sp	30	2	14
202	190	ot	1	0	1
	490	ye	1	0	1
	790	ye	165	2	75
	1090	on	271	0	93
	1390	on	263	0	82
	1650	on	255	1	37
203	190	ot	1	0	1
	490	ne	1	0	1
	790	ne	1	0	1
	1090	on	51	2	27
	1390	on	36	3	7
204	220	ot/gs	48	1	31
	520	sp	92	2	29
	820	gh	232	1	84
	1120	gh	278	0	28
205	230	ot	23	2	9
	530	gs	22	2	8
	830	gh	172	2	68 142
206	1130	gh	241	1	143
206	170	ot	263 274	1	100
	470 770	gs	274 265	0 0	28 50
	1070	gs gh	272	0	29
207	180	ot	116	3	65
201	480	sp	145	1	62
208	205	ot	131	2	58
200	505	gs	153	2	80
	750	gh	155	3	42
209	230	ot	123	2	78
200	530	ot/gh	221	2	139
210	190	ot	4	1	4
	490	ne	20	2	6
	790	ne	17	2 2	5
	1090	on	225	3	94
	1390	on	105	4	42
211	200	ot/gh	130	3	49
	500	gĥ	267	1	123
	800	gh	269	1	138
	1100	gh	271	0	79
212	200	ot	3	0	2
	500	ne	1	0	1
	800	ne	0	0	0
	1100	ne	1	0	1
	1400	on	2	0	1
213	180	ot	92	4	35
	480	ot/gh	160	3	78
	780	gh	179	3 3 2	82
	1080	gh	221	3	106
0.10	1380	gh	256	2	131
218	200	ot	88	3 2	46
	500	gh	186		144
	800	gh ~b	207	1	141
	1100	gh	208	1	113
220	1400	gh	208	1	113
220	175 475	ot ot	53 95	2	17 25
	475 775	ot	95	4	25
	775 1075	re	0 7	0	0 6
	1075 1375	on	210	1 3	30
	1375 140	on ot	50	<u> </u>	15
221		()I	อบ	J	10
221					
221	440	re	1	0	
221					1 2 2

Profile	Depth	Diagnostic	AD _{s>0.7}	F _{s>0.7}	D _{s>0.7} *
No.	(mm)	horizon	days year ⁻¹	events year ⁻¹	days event ⁻¹
222	180	ot	73	3	20
	480	ne	36	3 2	11
	780	ne	58		<u>36</u>
	1080	on	273	0	
225	220	ot	21	1	7
	520	ot/gs	111	2	43
	820	gs	83	3	21
	1120	sp	162	3	51
220	1420	so	166	2 2	90
226	190	ot	197		114
	490	gs	231	0	102
	790	gh	251	0	88
	1090 1390	gh	255 255	0 0	26 26
229	225	gh ot	153	3	64
229	525 525		264	0	97
	825	ot/gs	270	0	55
	1125	gs	267	1	180
230	150	gh ot	103	3	55
230	450	sp	85	3	30
	750	gh	248	1	123
	1050	gh	272	Ó	28
	1350	gh	272	0	28
231	150	ot	104	2	55
201	450	sp	197	2	115
	750	gh	169	2	102
	1050	gh	270	0	53
	1350	gh	270	0	53
232	230	ot	43	2	22
	530	sp	111	3	44
	830	sp	140	2	81
	1130	gh	248	1	99
	1430	gh	235	1	33
233	190	ot	8	1	6
	490	ye	8	1	5
	790	on	268	0	109
	1090	on	270	0	56
	1390	on	262	0	48
234	210	ot	6	1	5
	510	ot	20	2 2	5 9
	810	ye	184	2	
	1110	ye	251	1	54 7 0
	1410	sp/on	0	0	78
235	185	ot	129	2	58
	485 705	ot et/ab	268	0	83
	785	ot/gh	272	0	27
	1085	gh	272	0	33
226	1385	gh	272	0	48
236	190	ot ot/ab	93	3	40 80
	490	ot/gh	223	1	89 12
	790 1090	gh	269 270	0	13 22
		gh		0 0	
227	1390	gh	268 18	1	13 12
237	210 510	ot/sp	46	2	12 19
	810	ot/sp	139	2	73
	1110	sp sp	265	0	73 88
	1410	sp on	269	0	34
/-l	1410	-11-41	/-I1\ / F		-1\ D 41

^{*} $D_{s>0.7}$ (days event⁻¹) was calculated as (days year⁻¹) / $F_{s>0.7}$ (events year⁻¹). Because these values represent averages calculated over six years and have been rounded to whole numbers, $F_{s>0.7}$ x $D_{s>0.7}$ does not always equal $AD_{s>0.7}$.

Appendix C

Annual duration, frequency and duration of s>0.7 events for P201 to P237, over 7 years from 1 January 1997 until 31 December 2005

Table 1 Annual duration of s>0.7, for profiles 201 to 237, calculated from weekly neutron water meter data from 01/01/1996 until 31/12/2005

	trom	01/01/19	996 unti	1 31/12	2/2005											
Profile	Depth	Diag.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean M	Median	Std.
No.	(mm)	horizon							(days	year ⁻¹)						
201	160	ot	21	0	0	0	21	7	0	0	7	2	58	6	1	8
	460	gs	21	0	14	7	49	7	7	0	0	2	107	11	7	15
	760	sp	21	42	42	35	91	49	14	0	5	4	303	30	28	28
202	190	ot	0	0	0	0	0	7	0	0	7	0	14	1	0	3
	490	ye	0	0	0	0	0	0	0	0	7	0	7	1	0	2
	790	ye	77	238	161	119	245	133	238	140	147	147	1645	165	147	57
	1090	on	77	287	308	301	343	224	266	315	280	308	2716	271	294	75
	1390	on	77	287	308	287	343	224	266	315	273	245	2632	263	280	74
	1650	on	77	287	308	315	308	224	266	315	266	182	2555	255	277	76
203	190	ot	0	0	0	0	0	7	0	0	0	0	7	1	0	2
	490	ne	0	0	0	0	14	0	0	0	0	0	14	1	0	4
	790	ne	0	0	0	0	0	7	0	0	0	0	7	1	0	2
	1090	on	21	7	14	14	133	133	161	28	0	0	511	51	18	64
	1390	on	0	0	14	0	133	154	49	7	0	0	357	36	4	59
204	220	ot/gs	21	7	35	70	49	70	56	0	77	98	483	48	53	32
	520	sp	28	84	77	84	203	126	63	28	112	112	924	92	84	51
	820	gh	77	245	294	245	343	147	266	252	231	217	2324	232	245	74
	1120	gh	77	287	308	329	343	224	266	329	280	336	2786	278	298	80
205	230	ot	7	0	14	14	56	42	14	0	42	42	231	23	14	20
	530	gs	7	0	28	14	63	42	14	0	28	28	224	22	21	20
	830	gh	28	119	231	196	301	133	245	133	175	154	1722	172	165	77
	1130	gh	28	175	287	301	343	217	266	252	280	259	2415	241	263	88
206	170	ot	63	280	280	294	336	224	259	294	280	322	2639	263	280	77
	470	gs	63	287	301	336	343	224	259	329	280	322	2751	274	294	83
	770	gs	63	287	301	336	322	224	259	322	280	252	2653	265	284	79
	1070	gh	63	287	301	336	343	224	259	315	266	322	2723	272	294	82
207	180	ot	21	105	63	84	161	126	203	84	147	161	1155	116	116	54
	480	sp	49	238	112	119	343	133	217	119	63	56	1449	145	119	94
208	205	ot	42	140	70	112	252	126	196	28	196	147	1309	131	133	72
	505	gs	42	168	91	105	280	168	189	91	210	189	1533	153	168	70
	750	gh	49	196	56	119	231	161	217	105	224	196	1554	155	179	69
209	230	ot	70	154	140	119	203	133	189	28	77	119	1232	123	126	54
	530	ot/gh	70	245	294	322	336	182	203	147	175	231	2212	221	217	83
210	190	ot	0	0	0	0	7	14	7	0	7	7	42	4	4	5
	490	ne	0	0	0	0	77	70	7	0	14	28	196	20	4	30
	790	ne	0	0	0	0	42	70	42	7	. 7	0	168	17	4	25
	1090	on	70	245	259	308	273	210	245	238	217	189	2254	225	242	64
	1390	on	0	119	91	35	252	210	182	91	56	14	1050	105	91	85
211	200	ot/gh	14	35	35	98	210	119	196	175	182	238	1309	130	147	82
	500	gh	70	266	301	336	336	210	245	322	280	301	2674	267	291	80
	800	gh	70	280	308	336	336	210	245	322	280	301	2695	269	291	80
0.10	1100	gh	70	287	308	336	336	210	245	329	287	301	2716	271	294	81
212	200	ot	0	0	0	0	14	7	0	0	7	0	28	3	0	5
	500	ne	0	0	0	0	0	0	0	0	7	0	7	1	0	2
	800	ne	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1100 1400	ne	0	0	0	0	0 14	0	0	0	7 7	0 0	7 21	1	0 0	2
212		on	14	63	0 42	<u>0</u> 91	14 91	105		84	161		924	92	91	<u>5</u> 47
213	180 480	ot ot/ab							161			112				
	480 780	ot/gh	35 56	189 245	91 154	105 147	329 322	147 203	217 224	126 49	224 266	133 126	1603 1792	160 170	140	83 89
	1080	gh	63	266	154 224	224	259	210	245	238	273	210	2219	179 221	179 231	60
	1380	gh gh	63	280	224 287	308	343	210	245	301	280	245	2569	256	280	77
218	200	ot	7	126	49	105	98	147	98	63	189	0	882	88	98	60
210	500	gh	28	245	245	238	189	210	161	266	280	0	1862	186	224	98
	800	gh	14	266	287	322	189	224	161	322	280	0	2065	207	245	118
	1100	gh	14	266	287	322	189	224	161	329	287	0	2079	208	245	119
	1400	gh	14	266	287	322	189	224	161	329	287	0	2079	208	245	119
220	175	ot	0	0	28	49	98	77	126	14	56	77	525	53	53	43
0	475	ot	7	84	77	70	231	140	119	14	119	84	945	95	84	64
	775	re	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1075	on	0	7	0	0	7	28	14	7	7	0	70	7	7	9
	1375	on	63	280	259	217	259	217	252	182	217	154	2100	210	217	64
221	140	ot	0	7	35	63	70	70	126	7	49	77	504	50	56	39
'	440	re	0	0	0	0	0	7	0	0	7	0	14	1	0	3
	740	re	0	0	0	Ö	7	0	0	0	14	7	28	3	Ő	5
	1040	re	Ö	0	Ö	0	21	7	0	Ö	7	0	35	4	0	7
	1340	on	Ö	Ö	7	Ö	14	14	14	Ö	7	Ö	56	6	4	6
-																

Profile	Depth	Diag.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean I	Median	Std.
No.	(mm)	horizon							(days	year ⁻¹)						
222	180	ot	0	0	28	56	77	77	175	91	98	126	728	73	77	55
	480	ne	0	0	14	14	98	91	98	7	21	21	364	36	18	42
	780	ne	21	21	28	56	112	112	196	14	7	14	581	58	25	62
225	1080 220	on ot	70 21	287 0	308 0	336 0	336 21	217 42	266 77	322 0	273 14	315 35	2737 210	273 21	298 18	80 25
223	520	ot/gs	49	63	63	98	301	126	168	14	105	119	1106	111	102	80
	820	gs	28	105	63	84	189	119	77	0	91	70	833	83	81	51
	1120	sp	77	217	133	133	308	140	245	105	119	147	1631	162	137	71
	1420	so	56	245	112	140	273	217	245	105	126	140	1659	166	140	73
226	190	ot	28	168	266	301	315	168	231	91	259	147	1981	197	200	93
	490	gs	14	266	287	336	329	224	266	287	252	49	2317	231	266	111
	790	gh	28	273	287	336	329	224	266	322	259	189	2520	251	270	91
	1090	gh	28	287	294	336	336	224	266	329	259	189	2555	255	277	93
220	1390 225	gh	28	287	294	336 133	336	224	266 231	329 126	259 182	189 161	2555 1526	255	277 144	93 62
229	525 525	ot/as	21 35	147 287	140 301	294	245 336	140 210	266	322	266	322	2639	153 264	291	88
	825	ot/gs gs	35	287	301	329	336	210	266	329	280	322	2695	270	294	91
	1125	gh	35	287	294	329	336	217	259	322	273	315	2667	267	291	89
230	150	ot	7	42	42	91	91	126	203	77	168	182	1029	103	91	66
	450	sp	7	56	63	42	210	154	119	7	119	77	854	85	70	65
	750	gh	35	259	273	322	343	189	259	266	273	259	2485	248	263	85
	1050	gh	35	287	308	329	343	217	259	322	280	336	2723	272	298	92
	1350	gh	35	287	308	329	343	217	259	322	280	336	2723	272	298	92
231	150	ot	7	112	35	91	133	98	189	49	161	161	1036	104	105	60
	450 750	sp gh	14 14	189 189	161 126	133 119	336 329	210 210	203 203	259 154	252 196	217 154	1974 1701	197 169	207 172	85 81
	1050	gh	28	287	301	336	343	217	252	322	273	336	2702	270	294	94
	1350	gh	28	287	301	336	343	217	252	322	280	336	2709	270	294	94
232	230	ot	14	56	49	42	56	63	35	0	63	56	441	43	53	21
	530	sp	35	182	98	105	147	126	119	49	133	119	1120	111	119	43
	830	sp	56	154	119	105	203	126	259	126	126	126	1407	140	126	56
	1130	gh	56	287	308	273	231	210	259	308	259	287	2485	248	266	74
	1430	gh	56	287	308	336	217	175	84	308	266	315	2359	235	277	100
233	190	ot	0	0	7 7	0	14 35	14	7	0 7	14	28 7	84	8	7	9
	490 790	ye on	0 56	0 287	287	0 336	343	14 210	0 266	308	14 273	315	84 2688	8 268	7 287	11 84
	1090	on	56	287	287	336	343	217	266	308	273	322	2702	270	287	84
	1390	on	56	287	287	336	343	217	266	308	259	259	2625	262	277	82
234	210	ot	0	0	14	0	28	7	0	0	14	0	63	6	0	10
	510	ot	14	7	28	21	42	14	7	7	21	42	210	20	18	13
	810	ye	56	189	224	224	210	119	266	217	161	175	1848	184	200	60
	1110	ye	56	287	308	336	343	196	105	294	266	322	2520	251	291	100
225	1410	sp/on	<u> </u>	0 126	0 49	0 112	133	110	0 196	0 49	0 224	273	0 1295	0 129	0 123	0 83
235	185 485	ot ot	35	259	294	336	343	119 224	266	322	273	329	2688	268	284	91
	785	ot/gh	35	287	301	336	343	224	266	322	273	329	2723	272	294	91
	1085	gh	35	287	301	329	343	224	266	329	280	329	2730	272	294	91
	1385	gh	35	287	301	336	343	217	259	329	280	329	2723	272	294	92
236	190	ot	7	77	63	84	98	126	168	28	133	147	938	93	91	52
	490	ot/gh	35	182	245	259	343	140	224	245	259	294	2233	223	245	86
	790	gh	35	287	294	336	343	224	259	329	266	315	2695	269	291	90
	1090	gh	35	287	294	336	343	217	259	329	280	315	2702	270	291	91
227	1390	gh	35	287	294	336	343	224	259	322	266	315	2688	268	291	90
237	210 510	ot ot/sp	0 0	0 0	21 42	14 42	14 77	35 77	49 63	7 21	21 84	21 49	182 462	18 46	18 46	15 31
	810	sp	14	91	42 49	91	322	133	245	154	133	154	1393	139	133	90
	1110	sp	35	273	273	336	343	217	266	322	273	315	2660	265	273	90
	1410	on	35	287	280	336	343	217	266	329	280	315	2695	269	284	91

Table 2 Frequency of s>0.7 events, for profiles 201 to 237, calculated from weekly neutron water meter data from 01/07/1997 until 30/06/2003

D. 61		01/07/198				4000	0000	0001	0000	0000	0004	0005	T	N4		0/ 1
Profile No.	Depth (mm)	Diag. horizon	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean M	edian	Std.
201	160	ot	2	0	0	0	1	1	(events 0	year) 0	1	1	4	0	1	0
201	460	gs	2	0	2	1	3	1	1	0	0	2	10	1	1	1
	760	sp	2	4	2	2	2	4	1	0	2	2	17	2	2	1
202	190	ot	0	0	0	0	0	1	0	0	1	0	1	0	0	0
	490	ye	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	790	уe	0	1	6	0	3	1	0	3	2	1	16	2	1	2
	1090	on	0	0	0	2	1	0	0	0	1	2	5	0	0	1
	1390	on	0	0	0	1	1	0	0	0	2	5	4	0	0	0
	1650	on	0	0	0	3	3	0	0	0	2	7	8	1	0	1
203	190	ot	0	0	0	0	0	1	0	0	0	0	1	0	0	0
	490	ne	0	0	0	0	2	0	0	0	0	0	2	0	0	1
	790 1090	ne	0 0	0 1	0 2	0 2	0 6	1 1	0 2	0 3	0	0	1 19	0 2	0 2	0
	1390	on on	0	0	2	0	8	5	4	1	0	0	20	3	1	2 3
204	220	ot/gs	0	1	1	2	2	2	1	0	4	1	11	1	1	1
204	520	sp	0	3	3	0	3	2	1	3	3	0	17	2	3	1
	820	gh	Ö	2	2	1	Ö	2	0	2	4	3	9	1	2	1
	1120	gh	0	0	0	0	0	0	0	0	1	0	2	0	0	0
205	230	ot	0	0	2	2	2	4	2	0	4	2	16	2	2	1
	530	gs	0	0	2	2	6	3	2	0	3	2	19	2	2	2
	830	gh	0	1	4	2	4	1	0	2	3	2	16	2	2	2
	1130	gh	0	0	1	2	1	1	0	4	1	3	11	1	1	1
206	170	ot	0	0	2	2	1	0	0	3	1	0	8	1	1	1
	470 770	gs	0	0	0	0	0 2	0	0	0	1	0	2 4	0	0	0
	1070	gs gh	0 0	0 0	0 0	0 0	0	0	0 0	0 2	1 2	4 0	4	0 0	0 0	1 1
207	180	ot	0	4	2	2	3	2	1	4	3	1	20	3	2	 1
201	480	sp	0	2	2	1	0	1	2	2	5	4	12	1	2	1
208	205	ot	0	4	3	1	4	1	0	3	3	1	19	2	2	2
200	505	gs	Ö	3	2	1	2	2	1	6	3	2	20	2	2	2
	750	gh	Ö	4	4	1	6	2	0	6	4	4	26	3	4	2
209	230	ot	0	2	5	2	1	1	1	3	4	2	17	2	2	1
	530	ot/gh	0	2	1	1	1	2	3	2	5	5	14	2	2	1
210	190	ot	0	0	0	0	1	2	1	0	1	1	4	1	1	1
	490	ne	0	0	0	0	7	3	1	0	2	3	11	2	1	3
	790	ne	0	0	0	0	5	6	3	1	1	0	15	2	1	3
	1090 1390	on	0 0	1 6	3 8	4 5	5 6	1 1	2 3	4 2	6 3	4 2	22 31	3 4	4 3	2
211	200	on ot/gh	0	3	2	2	6	<u> </u> 1	2	<u> </u>	4	3	23	3	3	<u>3</u>
211	500	gh	0	0	1	0	1	1	1	0	2	0	6	1	1	1
	800	gh	Ö	Ö	1	Ö	1	1	1	0	1	Ő	6	1	1	1
	1100	gh	Ö	Ö	0	0	1	1	1	0	0	0	5	0	0	1
212	200	ot	0	0	0	0	2	1	0	0	1	0	3	0	0	1
	500	ne	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	800	ne	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1100	ne	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	1400	on	0	0	0	0	2	0	0	0	1	0	2	0	0	1
213	180	ot ot/ab	0	3	2	4	4	2	6	5	3	1	28	4	3	1
	480 780	ot/gh gh	0 0	4 4	2 4	1 1	2	2 2	3 1	5 4	2 3	1 3	21 21	3 3	2 3	1 1
	1080	gh	0	2	6	3	4	1	1	2	2	5 5	21	3	2	2
	1380	gh	0	2	3	3	0	1	1	2	1	3	12	2	2	1
218	200	ot	0	3	3	4	4	1	1	4	2	0	23	3	3	1
	500	gh	0	1	4	2	2	1	1	1	1	0	14	2	1	1
	800	gh	0	1	1	1	2	0	1	0	1	0	9	1	1	1
	1100	gh	0	1	1	1	2	0	1	0	0	0	8	1	1	1
	1400	gh	0	1	1	1	2	0	1	0	0	0	8	1	1	1
220	175	ot	0	0	2	4	2	2	5	2	6	7	17	2	2	2
	475 775	ot ro	0	6 0	3 0	2 0	6 0	3 0	4 0	2	4 0	4 0	27 0	4 0	4 0	2
	775 1075	re on	0 0	1	0	0	1	2	1	1	1	0	6	1	0 1	0 1
	1375	on	0	0	5	2	6	0	0	6	5	7	21	3	4	3
221	140	ot	0	1	2	4	2	3	5	1	7	5	18	3	3	2
	440	re	0	Ö	0	0	0	1	0	Ö	1	0	1	0	0	0
	740	re	Ö	Ö	Ö	Ö	1	Ö	Ö	Ö	2	1	1	Ö	Ö	Ö
	1040	re	0	0	0	0	3	1	0	0	1	0	4	1	0	1
	1340	on	0	0	1	0	1	1	2	0	1	0	5	1	1	1

No. (mm) horizon (events year)	Profile	Depth	Diag.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean M	ledian	Std.
480 ne		(mm)	horizon							(events	year ⁻¹)						
780	222																
1080																	
225 520																	
S20	225																
820 gs 0 5 3 0 7 2 3 0 4 2 22 3 3 3 3 2 3 1420 sp 0 2 2 5 2 6 2 0 7 7 4 1 26 3 2 3 2 3 1420 sp 0 2 2 5 2 6 2 1 6 1 1 2 2 4 4 4 18 2 2 2 2 2 2 1 9 9 1 9 1 9 1 9 1 9 1 9 1	223			-											-		
1120 sp																	
1420			-														
226 190 ot 0 2 1 2 3 3 2 2 3 1 3 16 2 2 1 1 490 gs 0 1 1 0 1 0 0 0 0 2 4 4 4 0 0 1 1 1 1 1 1 1 1		1420		0		2	1	6		1	2	4	4	18	2	2	
Typo	226		ot	0	2			3			3		3	16	2	2	
1090 gh																	
1390 gh																	
229 225														•	-		
S25 oVgs O O O O 1 1 1 O O C O O A O O O O O O O	220																
825 gs 0 0 0 0 0 1 1 1 0 0 0 0 3 0 0 0 0 0 1 1 1 1	229						•										
1125 9h			_														
230															-		
450 sp 0 6 2 3 2 3 4 1 5 3 22 3 3 4 1 1 5 3 23 3 3 3 2 7 5 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	230																
1050 9h			sp	0	6	2	3	2	3	4	1	5	3	23	3	3	2
1350 gh															-		
231															-		
450 sp 0 3 4 1 1 1 1 3 2 5 18 2 3 1 1 750 gh 0 0 2 4 1 1 2 1 1 1 6 2 2 19 2 2 2 2 1050 gh 0 0 0 0 0 0 0 0 0 1 1 0 1 0 2 0 0 0 0 0																	
750 gh 0 2 4 1 2 1 1 6 2 2 1 99 2 2 2 2 1 1 3 1 0 6 2 2 1 99 2 2 2 2 1 1 3 1 0 6 2 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	231																
1050 gh																	
1350 gh 0 0 0 0 0 0 1 0 1 0 1 0 2 0 0 0 0 0 1 1 0 1 5 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0																	
232 230 ot 0 0 2 2 2 2 2 2 3 2 0 3 1 1 15 2 2 1 1 530 sp 0 2 2 1 4 4 3 2 4 3 0 21 3 2 1 1 18 2 2 1 1 1130 sp 0 0 2 2 4 1 3 3 1 1 1 1 1 0 2 2 4 7 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1																	
830 sp	232		ot	0	2	2	2	2	3	2	0	3	1	15	2	2	1
1130 gh			sp	0			1										1
1430 gh			•										-				
233															-		
490 ye 0 0 1 0 3 1 0 1 2 1 6 1 1 1 790 on 0 0 1 0 0 1 0 </td <td>- 000</td> <td></td> <td>-</td> <td></td> <td></td>	- 000														-		
790 on 0 0 1 0 0 1 0 0 1 0 0 0 1 1 3 0 0 0 0 0	233														-	-	
1090 on																	
1390													-				
510 ot 0 1 2 2 3 2 1 1 2 4 14 2 2 1 810 ye 0 2 2 2 3 4 1 0 0 5 3 133 2 2 1 1110 ye 0																	
810 ye	234	210	ot	0	0	1	0	2	1	0	0	1	0	4	1	0	1
1110 ye			ot														1
1410 sp/on 0<			•														
235																	
485 ot ot of of ot ot of ot ot of ot	235																
785 ot/gh 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0	233						•										
1085 gh 0 0 0 1 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0											_		_	1			_
1385 gh 0 0 0 0 0 1 1 0 0 0 3 0 0 0 0 236 190 ot 0 3 2 0 7 1 2 3 4 2 20 3 2 2 490 ot/gh 0 1 3 3 0 1 0 2 2 2 11 1 2 1 790 gh 0		1085												2			
490 ot/gh 0 1 3 3 0 1 0 2 2 2 11 1 2 1 790 gh 0 <td< td=""><td></td><td>1385</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>		1385															
790 gh 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	236			-											-		
1090 gh 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0																	
237 210 ot 0 0 1 2 2 3 1 1 3 2 10 1 2 1 510 ot/sp 0 0 2 4 3 3 2 3 4 1 17 2 3 1 810 sp 0 3 2 2 3 1 1 0 2 2 14 2 2 1 1110 sp 0 0 1 1 0 0 0 0 0 1 0 3 0 0					-		_						-		-		
510 ot/sp 0 0 2 4 3 3 2 3 4 1 17 2 3 1 810 sp 0 3 2 2 3 1 1 0 2 2 14 2 2 1 1110 sp 0 0 1 1 0 0 0 0 1 0 3 0 0	227													-			
810 sp 0 3 2 2 3 1 1 0 2 2 14 2 2 1 1110 sp 0 0 1 1 0 0 0 0 1 0 3 0 0	231																
1110 sp 0 0 1 1 0 0 0 0 1 0 3 0 0 0		810															
1410 on 0 0 0 1 0 0 0 0 0 2 0 0 0	-	1410	•	0	0	0	1	0	0	0	0	0	0	2	0	0	0

Table 3 Duration of s>0.7 events, for profiles 201 to 237, calculated from weekly neutron water meter data from 01/07/1997 until 30/06/2003

		01/07/19				1000		2001								
Profile	Depth	Diag.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean M	Median	Std.
No.	(mm)	horizon	11	0			21	7	(days e		7	2	40		4	
201	160 460	ot	11 11	0 0	0 7	0 7	21 16	7 7	0 7	0 0	7 0	2 1	48 56	5 6	1 7	7 5
	760	gs sp	11	11	21	18	46	12	14	0	3	2	136	14	11	14
202	190	ot	0	0	0	0	0	7	0	0	7	0	14	1	0	3
202	490	ye	Ő	Ö	Ő	Ö	Ö	0	Ö	Ő	7	Ő	7	1	Ö	2
	790	ye	0	238	27	0	82	133	0	47	74	147	747	75	60	78
	1090	on	0	0	0	151	343	0	0	0	280	154	928	93	0	135
	1390	on	0	0	0	287	343	0	0	0	137	49	816	82	0	136
	1650	on	0	0	0	105	103	0	0	0	133	26	367	37	0	56
203	190	ot	0	0	0	0	0	7	0	0	0	0	7	1	0	2
	490	ne	0	0	0	0	7	0	0	0	0	0	7	1	0	2
	790	ne	0	0 7	0 7	0	0	7	0	0	0	0	7	1	0 7	2
	1090 1390	on on	0 0	0	7	7 0	22 17	133 31	81 12	9 7	0	0 0	266 74	27 7	4	46 10
204	220	ot/gs	0	7	35	35	25	35	56	0	19	98	310	31	30	29
204	520	sp	0	28	26	0	68	63	63	9	37	0	294	29	27	27
	820	gh	Ő	123	147	245	0	74	0	126	58	72	844	84	73	77
	1120	gh	0	0	0	0	0	0	0	0	280	0	280	28	0	93
205	230	ot	0	0	7	7	28	11	7	0	11	21	91	9	7	9
	530	gs	0	0	14	7	11	14	7	0	9	14	76	8	8	6
	830	gh	0	119	58	98	75	133	0	67	58	77	685	68	71	39
	1130	gh	0	0	287	151	343	217	0	63	280	86	1427	143	118	129
206	170	ot	0	0	140	147	336	0	0	98	280	0	1001	100	49	128
	470 770	gs	0 0	0	0 0	0 0	0 161	0 0	0	0 0	280 280	0 63	280 504	28 50	0 0	93 100
	1070	gs gh	0	0	0	0	0	0	0	158	133	03	291	29	0	64
207	180	ot	0	26	32	42	54	63	203	21	49	161	650	65	46	64
201	480	sp	0	119	56	119	0	133	109	60	13	14	622	62	58	52
208	205	ot	0	35	23	112	63	126	0	9	65	147	581	58	49	53
	505	gs	0	56	46	105	140	84	189	15	70	95	799	80	77	52
	750	gh	0	49	14	119	39	81	0	18	56	49	424	42	44	36
209	230	ot	0	77	28	60	203	133	189	9	19	60	778	78	60	72
	530	ot/gh	0	123	294	322	336	91	68	74	35	46	1388	139	82	125
210	190	ot	0	0	0	0	7	7	7	0	7	7	35	4	4	4
	490	ne	0	0	0	0	11	23	7	0	7	9	58	6	4	8
	790 1090	ne on	0 0	0 245	0 86	0 77	8 55	12 210	14 123	7 60	7 36	0 47	48 938	5 94	4 68	6 75
	1390	on	0	20	11	7	42	210	61	46	19	7	422	42	19	64
211	200	ot/gh	0	12	18	49	35	119	98	35	46	79	490	49	40	37
	500	gh	Ő	0	301	0	336	210	245	0	140	0	1232	123	70	141
	800	gh	0	0	308	0	336	210	245	0	280	0	1379	138	105	150
	1100	gh	0	0	0	0	336	210	245	0	0	0	791	79	0	136
212	200	ot	0	0	0	0	7	7	0	0	7	0	21	2	0	4
	500	ne	0	0	0	0	0	0	0	0	7	0	7	1	0	2
	800	ne	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1100 1400	ne	0	0	0	0	0 7	0	0	0	7 7	0	7 14	1 1	0	2
213	180	on ot	0	21	21	23	23	53	27	17		112	349	35	23	3 31
213	480	ot/gh	0	47	46	105	23 165	74	72	25	112	133	778	78	73	46
	780	gh	0	61	39	147	107	102	224	12	89	42	823	82	75	65
	1080	gh	0	133	37	75	65	210	245	119	137	42	1062	106	97	73
	1380	gh	0	140	96	103	0	210	245	151	280	82	1306	131	121	88
218	200	ot	0	42	16	26	25	147	98	16	95	0	464	46	25	50
	500	gh	0	245	61	119	95	210	161	266	280	0	1437	144	140	98
	800	gh	0	266	287	322	95	0	161	0	280	0	1411	141	128	136
	1100	gh	0	266	287	322	95 05	0	161	0	0	0	1131	113	47 47	137
220	1400 175	gh ot	0	266 0	287 14	322 12	95 49	39	161 25	0 7	9	<u>0</u> 11	1131 166	113 17	47 12	137 16
220	475	ot ot	0	14	26	35	49 39	39 47	30	7	30	21	247	25	28	12
	775	re	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1075	on	0	7	0	0	7	14	14	7	7	0	56	6	7	5
	1375	on	Ő	Ö	52	109	43	0	0	30	43	22	299	30	26	35
221	140	ot	0	7	18	16	35	23	25	7	7	15	153	15	16	10
	440	re	0	0	0	0	0	7	0	0	7	0	14	1	0	3
	740	re	0	0	0	0	7	0	0	0	7	7	21	2	0	4
	1040	re	0	0	0	0	7	7	0	0	7	0	21	2	0	4
	1340	on	0	0	7	0	14	14	7	0	7	0	49	5	4	6

Profile	Depth	Diag.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	Mean M	Median	Std.
No.	(mm)	horizon							(days e							
222	180	ot	0	0	14	14	19	39	58	13	16	25	199	20	15	17
	480	ne	0	0	7	7	16	30	16	7	11	11	105	11	9	9
	780	ne	0	7	28	19	22	56	196	7	7	14	356	36	16	61
	1080	on	0	0	0	0	336	0	0	0	273	158	767	77	0	136
225	220	ot	0	0	0	0	7	14	26	0	7	18	71	7	4	9
	520	ot/gs	0	32	32	0	60	126	84	14	21	60	428	43	32	39
	820	gs	0	21	21	0	27	60	26	0	23	35	212	21	22	18
	1120	sp	0	109	27	67	51	70	0	15	30	147	515	51	41	47
	1420	SO	0	82	56	140	46	217	245	53	32	35	904	90	54	81
226	190	ot	0	84	266	151	105	84	116	30	259	49	1143	114	95	84
	490	gs	0	266	287	0	329	0	0	0	126	12	1020	102	6	142
	790	gh	0	0	287	0	329	0	0	0	259	0	875	88	0	147
	1090	gh	0	0	0	0	0	0	0	0	259	0	259	26	0	86
220	1390	gh	0	<u>0</u> 37	0	0	<u>0</u> 49	0	0	0	259	0	259	26	0	86
229	225	ot ot/so			35	133		140	116	18	36	81	644	64	43	47
	525	ot/gs	0	0	0 0	294	336	210	0	0	133 0	0	973	97 55	0	140
	825 1125	gs	0	0	294	0 0	336 336	210	0 259	0 322	273	0 315	546 1799	180	266	124 152
230	150	gh ot	0	11	294	46	18	0 126	203	13	56	61	554	55	33	64
230	450	sp	0	9	32	14	105	51	30	7	24	26	297	30	25	30
	750	gh	0	130	137	322	0	189	0	89	273	86	1225	123	109	111
	1050	gh	0	0	0	0	0	0	0	0	280	0	280	28	0	93
	1350	gh	0	0	0	0	0	0	0	0	280	0	280	28	0	93
231	150	ot	0	37	35	91	33	49	189	12	27	81	554	55	36	54
201	450	sp	Ö	63	40	44	336	210	203	86	126	43	1152	115	75	102
	750	gh	0	95	32	119	165	210	203	26	98	77	1023	102	96	67
	1050	gh	0	0	0	0	0	0	252	0	273	0	525	53	0	116
	1350	gh	0	0	0	0	0	0	252	0	280	0	532	53	0	118
232	230	ot	0	28	25	21	28	21	18	0	21	56	217	22	21	15
	530	sp	0	91	49	105	37	42	60	12	44	0	440	44	43	34
	830	sp	0	77	30	105	68	42	259	42	63	126	811	81	65	70
	1130	gh	0	0	0	91	231	210	259	0	130	72	992	99	81	103
	1430	gh	0	0	0	0	109	44	42	0	133	0	327	33	0	52
233	190	ot	0	0	7	0	7	14	7	0	7	14	56	6	7	5
	490	ye	0	0	7	0	12	14	0	7	7	7	54	5	7	5
	790	on	0	0	287	0	0	210	0	0	273	315	1085	109	0	146
	1090 1390	on	0	0	287 287	0 0	0	0	0	0	273 130	0 65	560 481	56 48	0	124
234	210	on	0	0	0	7	14	7	7	0	7	7	49	5	7	98 5
234	510	ot ot	0	0	14	0	14	7	0	0	14	0	49	5	0	7
	810	ye	0	7	14	11	14	7	7	7	11	11	88	9	9	3
	1110	ye ye	0	95	112	75	53	119	0	0	32	58	543	54	55	44
	1410	sp/on	0	0	0	0	0	196	26	294	266	0	782	78	0	127
235	185	ot	0	63	25	112	44	119	0	8	75	137	582	58	54	50
	485	ot	0	259	294	0	0	0	0	0	273	0	826	83	0	138
	785	ot/gh	Ö	0	0	Ö	Ö	Ö	Ö	Ö	273	Ö	273	27	Ö	91
	1085	gĥ	0	0	0	329	0	0	0	0	0	0	329	33	0	110
	1385	gh	0	0	0	0	0	217	259	0	0	0	476	48	0	105
236	190	ot	0	26	32	0	14	126	84	9	33	74	397	40	29	42
	490	ot/gh	0	182	82	86	0	140	0	123	130	147	889	89	104	64
	790	gĥ	0	0	0	0	0	0	0	0	133	0	133	13	0	44
	1090	gh	0	0	0	0	0	217	0	0	0	0	217	22	0	72
	1390	gh	0	0	0	0	0	0	0	0	133	0	133	13	0	44
237	210	ot	0	0	21	7	7	12	49	7	7	11	120	12	7	14
	510	ot/sp	0	0	21	11	26	26	32	7	21	49	191	19	21	15
	810	sp	0	30	25	46	107	133	245	0	67	77	729	73	56	74
	1110	sp	0	0	273	336	0	0	0	0	273	0	882	88	0	148
	1410	on	0	0	0	336	0	0	0	0	0	0	336	34	0	112

Appendix D

Final infiltration rate measurements (If) for selected ecotopes in the Weatherley catchment

Table 1 Results of final infiltration rate measurements (If) for selected ecotopes in the Weatherley catchment

								SE		1.43					SE		2.85					Ц	J T	2.22						SE		2.58
								SD	(mm/hr)	3.19					SD	(mm/hr)	6.98					ט	(mm/hr)	4.97						SD.	(mm/hr)	5.76
								Mean	_	5.23					Mean)	13.12					Moon	שומ מ	7.77						Mean	_	10.46
6 th Run	Water	intercep	(ml)	50.0	56.0	70.0	4.9429	0.4563	0.92	10.0	21.0	35.0	32.0	2.5863	0.5492	0.79	13.0		12.0	18.0	2,1801	0 5600	1.0	12.8	70	10.0	0.71	18.0	2.5643	0.4003	0.89	6.3
9 1	Time	elap.	(min)	9.08	13.83	18.58					4 73	8.58	11.22						2.10	4.23					0 50	2. Z	3.00 1.00	5.73				
5th Run	Water	intercep	(ml)	55.0	53.0	49.0	21.0600	-0.1696	96.0	ı	30.0	37.0	45.0	3.5365	0.4903	0.97	11.9		14.0	17.0	3.3077	0.2717	0.88	1.4	7	0.0	10.0	18.0	2.0946	0.5351	96.0	10.4
5 th F	Time	\vdash	(min)	6.50	9.17	12.83					5,55	9.50	12.33						1.90	3.10	è				0.4.0	2 2	3.03	5.37				
4thRun	Water	intercep	(ml)	42.0	43.0	43.0	10.5730	0.0472	0.67	1.7	20.0	22.0	34.0	2.4505	0.5467	0.87	12.1		40.0	26.0	19,6460	0.6452	0.94		7	0.0	13.0	20.0	1.3392	0.7641	0.94	20.3
4 th	Time	elap.	(min)	8.33	10.17	13.33					4 00	6.53	10.53						2.55	4.20	5				77.0	7 7 7	4.07	6.07				
3 rd Run	Water	intercep	(Iml)	21.0	24.0	24.0	5.5340	0.0746	0.58	3.6	18.0	18.0	27.0	2.9164	0.3794	0.62	6.3		12.0	15.0	2.2533	0 1805	0.99	8.5	7	0.6	22.0	19.0	2.4692	0.4833	09.0	0.6
3 rd	Time	elap.	(min)	3.17	5.42	15.0					3 48		9.13						2.17	3.83	0.50				00 0	2.00	φ. 200.	5.96				
2 nd Run	Water	intercep	(Iml)	31.0	31.0	48.0	4.2200	0.3507	0.64	9.9	18.0	33.0	40.0	1.9582	0.7550	1.0	26.4		16.0	20.0	2,4236	0.57.80	1.0	12.1	0.01	77.0	0.41	17.0	2.3466	0.4150	0.99	6.3
2 nd	Time	elap.	(min)	6.22	12.42	19.48					3.42	8.02						Ī	3.00	4.50	0.40				20.0	2.43	ა. ეე	5.18				
1 st Run	Water	intercep	(ml)	37.0	45.0	44.0	7.5181	0.1967	0.68	4.2	30.0	32.0	39.0	4.5824	0.3930	0.93	9.0		16.0	16.0	4.0365	00000	0.82	4.	0 00	70.0	10.0	15.0	7.5021	-0.3420	0.98	ı
184	Time	elap.	(min)	5.71	9.12	14.0	၁	¥	Z	<u>+</u>	4.30	5.93	8.42	ပ	∡'	<u>~</u>	<u>+</u>		2.53	3.42	2 0	Y	∠ ⁷ Z	: <u>-</u>	03 6	2.30	دد.4 1	5.95	ပ	Y 1	'n	<u>-</u>
	Kall	gauge		_	2	3					_	- 2	က						_	7					7	- 0	7 (က				
	Site	no.			201							234								220						2	740					

										_]							10								_
								SE		5.17						SE		0.55						SE		1.24
								SD	(mm/hr)	11.55						SD	(mm/hr)	0.95						SD	(mm/hr)	3.05
								Mean		16.16						Mean		4.84						Mean		5.40
6 ^m Run	Water	intercep	(m)	17.0	15.0	14.0	6.4591	-0.3325	98.0	ı										10.0	13.0	17.0	2.2001	0.5833	0.99	10.9
9	Time	elab.	(min)	2.83	3.33	4.83														1.45	2.45	3.57				
5 th Run	Water	intercep	(m)	9.0	12.0	18.0	2.4008	0.5086	0.93	10.2		23.0	19.0	18.0	9.0470	-0.3382	98.0	ı	-	9.0	10.0	13.0	2.4477	0.3166	0.98	4 .1
5 _{th}	Time	elab.	(min)	1.00	2.33	3.67						3.10	4.22	6.27					-	1.00	1.62	3.25				
4thRun	Water	intercep	(lm)	8.0	10.0	15.0	1.7961	0.6702	0.99	15.3		10.0	12.0	21.0	2.1549	0.4165	0.93	5.8		10.0	12.0	15.0	2.3244	0.3791	0.99	5.4
4tt	Time	elab.	(min)	1.33	2.00	3.42						1.58	3.72	9.50						1.63	2.45	4.70				
3 rd Run	Water	intercep	(lm)	15.0	25.0	31.0	1.5471	0.8394	0.98	35.6		21.0	24.0	31.0	4.2311	0.2841	0.88	4.7	•	14.0	19.0	16.0	4.0819	0.1125	0.27	1.6
	Time	elab.	(min)	3.33	5.58	8.00						2.78	6.42	10.10						1.10	2.50	4.50				
2 nd Run	Water	intercep	(m)	18.0	18.0	25.0	3.1135	0.3325	0.79	5.3		29.0	31.0	27.0	9.8973	-0.1206	0.38	1		14.0	16.0	19.0	3.0789	0.3212	0.99	6.4
2 _{nd}	Time	elab.	(min)	2.58	4.11	7.10						4.15	5.47	8.38					•	2.00	3.25	5.17				
1 st Run	Water	intercep	(m)	12.0	19.0	22.0	1.8396	0.6191	96.0	4.4		16.0	17.0	21.0	3.3531	0.2662	0.89	3.9	-	11.0	15.0	15.0	2.7343	0.3740	69.0	5.7
1 st	Time	elab.	(min)	2.72	4.88	7.38	ပ	¥	ሺ	<u>-</u>		2.58	4.38	7.10	ပ	¥	ሌ	1		1.58	2.25	3.50	ပ	¥	~	_*
Rain	Galide	200	<u>.</u>	_	2	3					-	_	2	3					•	1	2	3				
	Site				212								235						_		221					