HYDROLOGICAL SYSTEMS MODELLING RESEARCH PROGRAMME: HYDROLOGICAL PROCESSES

Phase II Quantification of Hillslope, Riparian and Wetland Processes

Report to the

Water Research Commission on the project:

'*A Field Study of Two and Three Dimensional Processes in Hillslope Hydrology for Better Management of Wetlands and Riparian Zones*'
and
'Experimental and Laboratory Measurements of Soil Hydraulic Properties'

by

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Chapter 1

Introduction

The study of hillslope flow path mechanisms is a vital component of hydrology for a number of reasons. Mechanisms of rapid and slow responses at the hillslope scale affect the magnitude of storm flow peaks at the small catchment scale (< 10 km^2) and contribute to runoff hydrographs at the large (10 – 100 km^2) catchment scale. Mechanisms of water storage during wet periods and subsequent release from hillslopes during dry periods affect the sustainability of small catchment practices and can also have a significant control on low-flow rates at the large catchment scale. Mechanisms of lateral flow, accumulation, redistribution and residence times of water on the hillslope will influence the nature and location of land use practices. Conversely, changes in land use practices may affect all these hillslope flow path mechanisms and therefore the perturbations in flow generation mechanisms due to land use changes are important to define.

Two concurrent Water Research Commission (WRC) projects were initiated to observe and quantify hillslope, wetland and riparian mechanisms in order to enhance the ability for catchment scale prediction of water resources. The first project, (K5/1086), comprised the continued development of laboratory and field monitoring equipment, experimentation and measurement of the hydraulic characteristics required in the hydrological processes project as well as in the support of other WRC and industry funded research. The second project, (K5/1061), focused on the understanding of key hydrological processes.

1.1 Laboratory Measurements and Field Monitoring

The aim of this project, (K5/1086), was to support the direct observation of key hydrological processes. A further aim is to support WRC funded and other research projects where state-of-the-art techniques in measuring soil hydraulic properties, monitoring soil water dynamics and observation of hydrological processes are required. Chapter 2 presents a summary of the range of services to other projects delivered by this project. Selected details of the measurements and monitoring concluded for the hydrological processes study (K5/1061) are also presented in Chapter 2, while Appendix A contains a summary of the database developed for the monitored data. The results of soil water capillary pressure head dynamics of one of the key events used in the analysis of the hydrological processes at the Weatherley research catchment are presented in Appendix B and a comprehensive summary of all hydraulic characteristic measurements are presented in Appendix D. The value of the data and measurements is inherent in the analyses of hydrological processes, but the set of data can also be used as a reference in future evaluations of soil and porous media hydraulic behaviour.

1.2 Hydrological Processes

The second project, (K5/1061), which continued from a project aimed at identifying dominant hillslope processes, (Lorentz 1999), focused on the understanding and quantifying of key hydrological processes, recognizing that these are paramount for:

- efficient and sustainable water use in rural catchments and hillslopes and for
- developing realistic algorithms for hydrological models used in assessing the perturbations to water resources due to changes in land use.

The overall aims of the study were to:

- Perform direct observations of key hydrological processes in well instrumented catchments,
- evaluate the hydrological processes so that they can be integrated into agrohydrological modelling systems and to
- conduct observations and experiments at a range of scales for applied prediction of hydrological responses to land use changes.

There were four key objectives to the study as follows:

- <u>Hillslope Hydrology</u>
  To observe, define and model the dynamics of the hydrological cycle at a hillslope scale under specific land uses in order to understand the movement of different water reserves in and on hillslopes. Definition and appropriate modelling of these reserves will allow for accurate estimates of the effects of sustained agriculture, forestry, market gardening, grazing and subsistence agriculture on water resources. Monitoring of hydrological processes at certain research sites, which were identified and instrumented in the previous WRC project has continued in this project to lead to the identification of dominant hillslope processes and subsequent model development.

- <u>Upscaling Hydrological Processes</u>
  The objective in this component is to define dominant hydrological processes at different scales (local, hillslope, catchment and basin) by observing the hydrological responses at these scales and thus to develop appropriate algorithms to be included in the *ACRU* hydrological model for use at the different scales . A further objective is to determine the type and level of data and observation necessary to define and model the relevant processes adequately at the different scales.

- <u>Wetland and Riparian Processes</u>
  The objective of this part of the project is to define the interaction between hillslope and wetland riparian zones. This is necessary in order to assess the effects of land use change in the source

zone (hillslope) on the dynamics of the water reservoir in the wetland, riparian or near-stream zone.

- <u>Research Catchment Database</u>
  This component includes the development of an interactive database of the GIS coverages, hydrological and meteorological data of the research catchments. This will allow for convenient analysis of large amounts of data and provide easy access to these data for South African and International researchers, consultants and planners.

In order to address these objectives, detailed observations of surface and subsurface water dynamics have been made at three sites with distinctive geologies and climate. Analyses from measurements made in these catchments are used, firstly, to describe the streamflow generation mechanisms. Highlighting the significant features of these mechanisms at each site allows for some generalisation and a first insight into the classification of hillslope criteria required for estimating streamflow responses at catchment scales. The three research catchments are described in the first section of Chapter 3. Hillslope, wetland and riparian zone streamflow generation processes are then deduced from the hydrometric observations of the dynamics of soil water, groundwater and streamflow response to rainfall and evaporation. Thereafter, streamflow generation mechanisms are quantified using simple, physically based techniques. These techniques are then applied at the catchment scale in order to predict the observed streamflow and to define algorithms and methodologies for application in catchment scale deterministic hydrological models (Chapter 4). The methodology is offered, not as an alternative technique for catchment runoff simulation, but as a technique for identifying and quantifying the volumes, residence times and transfer rates of sources and streamflow generation mechanisms in order to parameterise or refine algorithms, already inherent in most physically based catchment scale simulation models. The convolution integral methodologies are particularly appropriate for defining sources, residence times and fluxes during rainfall events as well as during low flows.

It is concluded, (Chapter 5), that there is a need for a range of hilsllopes, wetlands and riparian zones to be monitored so that generalisations of behaviour can be made and built into deterministically based models. It is also evident that hydromteric observations alone are not sufficient to properly quantify streamflow generation sources and rates of transfer. It is recommended that the combination of natural isotopes or chemical species tracers sampling together with hydrometric observations of surface and subsurface phenomena must be used as widely as possible to narrow the error in describing volumes, residence times and transfer rates of the sources of streamflow.

Chapter 2

Soil Water Laboratory Measurements and Field Monitoring

A soil water laboratory was initiated during the WRC funded project K5/744 (1996-1999). This current project aimed at continuing the development of laboratory and field monitoring equipment, experimentation and the measurement of the hydraulic characteristics required in the hydrological processes project as well as in the support of other WRC and industry funded research. While the primary purpose of the project was to support the concurrent process hydrology project, both field and laboratory measurements as well as field monitoring were contributed to other projects. These included:

- Monitoring of soil water dynamics and measurement of profile hydraulic characteristics on riparian and wetland transects in the northern plains of the Kruger National Park. This work aims at explaining the variation of vegetation across the transects;

- Monitoring of profile soil water dynamics and measurement of hydraulic characteristics at three sites in the Mooi river irrigation scheme near Muden, KwaZulu-Natal. This work aimed at quantifying the irrigation efficiency of small scale, communal irrigation practices;

- Monitoring sediment yield at the Weatherley and Zululand research catchments and at a hillslope sheep stocking trial at the ARC Kokstad Experimental Station, (WRC Project K5/1059);

- Monitoring of hillslope soil water dynamics at the Two Streams research catchment, Seven Oaks, KwaZulu-Natal, (WRC Project K5/1284);

- Relationships between soil water regime and soil profile morphology in the Weatherley research catchemnt (K5/1317);

- Monitoring of profile soil water dynamics and water uptake and characterisation of the hydraulic properties in an industrial waste impoundment being researched for phytoremediation potential;

- Monitoring of transect and profile soil water dynamics in a small scale agricultural water use study at Bach's Fen, Ntshongweni, KwaZulu-Natal;

- Monitoring of lateral flow dynamics and surface runoff in the water balance of centre pivot irrigation research using gypsiferous mine water at various mines near Witbank, Mpumalanga, (WRC Project K5/858 and follow -on);

- Monitoring of the vadose zone and groundwater dynamics and characterisation of the formation hydraulic properties in *Eucalyptus* forests on the coastal plains of northern KwaZulu-Natal.

The soil hydraulic properties derived in these projects are summarised in Appendix D. The laboratory also supported the current processes hydrology project (K5/1061) in both soil property measurement as well as soil water dynamics monitoring. Measurements included laboratory determined soil physical characteristics, water retention properties and hydraulic conductivity characteristics as well as *in-situ* hydraulic characteristics. Monitoring included automated vadose zone tensiometric observations, automated groundwater elevation observations and periodic soil water content measurements using Time Domain Reflectometry (TDR) and neutron probe methods. The laboratory was also used to support meteorological, runoff plot and streamflow measurements. For the sake of completeness, the methods employed are repeated here from WRC project K5/744 and examples of typical results are presented. The full set of measurement results are summarised in Appendix D and the monitored data have been compiled into an interactive database, described in Appendix A.

2.1 Soil Hydraulic Characterisation

Soil hydraulic characterisation involves both in-situ and laboratory measurements. A consistent procedure has been adopted for characterising every profile investigated.

First, at each level in the profile, selected after the profile has been described, a duplicate set of measurements are made. The measurements include an in-situ tension infiltrometer test, followed by a double ring infiltrometer test. Thereafter an undisturbed core is taken and the water retention characteristic, bulk density and particle size distribution are determined in the laboratory. The particle size distribution and bulk density are used to develop pedotransfer relationships so that the spatial distribution of the hydraulic characteristics can be defined by making multiple textural and bulk density analyses. The specific methods employed in developing the hydraulic characteristics of the porous media are summarised in the next sections. Detailed descriptions of conventional methods are not included here, except where the methods used in this study differ from conventional test.

2.1.1 Water Retention Characteristic

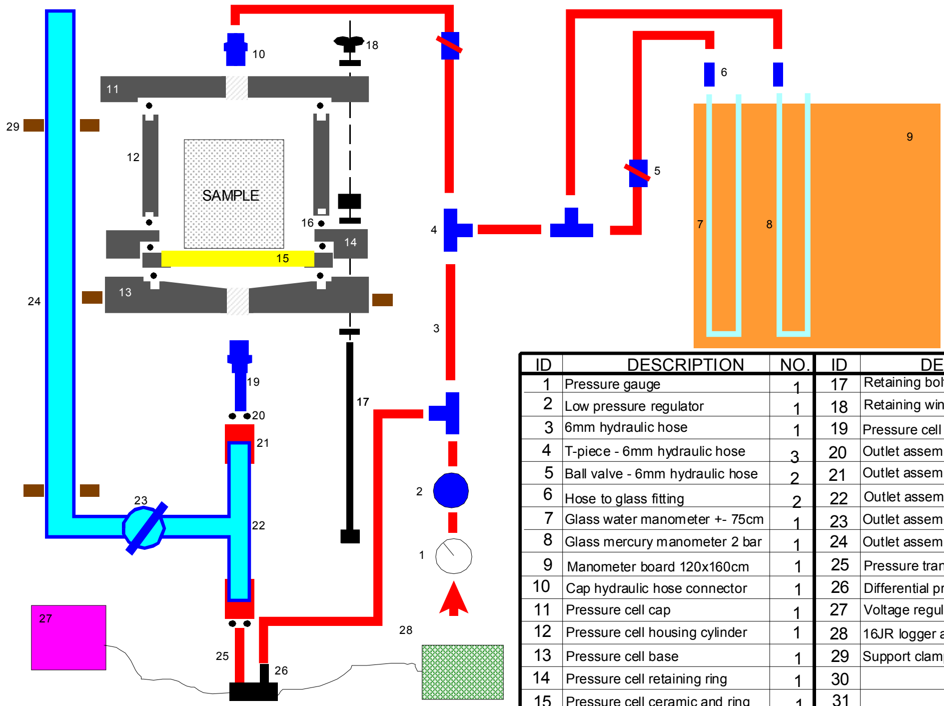
Conventional methods of soil water retention characteristic determination include both laboratory and field techniques (Klute, 1986; Bruce and Luxmore, 1986). Although many of the standard laboratory techniques have been used to determine the water retention characteristics of the porous media in this study, the modified controlled outflow method is reported in detail. This method holds some promise for the accurate characterisation of the soil pore structure over the range of moisture contents close to saturation. Accurate measurements over this range are desirable to characterise the larger pore characteristics which conduct water rapidly during intense rainfall. The retention characteristics of undisturbed samples are used together with field measurements of both saturated (ponded) and unsaturated conductivity to define the possible maro-pore nature of the soil.

Controlled outflow method description.

Recent emphasis on characterising unsaturated hydraulic characteristics of soils in hydrology, soil science and chemical transport studies has fostered renewed interest in liquid retention measurements. A new methodology for defining the liquid retention characteristic of porous media has been developed. In this method each point on the characteristic is determined by monitoring equilibration of the matric pressure rather than equilibration of the liquid volumetric content, as in conventional methods.

The matric pressure monitoring method allows for control of the volume of outflow rather than allowing the outflow to vary until equilibrium is reached. By monitoring the matric pressure during the equilibration cycle, the operator is able to discern the time at which equilibrium occurs. This results in a considerable time saving in running the test. A controlled outflow cell has been developed to measure the water retention characteristics of porous media, specifically over the range 0 to 1 bar. The apparatus, shown in Figure 2.1, includes a data logging systemto record and display the progress towards equilibration of the matric pressure at each setting.

Air pressure is applied to the cell and a predetermined quantity of liquid allowed to drain via the open stopcock. This comprises drainage cycle and is recorded by the pressure transducer as the difference between applied air pressure and head of the liquid phase in the burette. The stopcock is then closed and the pore liquid pressure increases until in equilibrium with the applied air pressure and the forces retaining the liquid in the porous medium. This comprises the equilibration phase and is recorded by the pressure transducer as the difference between applied air pressure and the pore water pressure in the sample. This difference in pressures decreases gradually as the pore liquid pressure increases, until it reaches an equilibrium, steady state value.



ID	DESCRIPTION	NO.	ID	DESCRIPTION	NO.
1	Pressure gauge	1	17	Retaining bolt, washers and nut	6
2	Low pressure regulator	1	18	Retaining wing nut and washer	6
3	6mm hydraulic hose	1	19	Pressure cell outlet port	1
4	T-piece - 6mm hydraulic hose	3	20	Outlet assembly O-ring	2
5	Ball valve - 6mm hydraulic hose	2	21	Outlet assembly retaining cap	2
6	Hose to glass fitting	2	22	Outlet assembly glass ports and T	1
7	Glass water manometer +- 75cm	1	23	Outlet assembly vacuum stop-cock	1
8	Glass mercury manometer 2 bar	1	24	Outlet assembly burette (50ml)	1
9	Manometer board 120x160cm	1	25	Pressure transducer hydraulic hose	1
10	Cap hydraulic hose connector	1	26	Differential pressure transducer	1
11	Pressure cell cap	1	27	Voltage regulator 6V and distribution	1
12	Pressure cell housing cylinder	1	28	16JR logger and distribution boards	1
13	Pressure cell base	1	29	Support clamps	4
14	Pressure cell retaining ring	1	30		
15	Pressure cell ceramic and ring	1	31		
16	Pressure cell O-ring	4	32		

Figure 2.1 Schematic of the controlled outflow cell for measuring water retention characteristics of undisturbed or packed samples.

2.1.2 Hydraulic Conductivity Characteristic

The saturated in-situ hydraulic conductivity is determined by a ponded tests known as the double ring infiltrometer. Here the steady state infiltration rate from a central ring is determined while maintaining an outer source of water at the same ponded head.

The unsaturated hydraulic conductivity is determined in the field by means of a tension infiltrometer. This method requires maintaining a tension in the water supply and recording the steady state inflow rate at different tension settings. Both the tension and double ring infiltrometers are shown in Figure 2.2.

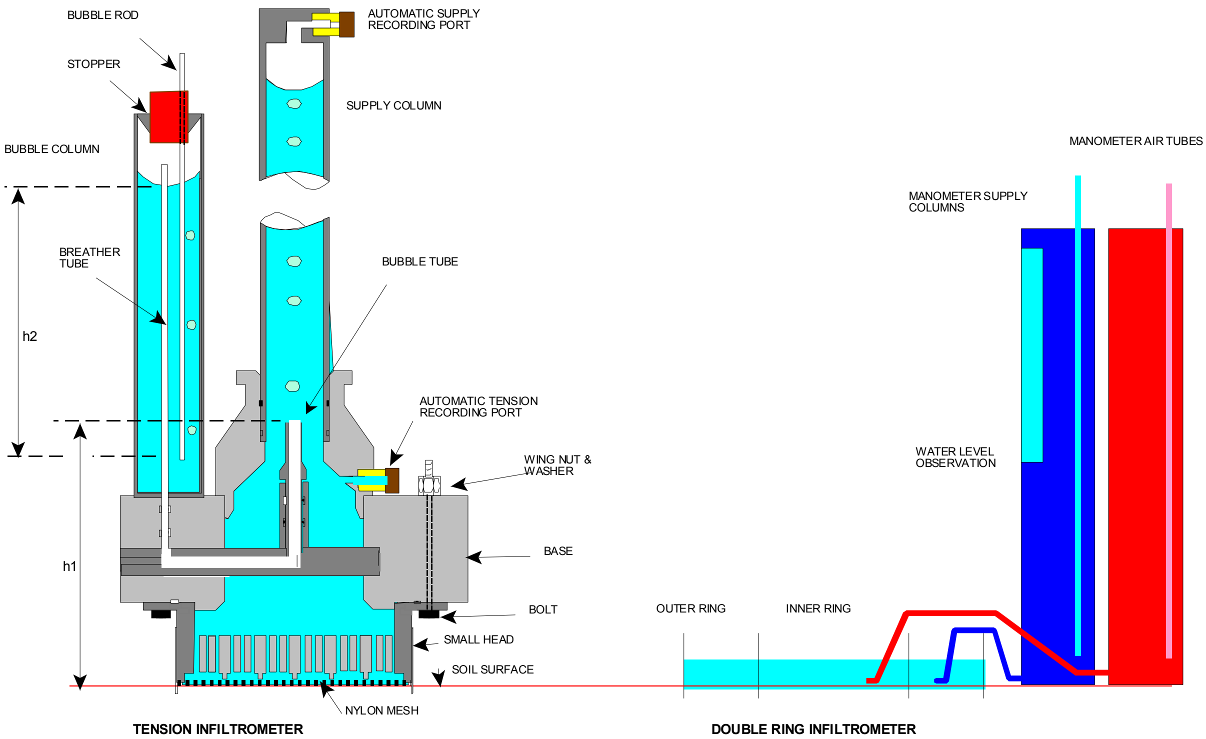


Figure 2.2 Schematic of the tension infiltrometer and double ring infiltrometer for measuring the hydraulic conductivity of *in-situ* materials.

An typical example set of data for measurements performed at the Weatherley experimental catchment n the MONDI, Northern Eastern Cape Forest estates are shown in Figures 2.3 to 2.5. The results of the ponded, double ring test shows that steady state conditions are established in the inner ring after some 5 minutes in this sandy topsoil (Figure 2.3). The test was continued for 30 minutes to yield a constant inflow rate of 200ml/min, which translates into a saturated hydraulic conductivity of 7mm/h. The tension infiltrometer test was conducted at tension of 10mm, 60mm, 100mm and 165mm (Figure 2.4). The inflow rate reaches steady state at the smallest tension, (10mm), after some 50 minutes. Thereafter the inflow rates reach steady state rapidly at each of the tension settings. The inflow rates translate into unsaturated hydraulic conductivities ranging from 0.001mm/h at the 10mm tension to 0.0002mm/h at the 165mm tension (Figure 2.5). The large difference between saturated hydraulic conductivity (7mm/h) and the hydraulic conductivity under a small tension (0.001mm/h), shown in Figure 2.5, is indicative of the significant macro-pore properties of the soil at this location. The water moves rapidly through a set of large pores during the ponded, saturated hydraulic conductivity test, yielding a high hydraulic conductivity. With the large set of pores efectivley isolated by the application of a small tension, the hydraulic conductivity falls dramatically.

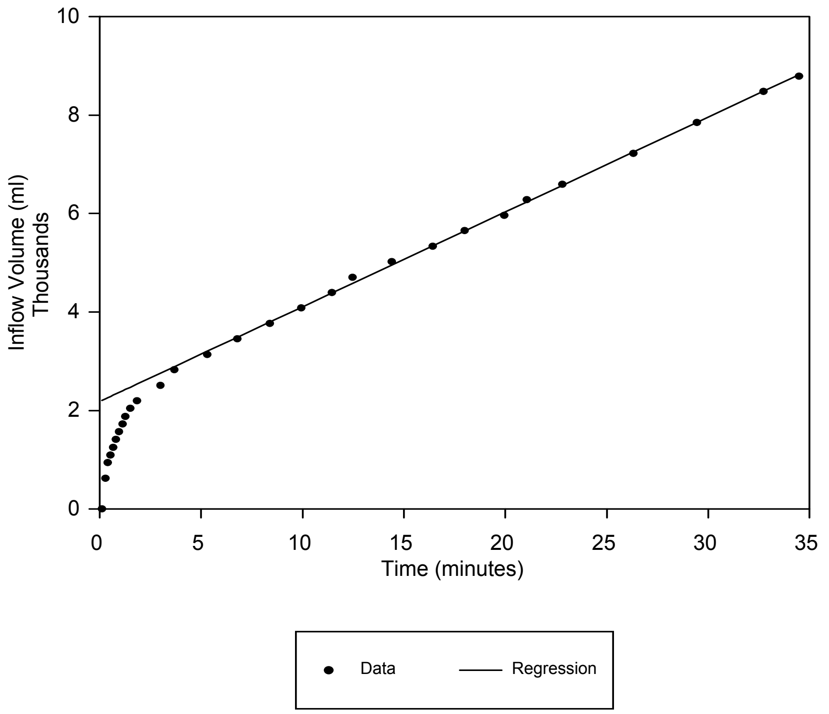


Figure 2.3 Double ring infiltrometer data from a surface measurement at site 1, Weatherley research catchment, NECF.

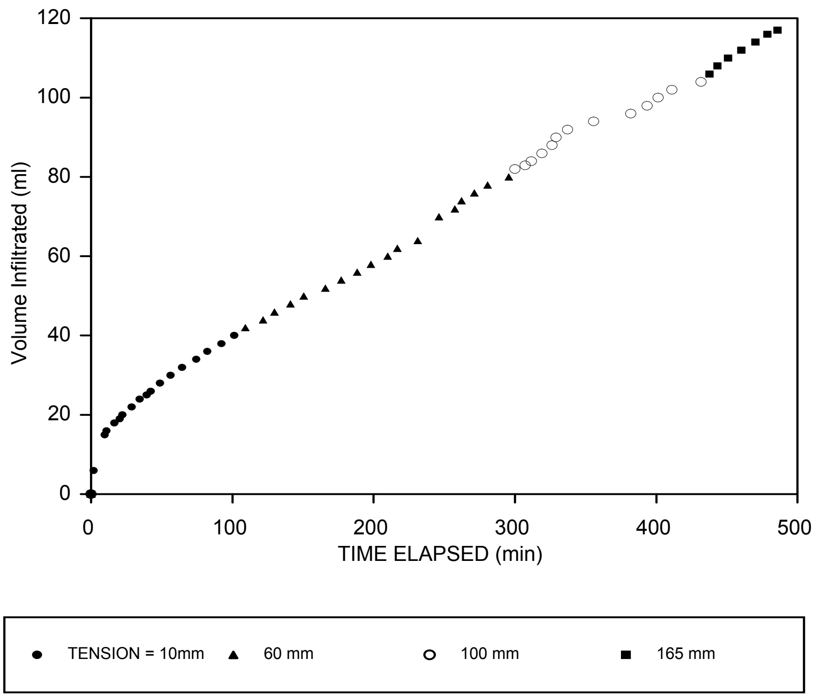


Figure 2.4 Tension infiltrometer data from a surface measurement at site 1, Weatherley research catchment, NECF.

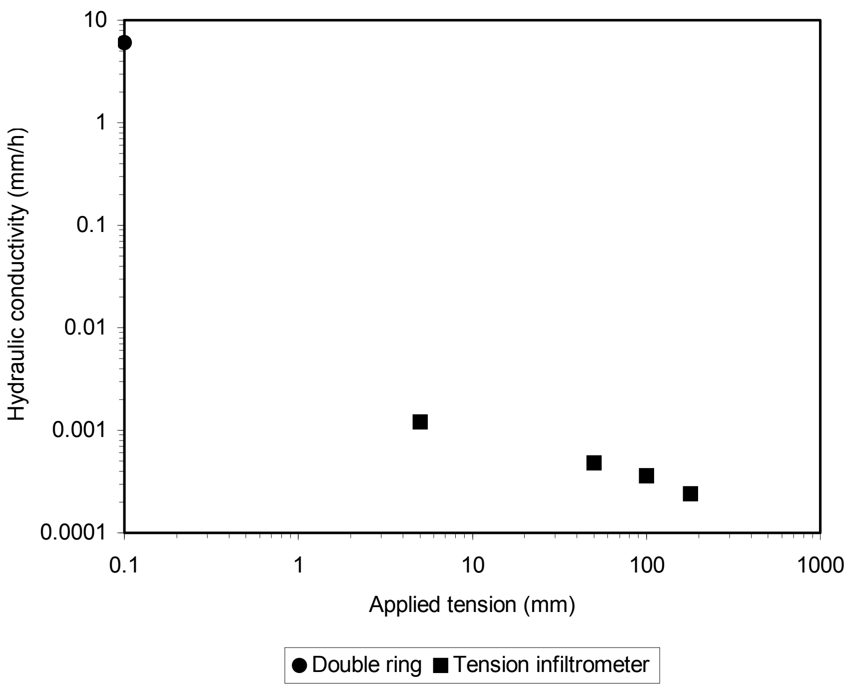


Figure 2.5 Final hydraulic conductivity characteristic from double ring and tension infiltrometer measurements, site 1, Weatherley experimental catchment, NECF

2.2 Soil Water Status Monitoring Methods

There is a plethora of instruments available for monitoring the status of soil water and a complete evaluation of these is not intended in this project. A few selected techniques and instruments are evaluated where they have been used in hydrological processes research. Nevertheless, excellent reviews of monitoring instrumentation are available for assessing one's needs in most situations (Klute, A. 1986b; Charlesworth, 2000; Stephens, 1996; Metelerkamp, 2001).

During the establishment phase of the hydrological processes laboratory, specific methods of monitoring the soil water matric potential and water content were used. These included tensiometers, heat pulse dissipation sensors and nylon resistivity sensors to measure matric potential or matric pressure heads and time domain reflectometry, neutron probe and gravimetric methods to estimate soil water content. During this current study, emphasis was given to the use of automated methods for recording the soil water potential with instrumented tensiometers and the water table elevation with pressure sensors.

2.2.1 Automated Tensiometers

A four channel logger was developed to record signals from pressure transducers attached to tensiometers and submerged in groundwater wells as shown in Figure 2.6. The automatic tensiometer houses the water phase in a hydraulic hose which is protected using PVC conduit. Hydraulic hose fittings seal the water phase and provide a convenient connection to the pressure transducer. A section of clear hydraulic hose connects the pressure transducer to the main hose. This allows for inspection of air pockets in the upper part of the tensiometer. The components are all modular, which allows for convenient assembly in the field to lengths determined *in-situ*. After careful installation, the depths D1 and D2 (Figure 2.6) must be recorded for later resolution of the data.

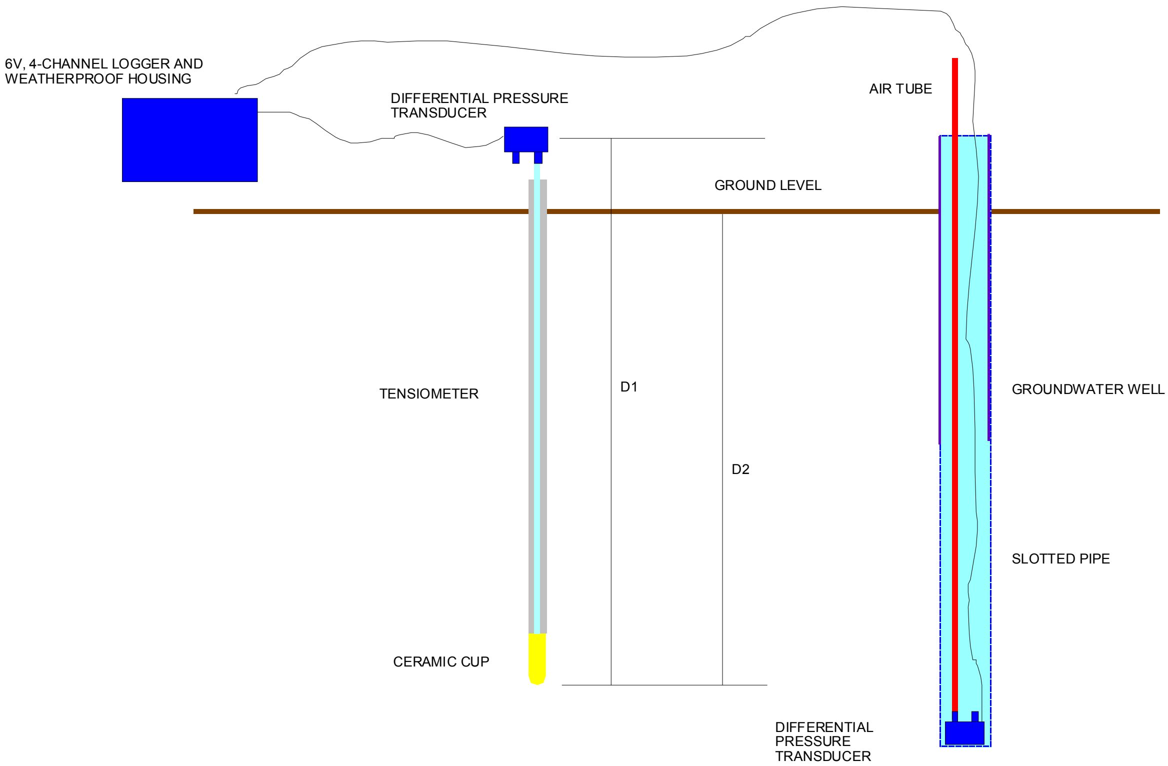


Figure 2.6 Schematic of the automatic tensiometer (left), for measuring soil matric pressure head and a ground water well(right), for measuring ground water level.

A typical sequence of monitored soil matric pressure heads and piezometer ground water levels are shown for the Weatherley research catchment in Figure 2.7. A rainfall event on December 2, 1998 causes a rapid decrease in matric pressure head in the tensiometers located near the surface (0.45 and 0.84 m below ground), while the deeper tensiometer responds over a period of three days, first decreasing to -0.75 m (the negative value indicates that the phreatic surface has moved past the tensiometer ceramic cup position) and then increasing to 0 m. The movement of the groundwater past the ceramic cup is verified by the piezometer reading which indicates a rise in the water table of 1 m during this period.

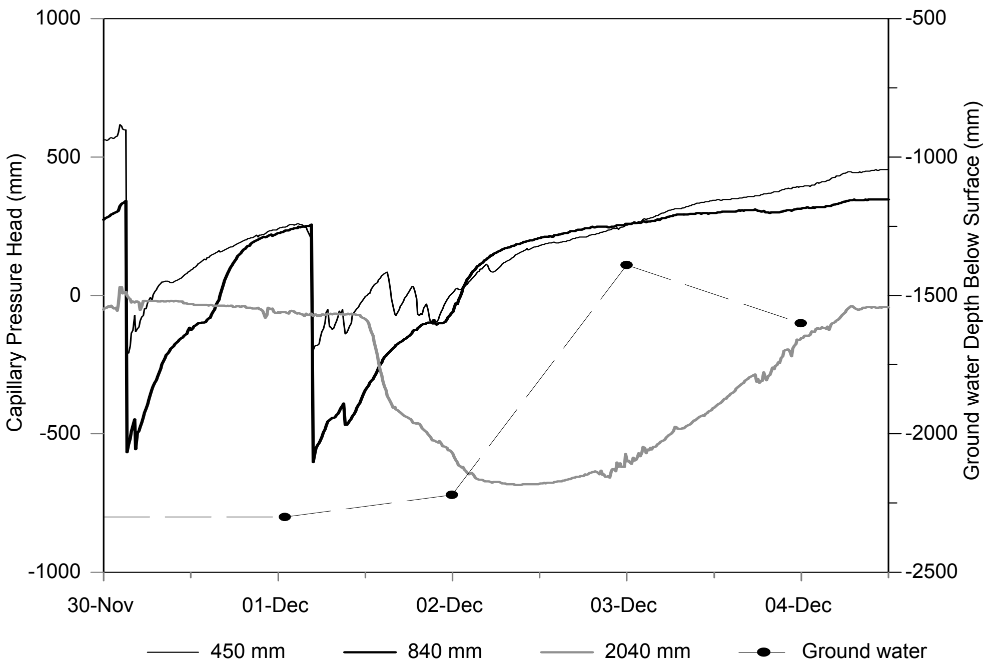


Figure 2.7 Example of tensiometer (0.45 m, 0.84 m and 2.04 m below surface) and ground water level data from Nest 2, Weatherley experimental catchment, 1998.

Calibration of the pressure transducers used in the tensiometers has been very successful as is indicated in Figure 2.8. These calibrations typically have an R^2 of 0.998 and are routinely performed prior to installing the tensiometers in the field.

Most automatic tensiometer data exhibited a minor diurnal fluctuation pattern with increases in tension during the night and decreases during the day. This is counter intuitive as one would expect that tensions would increase during the day as the profile dries under evapotranspiration forces, and decrease at night when evapotranspiration is relaxed. It is hypothesised, however, that this observed variation in recorded tensions is due to temperature expanding and contracting the water or air pockets inside the tensiometers.

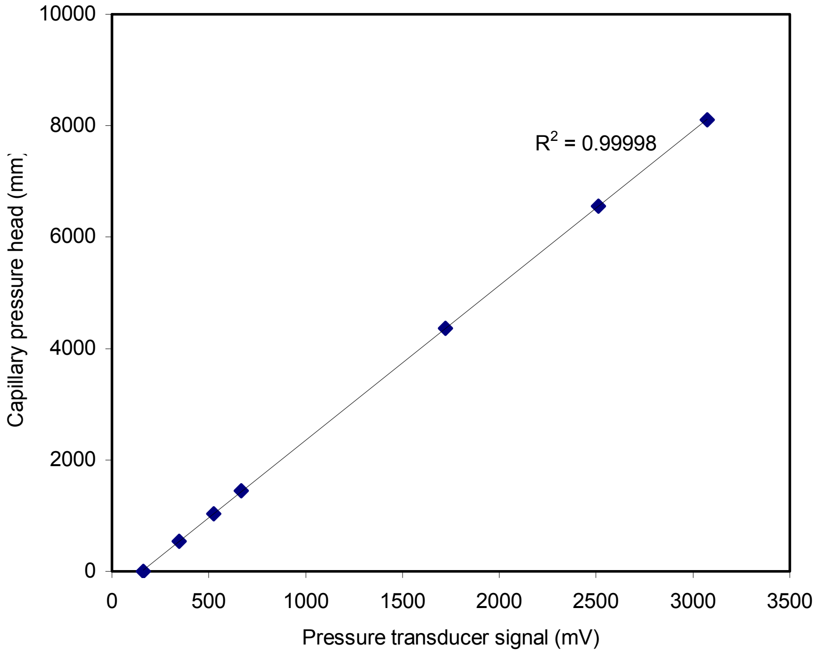


Figure 2.8 Typical laboratory calibration of a tensiometer pressure transducer.

A series of test were therefore conducted to define the influence of temperature on the tensiometer performance.

Three tensiometers were set up outdoors at the Ukulinga experimental farm. Two were inserted into a 200l drum of soil and the third was installed next to the drum in the soil. The first of the two tensiometers in the drum was filled completely with de-aired water while a small pocket of air was left at the top of the second. A "dummy" differential pressure transducer was also placed on the drum without connection to any tensiometer and with both ports open. This was the standard to gauge temperature effects on the electronics of the transducers. The results are presented in Figures 2.9 and 2.10.

A similar drum was set up inside the temperature controlled soil physics laboratory. These results are shown in Figure 2.11.

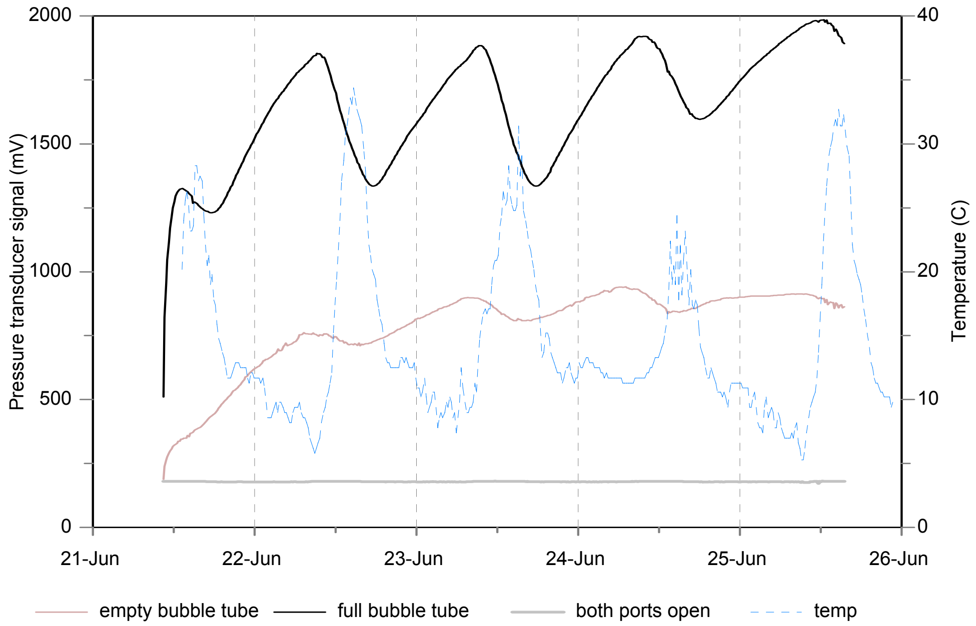


Figure 2.9 Tensiometer test in a drum outside at Ukulinga experimental farm. The drum and soil sample heat up and cool with the ambient air temperature and thus there is a significant variation in tensiometer signal, even though the water content in the drum was constant throughout the test period.

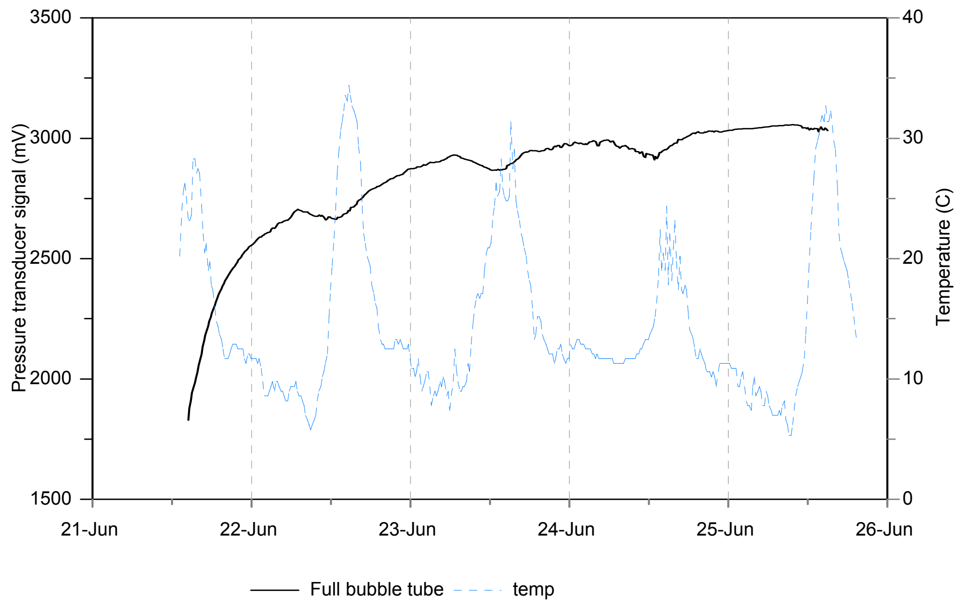


Figure 2.10 Tensiometer test in the soil profile. The soil provides some insulation to the temperature affects on the tensiometer signal, but there is still a diurnal fluctuation.

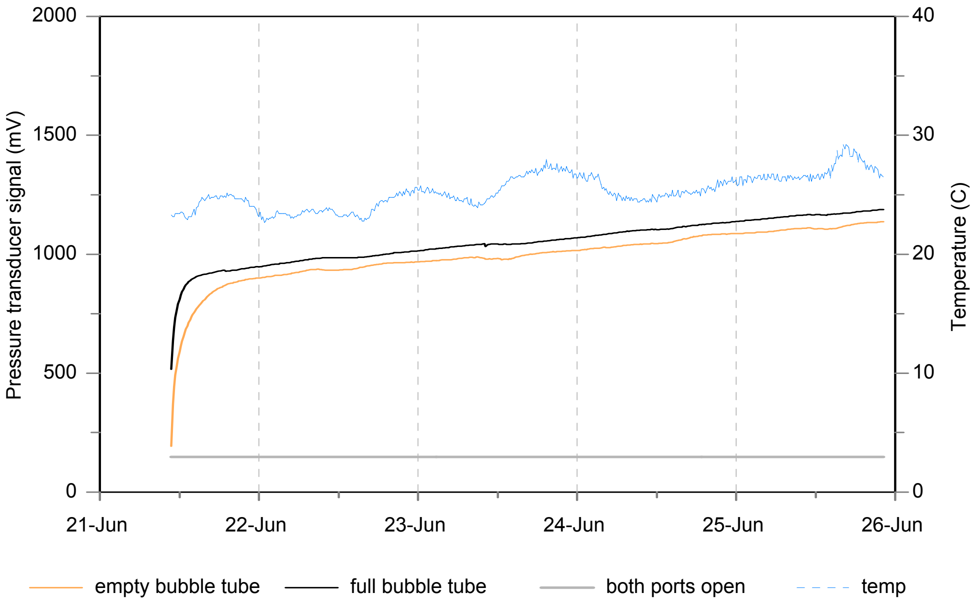


Figure 2.11 Tensiometer test in a drum in a temperature controlled laboratory. The slight variation in temperature is insufficient to affect the tensiometer readings, which show a slow drying of the material in the drum.

The results of this series of tests indicate that:

- the minor diurnal fluctuations in automatic tensiometer signal appears to be the result of expansion and contraction of air entrapped in the tensiometer,
- the effect is most pronounced where the temperature fluctuations in the tensiometer water are not dampened by being housed underground,
- there does not appear to be any temperature affect on the electronics that would cause observable signal fluctuations and
- the amount of air entrapped in the tensiometer tube affects the degree of dependance on temperature variation.

Hence the use of automated tensiometers must be accompanied by a rigorous maintenance program, ensuring that air pockets are removed from the apparatus at regular intervals. Experience during this project has shown that tensiometer replenishment at two week intervals is acceptable, but more frequent visits are recommended to check for the air pocket build-up. The automated tensiometer results are used in Chapter 3 and 4 to identify hillslope processes and to quantify the vertical and lateral fluxes.

2.2.2 Neutron Probe Water Content Measurements

Volumetric water content measurements were conducted at numerous sites in the Weatherley research catchment on a periodic basis. These measurements are valuable in assessing the water balance of the profiles and hillslope transects and are included in the database described in Appendix A.

In assessing the relationship between water content and capillary pressure head (tension) a comparison was made between the prevailing capillary pressure head recorded by the automatic tensiometers at the time of the neutron probe manual measurements. The resultant capillary pressure head data are plotted against the corresponding water content measurements in the form of a water retention characteristic. Where laboratory retention characteristics were determined using the controlled outflow method, these results are superimposed on the field measurements. A typical result of this comparison is presented in Figure 2.12 and the full set of data is presented in Appendix C.

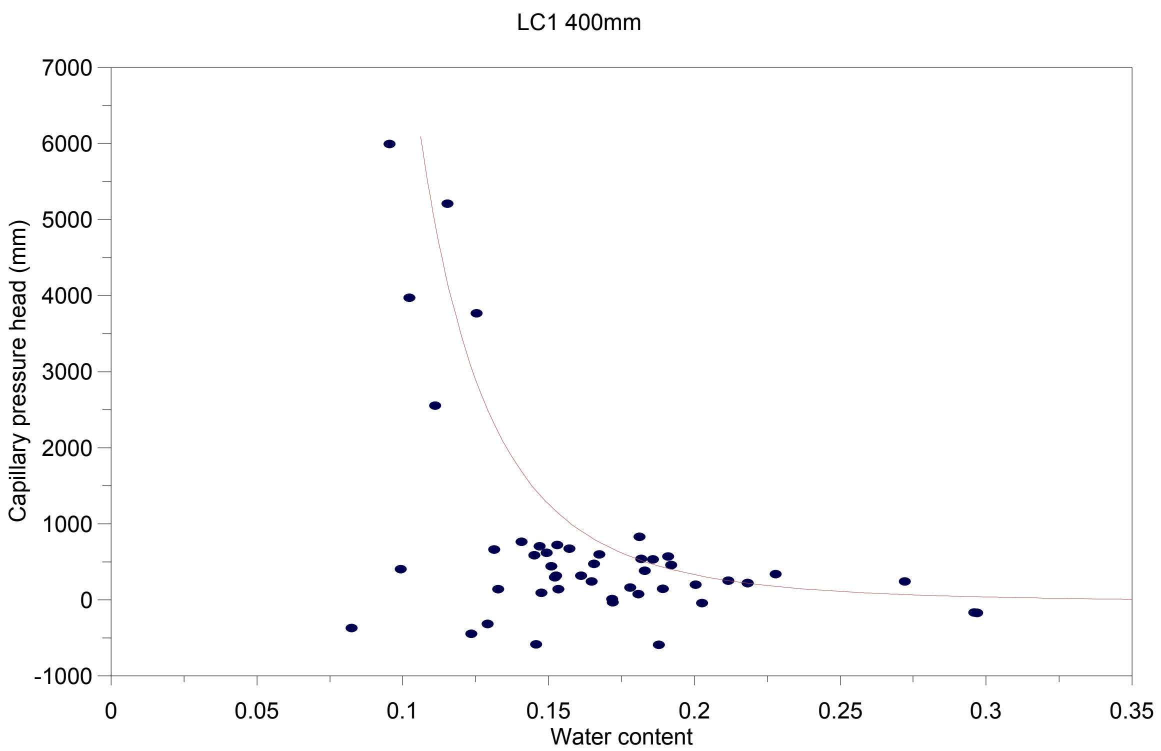


Figure 2.12 Comparison of *in-situ* derived and laboratory measured water retention characteristic for Weatherley catchment, nest 1.

There is significant scatter of the tensiometer/neutron probe data pairs. This is probably mostly attributed to hysteresis of wetting and drying characteristics. However, the inaccuracy of neutron probe measurements near the surface, the differences in soil hydraulic properties between the neutron probe and tensiometer locations as well as perturbations in subsurface water distribution could contribute to the inaccuracies. Nevertheless there is some agreement between *in-situ* and laboratory determined data sets, even thought the field data are recorded under dynamic conditions.

The results of the hydraulic property determinations and the set of monitored data are used in the following chapters to define the hydrological processes at the hillslope and catchment scales and to develop algorithms for source zone travel time distributions.

Chapter 3

Quantification of Hillslope Hydrological Processes

Detailed observations of surface and subsurface water dynamics have been made at three sites with distinctive geologies and climate. Analyses from measurements made in these catchments are used, firstly, to describe the streamflow generation mechanisms. Highlighting the significant features of these mechanisms at each site allows for some generalisation and a first insight into the classification of critical hillslope criteria required for estimating streamflow responses at catchment scales.

The three research catchments are described in the first section of this chapter. Hillslope, wetland and riparian zone streamflow generation processes are then deduced from the hydrometric observations of the dynamics of soil water, groundwater and streamflow response to rainfall and evaporation. In the final section of this chapter, the streamflow generation mechanisms are quantified using simple, physically based techniques. In the following chapter these techniques are applied to the catchment scale in order to predict the observed streamflow and to define algorithms and methodologies for application in catchment scale deterministic hydrological models.

3.1 Research Catchments Descriptions

3.1.1 The Weatherley Research Catchment

The Weatherley catchment is a research catchment in the Umzimvubu basin of the northern Eastern Cape Province. This area is sensitive to anthropogenic influences, where commercial agriculture, irrigation, domestic and rural settlements and forestry compete for water use. An adequate supply of water to this region is seen as imperative in the light of the recent establishment of forest cultivation. In order to provide a sound assessment of the impacts of the afforestation, the hydrological processes on typical Molteno-Elliot sedimentary formations must be clearly understood. For this reason a detailed hillslope and nested sub-catchment experiment has been initiated in a 1.5 km^2 research catchment, representative of the soils, geology, topography and climate of the region. The Weatherley research catchment was established in 1995 and has been developed into a prime research location involving many institutions. The hydrological experiment was designed for the long-term observation of hillslope processes prior to and following afforestation, (Esprey, 1997, Lorentz and Esprey, 1998, Hickson *et al.*, 1999). The Weatherley research catchment is located approximately 5 km south west of Maclear in the northern Eastern Cape Province (31^o 06' 00" S, 28^o 20' 10" E) at an altitude of approximately 1 300 m above mean sea level and is 1.5 km^2 in extent. The research catchment was chosen for its typical Molteno-Elliot formation hillslope profile and has been described in detail in Lorentz (2001b). The catchment drains in a northerly direction and the contributing hillslopes are each divided longitudinally into two segments, separated by a Molteno sandstone outcrop (Figure 3.1). The slopes are steep, with an average of 12% on the eastern and southern slopes where the sandstone outcrop forms a bench and 18% on the western slope were the outcrop is not as well defined. Evidence of other sandstone layering is present elsewhere on the upper half of the hillslopes.

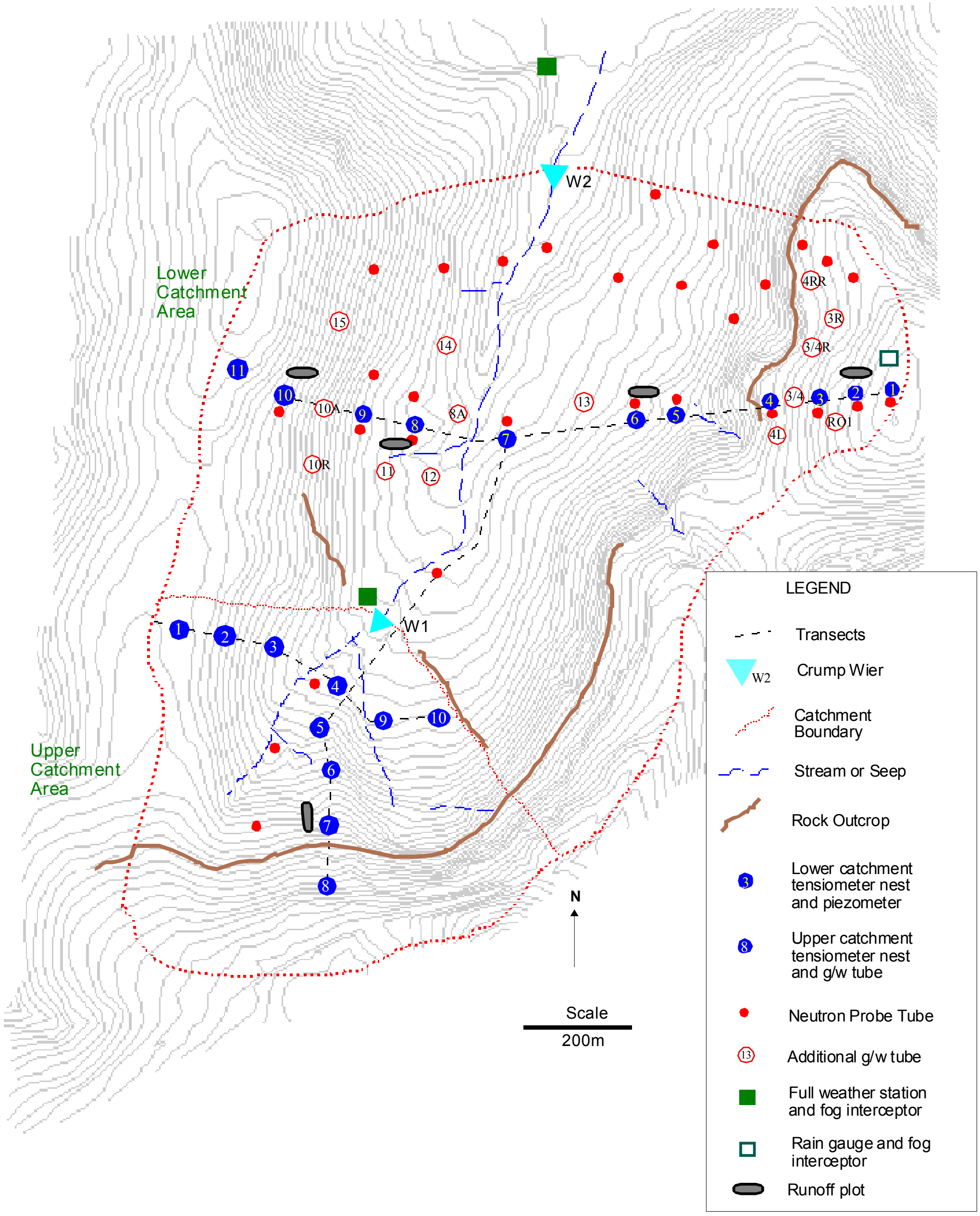


Figure 3.1 Layout of the experimental catchment, Weatherley, in the northern Eastern Cape Province, showing measurement instrumentation and structures.

The land cover at Weatherley is predominantly Highlands Sourveld grassland, which is generally in a moderate hydrological condition with a basal cover of 50-75% on the hillslopes, (Esprey, 1997). Wetland conditions exist along the entire reach of the stream and range in width from 100 to 400 m, being widest where marshy conditions are associated with lines of seepage from the hillslopes. Weatherley is considered to be in a marginal rainfall region for forest production with a Mean Annual Precipitation (MAP) of 740 mm and a Mean Annual A-pan Evaporation (MAE) of 1488 mm (Esprey 1997). Average daily temperatures range from 11°C in the winter to 20 °C in the summer, with severe frosts and snow falls at higher altitudes in winter. A monthly summary of rainfall, evaporation and daily temperatures is presented in Figure 3.2.

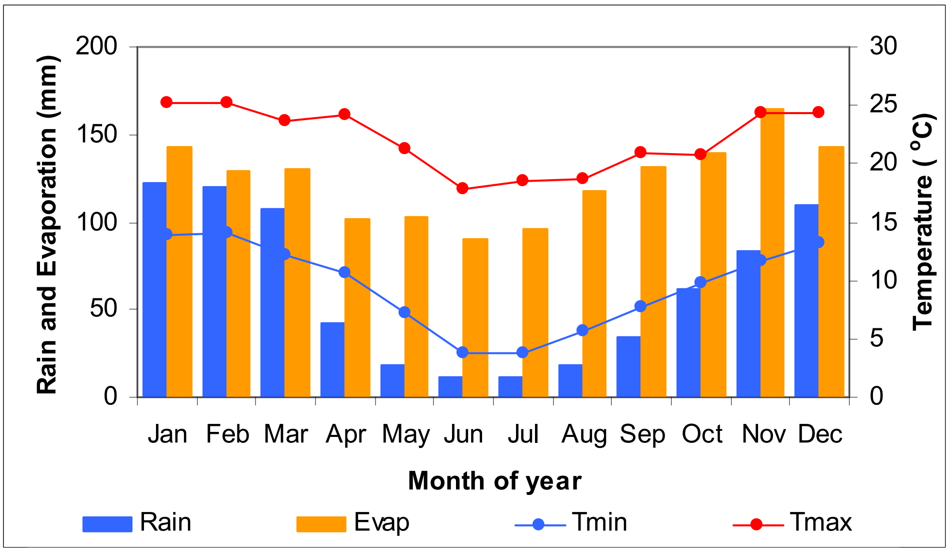


Figure 3.2 Climatic information recorded at the Weatherley experimental catchment

A very complex soil system exists with large spatial variation. A detailed soil survey was carried out by the Institute for Soil, Climate and Water (ISCW) and 16 different soil forms were identified within the 1.5 km^2 catchment boundary (Roberts *et al.,* 1996). These soils display a varying degree of wetness and colour and include red and yellow apedal mesotrophic soils as well as neocutanic and hydromorphoc soils.

The instrumentation network in the catchment is extensive and has been systematically developed over the years as summarized in Tabe 3.1. The instrumentation network includies transects of automatic recording tensiometer and groundwater observation stations and neutron probe access tubes in an upper and lower sub-catchment, each served by a crump weir (Figure 3.1). The main transect, comprising 11 stations, runs East-West, from the crest of the eastern slope in the lower sub-catchment, down into the wetland, across the stream and up the western slope. A similar transect runs West-East in the upper sub-catchment and a final transect runs from the southern slopes of the upper sub-catchment, parallel with the stream, to intersect with the main transect in the lower sub-catchment. Full weather stations are located near the upper and lower weirs and there is an additional rain gauge on the crest of the eastern hillslope. Surface water runoff plots have been established on the upper and mid-slopes as indicated in Figure 3.1.

Table 3.1 Highlights of Weatherley research catchment development

Year	Month	Description
1995	Apr.	Team assessment of research catchment
	Aug.	Neutron probe soil moisture stations 1 – 29
	Sep.	Detailed soil survey
	Oct.	Installation of rain gauge
1996	Jun.	Soil hydraulic property measurements at nests 1 – 4 and 8 - 10
	Aug.	Ground penetrating radar transect 1 – 7
	Sep.	Installation of meteorology stations at u/s and d/s weir locations
	Dec.	Installation of tensiometers and g/w wells at nests 1 – 4
1997	Jan.	Intensive monitoring period
	Feb.	Automation of tensiometers at nests 1 – 4
	Dec.	Upstream and downstream weirs completed and instrumented
1998	Jan.	Installation of tensiometers and g/w wells at nests 5 – 10
	Sep.	Installation of tensiometers and g/w wells at nests UC1 – UC10
	Nov.	Intensive monitoring period 2
	Dec.	Automation of selected g/w wells
1999	Jul.	Soil hydraulic property measurements at nests 5 – 7 and UC1 – UC10
2000	Feb.	Installation of ISCO water sampler at lower weir
	Sep.	Installation of surface runoff plots and instrumentation
2001	Mar.	First afforestation assessment
	Feb.	Second afforestation assessment
	Dec.	Source sampling of selected water quality species
2002	Jan	Source sampling of selected water quality species
	Jun.	Local mapping of planned afforestation
	Aug.	Afforestation

3.1.2 The Zululand Research Catchment (W1H017)

The Zululand catchment is located in the Ngoye hills near Empangeni and Richards Bay metropolitan area of the Natal Coastal Belt. The research catchment (W1H017) is part of the nested Ntuze research catchments of the University of Zululand in the Ngoye hills, (28° 50' 00” S, 31° 45' 05" E).

The mean annual precipitation of the catchment is 1321 mm. Maximum daytime temperatures often exceed 40°C during the summer while winter night-time temperatures drop to 10°C. The mean annual potential (A-pan) evaporation is 1750 mm. A summary of the rainfall, temperatures and evaporation is presented in Figure 3.3.

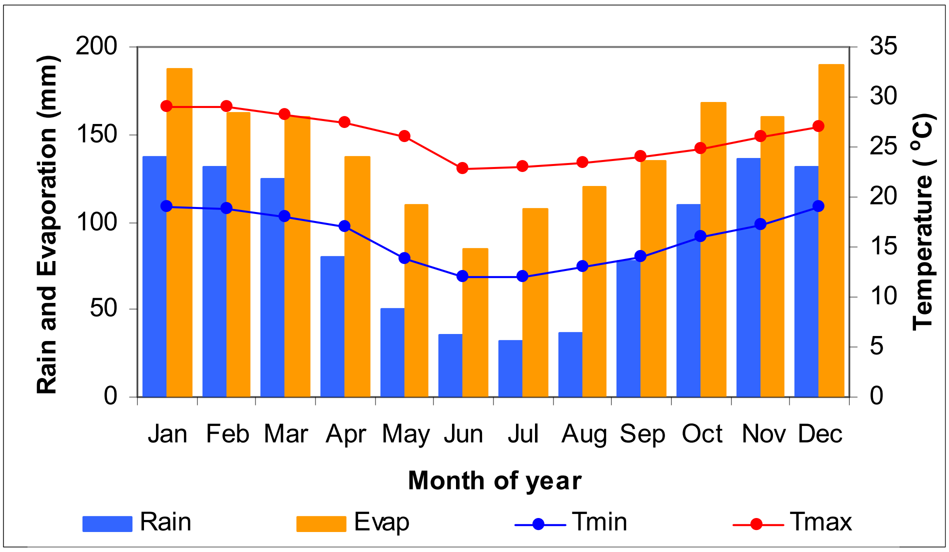


Figure 3.3 Climatic information recorded at the W17 Zululand experimental catchment

The drainage area of W1H017 is approximately 0.7 km^2. The topography is typical of the rolling Zululand coastal hills. Elevations range from 330 AMSL in the western hills to some 258 AMSL at the weir outlet and slopes range between 10% and 20%, (Mulder and Kelbe, 1991). The geology of the Ngoye hills, with typical Bornhardt structures, are underlain by the Ngoye overthrust unit (Mfongosi group). The drainage patterns that developed in the granite-gneiss are rhomboidal as a result of characteristic parallel seam system present in the granite. The soils in the catchment are weakly developed with mainly coarse sand clayey loam texture and high infiltration rates (van Zyl and Lorentz, 2003). Land use comprises small scale sugar cane plantations, subsistence cropping in traditional homesteads, natural grassland and riparian vegetation. A relatively new phenomenon in the catchment is that riparian areas are drained and cultivated for vegetable gardens, amadumbe and small banana plantations.

Soil water tension has been monitored at one hillslope consisting mainly of grassland (three tensiometer nests) and one under sugarcane (four tensiometer nests) as illustrated in Figure 3.4. Three runoff plots, (20 x 3 m) were installed next to the tensiometer nests at the hillslope consisting mainly of grassland. However, few measurements were made due to repeated vandalism to the tipping bucket switch mechanisms and loggers. Runoff and rainfall are monitored at the compound V-notch weir using an Ott chart recorder, which has been automated by installing a logger and encoder. An automatic recording tipping bucket rain gauge was installed some 200m upstream of the weir. An ISCO sampler was installed at the weir on the 25th of January 2001. An additional monitoring point upstream of the dense riparian vegetation comprises an H-flume with ISCO-sampler, encoder and logger.

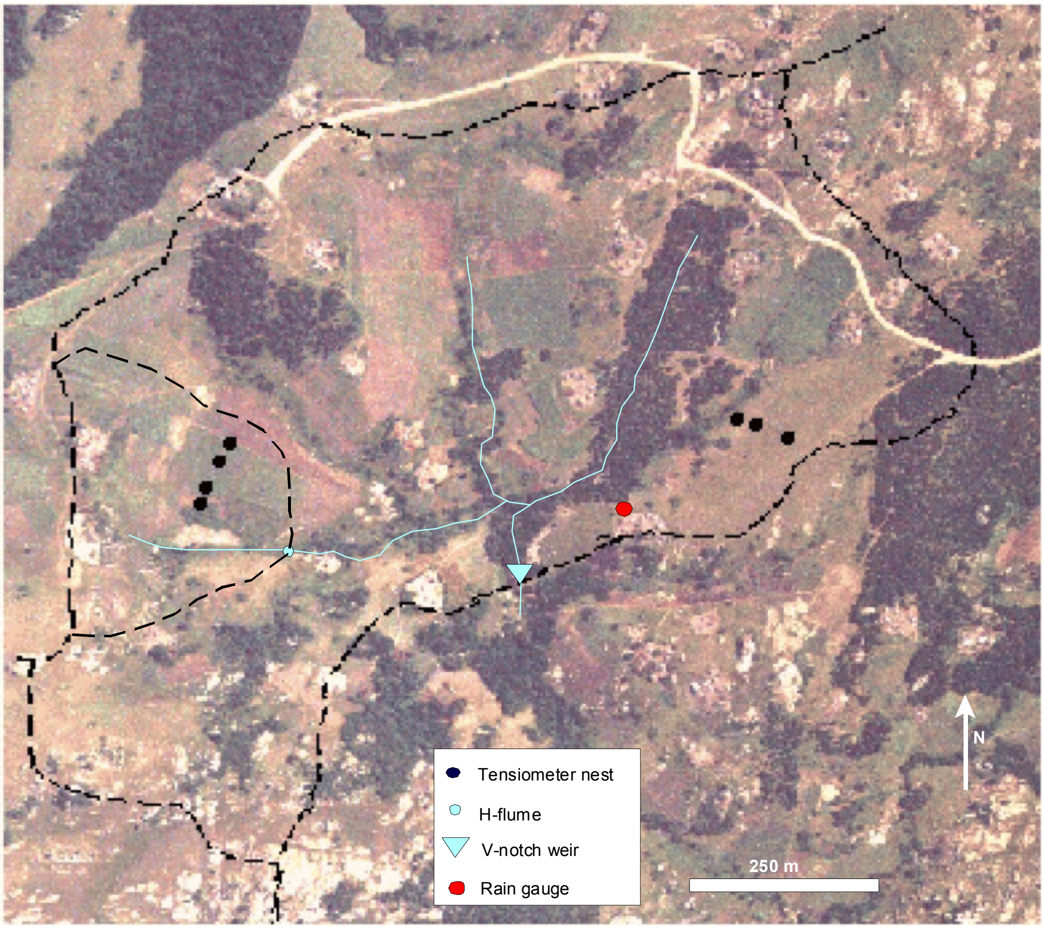


Figure 3.4 The Zululand W1H017 catchment, showing the location of the tensiometer nests, V-notch weir, H-flume and rain gauge.

3.1.3 The Two Streams Research Catchment

A small catchment, planted predominantly with 13-year-old wattle was carefully selected as the study site. The catchment is situated at 29º11'S, 30º38'E on the Mistley-Canema Estate (Mondi Forests) in the Seven Oaks district, approximately 70 km from Pietermaritzburg. The catchment is 0.73km^2 in extent, at an altitude of 1050mm and the land use comprises wattle and *eucalypt* plantation and a small area of sugar cane.

Average monthly totals of A-pan equivalent evaporation data as well as monthly means of daily maximum and minimum temperatures were extracted from the South African Atlas of Agrohydrology and – Climatology (Schulze, 1997). The MAP is 941mm and the average monthly rainfall has been summarised from a five year record at the research site (1997-2002) in Figure 3.5.

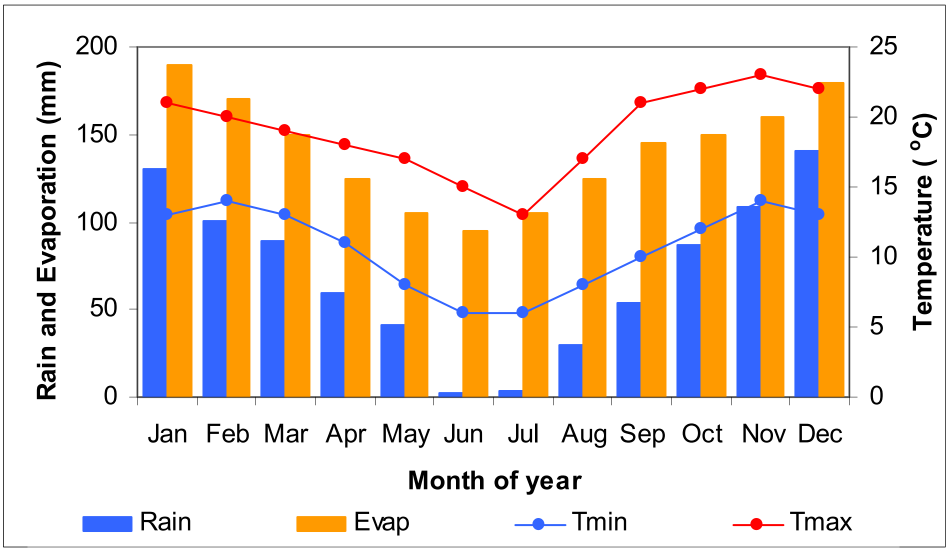


Figure 3.5 Monthly climatic data for Two Streams (After Everson *et al.,* 2002).

The experiment consists of a V-notch weir built in the river of the catchment to be cleared. A second weir was established on an adjoining stream to act as a control. The trees in the riparian zone have been systematically removed during the period of monitoring in order to assess the impact of riparian growth on the water resource. Two opposing hillslopes are instrumented with automatic tensiometers, TDR, neutron probe access tubes and groundwater monitoring wells as shown in Figure 3.6.

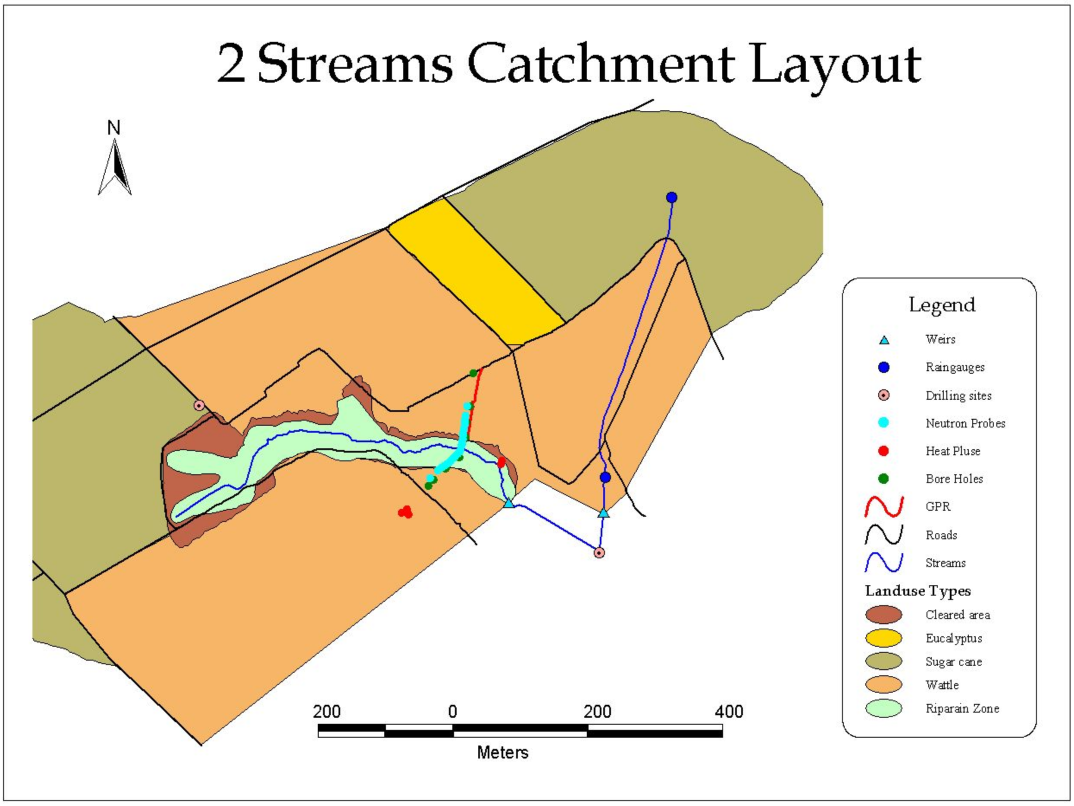


Figure 3.6 Layout of the Two Streams research catchment showing the location of the monitored hillslopes (Everson *et al.* 2002).

3.3 Description of Hillslope, Wetland and Riparian Streamflow Generation Mechanisms

The dominant flow generation mechanisms on the hillslopes of each research catchment have been identified and described from the examination of subsurface soil moisture sensor signals, rainfall and runoff data. These mechanisms are described for each catchment with an emphasis on the Weatherley research catchment.

3.3.1 Weatherley research catchment

Streamflow generation mechanisms have been described in a number of studies, throughout the development of the Weatherley catchment, (Esprey, 1997, Lorentz and Esprey, 1998, Hickson and Lorentz, 1999, Lorentz, 2001a). A study of tensiometer responses along the main transect from nest 1 to nest 11, in the lower catchment, (Figure 3.1), reveals the dominant mechanisms of streamflow generation during a set of rainfall events.

A typical sequence of soil water capillary pressure head responses illustrates the method in which the streamflow generation mechanisms have been derived. An example sequence, for 7 to 17 April 2001, is presented in Appendix B. The example sequence presents tensiometer sensor responses for Transect 1, from the upper eastern slope, (nests 1 - 4), though the wetland, (nest 5), and riparian zone, (nests 7 and 9), and up the western slope, (nest 11) for the 10 day period. However, the reader is encouraged to peruse the interactive database described in Appendix A, in order to confirm the mechanisms deduced from these data. The rainfall occurring during the example period is summarised in Table 3.2. Some mild rain occurs between the tabulated events, but does not affect the soil water capillary pressure head response at the depth of the tensiometers.

Table 3.2 Description of the rainfall during 7 – 17 April 2001

Date	Depth (mm)	Intensity (mm/h)
8 April	9	8 Low
10 April	33	70 High
16 April	14	1.5 Low

During the first, low intensity event of 9mm, nests 1 to 3 in the top part of the slope (Figure 3.1) exhibit capillary pressure head responses only in the shallow tensiometers of between 300mm and 500mm deep (Figures B1 to B3). These responses indicate that the soil profiles above 500mm do not become saturated at nests 1 and 2. At nest 3 further down the slope, however, even this low intensity event results in saturated conditions at 500mm within 15 minutes of the start of the event. In fact, the capillary pressure head of the tensiometer at 500mm depth becomes negative, indicating a positive hydraulic head at the depth of the tensiometer and hence ponded conditions. This is likely to be the result of upslope contributions to the water content at nest 3. At the toe of the first section of the slope, nest 4, prior to the outcrop of the sandstone, saturated, ponded conditions prevail throughout the sequence.

During the high intensity event, the degree of ponding of water in the soil becomes progressively deeper downslope. The ponded response recovers to unsaturated conditions within 6 to 12 hours of the event, although some saturated conditions appear to prevail at the 500mm depth between nest 3 and 4. No significant wetting is observed at tensiometers below the 500mm depth. Signals of tensiometers at 800mm depth, respond slowly to the arrival of the wetting front some 48 hours after the event (Figure B3). These observations indicate that there is rapid arrival of water to a depth of 500mm during moderate to intense events. These fluxes could only be possible if a significant network of macro-pores is present in upper 500mm of the profile. With a less permeable material below the 500mm level, water is held in the upper 500mm and conducted rapidly downslope in this layer, with complete inundation occurring at the outcrop of the sandstone. Water discharges over the edge of the outcrop or seeps through cracks in the rock into the flatter and wetter, concave profile below.

In the lower part of the hillslope, between the sandstone outcrop and the stream, the slope profile is concave and wetland conditions prevail. The signal at nest 5 indicates water ponded above the 900mm deep tensiometer. This depth of ponding responds rapidly to the added input of the rainfall events, (Figure B5). In fact, immediately after the intense event of 33mm, the signal indicates that the entire profile is saturated, evidently from direct and upslope contributions. Again, the rate at which the capillary pressure head reduces indicates a freely conducting macro-pore structure. Another explanation, which could account for the rapid drop in capillary pressure (or rise in hydraulic head), is that air may be entrapped in the pore space between the invading wetting front above and the deeper water below. The pressure exerted on the air pocket is transferred to the deeper water and sensed by the tensiometer (Flůhler, 2001). However, an examination of the hydraulic characteristics of the materials as measured *in situ* and the field observation of extensive worm activity and subsurface piping, make the first explanation more plausible.

Near the stream, the hillslope profile becomes convex and the soil profile at nest 7, (Figure B6), is continuously close to saturation between 700mm and 900mm, but the near surface, behaves in a similar way to the profiles on the upper part of the slope (nests 1 to 3). There is no evidence of ponded water table conditions at this location as this nest has been positioned on a spur parallel to the transect. A more typical near-stream behaviour pattern is evident at nest 9 (Figure B7). Here, the profile is inundated with ponded water from the bottom of the profile and up to 300mm below the surface. The rainfall events increase the degree of ponding and a fully saturated profile occurs during the 33mm rainfall event. There appears to be a low permeability barrier between the 700mm and 1100mm deep sensors as the 1100mm sensor does not reflect the full hydraulic head implied from the 300mm and 700mm deep tensiometers. On the upper western slope at nest 11, (Figure B8), the soil profile is unsaturated throughout its depth. The effects of the intense 33mm event are evident at 600mm below the surface as a slow wetting up some 24 hours after the event. There is no perched water table and downslope fluxes will be unsaturated.

The mechanisms described have been observed throughout the record of measurements. The descriptions have been generalised and illustrated in Figure 3.7 and described in Table 3.3.

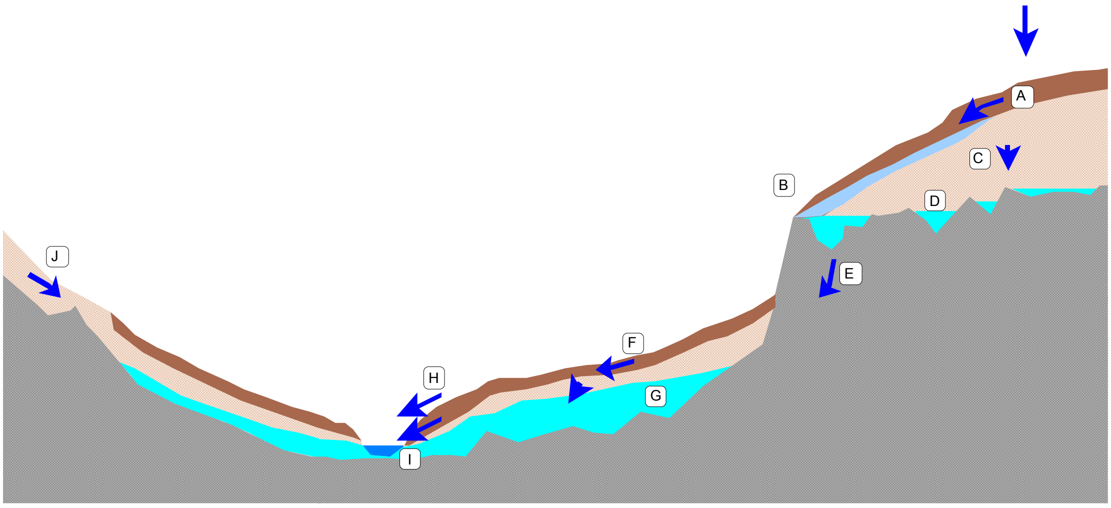


Figure 3.7. Schematic diagram of dominant flow processes and flow pathway zones (Depths of the soil profiles are exaggerated 4x the vertical scale. Drawn facing downstream).

Table 3.3. Summary of streamflow generation mechanisms and their occurrence, Weatherley research catchment.

CODE	DESCRIPTION	OCCURRENCE
A	Rapid lateral flow near the surface due to macro-pore conductance. Local perched water table of short duration. Matric pressure head discontinuity with deeper perched water table, D.	In upper slope segments in downstream catchment during high intensity events and some low intensity events with large volumes (>30 mm).
B	Accumulation at the toe of the slope segment with emergence and flow over bedrock.	In upper slope segments in the downstream sub-catchment .
C	Slow percolation to water tables perched on bedrock.	In all slope segments for most events except low intensity and volume.
D	Water tables perched on bedrock and in bedrock hollows.	Disconnected from soil water in upper slopes of eastern side of downstream catchment, but connected in lower slopes and in upstream catchment during moderate to intense events.
E	Seepage of groundwater through fractured bedrock.	Assumed to occur in all slope segments.
F	Rapid macro-pore, lateral flow in flatter marsh slopes and infiltration to marsh ground water.	Vertical recharge is more rapid than lateral movement in lower slopes of downstream catchment and in upstream catchment, except when groundwater rises into macro-pore layers.
G	Marsh ground water level fluctuation	Rapid for most events in lower downstream catchment. Slower, but connected in upper catchment.
H	Exfiltration, surface runoff and macro-pore discharge to stream	In downstream catchment. Exfiltration not observed in upstream catchment.
I	Groundwater discharge into stream	Occurs in upstream and downstream catchments. Some near stream groundwater ridging during intense events.
J	Unsaturated redistribution of soil water to bedrock. No groundwater on soil/bedrock interface.	In upper parts of western slope. Generates slowly to soil/bedrock water table downslope.

A comparison of wet and dry season soil water fluxes is presented in Figure 3.8a to 3.8d for an upslope position, nest 1, and one at the toe of the upper slope, nest 4. At nest 1, during the wet season, (November 2000), the soil profile responds rapidly to rainfall events and remains close to saturation for much of the record (Figure 3.8a). There is evidence of the near surface perched water in the macro-pore zone, either after intense events (November 10) or when the near surface layers have a high antecedent moisture content or low antecedent capillary pressure head (Novermber 21). During the dry season (Figure 3.8b) the capillary pressure head near the surface increases continuously in response to evapotranspiration demands. The lower layers in the profile are unsaturated and it is likely that all downslope accumulation of water from this location have ceased.

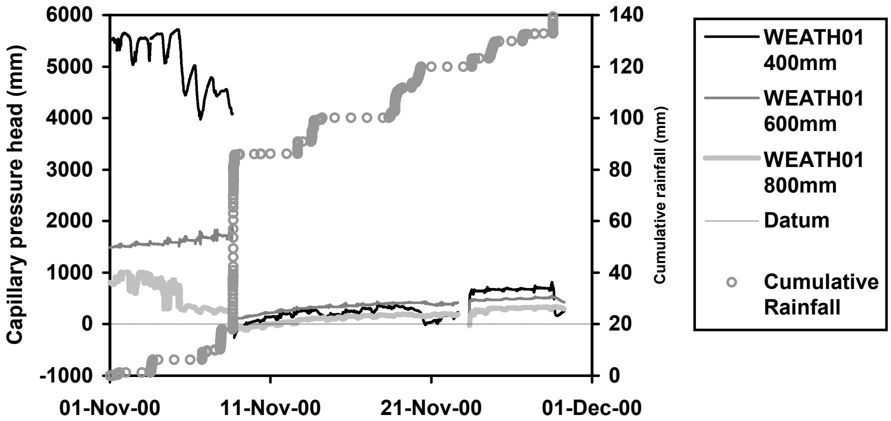


Figure 3.8a A sequence of rainfall events and tensiometer responses (depths 400mm, 600mm and 800mm) during the wet season at nest 1, (WEATH01), November 2000.

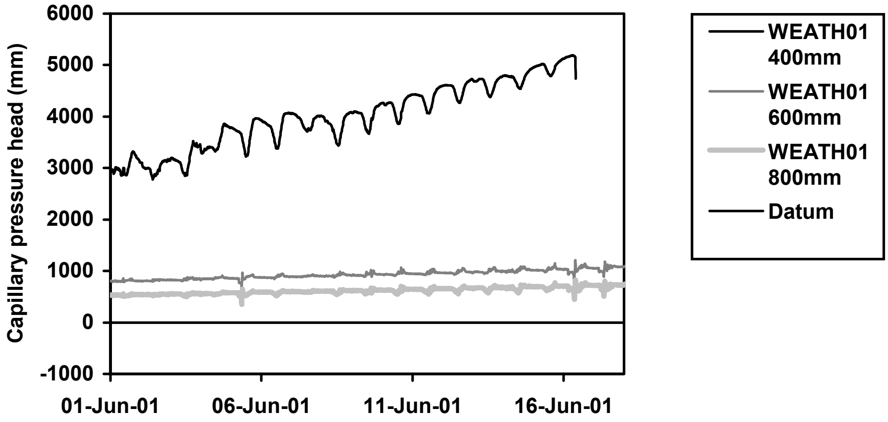


Figure 3.8b A sequence of tensiometer responses during the dry season at nest 1, (WEATH01), June 2001.

At the toe of the slope (nest 4), during the wet season, upslope lateral flow accumulates after a significant rainfall event and ponded water prevails in the profile thereafter (Figure 3.8c). Subsequent rainfall events serve only to replenish the depth of ponding periodically. During the dry season, the soil profile remains unsaturated (positive capillary pressure heads) as shown in Figure 3.8d. However, the profile is not as dry during this period as it is in the soil profile near the crest of the slope at nest 1 (Figure 3.8b). This reflects a continuous accumulation of soil water to the base of the slope section throughout the year. This could occur either by later movement of unsaturated water or the saturated accumulation of a shallow perched layer at the soil-bedrock interface.

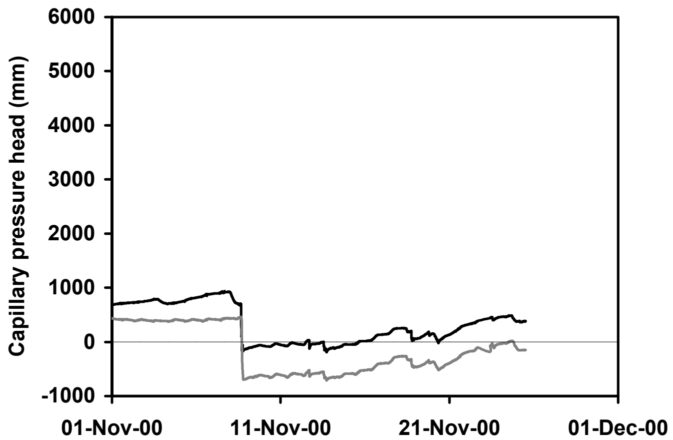


Figure 3.8c A sequence of tensiometer response during the wet season at nest 4, (WEATH04) during November 2000.

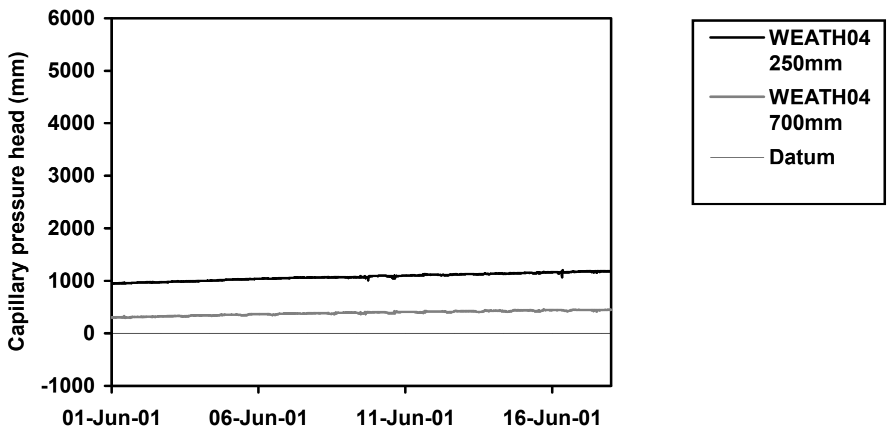


Figure 3.8d A sequence of tensiometer response during the dry season at nest 4, (WEATH04) during June 2001.

3.3.2 Zululand research catchment

The Zululand hillslopes under grass and sugar cane respond in similar fashion. A sequence of tensiometer response for the sugar cane hillslope is described and the streamflow generation mechanisms summarised. On the upper part of the hillslope, the soil profile is deep (some 5m) and well drained. Although the response to all rainfall events is rapid, there is no evidence of water being perched in the upper layers (Figure 3.9a). The upper tensiometer at 330mm depth responds rapidly to rainfall, but does not reach saturation or ponded conditions, indicating an unsaturated wetting front. The response at 1000mm is slower, but becomes progressively wetter with each event, reaching saturated conditions for short periods after a rainfall event when antecedent moisture content is high. Some saturated lateral flow could occur for short periods after these events.

In the midslope at nest 2, the soil profile is still deep and the soil capillary head response to rainfall is very similar to that at nest 1 (Figure 3.9b).

At the toe of the slope, the hillslope profile is flatter and the soils are poorly drained. Here water accumulates so that ponded conditions are evident at about 500mm below the surface after October 12 (Figure 3.9c). Further rain causes the ponding to rise to 350mm below the surface. It is clear that these conditions would give rise to rapid saturation excess overland flow in this part of the slope, provided the antecedent moisture content is high.

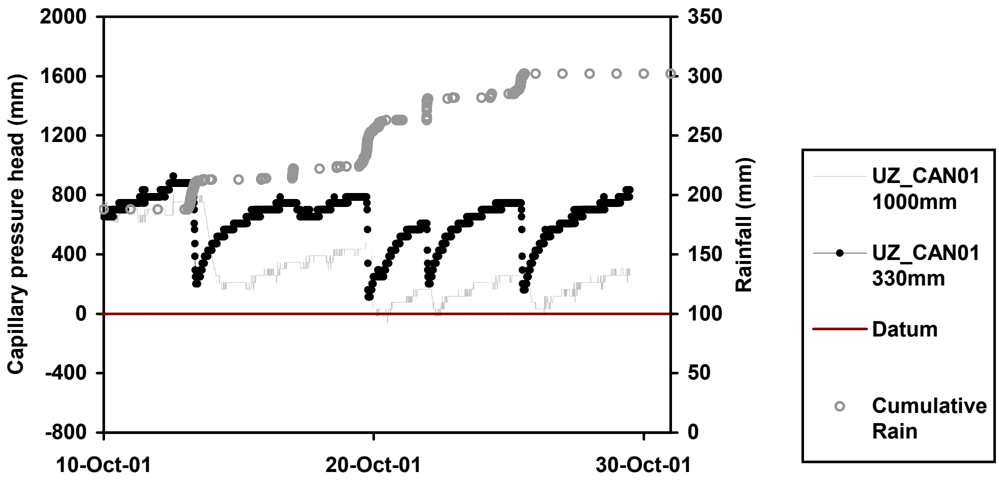


Figure 3.9a Rainfall and tensiometer response at the sugar cane hillslope, nest 1, during October 2001.

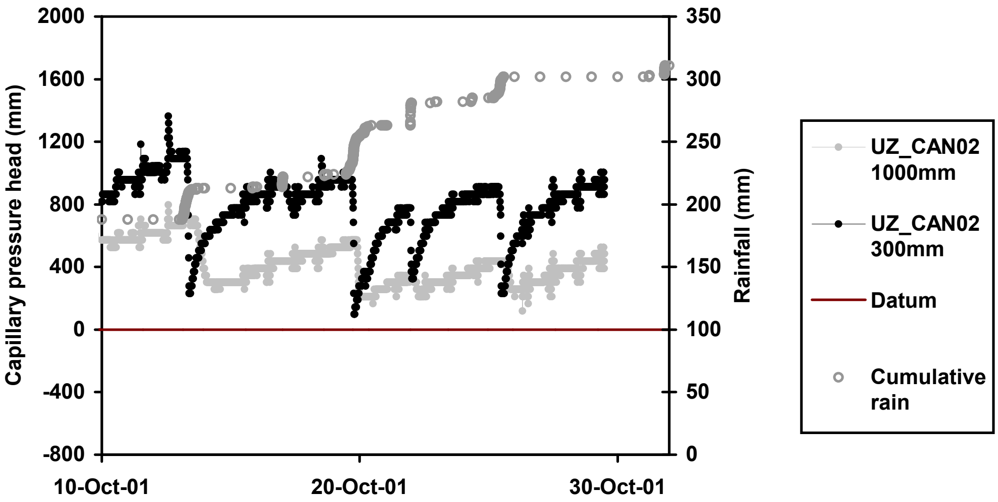


Figure 3.9b Rainfall and tensiometer response at the sugar cane hillslope, nest 2, during October 2001.

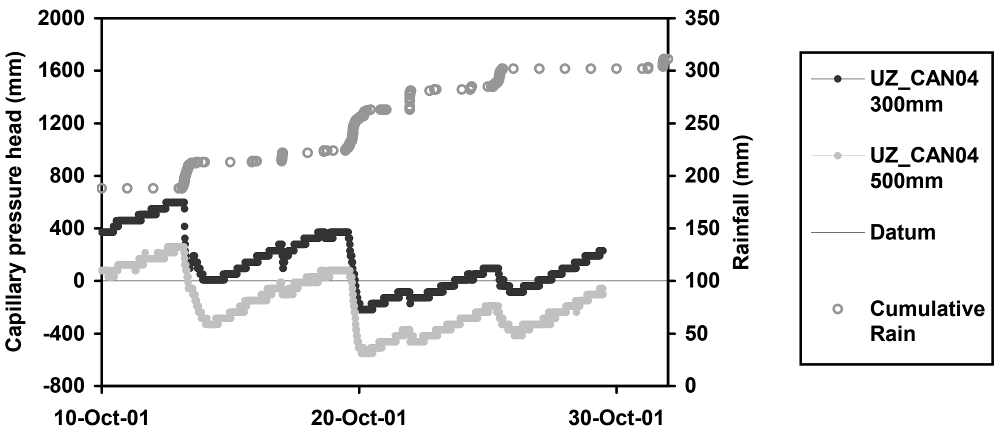


Figure 3.9c Rainfall and tensiometer response at the sugar cane hillslope, nest 4, during October 2001.

The tensiometer responses have been summarized in the general behaviour of the Zululand cane field hillslope illustrated in Figure 3.10 and described in Table 3.4.

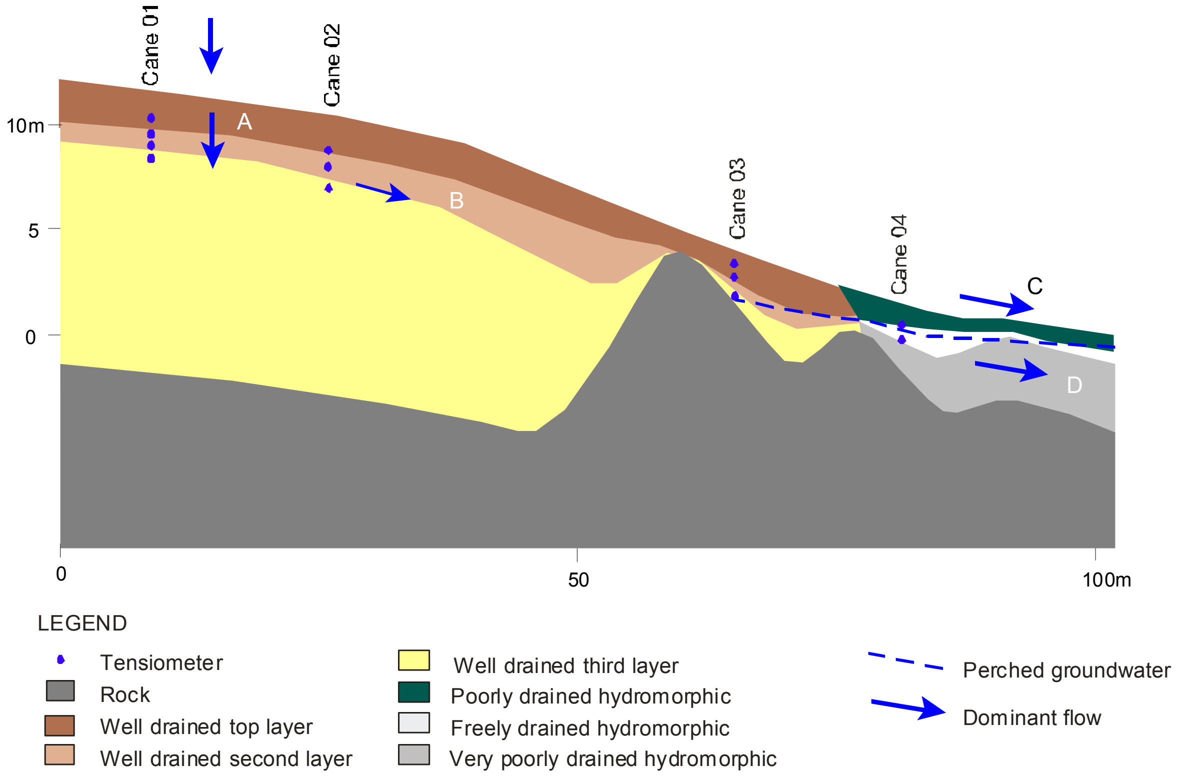


Figure 3.10 Cross section of the hillslope at the cane site, showing the soil profile (after van Zyl, 2002), tensiometer locations and directions of dominant flow.

Table 3.4. Summary of streamflow generation mechanisms and their occurrence, Zululand research catchment.

CODE	DESCRIPTION	OCCURRENCE
A	Rapid infiltration into freely drained profile.	In upper section of the hillslope in deep soil profile of well drained soils.
B	Saturated lateral subsurface flow.	In upper section of the hillslope in deep soil profile during intense events with high antecedent moisture content.
C	Saturated overland flow.	In lower, flatter hillslopes during high intensity events with high antecedent moisture content.
D	Perched water table from upslope flow accumulation.	Progressive accumulation during a series of rainfall events. Ponded depth decreases rapidly between events.

3.3.3 Two Streams research catchment

The hillslope profile at Two Streams research catchment is shown in Figure 3.11. The soil profile is deep, ranging from some 13m at the crest, to 7.5m in the midslopes and approximately 5m near the stream. The stream has cut a steep bank, making the hillslope profile distinctly convex. Groundwater depths have been monitored by the CSIR, Environmentek and are shown to fluctuate very little during the monitored period between the March 2000 and June 2002, although the greatest variation is shown by the two monitored boreholes closest to the stream. Here the groundwater levels vary some 100mm between the wet and dry seasons. The boreholes monitor what must be considered as a perched water table at the interface between the soil profile and bedrock. Examination of the tensiometer data for the period July 2001 to June 2002, particularly those near the stream does not reveal any convincing evidence that the phreatic surface is linked to the stream. Tensiometers close to the stream at S1, N1 and N2 (Figure 3.11) display unsaturated conditions at all depths, both during the wet and dry season, except for brief periods after a rainfall event of 25mm or more. Wetting fronts appear to be stable, with no rapid wetting up of deep profiles. The soil water capillary pressure heads are significantly higher (drier conditions) at the crests and midslopes than they are near the stream, clearly indicating evidence of the water uptake by the trees on the upper slopes.

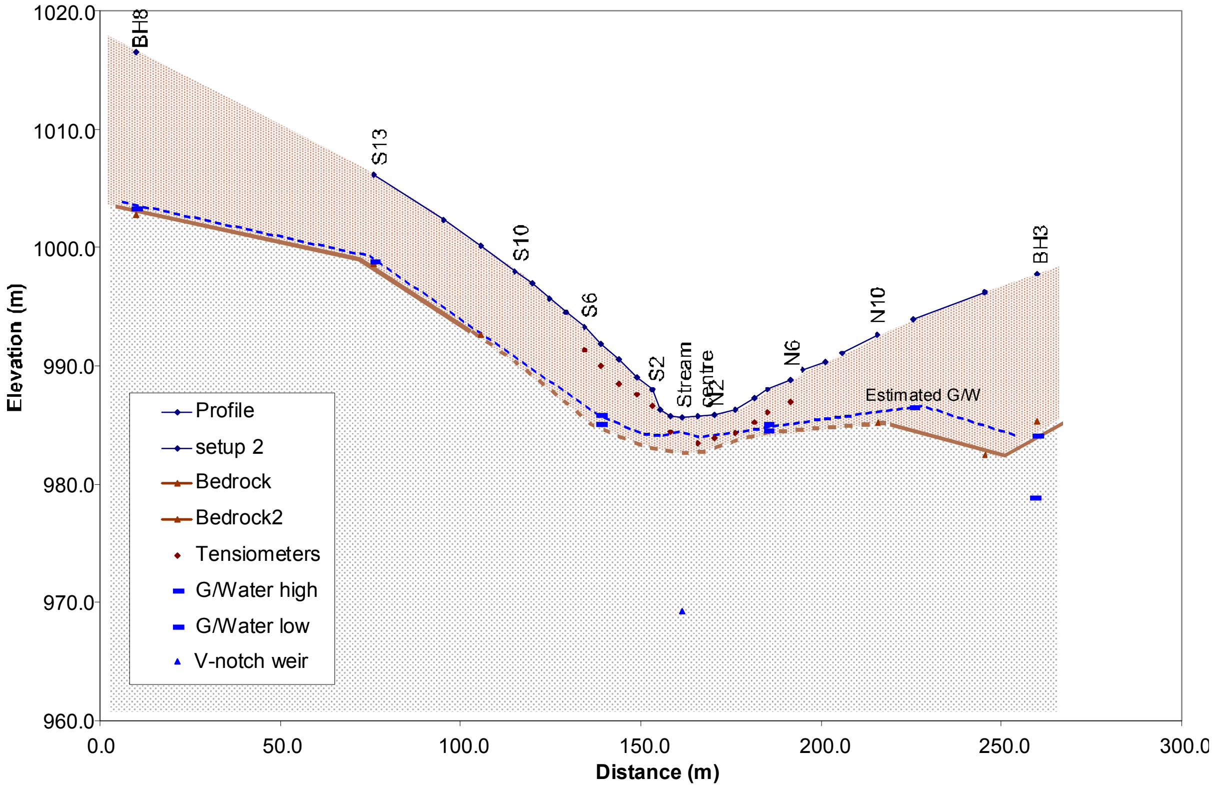


Figure 3.11 Cross section through the soil water sensing transect at Two Streams research catchment, showing depth of deepest tensiometer and high and low levels of groundwater recorded between March 2000 and June 2002 by CSIR, Environmentek (Section surveyed and prepared by SBEEH).

3.4 Quantification of Hillslope, Wetland and Riparian Streamflow Generation Mechanisms

Hillslope, wetland and riparian responses have been described in 3.3 by examining the soil water capillary pressure head time series. In this section, the predominance of the water status at critical locations on the hillslope are first examined to confirm the mechanisms previously identified by examining individual event sequences. This analysis is followed by quantifying specific subsurface fluxes at critical times in order to derive a set of reasonable fluxes for inclusion in model algorithms, which would be designed to transfer water from one response unit "reservoir" to another. Finally, the dominant components of stream generation are quantified using an analysis of the physics of flow as well as estimates of the distribution of travel times for water generated in each of the different components. These analyses are performed for the Weatherley catchment, which has the most comprehensive record of data required for quantifying the streamflow generation components.

3.4.1 Predominance of hillslope, wetland and riparian soil water status

In order to assess the predominance of soil moisture status at specific locations the time series of soil water capillary pressures, over the tensiometer range, at selected depths and at certain nests have been ranked and evaluated for their percent exceedance. A comparison of these ranked data is valuable in determining the amount of time certain soil profile layers maintain specific levels of wetness, compared to other soil profiles. Of particular interest is the amount of time particular levels of the profiles are saturated or ponded. Ponded conditions can be identified by negative values of the soil capillary pressure head. Positive values indicate unsaturated conditions and the greater the positive value of capillary pressure head, the drier the soil. Conversely, the greater the negative value of capillary pressure head, the greater the level of the phreatic surface above the depth of the tensiometer ceramic.

A series of these ranked data, comparing nest 1, near the crest of the eastern hillslope, with nest 4 at the toe of the hillslope section, is presented in Figure 3.12. A comparison using the full data set, November 1999 to March 2002 indicates that the deeper part of the profile (700mm) at nest 4 is predominantly wetter than the 800mm depth at nest 1, confirming that the accumulation of water at the toe of the slope is a dominant feature of the hillslope water fluxes. The 700mm level at nest 4 is below the phreatic surface almost 60% of the time (the 0 value is exceeded 40% of the time), while the 800mm level at nest 1 is saturated for only 35% of the period (Figure 3.12a). The profile at nest 1 exhibits dry conditions (capillary pressure head > 2000mm), for longer periods than even the near surface (250mm depth) at nest 4. The wet season and dry season records are evaluated separately in Figures 3.12b and 3.12c, respectively. During the wet season, the profile at nest 4 is inundated up to the 250mm level at least 62% of the time (Figure 3.12b) while inundation of 700mm below surface occurs 82% of the time. In contrast, nest 1 at the 400mm depth is inundated only 20% of the time and 45% of the time at the 800mm depth. The soil at 800mm below surface at nest 1 is drier than nearer the surface (400mm), indicating the near surface layers enjoy wetter conditions from rainfall replenishment. During the dry seasons, (Figure 3.12c),

however, the 400mm layer at nest 1 is drier than the 800mm layer for most of the record, reflecting the evaporation demands near the surface and the stable wetter conditions deeper in the profile.

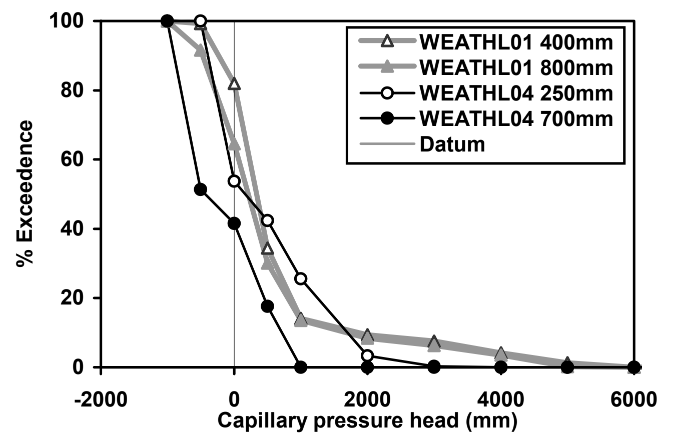


Figure 3.12a Comparison of ranked soil capillary pressure head between nest 1 on the crest, (WEATHL01) and nest 4 at the toe, (WEATHL04) for the whole record November 1999 to March 2002.

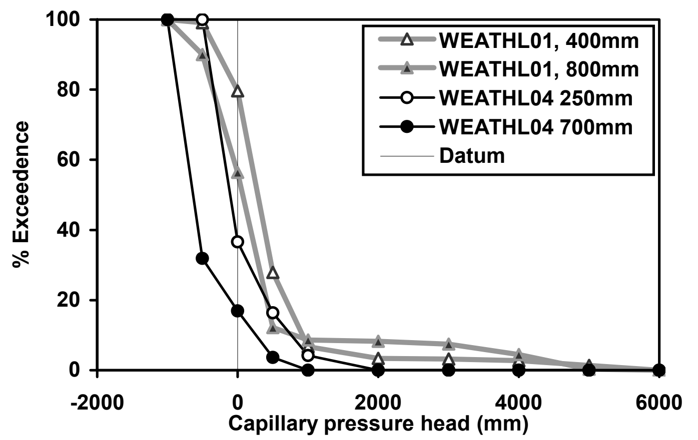


Figure 3.12b Comparison of ranked soil capillary pressure head between nest 1 near the crest, (WEATHL01) and nest 4 at the toe, (WEATHL04) for the wet seasons only, October 1999 to March 2002.

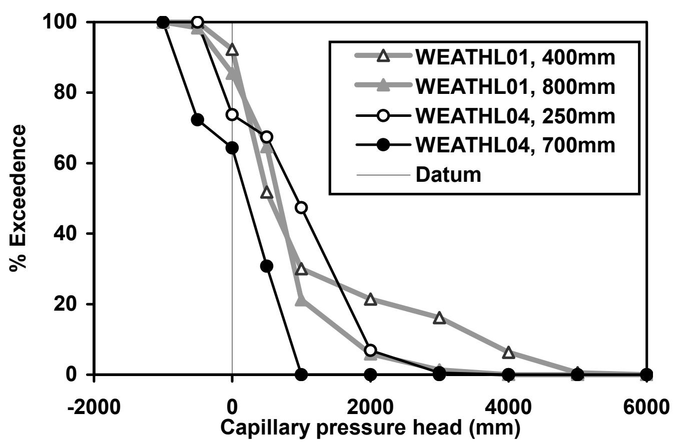


Figure 3.12c Comparison of ranked soil capillary pressure head between nest 1 near the crest (WEATHL01) and nest 4 at the toe, (WEATHL02) for the dry seasons, April to September from 2000 and 2001.

Similarly ranked capillary pressure head data for the entire monitored period are shown for nest 5 (wetland), nest 8 (riparian) and nest 10 (east midslope) in Figures 3.13a-c.

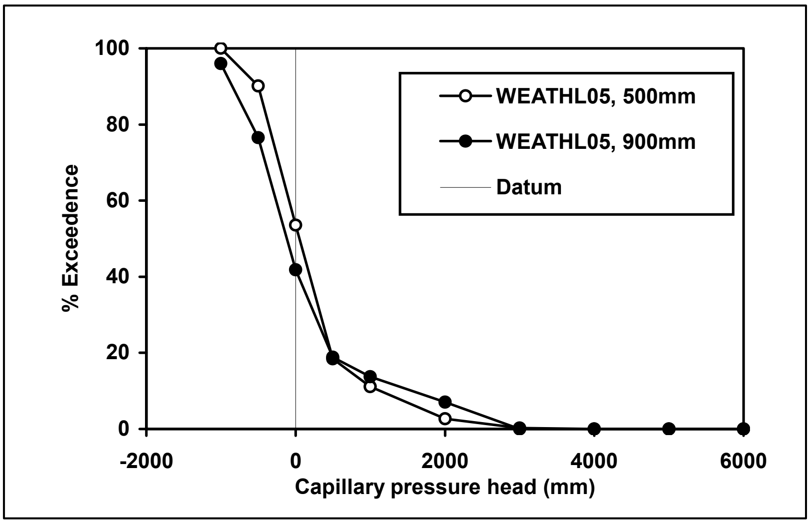


Figure 3.13a Ranked soil capillary pressure head for nest 5, (WEATHL05) in the wetland for the whole period Nov 1999 to March 2002.

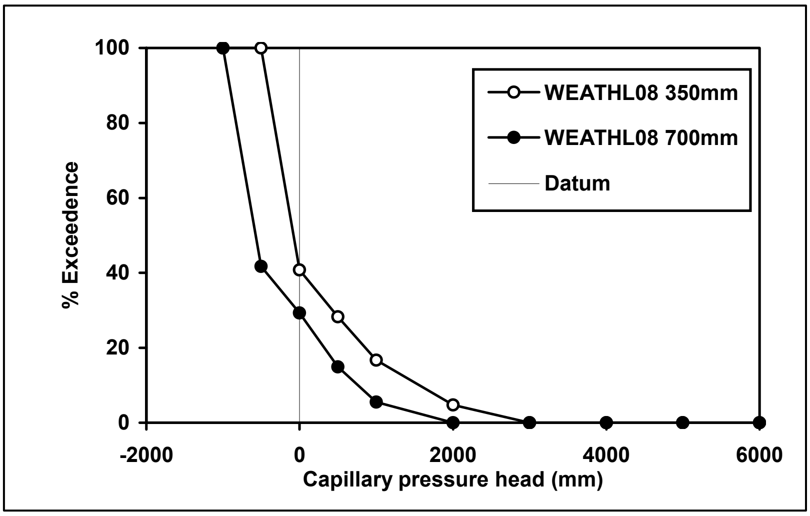


Figure 3.13b Ranked soil capillary pressure head for nest 8, (WEATHL08) near the stream for the whole period November 1999 to March 2002.

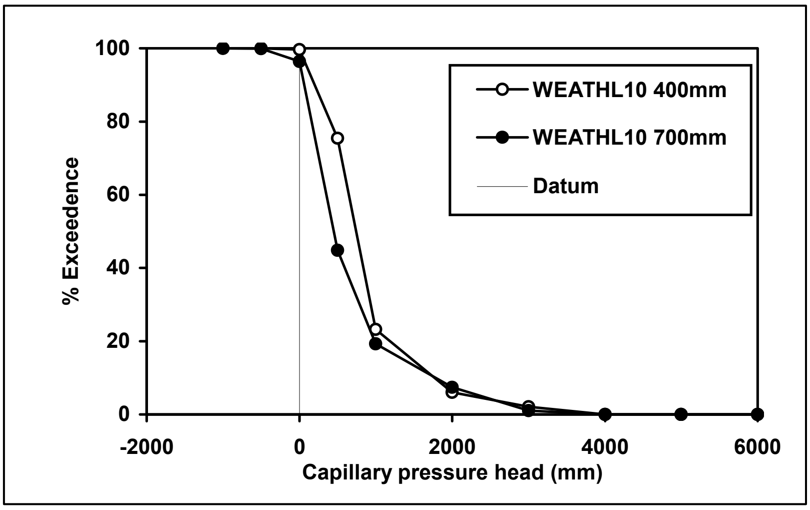


Figure 3.13c Ranked soil capillary pressure head for nest 10, (WEATHL10) on the upper slope for the whole period November 1999 to March 2002.

In the wetland at nest 5, the phreatic surface moves up to the 500mm depth for 45% of the time, while the 900mm depth is inundated 55% of the time (Figure 3.13a). The riparian zone, at the foot of the steep eastern hillslope is wetter than the wetland site, with the 700mm level being inundated 70% of the time and the 350mm level, 60% of the time (Figure 3.13b). In stark contrast, the midslope soil profile at nest 10 is practically never saturated at the 400mm and 700mm depths (Figure 3.13c).

These comparisons confirm the general mechanisms described in 3.3 and give an indication of the duration of the wetting phenomena leading to the mechanisms described.

3.4.2 Evaluation of soil water fluxes

Specific flow rates (fluxes) have been evaluated for various depths in the profile during different stages of streamflow generation. The fluxes were evaluated using the capillary pressure head records at two tensiometers separated vertically at a specific nest. Since the profile is unsaturated between the two tensiometer locations, a linear hydraulic gradient between the two cannot be assumed. The water content, hydraulic conductivity and capillary pressure head vary non-linearly between the two locations. Hence, the recorded capillary pressure head at a certain instant in time for each of the two tensiometers was used as a constant head boundary condition in the HYDRUS-2D model (Šimünek, 1994) to simulate the resultant equilibrium flux between the two points. The relevant soil hydraulic characteristics, presented in Chapter 2 and Appendix C, were used in the model to simulate the fluxes. The results, presented in Table 3.5, show a marked difference in vertical fluxes occurring during an event compared to those prior to the event and during baseflow. During baseflow conditions the flux on the eastern slope and in the riparian zone are in an upward direction, while on the western midslope, a very slow flux occurs in the downward direction.

Table 3.5 Evaluation of selected soil water fluxes

Nest	Conditions	Flux evaluated between		Vertical Flux	Flux direction
		Depth 1 (mm)	Depth 2 (mm)	(mm/h)	
Nest 1 (crest)	Prior to rainfall, summer	400	800	0.06	Downward
	During event	400	800	78.0	Downward
	Baseflow	400	800	0.04	Upwards
Nest 4 (toe)	Prior to event, summer	250	700	0.01	Downwards
	During event	250	700	0	Receiving from upslope
	Baseflow	250	700	0.015	Upwards
Nest 8 (riparian)	Prior to rainfall, summer	350	700	-	Not evaluated
	During event	350	700	2.0	Downwards
	Baseflow	350	700	0.017	Upwards
Nest 10 (midslope)	Prior to rainfall, summer	400	700	-	Not evaluated
	During event	400	700	1.7	Downwards
	Baseflow	400	700	0.008	Downwards

3.4.3 Quantification of streamflow components

The identification of the sources and the quantification of the response dynamics of components of streamflow have been the subject of considerable research (McDonnell, 1990; McCartney and Neal, 1999; McGlynn *et al*., 2001a; Seibert, *et al*., 2001; Sidle *et al*., 2001). While there has been considerable effort in the scientific community in using environmental isotopes and other natural tracers in interpreting flow mechanisms by end member mixing models (McDonnell and Stewart, 1991; McDonnell *et al*, 1991; McCartney and Neal, 1999), there has been some doubt as to their reliability, given the many variabilities in source signal and mixing flowpaths. Clearly these methods require a more complete integration with hydrometric methods in order to derive reliable definitions of flow pathways, residence times and fluxes (Buttle, 1994). The long record of hydrometric measurements at Weatherley lends itself to the estimation of these components of flow using physically based estimation techniques.

The analysis of streamflow generating mechanisms follows three distinctive steps. The first comprises the identification of the dominant mechanisms of streamflow generation, the second a physical quantification of the magnitude and response timing of the mechanisms and the third, the definition of typical response functions that are capable of representing the dominant mechanisms through a range of events. These functions can then be used in designing modifications to catchment scale models such as *ACRU*.

The dominant streamflow generation processes have been identified in Section 3.3 and illustrated in Figure 3.14. Three sources are considered for analysis. These are overland flow adjacent to the stream and local tributaries, rapid generation of near surface flow from the macro-pore zone and a slow response from groundwater perched at soil-bedrock interface.

These responses are quantified using the observations of rainfall, surface runoff, soil water and groundwater dynamics together with the hydraulic characteristics of the materials. Overland flow adjacent to the stream and local tributaries is determined by analysis of the runoff plot data. Rapid generation of near surface flow from macro-pore zone is determined by analysis of the infiltration excess from the runoff plot data combined with the tensiometer responses between two positions on the hillslope. The slow response from groundwater perched at soil-bedrock interface is determined from tensiometer and groundwater level records.

Once these mechanisms have been quantified using the physical measurements, a unit response function is derived for each and combined in a convolution integral with an excitation function to simulate the observed response. (Stewart and McDonnell, 1991; Lorentz and Kienzle 1994; Yue and Hashino, 2000).

The latter two steps are developed in detail in the following section, using a rainfall event in the Weatherley catchment, which occurred between April 10 and 11, 2001

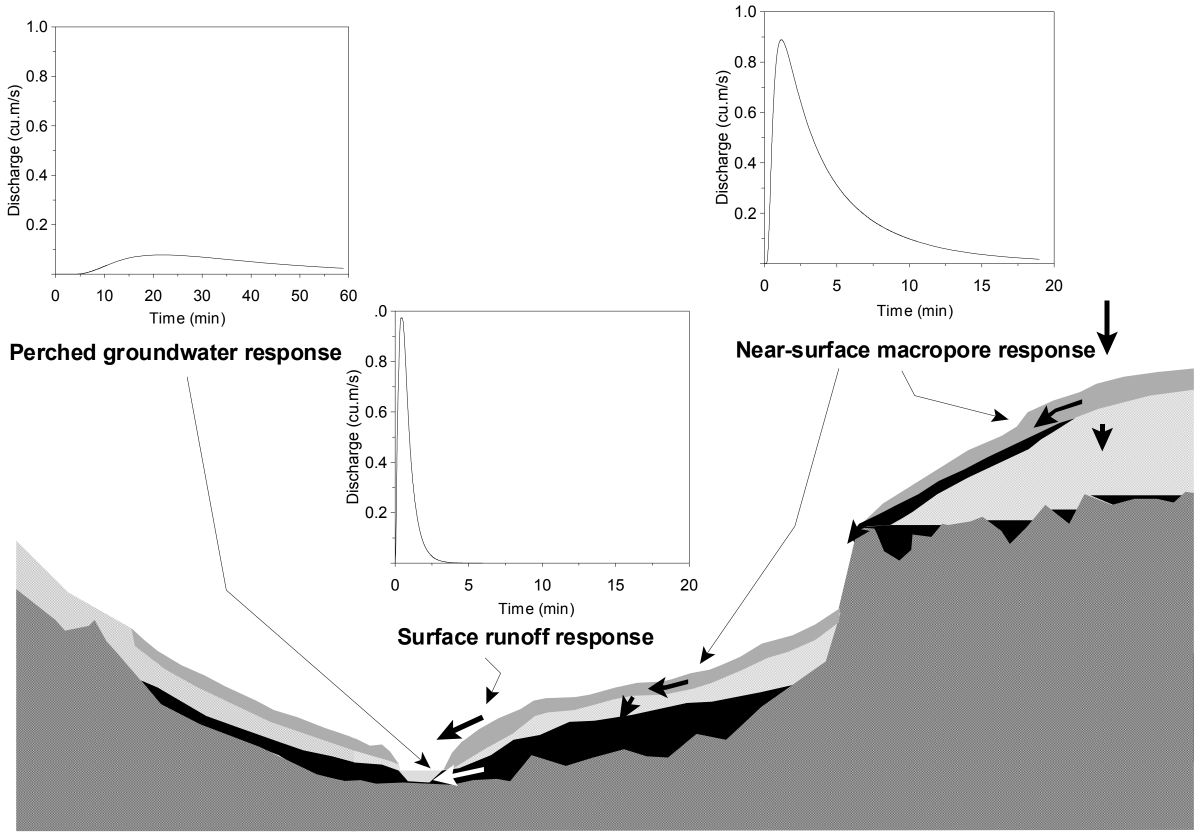


Figure 3.14. Schematic representation of the three dominant streamflow generating mechanisms at the Weatherley research catchment.

Figure 3.15 shows the rainfall-runoff time series for the three weeks prior to the event, which generated a peak flow of 2.8 m^3/s in the lower weir due to a rainfall of steadily increasing intensity, with a peak intensity of 150mm/h and of 20 minutes duration, yielding 31.4 mm. The event is relatively isolated in time, (a minor event of 9 mm occurred two days before) and so is ideal for examining the flow generation processes. The dynamics of the surface runoff, the near-surface, macro-pore zone discharge and the groundwater contributions to the stream during the event, are examined in detail to quantify these sources.

In Chapter 4, the convolution integral approach is then used over the entire catchment to simulate the runoff recorded at the weirs.

3.4.3.1 Surface runoff

The surface runoff mechanism is analysed using the runoff response measured at runoff plot 1 on the upper slopes of the lower catchment near station 2 (Figure 3.1). A model of the discharge is derived using a kinematic overland flow mass balance scheme together with a Green-Ampt/Horton infiltration mechanism, (Moore and Foster, 1990). In the model, the runoff plot is divided into 10 elements, each of length x_e, and the conservation of mass is performed by finite difference on each element as represented in Figure 3.16. The conservation of mass includes the rainfall input to the surface of the element, the water flux into the element from upslope, the loss of water from the downslope face of the element and the loss of water from the base of the element, into the soil.

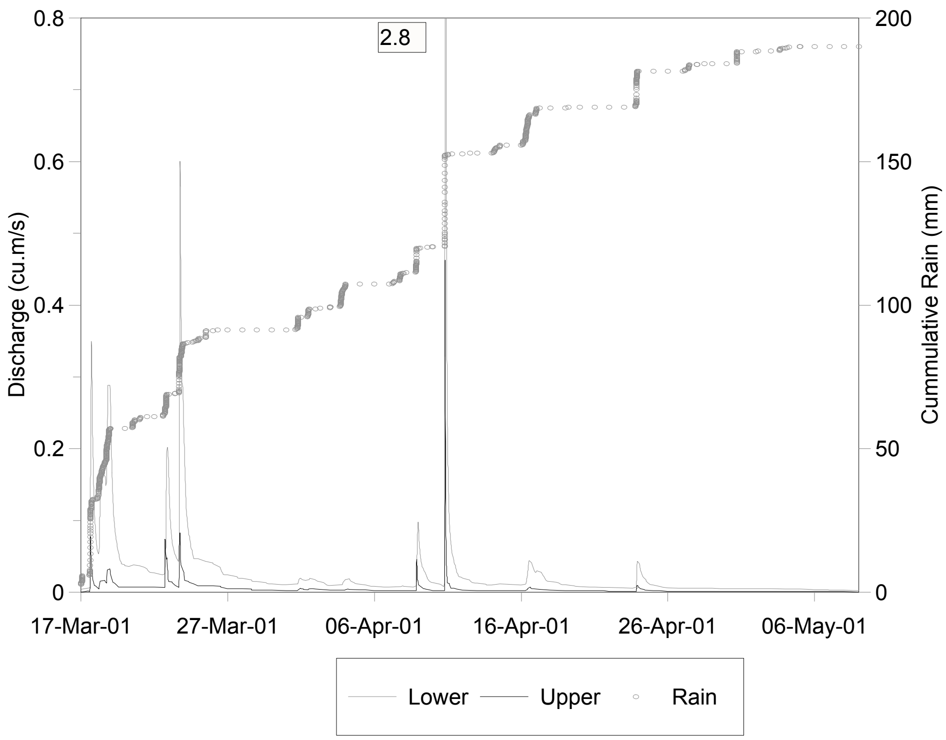


Figure 3.15. Runoff response and cumulative rainfall during 17 March 2001 to 8 May 2001. The peak runoff response at the lower weir on 10 April was 2.8m^3/s.

First, the time to ponding, t_p is calculated from the application of the Green-Ampt/Horton equation, (Morel-Seytoux, 1988), given as:

$$t_p = \frac{Ks(\theta_s - \theta_i)H}{i(i - Ks)} \qquad 3.1$$

where:

Ks = saturated hydraulic conductivity (mm/h),

θ_s, θ_I = saturated and initial water content in the profile,

H = capillary pressure head at the Green-Ampt wetting front (mm) and

i = rainfall intensity (mm/h).

The infiltration rate, f, at each segment during any time interval, Δt, is given as:

$$f = i \qquad \text{for } t < t_p$$

$$f = Ks + \frac{1}{k\Delta t}(i_p - Ks)(e^{k\Delta t} - 1)e^{-k(t-t_p)} \qquad \text{for } t > t_p \qquad 3.2$$

where:

k = $8Ks/((\theta_s - \theta_i)H)$ (h^{-1}) and

i_p = rainfall intensity at the ponding time (mm/h).

The hydraulic head at the wetting front, H, is given, for a soil described by Brooks-Corey parameters (Corey 1977) as:

$$H = \frac{(2+3\lambda)}{(1+3\lambda)}\frac{h_b}{2} \qquad 3.3$$

The Brooks and Corey parameters have been defined for recording stations throughout the catchment and are listed in Appendix D.

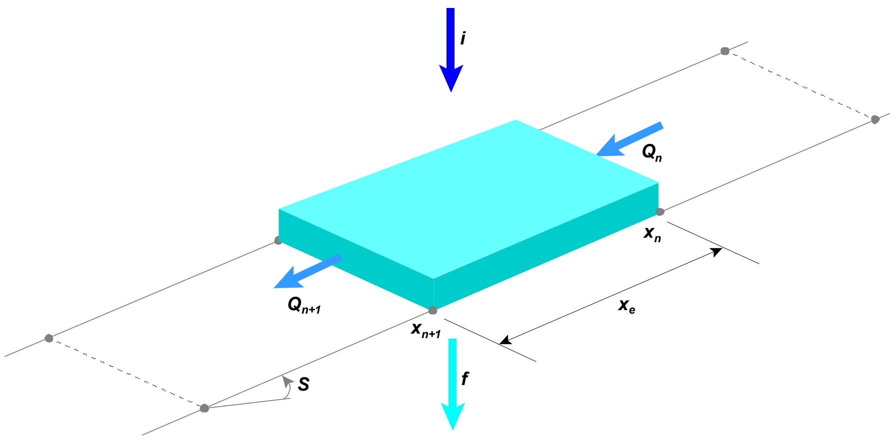


Figure 3.16. Schematic view of the kinematic, finite difference surface runoff algorithm showing the mass balance of a surface runoff element.

Once the time to ponding has been established, a mass balance of inflows and outflows to the elemental volume of water on the slope can be evaluated.

For each time increment, rainfall excess, i_e, being the difference between rainfall intensity, i and infiltration rate, f after ponding is the inflow (or withdrawal after rainfall ceases and i = 0) of water to the surface water element (Figure 3.16). Upslope inflow, Q_n is also an input, while the downslope discharge, Q_{n+1} is the output. These discharges are balanced with the change in storage, governed by the flow height (or cross sectional area, A), which, of course, also controls the discharge. This balance is derived by Newton-Raphson iterative solution of the downstream cross-sectional area of flow for the current time step, $A_{n+1,t+1}$. To start the iterative solution, the most upstream cross sectional area and all initial cross sectional areas are taken to be zero.

The finite difference for of the continuity equation is used in the form:

$$\frac{A_{n+1,t+1}}{2} + Q_{n+1,t+1}\frac{\Delta t}{\Delta x_e} = \frac{A_{n,t} + A_{n+1,t} - A_{n,t+1}}{2} + Q_{n,t+1}\frac{\Delta t}{\Delta x_e} + i_e A_e \frac{\Delta t}{\Delta x_e} \qquad 3.4$$

where suffixes n and t refer to the upstream node and previous time step, respectively and $n+1$ and $t+1$, to the downstream node and current time step. A_e is the surface area of the flow element and Δt, (1 minute), and Δx_e, (2.2 m), are the time and space increments. The discharge, Q, is governed by Manning's equation for broad sheet flow on a slope, s, where the hydraulic radius reduces to h, the depth of flow (Moore and Foster, 1990) as:

$$Q = \alpha A^{5/3} \quad \text{where} \quad \alpha = \frac{1}{n} w^{-2/3} s^{1/2} \qquad 3.5$$

where n is Manning's roughness co-efficient and w is the width of the segment (2m).

Applying this methodology and using measured hydraulic characteristics of the soils from the upper slope near the runoff plot as initial estimates, yields the simulated overland flow (OFM) shown in Figure 3.17 together with the measured runoff (open circles) and rainfall (solid circles). The simulated runoff has the same volume and shape as that measured, but the peak flow occurs two minutes prior to that measured.

The early peak is probably due to assuming a direct downslope flow path in the model. The actual flow path could be somewhat more tortuous and thus require an increased simulation flow length. A summary of the parameters used in the simulation are presented in Table 3.6. These correspond to measured characteristics and initial conditions as observed from soil moisture sensors together with an estimate of Manning's n from the literature.

Table 3.6. Summary of parameters used in the overland flow model (OFM) in runoff plot 1. (Values in brackets are data measured in the top 0.4m at nest 2)

Mannings n	Slope	K_{sat}	Brooks-Corey Soil Water Retention Characteristics				Initial water content
			h_c	λ	θ_r	Porosity	
s/m$^{1/3}$	%	mm/h	mm				
0.2	7	76 (2.2 -40)	600 (215 - 392)	0.2 (0.15 - 0.4)	0.0 (0.0)	0.32 (0.27 - 0.34)	0.30

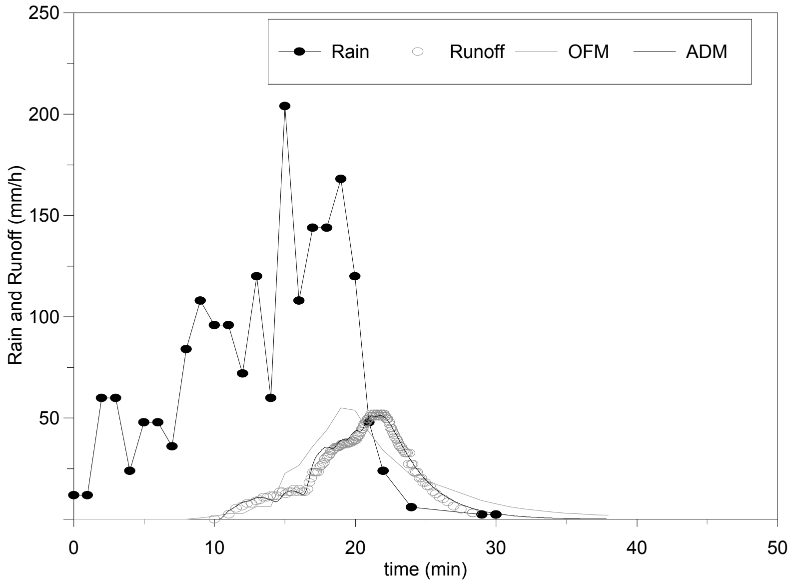


Figure 3.17 Results of surface runoff estimation for event on 10-11 April 2001, showing discharges generated by the Overland Flow Model (OFM) (light grey) and the Advection-Dispersion Model, (ADM) (black solid line).

The results demonstrated in Figure 3.17 are encouraging, given the simplification of the physical process in the model. Therefore, the infiltration rates, f, resultant from the surface runoff water balance, can be used with some confidence in estimating the mass balance of flow in the macro-pore layers. The runoff simulation of the 22 m runoff plot revealed that the overland flow mass balance approached equilibrium at the downstream end, indicating that no more than 20 to 30 m of upslope surface would generate runoff at this location. This was noted for the simulation of surface runoff to the stream in the evaluation of catchment scale runoff, (Chapter 4). However, applying this physical analysis of surface runoff at catchment scale would be prohibitive in terms of the amount of parameterisation and spatial data required. Hence, an even more simplified approach for estimating the surface runoff is used in order to derive a methodology that could be transferable to different scales and could be used in a zoned or Hydrological Response Unit approach.

The overland flow mechanism is considered to contain an advection and dispersion component and adhere to the mass balance of an advection-dispersion model (ADM). The ADM represents the travel time distribution of flows contributing to the surface runoff. An analytical solution, comprising some degree of asymmetry, is used to describe the surface runoff, q_{out}, based on a dispersion coefficient, D and a mean residence time, τ, (McDonnell and Stewart, 1991). This analytical solution represents the response of the mechanism to a unit impulse and is illustrated in Figure 3.18. The observed runoff response is then simulated using the analytical solution in a convolution integral:

$$q_{out} = \int_0^\infty g(t').\delta(t-t').dt' \qquad 3.6$$

where $\delta(t)$ is the excitation function, in this case, the time series of excess rainfall, i_e. Applying this excitation to the unit response function, $g(t)$, (Figure 3.18), yields the ADM simulated runoff shown in Figure 3.15. The function g(t) is given as:

$$g(t) = \left(\frac{4\pi Dt}{\tau}\right)^{-1/2} t^{-1} e^{\left(-1(1-t/\tau)^2 \tau/(4Dt)\right)} \qquad 3.7$$

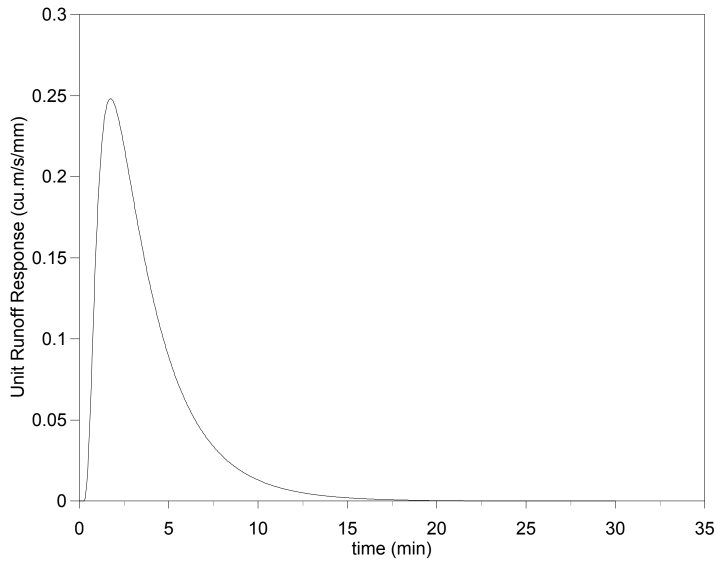


Figure 3.18. The Advection-Dispersion Model unit response function used to simulate the surface runoff (D = 0.25 m^2/s; τ = 3 min).

The resultant convolution integral solution, used in a one minute time step yields an accurate fit to the observed runoff plot data, (Figure 3.17), despite the isolated high rainfall intensity peak of 200 mm/h occurring at the 15th minute. This convolution integral is applied to the catchment scale runoff simulation and is described in the section under catchment response.

2.4.3.2 Near-surface, macro-pore flow

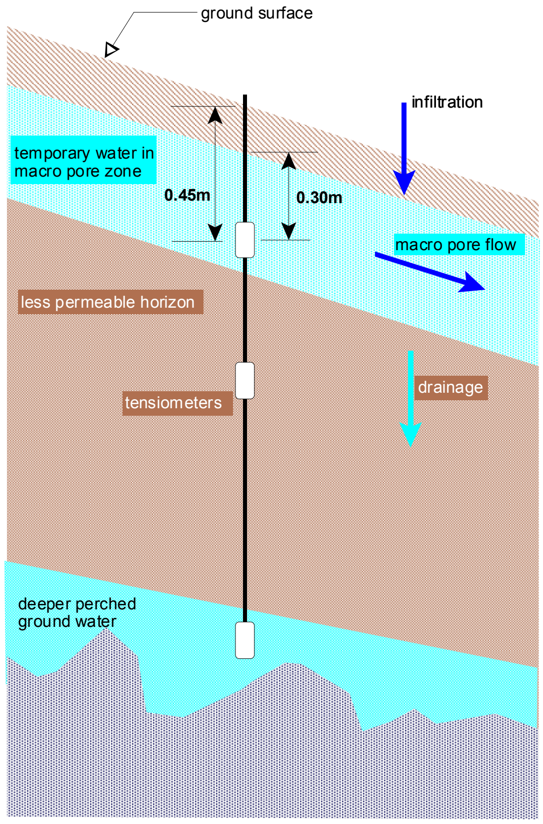
Discharge in the near-surface, macro-pore layers is easily discernable from an examination of the soil tensiometric data as described in 3.3. This phenomenon has been observed by McDonnell, 1990, to account for a significant discharge of "old" water in a steep, humid catchment. It is proposed that in the Weatherley catchment, the macro-pore discharge comprises mostly high intensity event water. The near-surface and deep water tables are shown schematically in Figure 3.19a and the response of the tensiometer at a depth of 0.45 m below surface at nest 2 is shown in Figure 3.19b. It can be seen that the capillary pressure head moves from the initial dry state (positive) prior to the storm of 10-11 April 2001, to an inundated state at the onset of the event (negative). The relationship between capillary pressure head, h_c, the pore air pressure, P_a, and pore water pressure, P_w, is

$$h_c = (P_a - P_w)/(\rho g), \qquad 3.8$$

where ρ is the density of the pore water and g is the gravitational acceleration.

Therefore, a negative value for capillary pressure head means that the soil water pressure, P_w, is positive, (P_a is assumed to be atmospheric, equal to 0) and that a phreatic surface has moved up above the ceramic to a height equivalent to the negative value of the capillary pressure head. The capillary pressure head at the depth 2.04 m, however, does not reduce significantly and certainly does not reflect the development of the phreatic surface suggested by the upper tensiometer. This phenomenon is typical of the records from nests on the higher slopes in both the upper and lower catchments and can be interpreted by referring to Figure 3.19a. Two separate saturated water bodies exist. The near-surface water table inundates the macro-pore layer rapidly and then dissipates with time. Ponded conditions prevail above the 0.45 m tensiometer for some 18 hours after the rainfall (Figure 3.19b).

Analysis of this mechanism involves a mass balance of the flow between the upslope nest, (Nest 1) and observation nest, Nest 2. Inputs to the mass balance are the infiltration water, resultant from the surface runoff simulation, while outflows are the drainage into the deeper soil matrix and the downslope macro-pore flow. Changes in storage are assumed to occur in the macro-pore space only. This mass balance is somewhat simpler than the surface flow mass balance if the physical measurements of the matrix hydraulic conductivity and the macro-pore porosity are deduced from field measurements. These are applied in producing the maro-pore discharge per 2 m width. The results are shown in Figure 3.19c. A second ADM has been fitted to the macro-pore discharge data. The ADM fits the data adequately, but does not represent the immediate peak and the sustained recession of the estimated flow accurately (Figure 3.19c). Nevertheless, this model is retained for simulating the catchment scale response to the event in which travel times in the flatter slopes are likely to retard the macro-pore response.



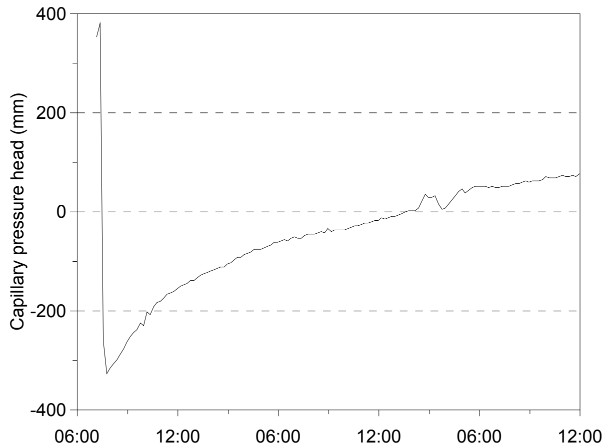


Figure 3.19a. Schematic diagram of flow in macro-pore layer, showing depth of flow indicated in upper tensiometer and disconnection with lower water table indicated by response in deep tensiometer (left).
Figure 3.19b Response in upper tensiometer (0.45 m depth) during event on 10-11 April 2001 (right).

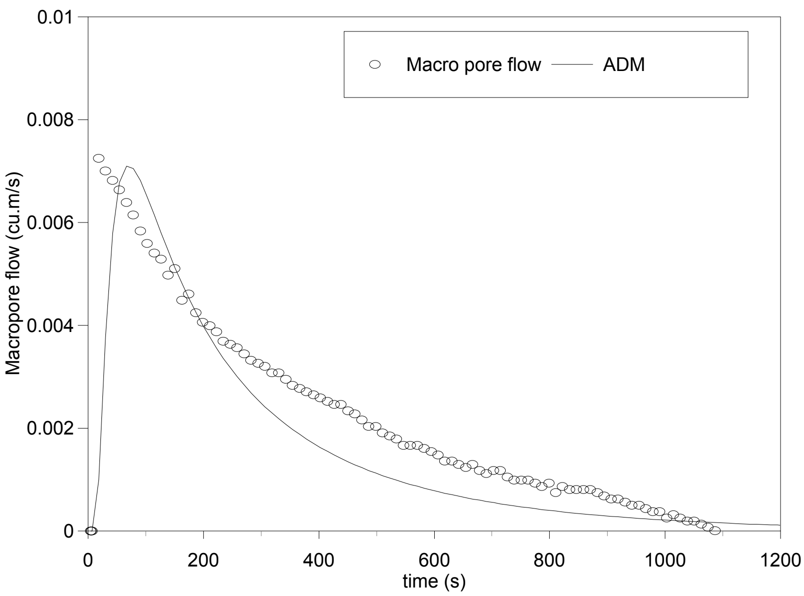


Figure 3.19c. Results of macro-pore flow estimation between nests 1 and 2.

3.4.3.3 Groundwater flow

The groundwater responses are estimated from the increased gradients due to the input of water from upslope and infiltration. In addition, near stream increases in groundwater elevation will increase the sectional area of water discharging into the stream. Despite these increases the groundwater discharge flows into the stream during the event are at least an order of magnitude lower than those from the macro-pore zone. The flux of groundwater, however, suggests that new water entering the deep groundwater table in the upper slopes, may have travel times of two to three years to reach the stream. Peak discharge from the perched groundwater per unit metre of stream length, occurs during the event and is estimated using a unit hydraulic gradient to be 0.006 m^3/h per metre run of stream length. Observed gradients after the event yield a flow rate into the stream an order of magnitude lower, 0.0003 m^3/h per metre run of stream length. The phenomena of groundwater ridging and pressurised piston flow require detailed measurements in order to quantify the flows due to these mechanisms. Nevertheless, it is apparent that the contribution to streamflow from groundwater is significantly less than that from the near-surface macro-pore layers.

The response functions developed here are used to estimate the runoff in the Weatherley research catchment and to provide guidelines for application in deterministic modelling at larger scales.

Chapter 4

Application at Catchment Scale

In order to confer the dominant mechanisms observed and quantified at the hillslope, wetland and riparian scale to the catchment scale, considerable simplification is required. This process is difficult as there are no direct measurements available to quantify how these mechanisms should be transferred. In fact there are those who subscribe to the view that "regardless of our understanding of hillslope processes, our ability to make predictions at watershed scale has advanced relatively little" (Sivapalan, 2001). Nevertheless, considerable work has been done in applying response functions to the different mechanisms of streamflow generation and integrating these over the applicable response zones and time scales in order to derive catchment scale flows and solute concentrations (McDonnell and Stewart, 1991; Kirchner *et al.,* 2000; Kirchner *et al.,* 2001; Kirchner, 2001). Attempts have also been made to estimate catchment scale runoff in terms of observed sources and timing of hillslope and riparian zones (Duffy, 2001; Lorentz, 2001b; McGlynn *et al*., 2001b).

Upscaling from the local and hillslope processes described in Chapter 3 have been applied to the catchment scale by using the convolution integral approach for the isolated, intense event of April 10-11 2001. Two further events are then analysed to test the approach on a low and high antecedent water content scenario.

4.1 Application at Weatherly Research Catchment

The flow mechanisms identified and quantified in Chapter 3 have been grouped into five zones, each with a similar response in generating discharge to downstream slopes or to seepage zones or the stream. The zones are indicated in the cross sectional sketch in Figure 3.4 and are described in Table 3.7. The distribution of the zones throughout the catchment has been identified by field observations and is mapped in Figure 4.1 and described in Table 4.1. Three dominant streamflow generation mechanisms, (overland flow, near surface macro-pore flow and groundwater flow), are assumed to contribute to the stream and local seepage zones linked to the stream. The length of stream is then divided into 100 m reaches and the overland flow, macro-pore flow and groundwater flow ADM's were applied to both sides of the stream and seepage zones and routed to the weirs in the upper catchment (UC)and lower catchment (LC) separately. The results are shown in Figure 4.2 for the upper and for the lower catchment. The simulations show a remarkably good fit to the data, although the macro-pore response appears here to over predict the recession limb. A summary of the parameters used in the catchment response simulation is presented in Table 4.2. In both the upper and lower catchment, the near-surface discharge yields significantly more water than the surface runoff. In the upper catchment, the macro-pore layers yield approximately 70% of the discharge while in the lower catchment this source yields some 92% of the total flow generated.

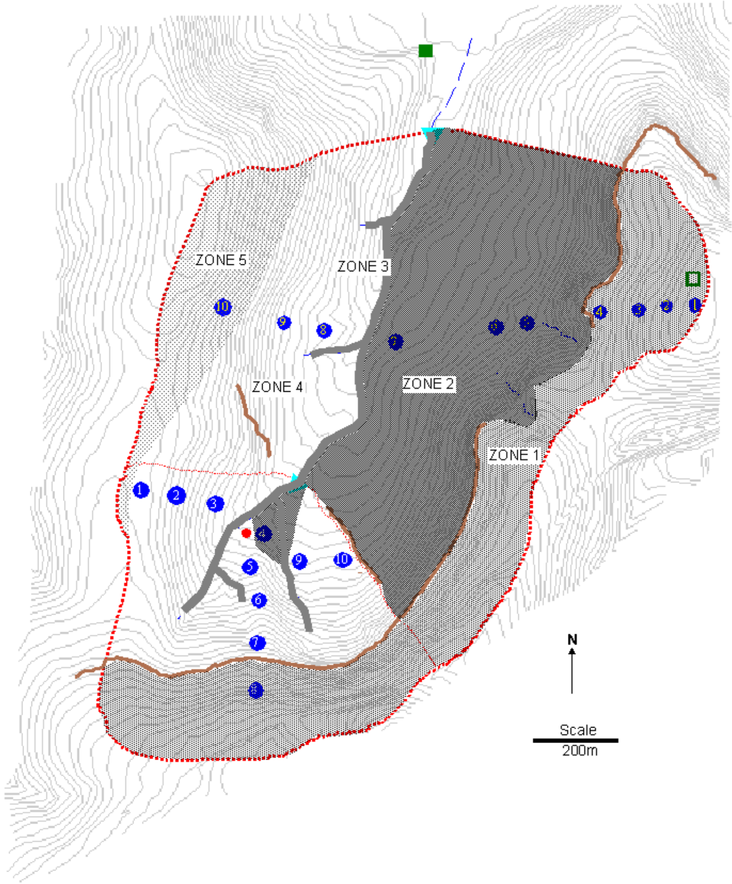
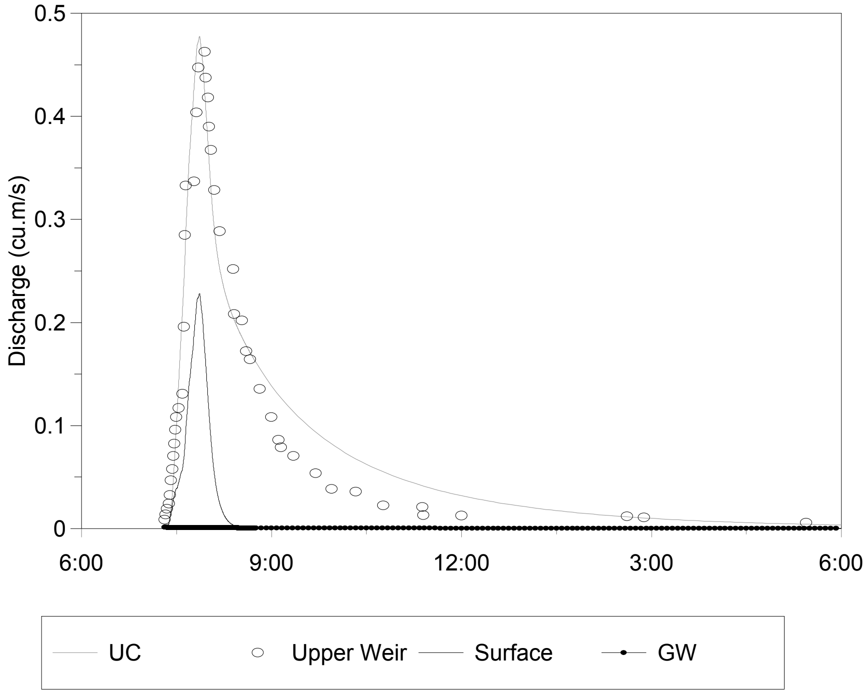


Figure 4.1. Areas of assumed similar flow pathway zones, Weatherley.

Table 4.1. Summary of flow generation zones, Weatherly research catchment.

ZONE	DESCRIPTION
1	Upper slopes of eastern half of the catchment, where delivery of water in a disconnected near surface macro-pore zone delivers water to bedrock outcrop at the toe of the slope. Soil matric pressure is not continuous between responses in near-surface layers and deeper layers near bedrock. Surface water runoff generation for no more than 20 to 30m upslope contributes to flow at the toe. Slow deep groundwater from soil/bedrock interface recharges to toe and to lower slopes and bedrock. All water from this zone is delivered to Zone 2.
2	Recharge from upslope zone and infiltrating water raise groundwater levels at seepage lines and wetland areas. Some flow in near-surface macro-pores. However, it is normally associated with the resident groundwater rising into the macro-pore layers, particularly adjacent to the stream and seepage lines leading to the stream. Some groundwater ridging near the stream yields increased hydraulic gradients for short periods during moderate to intense events.
3	Near stream surface and near-surface water runoff, dominated by groundwater intersecting rapid delivery macro-pore layers.
4	Some flow in near-surface macro-pore layers, but mostly due to intersection of soil/bedrock perched water. There is generally soil matric pressure continuity between upper and lower layers. Near the stream, water is delivered through groundwater rising into macro-pore layers.
5	No perched water tables are evident, even during intense events. Little macro-pore discharge in near-surface layers, even during intense events. Significant wetting to deep horizons with slow delivery of unsaturated water to lower slopes.



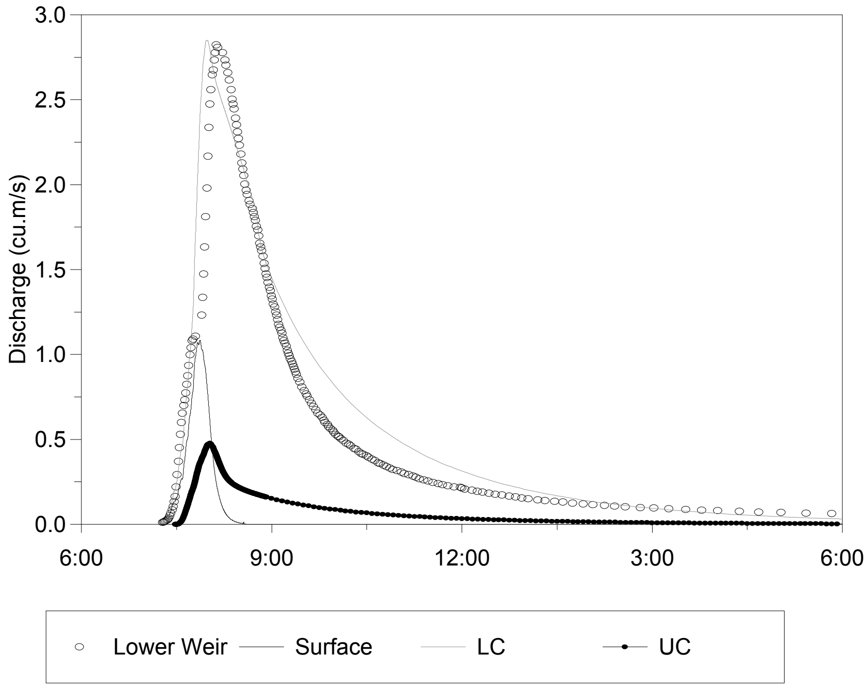


Figure 4.2. Application of the ADM to the upper catchment during the event of 10-11 April 2001, (above) and application of the ADM to the lower catchment during the event of 10-11 April 2001 (below).

Table 4.2. Summary of the ADM parameters and the yield from the components of discharge. The upper catchment is approximately $0.4km^2$ and the lower catchment $1.1km^2$.

	Upper Catchment (UC)			Lower Catchment (LC)			UC+LC
	Surface	Macro-pore	G/W	Surface	Macro-pore	G/W	
D (m^2/s)	0.25	0.5	10000	0.25	0.5	10000	
τ (min)	3	100	10	3	100	10	
Yield (mm)	1.8	5.2	0.04	1.2	13.7	0.03	13.9

The ADM parameters for the overland flow model and the near-surface macro pore model are the same for the upper and lower catchment, indicating similar flow generation mechanisms in these areas. The relative volumes, residence times and sources of flow are successfully estimated by applying simple analyses of the physics of flow generation to the hydrometric observations in the catchment. These estimates may be improved, however, by measuring specific chemical or natural isotopes species of the various sources of water, together with the signature of these species in the discharge responses at the wiers during and between events. The physics of the groundwater gradients and discharges also needs examination for the period between events in order to define the residence times and discharge responses contributing to low flow periods. Nevertheless, this first analysis of responses from source areas during the April 2001 event is encouraging and demonstrates the usefulness of this approach to define runoff generation pathways, storage zones, residence times and fluxes.

In order to test the technique over events of different magnitudes, intensities and initial conditions, two further events (Figure 4.3) were analysed.

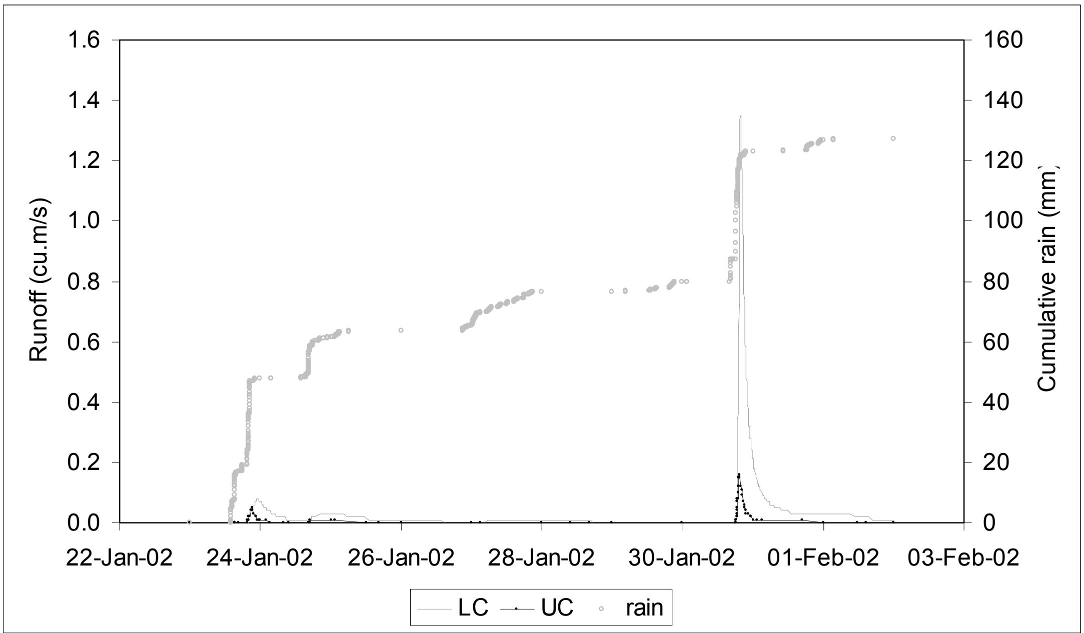


Figure 4.3 Two rainfall events of January 2002 showing the runoff response at the upper and lower weirs.

The first rainfall event, occurring the day after some 20mm of rain, comprised 47mm over a period of 6.5 hours and occurred on January 24, 2002 when the profiles had a low antecedent water content. The second rainfall event occurred on January 30 2002 and comprised 43mm over a period of 5 hours. However, the catchment soil water content had increased considerably, due to the event of January 24 and others prior to January 30. The increasing water content over the period between the events is illustrated by the decreasing capillary pressure heads at the tensiometer nests 3, 4, 7 and 11 as shown in Figure 4.4a-d.

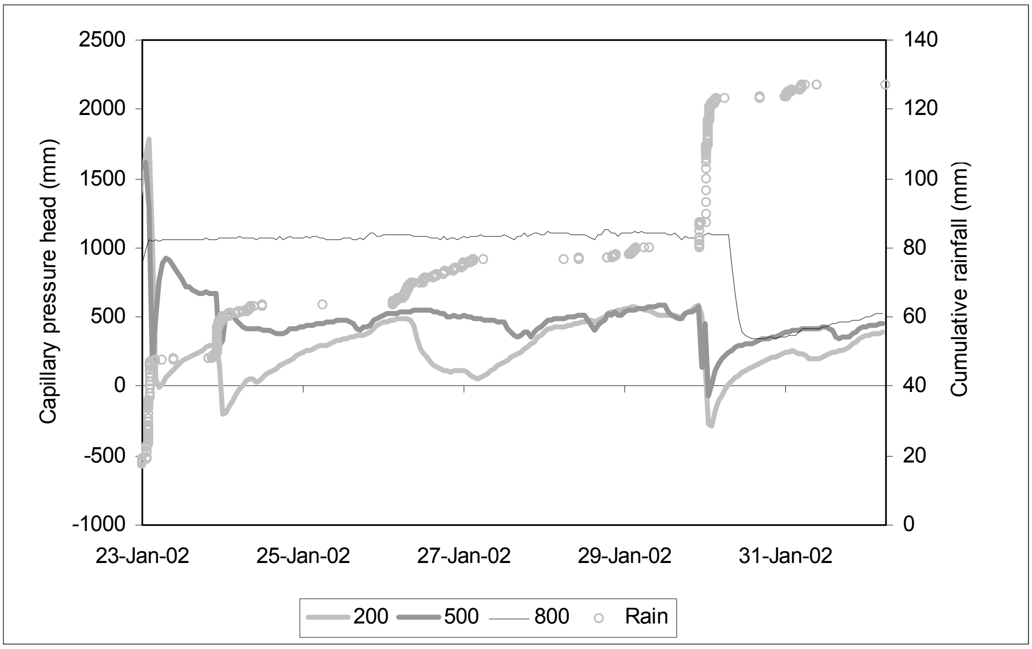


Figure 4.4a. Tensiometer record at nest 3 on the upper eastern slope during January 2002.

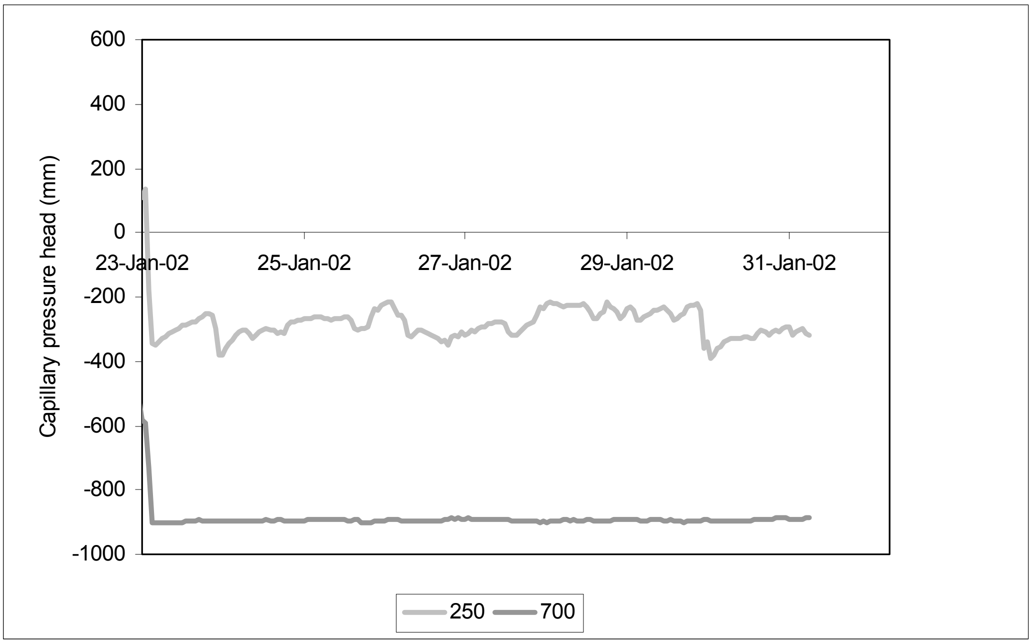


Figure 4.4b. Tensiometer record at nest 4 at the toe of the upper eastern slope during January 2002.

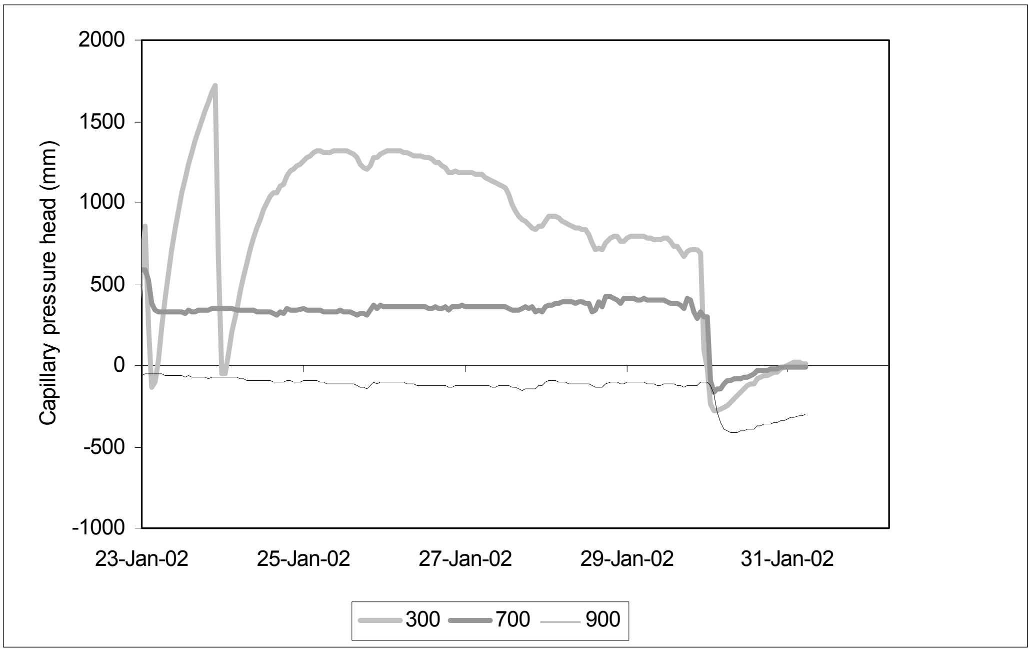


Figure 4.4c. Tensiometer record for nest 7 on the riparian zone during January 2002.

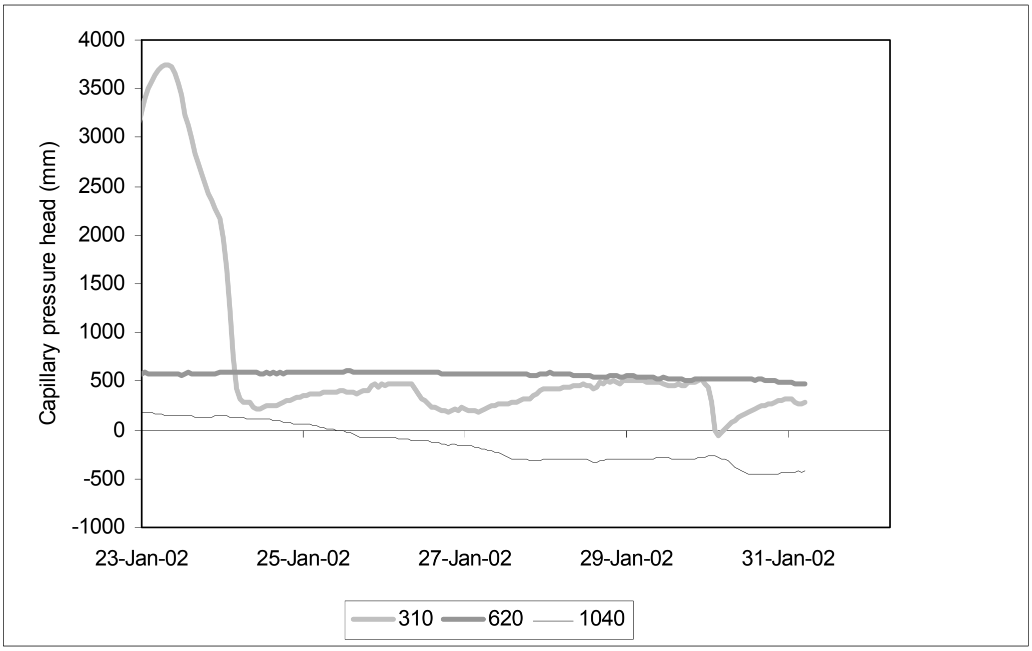


Figure 4.4d. Tensiometer record for nest 11 on the west slope during January 2002.

Despite the marked differences in runoff responses from the two events, the application of the ADM to the surface runoff, near surface macro-pore response and the groundwater simulated the observed runoff at the lower weir accurately as shown in Figure 4.5 for the first event and Figure 4.6 for the second. The response of the macro-pore zone is dominant in both events. The parameters used in the unit response function for the macro-pore zone are summarised for all the events analysed in Table 4.3.

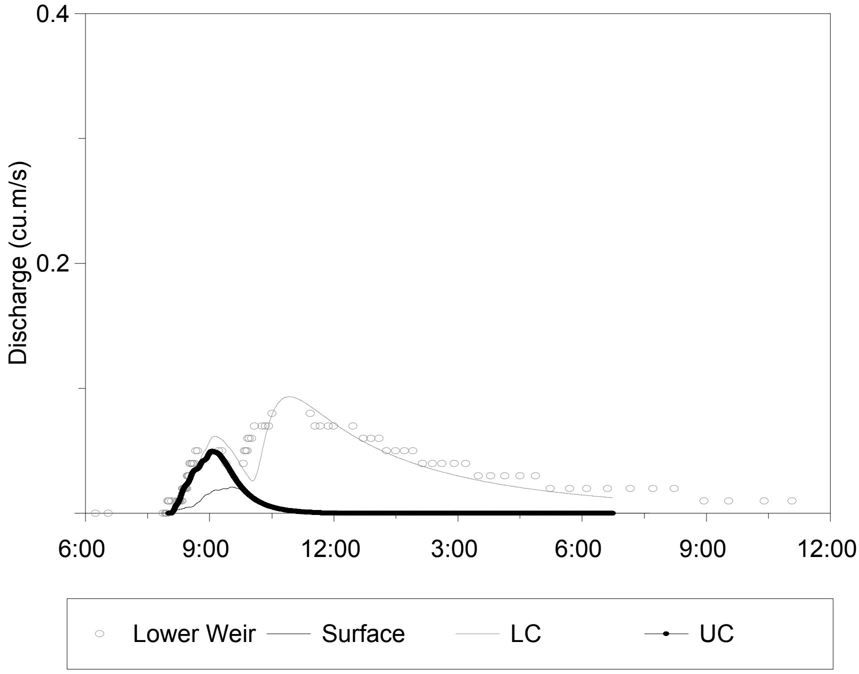


Figure 4.5 Observed runoff response at the lower weir (open circles) and ADM simulated upper catchment (solid dots), surface runoff (dark line) and combination of upper catchment, surface, macro-pore zone and groundwater response (light line). January 24, 2002.

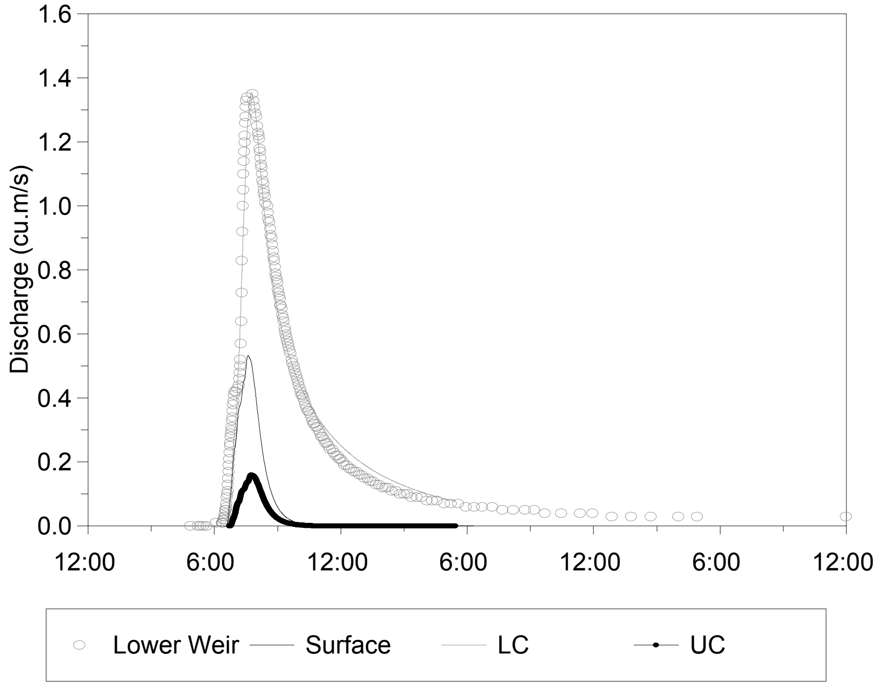


Figure 4.6 Observed runoff response at the lower weir (open circles) and ADM simulated upper catchment (solid dots), surface runoff (dark line) and combination of upper catchment, surface, macro-pore zone and groundwater response (light line), January 30, 2002.

Table 4.3. Summary of the ADM parameters of the macro-pore response mechanism for the events of April 10, 2001, January 24, 2002 and January 30, 2002.

	April 10, 2001	January 24, 2002	January 30, 2002
Response factor	1	0.167	0.667
D (m^2/s)	0.5	0.5	0.5
τ (min)	100	200	200

The dispersion coefficients, indicating the relative travel times of components of the macro-pore zone is the same in all events and the lag time is shorter for the more intense event of April 10, 2001. However the magnitude of the response, indicated by a response magnitude factor relative to the April 2001 event, differs significantly between the events, with the response for the low antecedent water content event of January 24, 2002, being 6 times lower than that for the April 2001 event and that for the event of January 30, 2002, being two thirds of the April 2001 event. These analyses indicate the dependence of the macro-pore response mechanism on the rainfall intensity and antecedent water content conditions.

While the methodology demonstrated here is not intended as a new modelling technique, it is intended as a method for characterising responses of runoff and subsurface storage and release for various typical formations throughout South Africa. Once characterised in this way, the results can be used to improve the parameterisation or algorithms of the many catchment models which already include quick, slow and baseflow response components, such as those included in the *ACRU*, (Schulze, 1994) and HYMAS, (Hughes and Sami, 1994) models. It is particularly important to define these responses when land use changes are to be simulated. Incorrect definition of source zones and release rates may result in inaccurate simulations of low flow responses. Errors will occur, if, for example, these low-flows are assumed to be generated from a fractured aquifer source, whereas, in reality, the water is still resident on the hillslope and thus available for uptake by trees, which may have been introduced.

4.2 Implications for Catchment Scale Deterministic Models

The value of successfully applying the hillslope, wetland and riparian zone streamflow generation mechanisms, defined and quantified in previous sections, to medium and large scale deterministic modelling is clear. It is not only valuable to find a minimum representation of the catchment response by extracting only those hillslope mechanisms which contribute to the observed time scales of runoff variability in the catchment outflow (Duffy, 2001), but it is important to identify the sources of the streamflow generation. If this is not achieved, it will be difficult to identify or predict the catchment streamflow impact potential of changes in land use at the hillslope scale. It is apparent that certain mechanisms observed and quantified at the three research catchments studied can form the basis of new methodologies or algorithms in deterministic models. These are summarised for distinctive zones of streamflow generation:

- **Surface runoff**. It is evident that surface runoff into streams occurs predominantly in narrow zones adjacent to the primary watercourses. Surface water runoff on hillslopes is not likely to reach streams before infiltrating to form part of the near surface lateral flows and contribute to the accumulation or driving pressure on perched saturated groundwater contributing to the streamflow. Factors affecting the rate of surface runoff generation near the stream and the width of the contributing zone include the slope of the surface, the hydraulic characteristics of the near-surface soils, the surface roughness and the antecedent moisture content.

- **Near surface lateral flow.** The importance of macropore structures in conducting near-surface water rapidly and in large volumes to the stream cannot be overlooked, at least at the small catchment scale (Flühler and Hagedorn, 2001; Clothier, *et al*., 2001) as has been demonstrated in Chapter 3. The influence of this lateral macropore induced streamflow generation mechanism has been shown to decrease with catchment size (Brown *et al.*, 1999), but it may have considerable implications in a catchment of any size if land use should alter the effect of the macro-pore structure on a large scale.

- **Shallow groundwater**. The shallow groundwater, usually perched on soil-bedrock interfaces, but also possible within the profile, contributes to streamflow by a number of possible mechanisms, which would need to be included in deterministic models. Shallow groundwater can be pressurised into delivering rapidly to streamflow by "piston flow", where invading infiltrated water (new water) displaces the antecedent saturated water (old water). Although there is little physical evidence of this phenomenon it has been deduced from observation of the chemical signature of "new" and "old" water during runoff events. A plausible explanation may be that the invading wetting front traps and pressurises air in the pore structure between the front and the groundwater, thus increasing the hydraulic gradient of the groundwater towards the stream. The shallow groundwater can also discharge significant volumes of pre-event water by "groundwater ridging". This is described as occurring near a stream, where a significant layer of saturated soil is maintained by capillary forces above the groundwater phreatic surface (often referred to as the capillary fringe). An invading wetting front reaches the saturated zone, which immediately transfers the full hydraulic head of the saturated zone on the groundwater body, again increasing the hydraulic gradient towards the stream instantaneously.

- **Deep groundwater.** The contribution of deep groundwater to the stream has not been studied in any detail in this work. There is clear evidence that the deep groundwater is not connected to the streamflow in the Two Streams catchment and it is not likely to be in the other two, headwater research catchments. What is clear, however, is that the rates and volumes of contributions from the hillslope shallow groundwater and the replenishment of this water from the unsaturated zone can accumulate and have sufficiently long residence times that its arrival at a large catchment outlet could well be incorrectly interpreted as a deep aquifer contribution. This needs to be studied in more detail since the implications on low flow contributions after a land use change at the hilslope scale would be significant.

While it is important to recognize and parameterise the reservoirs or source mechanisms contributing to streamflows (Uhlenbrook and Leibundgut, 2002), it is equally critical to define the residence times and rates of transfer between reservoirs and from reservoirs to the stream (Hooper, 2001). These responses, particularly between shallow unsaturated and saturated zones tend to have long tailed travel time distributions. Deterministic models which use exponential decay curves for these transfers (*ACRU*), could well under predict discharges during dry periods. Many asymmetric travel time distributions have been identified (Lorentz, 1986; McDonnell and Stewart, 1991; Kirchner, 2001) and need to be tested in deterministic models.

The results described in this report clearly indicate that there is an advantage, when applying deterministic models such as *ACRU* to the catchment scale, to delineating the sub-catchment response units in respect of their position on a catena. As a result of the findings in this study, simulations of sediment yield have been performed with the ACRU model parameterised for response units on a catenal basis and with modifications to the soil profile fluxes to allow upslope A and B-horizon water to discharge into the soil profile lower on the slope, (van Zyl and Lorentz, 2003).

The three hillslopes described in this study have distinctly different behaviour. These differences need to be parameterised in terms of the hillslope features in order to begin a process of generalisation of hillslope behaviour (Sivapalan, 2001). These generalisations can then be applied to the simulation of catchments using distributed modelling. A parallel effort must also be aimed at inferring model conceptualisations directly at the watershed scale using rainfall/runoff data measured at the catchment scale. There is also a need for increased dialogue between modeller and experimentalist in which the value of “soft” data is realised. These data would include descriptions of mechanisms or processes which are not rigorously parameterised, but which could be simplified to limit the boundary conditions in the catchment scale model (Siebert, *et al*., 2001).

Chapter 5

Conclusions and Recommendations

Three research catchments have been studied in terms of their hillslope, wetland and riparian hydrological responses. A method of applying simple physics to estimate flow generation of surface runoff, near-surface macro-pore zone discharge and groundwater flows during an event, has been successfully combined with a convolution integral approach to streamflow simulation in the Weatherly research catchment. The method quantifies the residence times and fluxes of the sources of runoff. Analysis of an intense rainfall event reveals that the dominant source of streamflow is from the near-surface, macro-pore layers adjacent to the stream and seepage areas. The convolution integral analysis, which includes an advection-dispersion solution to flow generation from different sources, can be used to characterise the flow generation responses in various typical formations. These characterisations can be used to improve the parameterisation and algorithms in catchment scale models, which include time related discharge responses. The convolution integral methodologies described are particularly appropriate for defining sources, residence times and fluxes during rainfall events as well as during low flows. The implications for using these flow generation mechanisms in catchment runoff simulation using deterministic models has been summarised. It is concluded that:

- Physically based mechanisms were successful in estimating selected observed responses in surface and near-surface runoff. Simple generalised travel time distributions were also successful in estimating these responses.

- Macro-pore induced flow mechanisms are a significant contributor to streamflow generation at the Weatherley catchment, but do not contribute significantly to streamflow generation at the Zululand and Two Streams research catchments.

- A valuable set of data has been generated and included in an interactive database. Significant improvement on the estimation of hillslope, wetland and riparian zone responses can still be made by using the full data set.

From the results of the observations and analyses made in this study and other international research, it is recommended that:

- A detailed study of near-stream flow generation mechanisms is required in order to observe and quantify “piston flow” and groundwater “ridging” phenomena.

- As many hillslopes as possible need to be studied in order to obtain a full spectrum of hillslope, wetland and riparian zone strreamflow generation mechanisms.

- The differences in hillslope flow generation performance need to be parameterised in terms of the hillslope features in order to begin a process of generalisation of hillslope behaviour for application in deterministic catchment scale models.

- The generalisations should then be applied to the simulation of catchments using distributed modelling. A parallel effort must also be aimed at inferring model conceptualisations directly at the watershed scale using rainfall/runoff data measured at the catchment scale.

- Modellers and experimentalists must increase their efforts in dialogue in which the value of "soft" data is realised. These data would include descriptions of mechanisms or processes which are not rigorously parameterised, but which could be simplified to limit the boundary conditions in the catchment scale model.

- Nested catchments are required in order to transfer observed streamflow generation mechanisms between scales and

- The combination of natural isotopes or chemical species tracers sampling together with hydrometric observations of surface and subsurface phenomena must be used as widely as possible to narrow the error in describing volumes, residence times and transfer rates of the sources of streamflow.

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Appendix A

Monitored Catchments and Processes Database

Sean Thornton-Dibb and Simon Lorentz

Monitoring of hydrological processes at the University of Natal has been an ongoing endeavour for many decades and has encompassed a wide range of processes and land uses. Historic monitoring comprised mostly the recording of rainfall, meteorological variables and runoff in small catchments with specific land uses. These data were used to verify deterministic hydrological models at a scale commensurate with the runoff measurement. Some attempts were made to define local processes, such as specific vegetation water uptake. Recently the focus has been on observing the hillslope water generating mechanisms and attempting to integrate these in order to simulate the observed runoff.

Two aspects of the routinely monitored catchments and local scale processes monitoring have been reported previously (WRC Report No 637/1/01). The first details the extent of the monitoring program, both historic and current and presents a summary of the data available for all major catchments and locations. The second presents details of the new relational database.

A.1 Extent of the Monitoring Program

A.1.1 Historic Catchment Monitoring (Ntabamhlope and Cedara)Rainfall and runoff data have been collected in the Ntabamhlope-De Hoek catchments since 1964 and form an extensive data set of the process hydrology of the Natal escarpment, including wetland, agricultural and grassland land uses. The School of Bioresources Engineering and Environmental Hydrology, SBEEH, (formally Department of Agricultural Engineering) has been responsible for the maintenance of the catchment monitoring systems set since 1976, (Schmidt and Schulze, 1989a; Smithers and Schulze, 1994a). More intensive agriculture has been monitored in small catchments at the Cedara research station since 1974, (Schmidt and Schulze, 1989b; Smithers and Schulze, 1994b).

In 1998 an evaluation of the databases and an assessment of the catchment monitoring program was initiated. This evaluation is summarised in Table A.1. Considerable liaison is underway between the Chairman of the Amahlube Trust, Mr Pewa, the Institute for Natural Resources (INR), local authorities and SBEEH, in order to return to monitoring at Ntabamhlope. Historic data for the Cedara and Ntabamhlope catchment are scheduled for inclusion in the relational database.

Table A.1a Monitored catchment evaluation for Ntabamhlope.

CATCHMENT	LAND USE	PURPOSE	INSTRUMENT.	MET. STATION	LAND USE CHANGE	STATUS	DECISION
V7H007 (69, 87-95)	Grassland/Maize	Natural headwater Wetland processes	Weir Rain gauges	Metsite (92-99) RG 40	Amahlube T.A settlement and small scale irrigation	All down except met site	Reinstate
V7H004 (68-72, 89-99)	Forest	Grass to forest historical change	Weir Rain gauge Neutron probe	RG 23 (64-99)	None expected (Masonite property)	All down except neutron probe measurements	Reinstate
V7H005 (69, 76-82)	Feedlot/Farm	Small inlet to wetland Feedlot water quality	Weir		Farm offices will be used by Amahlube T.A.	Down	Abandon
V7H008 (69, 77-78, 93-99)	Grassland/Forest	Natural side inlet to wetland	Weir Rain gauge	RG 18 (76-95) RG 41 (88-99)	None expected	All down	Reinstate
V7H011 (63-99)	Outlet from wetland	Wetland processes Forest response	Weir Rain gauges	RG 23 (63-99) RG 14 (70-99) Metsite (92-99)	From grassland to market garden and subsistence agriculture	Weir down	Reinstate
V7H028 (70-72, 76-99)	Small grassland and natural woodlot	Natural grassland/grazing Hillslope processes	Weir Rain gauges Neutron probe	RG 14 (70-99)	From stock grazing to community grazing	Weir down	Reinstate
V7H020 (64-68,85-96)	Forest and grassland downstream of V7H028	Forest response Post fire response	Weir Neutron probe	RG 14 (70-99) RG 20 (85-95)	None	Weir down RG 20 down	Reinstate
V7H003 (70-72, 76-95)	Grassland	Small inlet to wetland on steep slope	Weir Rain gauge	RG 18 (76-95)	From grassland to market garden agriculture	All down	Reinstate

Table A.1b Monitored catchment evaluation for Cedara

CATCHMENT	LAND USE	PURPOSE	INSTRUMENT.	MET. STATION	LAND USE CHANGE	STATUS	DECISION
U2H016	Small scale agriculture and forest	Mixed agriculture Has small dam u/s of weir	Weir Rain gauges	MC 162 MC 164 MC 165	None expected	Running	Abandon
U2H018	Forest	Forest hydrology	Weir Rain gauge	MC 181 MC 182	None expected (some felling)	Weir up Rain gauges down	Abandon
U2H020	Grassland Old forest	Steep grassland	Weir Rain gauges	MC 191 MC 202	None expected	All up	Abandon
U2H017	Agriculture						Abandoned 1997

A.1.2 Catchment Monitoring (Helney Weir on Umsinduzi)

A useful period of monitoring at the Henley weir on the Umsinduzi river (U2H011) was conducted from 1994 to 1998, (Howe and Lorentz 1995; Howe 1998). These data included rainfall, runoff and flow related sediment, phosphorus and *E.coli* sampling. Unfortunately the data set is not continuous due to vandalism and instrumentation failures, however a useful set of events has been recorded. An extreme event during 1997 also inundated the recording house and the data for this event were, unfortunately, irrecoverable. Nevertheless, the remainder of the data set comprises an integrated response to forest, small scale cropping, formal and informal rural settlement land uses.

A.1.3 Current Catchment Monitoring

Catchments which are currently being monitored include the Weatherley research catchment in the North Eastern Cape Forest (NECF) development near Maclear, the Stanger catchment on rehabilitated sugar cane land, the research catchment W17 near the University of Zululand and the experimental farm catchment at Bach's Fen, Ntshongweni. A summary description of these catchments is presented in Table A.2. In addition, the SBEEH team collaborates in research being conducted by the CSIR at the Twin Streams research catchments, near Seven Oaks in the Natal Midlands. The research catchment at Weatherley, NECF, is described in detail in the Chapter 2 of this report and selected periods of the monitored record have been captured into the new database (Section A.2).

A.1.4 Current Local, Field and Hillslope Scale Monitoring

While all the current catchments being monitored include the observation of local and hillslope scale processes, there are a few locations where these processes are being observed without the integrated runoff measurements. The characteristics of these locations are summarised in Table A.3 and include hillslope transects in forested (Ben Vollich), stocked grassland (Kokstad), Phugwani (KNP), Roan (KNP), rehabilitated mine land (Kleinkopjes) and in an industrial waste impoundment (AECI, Umbogintwini).

Table A.2 Catchment scale monitoring status (December 2000)

CATCHMENT	LAND USE	PURPOSE	AREA (km^2)	INSTRUMENTATION	ESTABLISHMENT	STATUS
U2H011 (Henley Weir on Umsinduzi)	Mixed grassland, forest and semi-formal and formal agriculture	Sediment yield Topographic *ACRU* verification	178	Weir ISCO sampler Rain gauges	1994 - 1998 1994 - 1998 1995 - 1998	Complete Complete Complete
STANGER	Sugar cane	Sediment yield on rehabilitated sugar cane slopes	0.5	Parshall flume Sediment splitter Rain gauge	1996 - 1996 - 1996 -	On-going On-going On-going
WEATHERLEY: NECF	Grassland Afforestation: 2002	Hillslope hydrology Forest hydrology	1.5	Rain gauge Automatic tensiometers Man./Auto. g/w observation Neutron probe Met stations Nested crump weirs ISCO sampler d/s weir Runoff plots	1995 - 1996 - 1996 - 1995 - 1996 - 1998 - 2001 - 2001 -	On-going On-going On-going On-going On-going On-going On-going On-going
ZULULAND W17	Small scale cropping and grassland	Hillslope hydrology and sediment yield	0.7	V-notch compound weir Rain gauge Automatic tensiometers	1999 - 1999 - 1999 -	On-going On-going On-going
NTSHONGWENI	Small scale agriculture, grazing and wetland	Hillslope hydrology Small scale agriculture water use	0.1	V-notch compound weirs Rain gauge	1998 - 1998 -	On-going On-going

Table A.3 Local, field and hillslope scale monitoring status (December 2000)

CATCHMENT	LAND USE	PURPOSE	AREA	INSTRUMENTATION	ESTABLISHMENT	STATUS
BEN VOLLICH: NECF	Afforested (Pine): 1994	Forest hydrology on hillslopes	Hillslope transects	Neutron probe Automatic tensiometers	1996 - 1999 -	On-going On-going
KOKSTAD	Grassland trials	Sheep stocking rate effects on runoff and erosion	Hillslope camps	Runoff plots Rain gauge Automatic tensiometers	1999 - 1999 - 1999 -	On-going On-going On-going
KLEINKOPJE MINE (Tweefontein Pivot)	Rehabilitated mine land	Irrigation and runoff from rehabilitated mine land	30 ha centre pivot	Rain gauge Automatic tensiometers Heat dissipation sensors Time domain reflectometry Neutron probe	1998 - 2000 1998 - 2000 1998 - 2000 1998 - 2000 1998 - 2000	Complete Complete Complete Complete Complete
AECI	Industrial waste	Determine water balance	Local scale	Rain gauge Automatic tensiometers	2001 -	On-going
PHUGWANI: KNP	Natural	Determine water balance	Riparian transect	Automatic tensiometers	1999 -	On-going
ROAN: KNP	Natural	Determine water balance	Wetland transect	Rain gauge Automatic tensiometers	1999 -	On-going

A.2 Monitored Processes Database

The observation of hydrological processes is time consuming, frustrating and costly. In addition, cooperative research which would share these burdens is often difficult. Field studies and process observations are therefore not pursued by many institutions. It becomes increasingly important, therefore, that sound observation data sets are stored safely and are widely accessible to researchers and industry. A WDM - based interactive database has been developed using GenScn (USGS) software (WRC Report No 637/1/01). Since support for this system was considered difficult to obtain and the integration of data processing was required, a new in-house relational database system has been developed using a Microsoft Access as the database management system (DBMS) and standard Structured Query Language (SQL).

A.2.1 Database Summary (Meta Database)

A summary of the major data sets housed by the School of Bioresources Engineering and Environmental Hydrology, University of Natal, (SBEEH), is presented for catchment observations in Table A.4 and for local, field and hillslope scale observations in Table A.5. These summaries include the format in which the data are currently contained as well as an indication of which data sets have been installed into the old WDM database and which have been installed into the new relational database. This new relational database is continuously being updated.

A.2.2 The New Relational Database

Rainfall and runoff data collected by the SBEEH, has in the past been error checked and then stored in an ASCII based format called “agengfmt” (Schulze and Arnold, 1980). Due to the large amount of historical data stored in this format and the error checking procedures that the data goes through before being stored (WRC Report No 637/1/01), it was decided to extract the data at this point into the new system. Two conversion programs have been written for this purpose.

Table A.4 Monitored catchment data summary

CATCHMENT	RUNOFF and SAMPLING	RAINFALL	MET	SOIL WATER	SOIL PROPERTIES	GROUNDWATER	SURVEYS
Ntabamhlope/ De Hoek	V-notch compound ***MCS*** ***DB***	Automatic ***MCS*** ***DB***	1 station ***MCS*** ***DB***	Neutron probe ***Spreadsheet, ASCII***	U2H011 Hydraulic prop. ***Spreadsheet***	Historic and selected ***Reports***	Soils ***Report*** Topo ***GIS*** Land use ***GIS, DB***
Cedara	V-notch compound ***MCS***	Automatic ***MCS***	1 station ***MCS***	Neutron probe ***Reports, ASCII***			Soils ***Reports*** Topo ***Paper print*** Land use ***Paper print***
NECF Weatherley	2 nested crump weirs ***MCS, DB, RDB*** ISCO sampler (d/s) ***MCS, Spreadsheet***	3 Automatic ***MCS, DB, RDB***	2 stations ***MCS*** Bowen ratio ***CSIR***	20 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII, DB, RDB*** Neutron probe ***Spreadsheet, ASCII***	Hydraulic and physical ***Spreadsheet***	Auto. and manual ***Spreadsheet, RDB***	Soils ***Report, GIS*** Topo ***GIS*** Land use ***GIS***
Stanger	Parshall flume ***MCS*** Flow splitter/sump ***Spreadsheet***	Automatic ***MCS***			Selected hydraulic prop. ***Spreadsheet***		Topo ***Paper print*** Land use ***Paper print***
Ntshongweni	V-notch compound ***HOBO*** ***RDB***	Automatic ***MCS*** ***RDB***		(planned for 2002)	Selected hydraulic prop. ***Spreadsheet***	(planned for 2002)	Topo ***Paper print*** Land use ***Paper print***
Zululand W17	V-notch compound ***MCS, RDB*** ISCO sampler ***MCS, Spreadsheet***	Automatic ***MCS*** ***RDB***	U. Zululand ***Spreadsheet***	7 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII, RDB***	Hydraulic and physical ***Reports, Spreadsheet***		Soils ***Report, GIS*** Topo ***GIS*** Land use ***GIS***
Henley	Compound weir ISCO Sampler ***MCS***	3 Automatic ***MCS***					Soils ***GIS ISCW*** Topo ***GIS*** Land use ***GIS***

Table A.5 Monitored local scale data summary

LOCATION	RUNOFF and SAMPLING	RAINFALL	MET	SOIL WATER	SOIL PROPERTIES	GROUNDWATER	SURVEYS
NECF Ben Vollich		Automatic ***MCS***	1 station ***MCS***	12 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII*** Neutron probe ***Spreadsheet, ASCII***			Soils ***Report*** Topo ***Paper print*** Land use ***Paper print***
AECI		Automatic ***MCS***	1 station ***HOBO*** Bowen ratio ***CSIR***	4 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII*** 4 Advanced tensiometer nests ***HOBO, ASCII***	Hydraulic and physical ***Spreadsheet, report***		Soils ***Reports***
Kleinkopjes Mine: Tweefontein Pivot	Crump weir ***CS, Spreadsheet*** [1] Ion sampler ***CS, Spreadsheet*** [1]	Automatic ***CS*** [1]	1 station ***CS*** [1]	4 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII*** Neutron probe ***Spreadsheet, ASCII*** [1] Heat dissipation, TDR, ***CS*** [1]	Hydraulic and physical ***Spreadsheet***		Soils ***Report*** Topo ***Spreadsheet*** Land use ***Spreadsheet***
Kokstad	Tipping bucket: plots ***HOBO, Spreadsheet, RDB*** Flow splitter/sump ***Spreadsheet***	Automatic ***MCS, RDB***	1 station ***MCS*** [2]	3 Auto. tensiometer nests ***HOBO, Spreadsheet, ASCII, RDB***	Surface hydraulic ***Spreadsheet***		Soils ***GIS*** Topo ***GIS*** Land use ***Paper print***
KNP Phugwani				8 Auto. tensiometer nests ***HOBO, ASCII, RDB***	Hydraulic and physical ***Spreadsheet***		Hydraulic properties
KNP Roan		Automatic ***HOBO***		12 Auto. tensiometer nests ***HOBO, ASCII, RDB***	Hydraulic and physical ***Spreadsheet***		Hydraulic properties

MCS Mike Cotton logger system
HOBO SBEEH logger system
CS Campbell Scientific logger system
RDB Selected periods entered into the new relational database
DB Selected periods entered into old WDM database
[1] Data collected and housed by: Plant Production and Soil Science; U. of Pretoria
[2] Data collected and housed by: ARS, Cedara, KwaZulu-Natal
CSIR Collaborated research with CSIR

The objective during this contract was to transform these data into a more universal format and hence promote their usefulness and accessibility. The tensiometer data has been focused upon with regards to the relational database development as it was previously processed in spreadsheets, which had its limitations. The complexity of this data as well as the large amount of data being collected required a system that was dynamic and would allow for rapid recalculation of data.

A relational database structure has been adopted due to its flexibility and the use of SQL. This allows for the storage of raw data that are processed as retrieved according to the calibration values for site, location and date/time. Thus allowing recording instruments calibration values to change over time. Although the storage and processing of tensiometer data has been the focus, the nature of the data structure is that a vast number of different data sets can be accommodated including simulated data. The structure is presented in Figure A.1. Rainfall, runoff and ground water levels have already been incorporated. The runoff is stored as a stage and is converted to a flow using a rating table similar to that of the tensiometer data.

The data structure allows for the storage of both fixed time step, and breakpoint data. The data can then be grouped as required with the use of SQL. One of the main advantages of having the data in a relational database is that it is easily accessible and can be readily exported to other databases or formats. Data redundancy is also kept to a minimum. The wide use of relational database structure in Geographic Information Systems (GIS) also allows for the incorporation of spatial systems and data analysis. The spatial link for the Weatherly Catchment is presented in Figure A.2.

The new relational database and comprehensive manual is available for the Weatherley and Zululand catchments described in this report from:

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University of Natal
Box X01
Scottsville, 3209
South Africa

+27 33 2605701
+ 27 33 2605818 (fax)

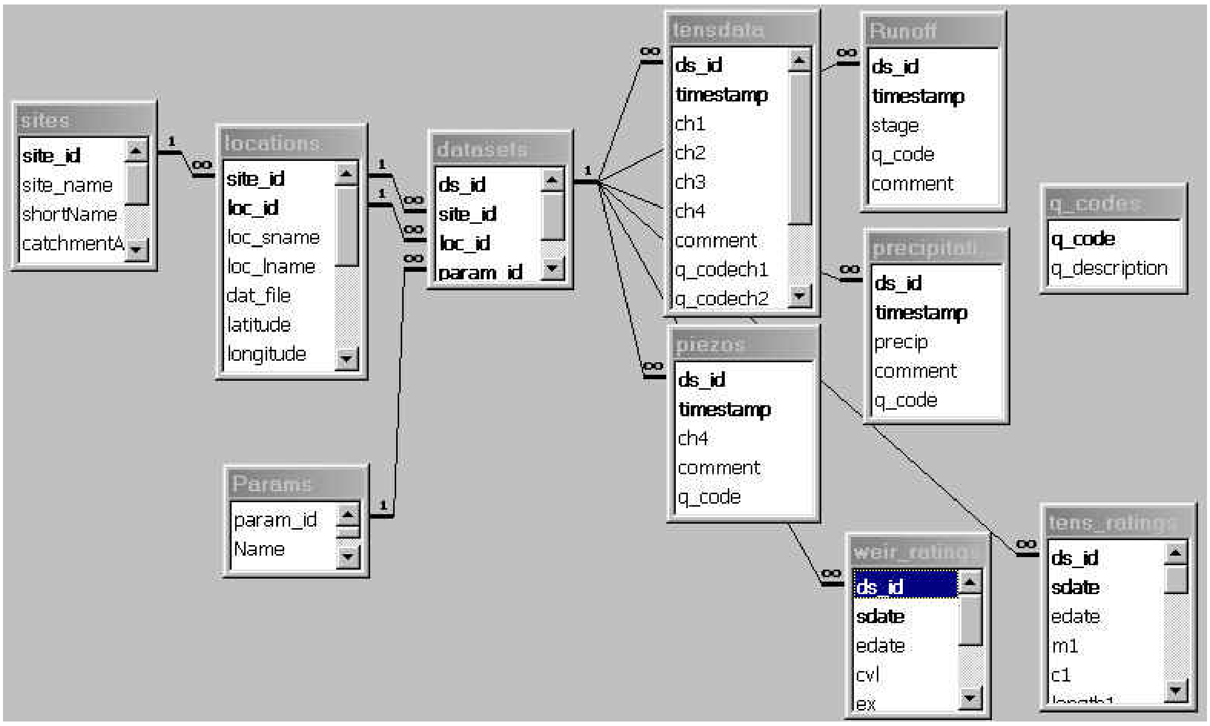

Figure A.1 Diagram showing the database relational structure

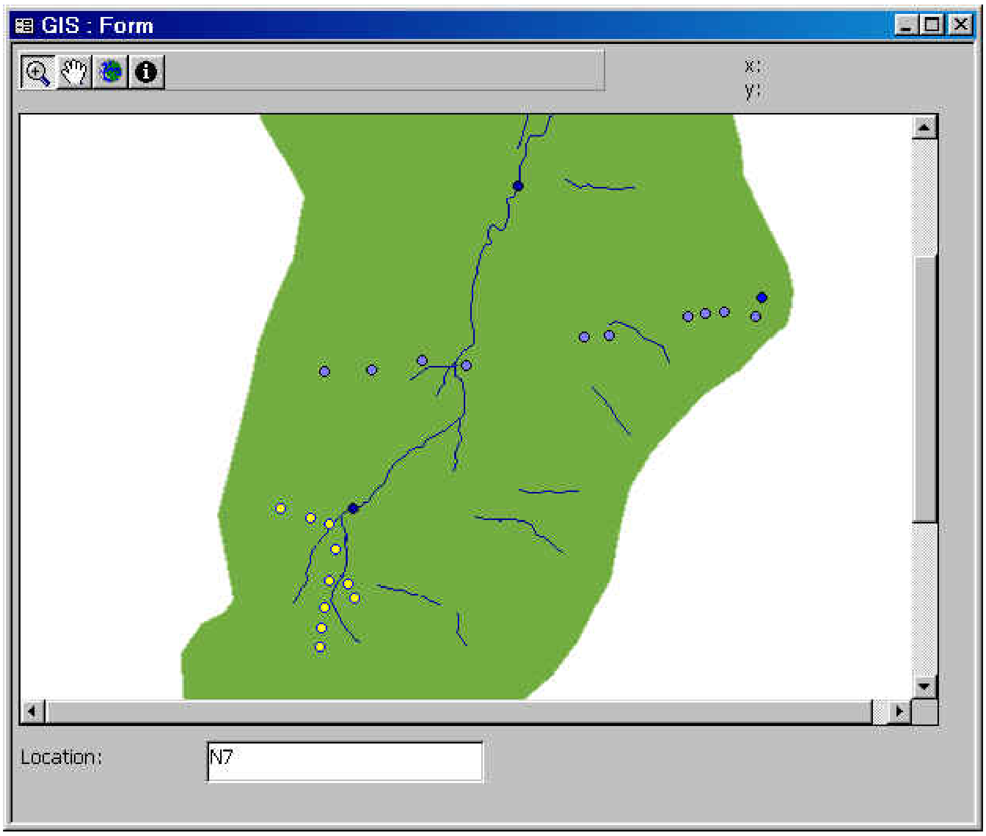

Figure A.2 Interactive GIS window for Weatherly catchment.

An example of the of a screen form the DBMS showing the selection of runoff and the subsequent graph generated is presented in Figure A.3. The data structure incorporates the use of quality code flags so as to enhance the value of the data. The data can be selected according to these flags. The tensiometer data error checking form is presented in Figure A.4 and a graphical output of tensiometer data together with accumulative breakpoint rainfall is presented in Figure A.5.

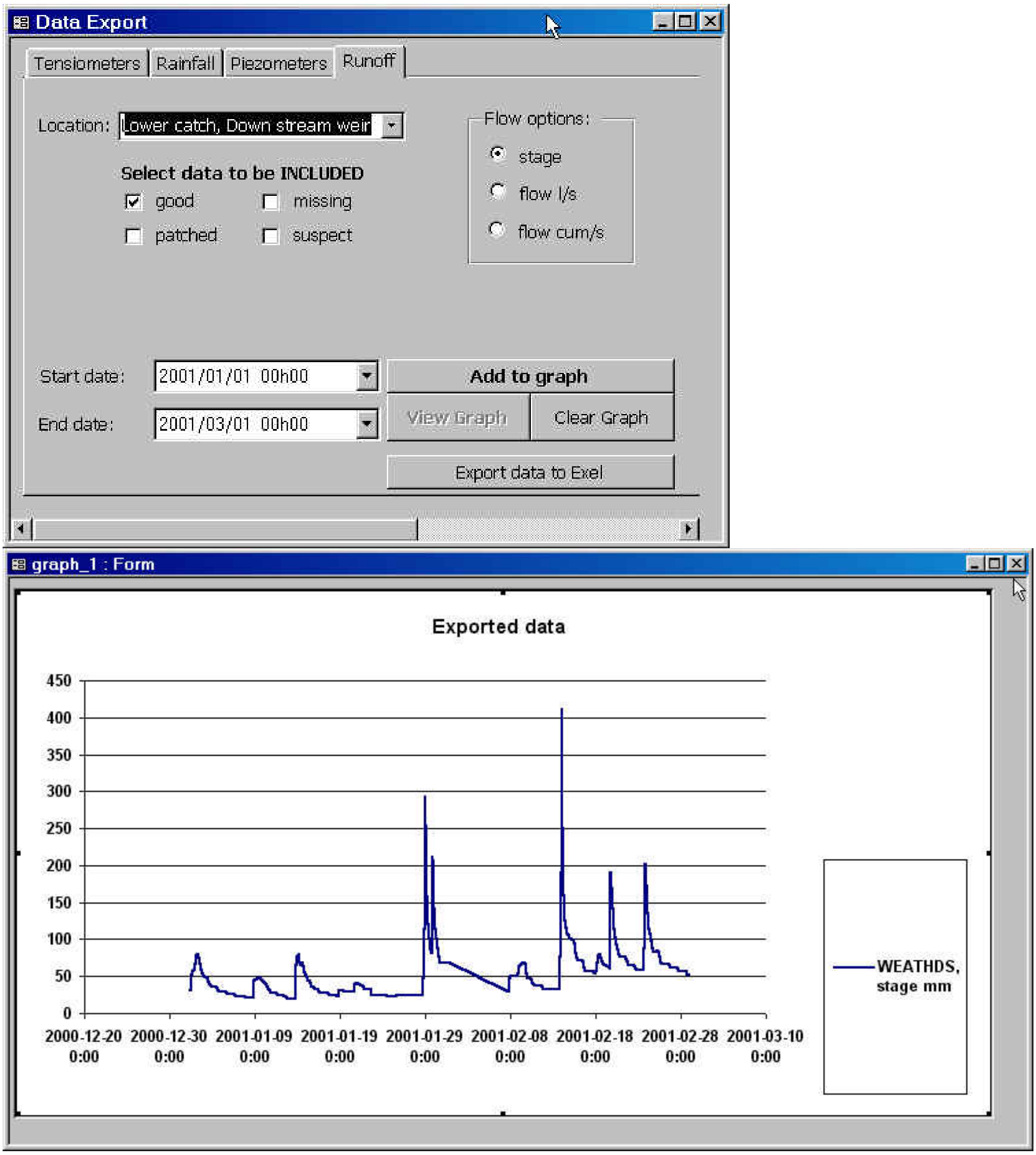

Figure A.3 Interactive screen for the export of runoff data.

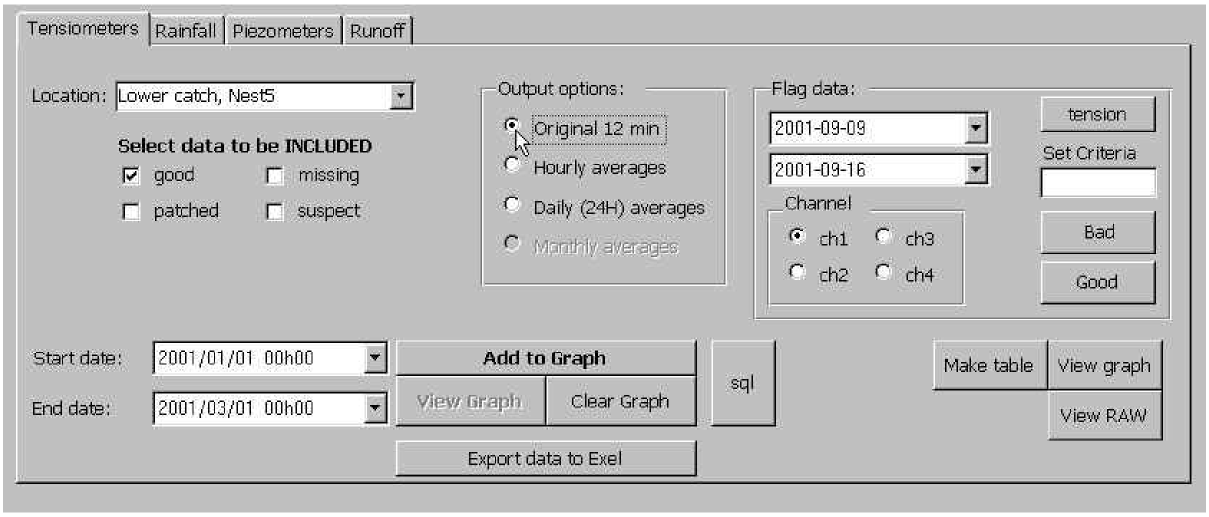

Figure A.4 Tensiometer data checking

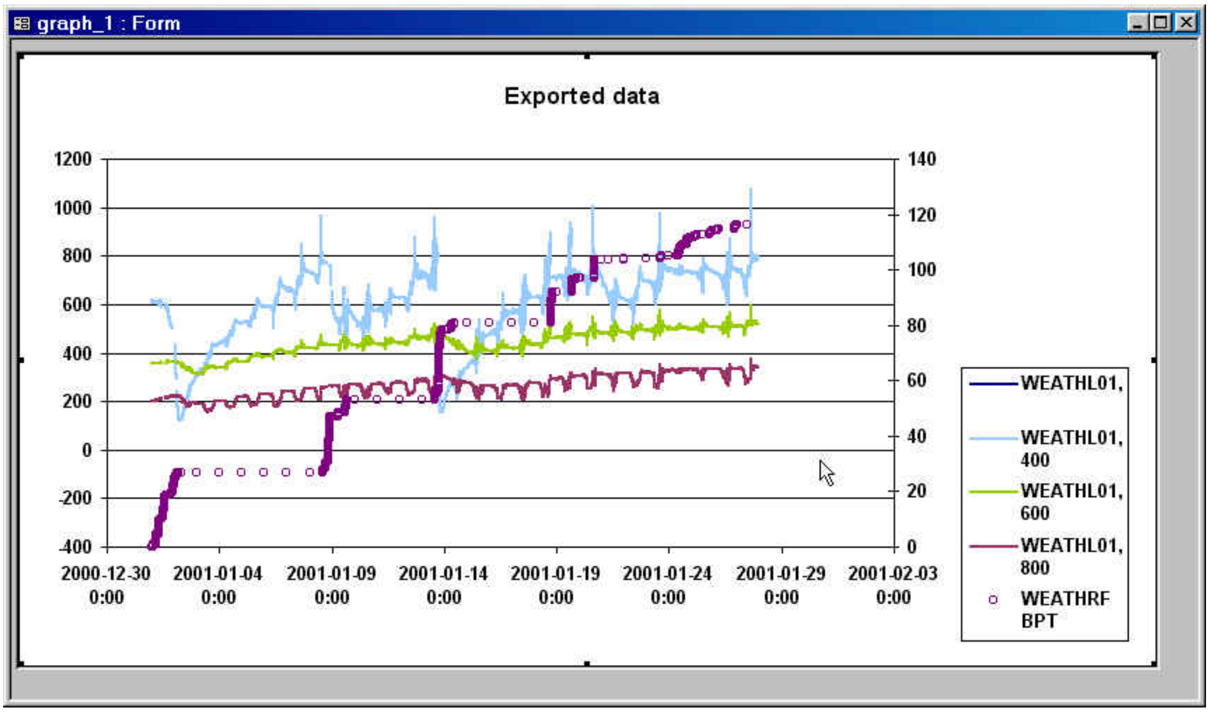

Figure A.5 Graphical output of both tensiometer and rainfall data

There is a separate database for each project. These could be linked though a common interface at any time. Some data analysis tools have been incorporated at this stage, one such feature comprises the ranking of tensiometer data and calculation of percentage exceedence values at specified thresholds. More analysis tools will be incorporated in the future. Already the ability to display tensiometer data for longer periods than “download to download” (usually one month) and the viewing of various parameter sets on the same axes is proving valuable insight into the hydrological processes.

Appendix B

Tensiometer Data for April 2001: Weatherley

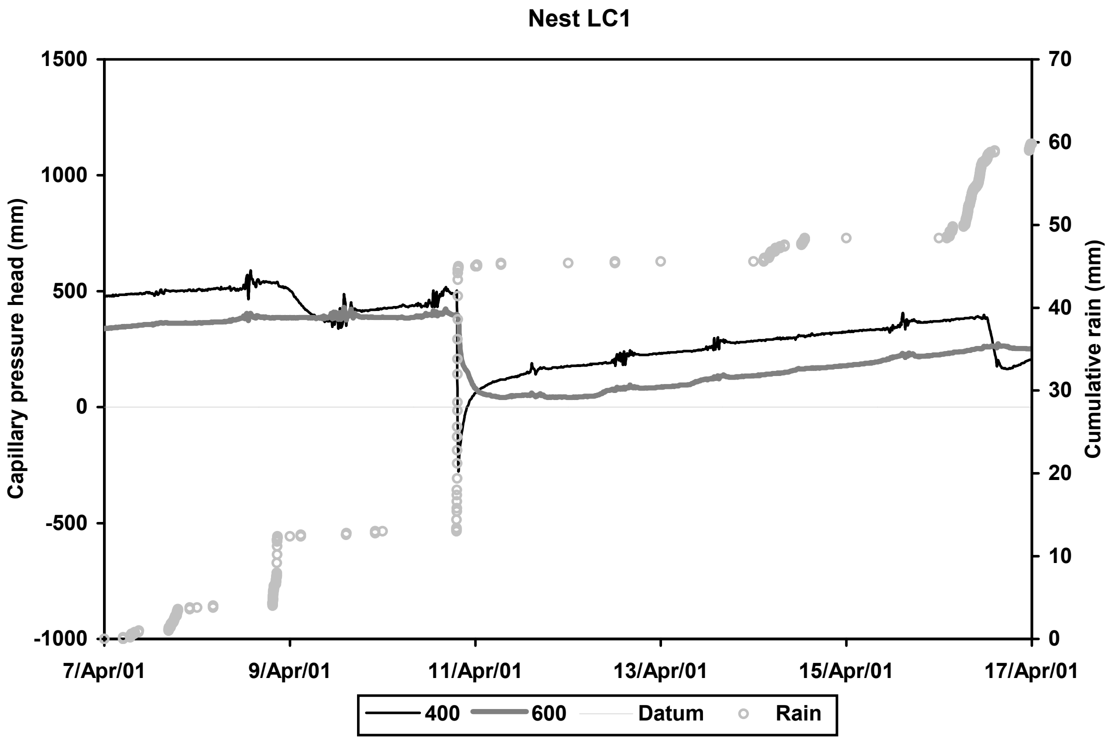

Figure B1 Tensiometer response at nest 1, lower catchment, during April 2001

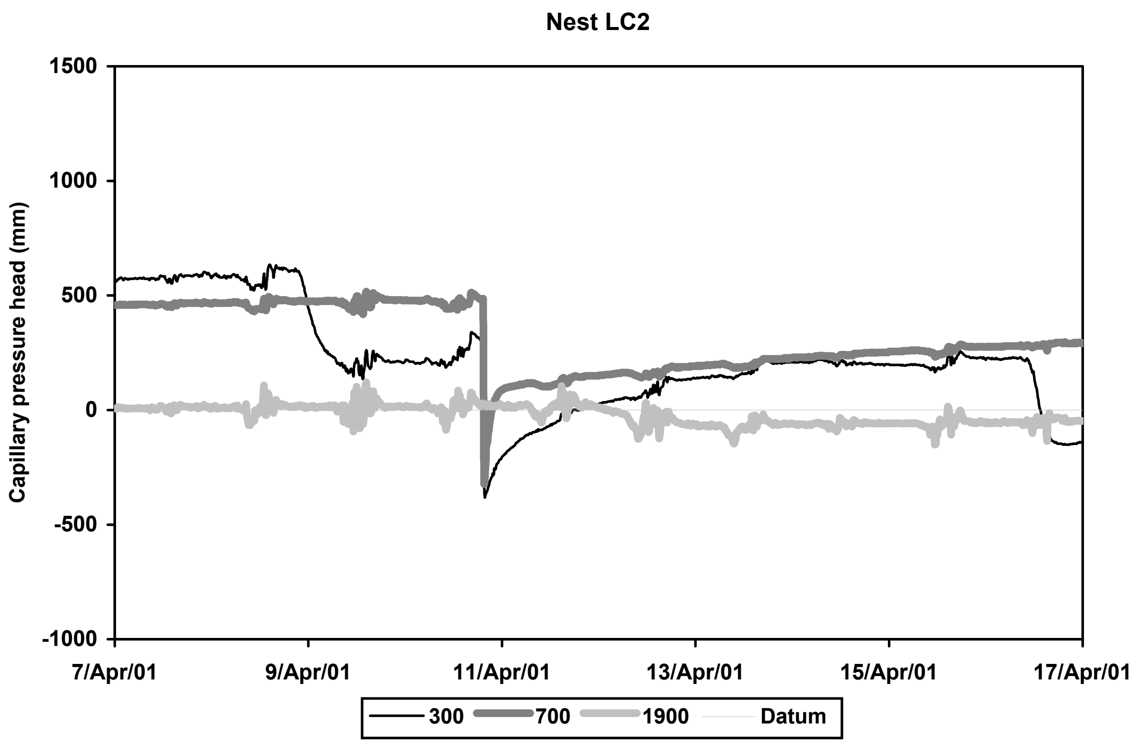

Figure B2 Tensiometer response at nest 2, lower catchment, during April 2001

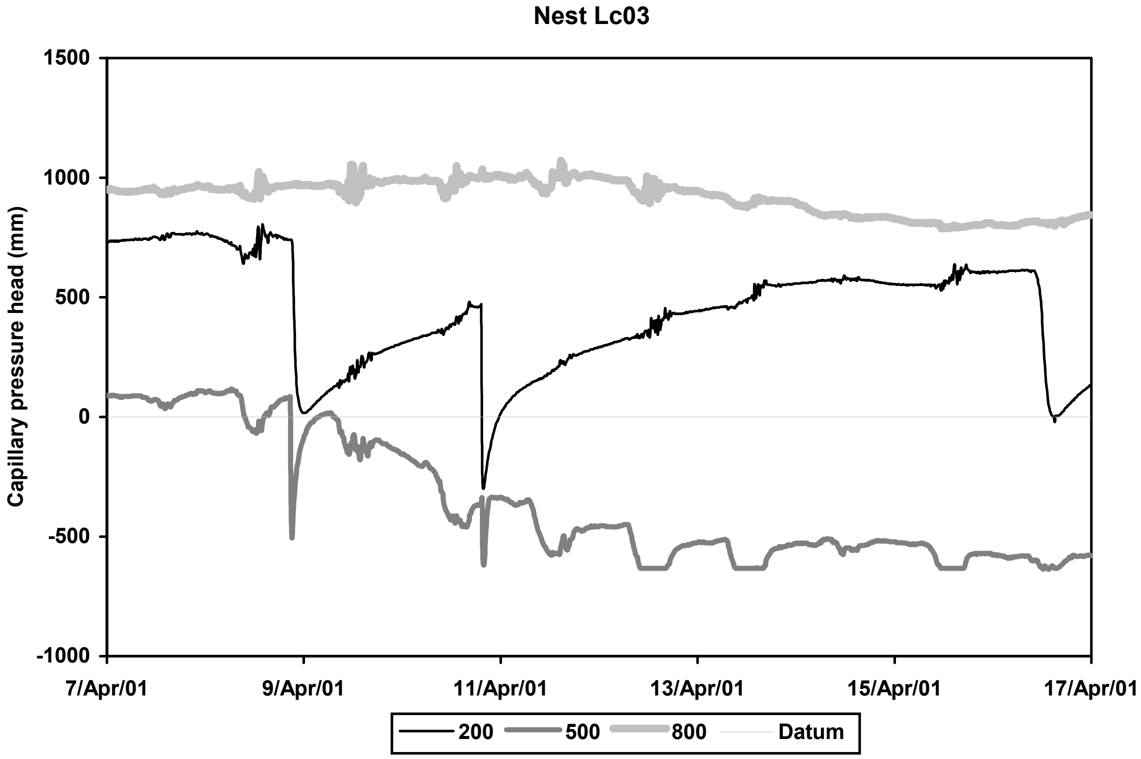

Figure B3 Tensiometer response at nest 3, lower catchment, during April 2001

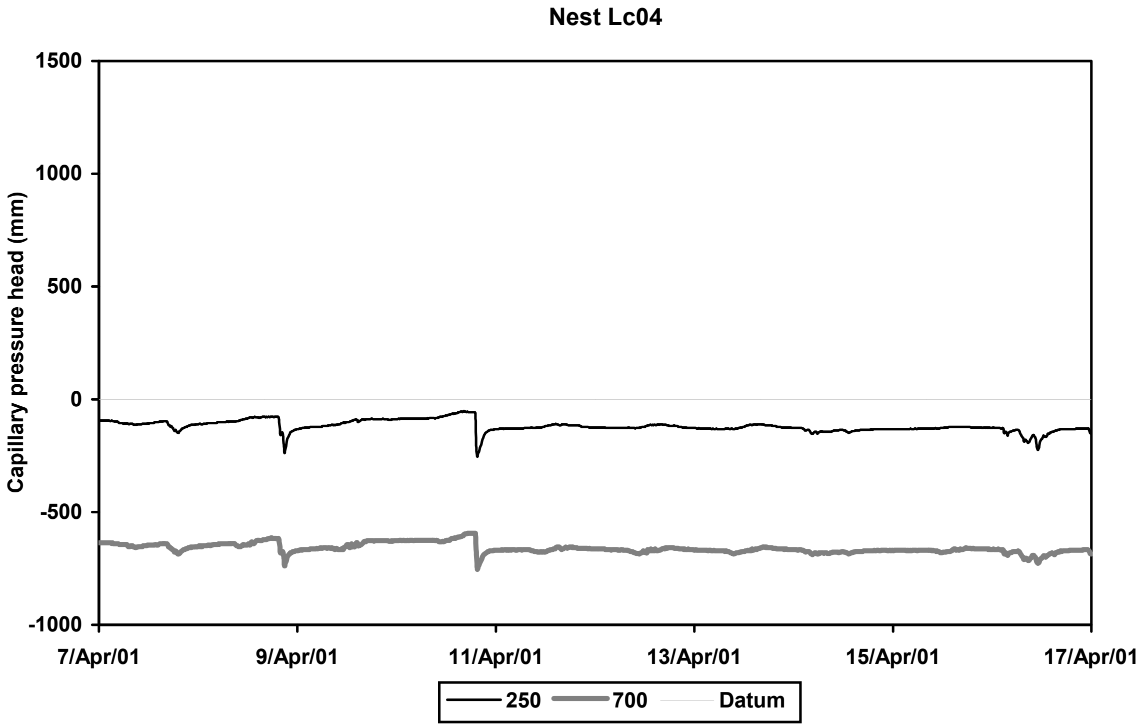

Figure B4 Tensiometer response at nest 4, lower catchment, during April 2001

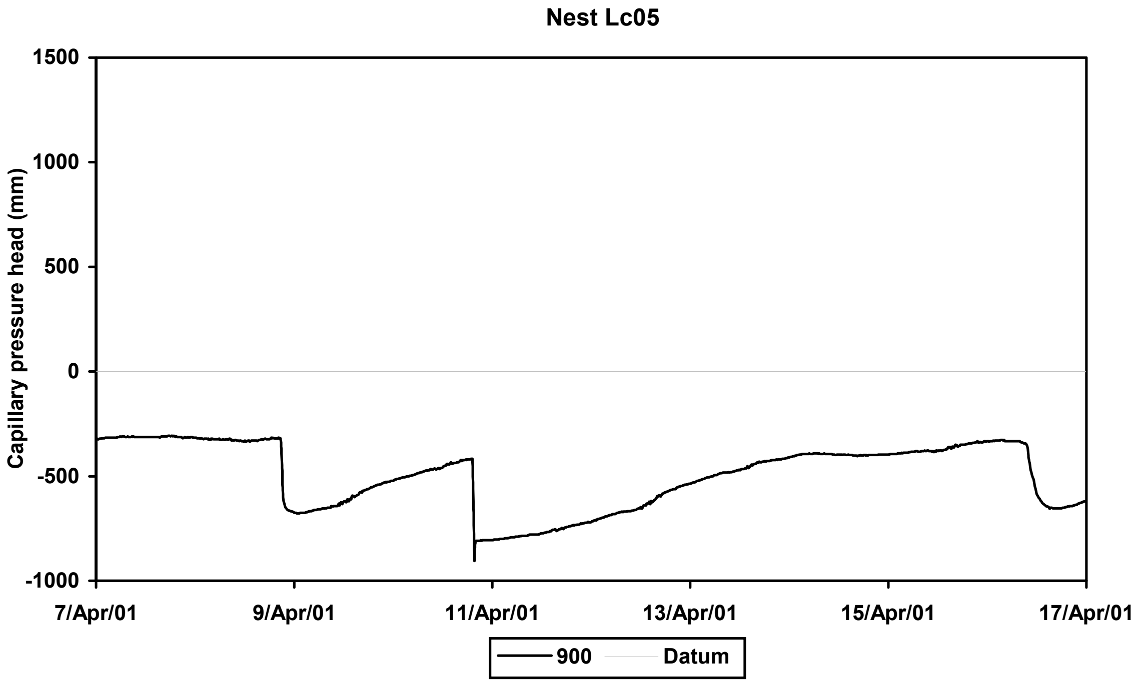

Figure B5 Tensiometer response at nest 5, lower catchment, during April 2001

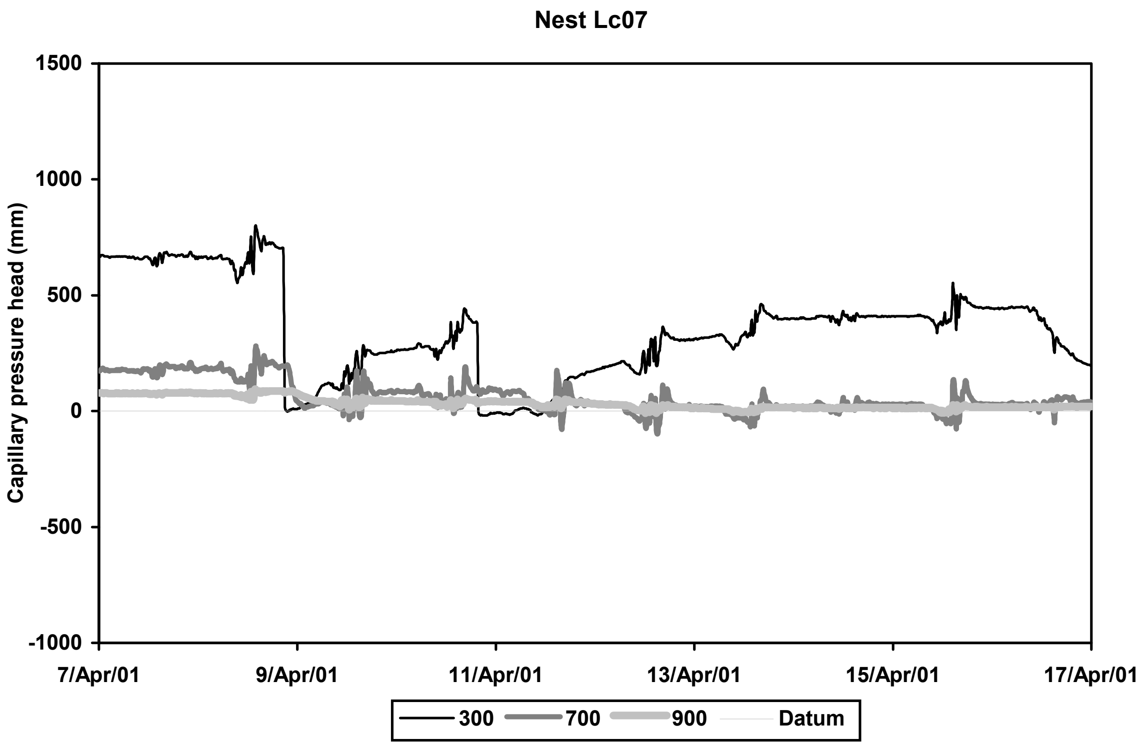

Figure B6 Tensiometer response at nest 7, lower catchment, during April 2001

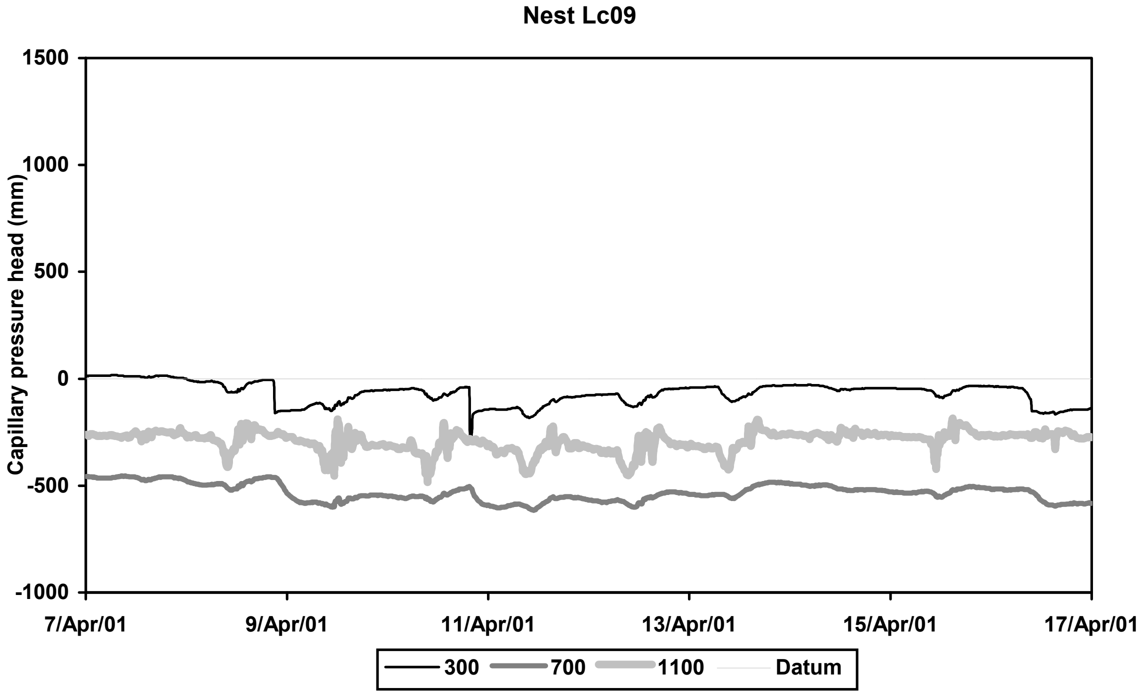

Figure B7 Tensiometer response at nest 9, lower catchment, during April 2001

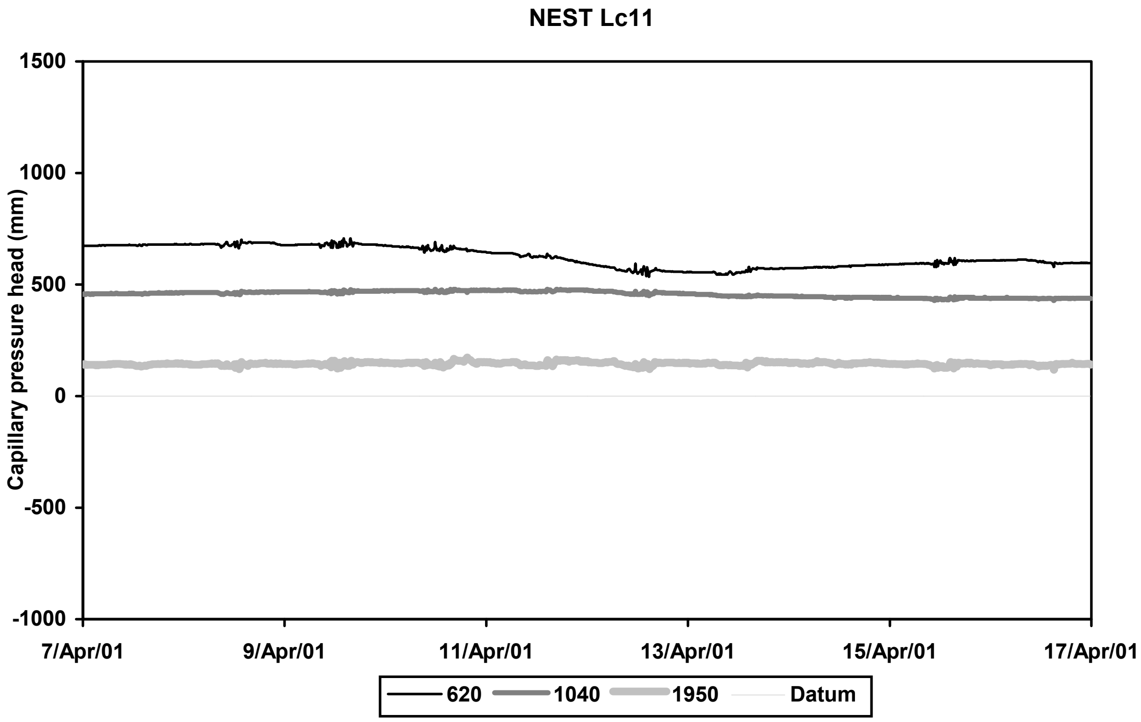

Figure B8 Tensiometer response at nest 11, lower catchment, during April 2001

Appendix C

Comparison of Measured Soil Water Content (NP) and Capillary Pressure Head (Tensiometer) Data

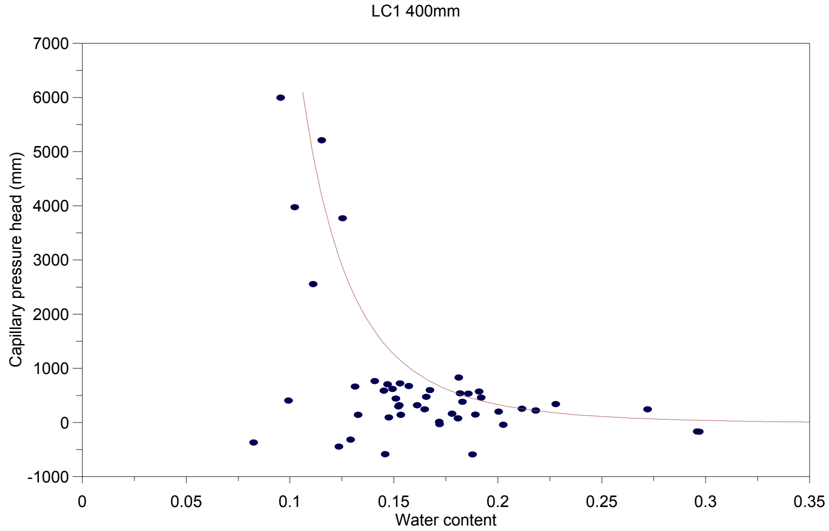

Figure C1 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 1 at 400mm showing curve fitted to laboratory data.

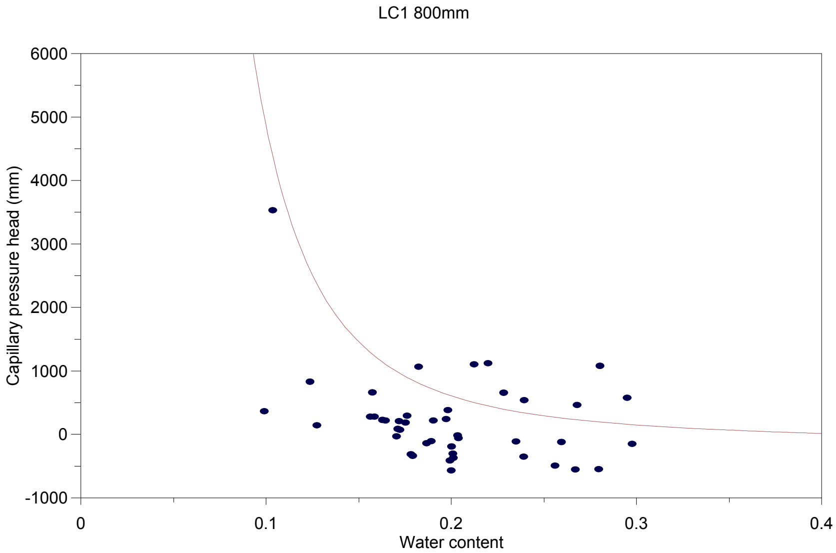

Figure C2 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 1 at 800mm showing curve fitted to laboratory data.

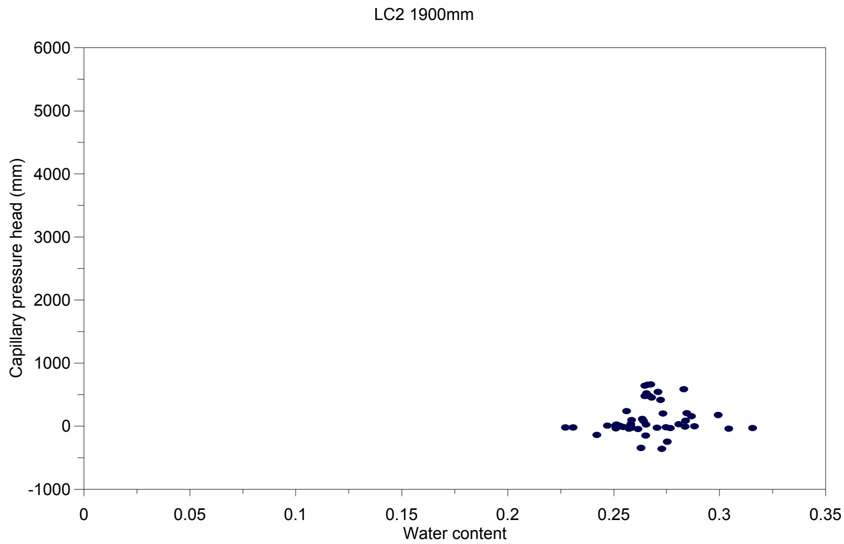

Figure C3 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 2 at 1900mm.

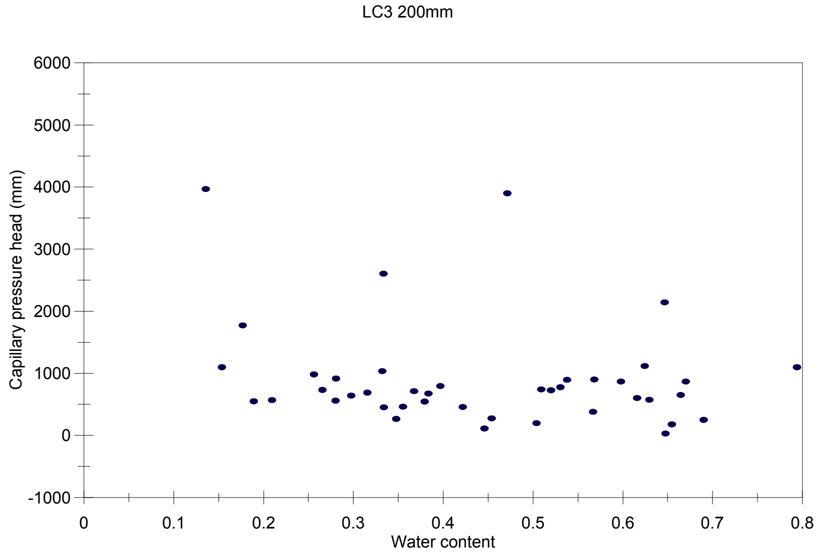

Figure C4 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 3 at 200mm.

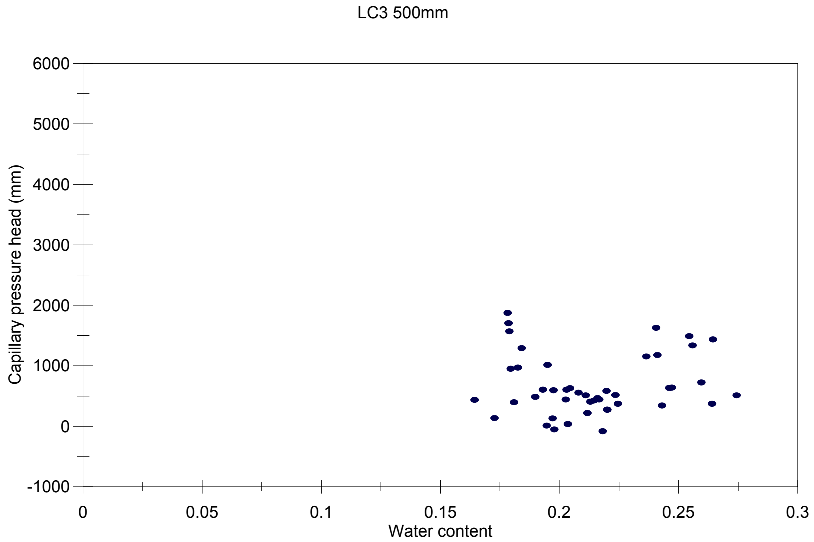

Figure C5 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 3 at 500mm.

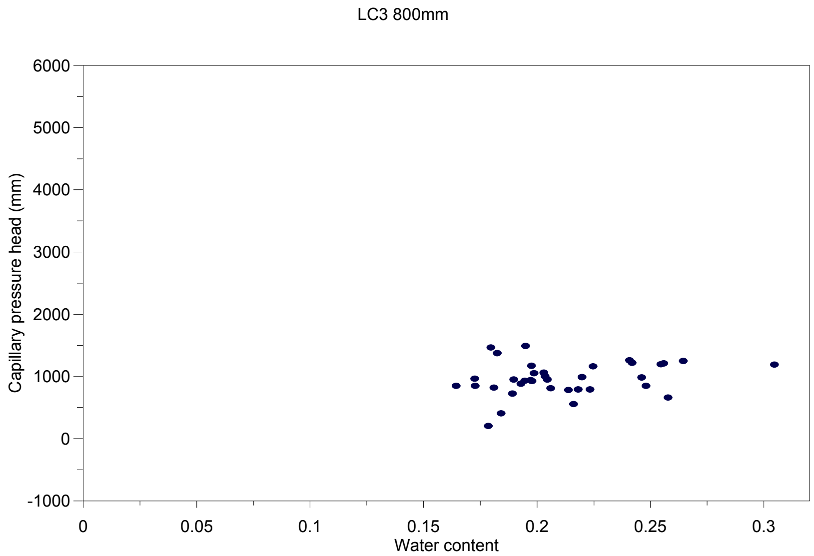

Figure C6 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 3 at 800mm.

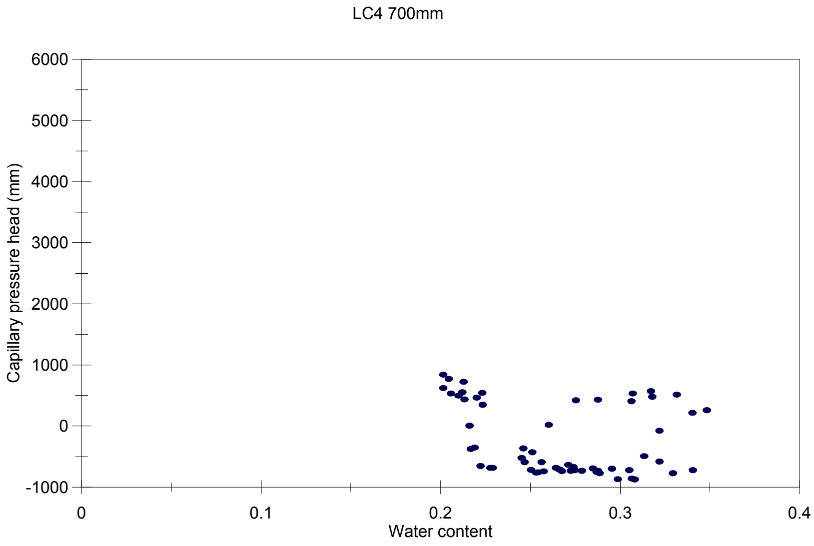

Figure C7 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 4 at 700mm.

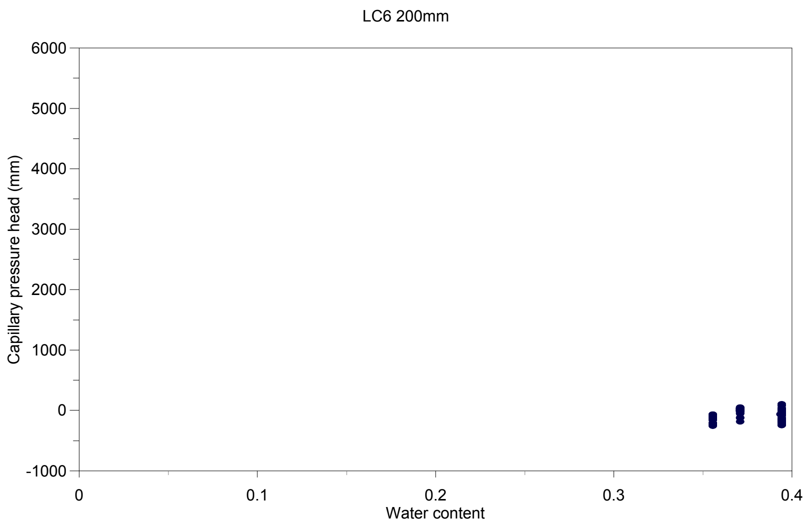

Figure C8 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 6 at 200mm.

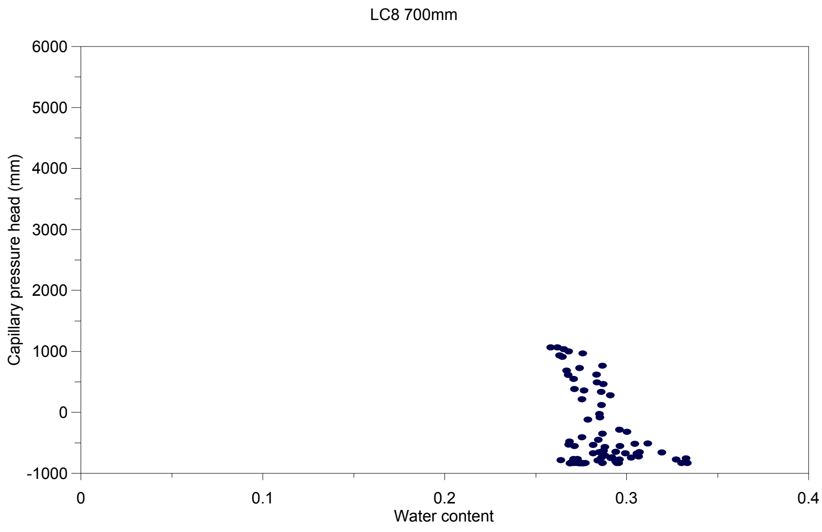

Figure C9 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 8 at 700mm.

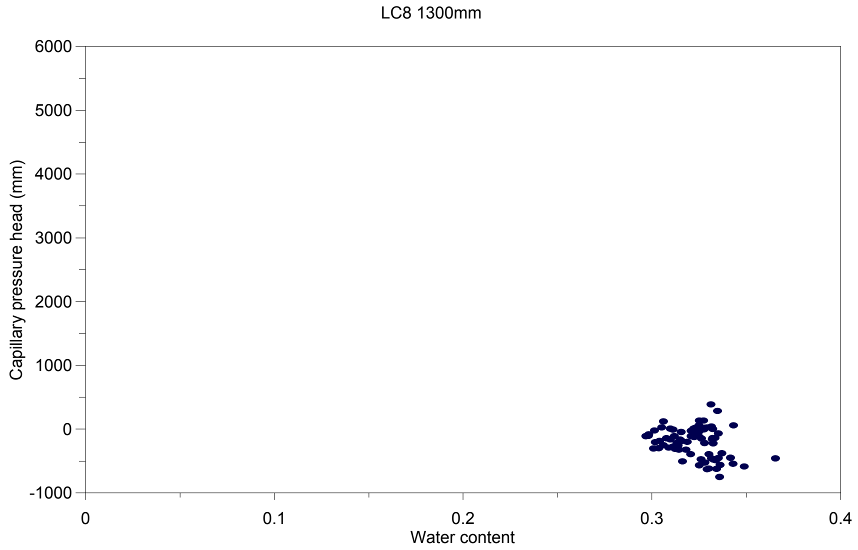

Figure C10 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 8 at 1300mm

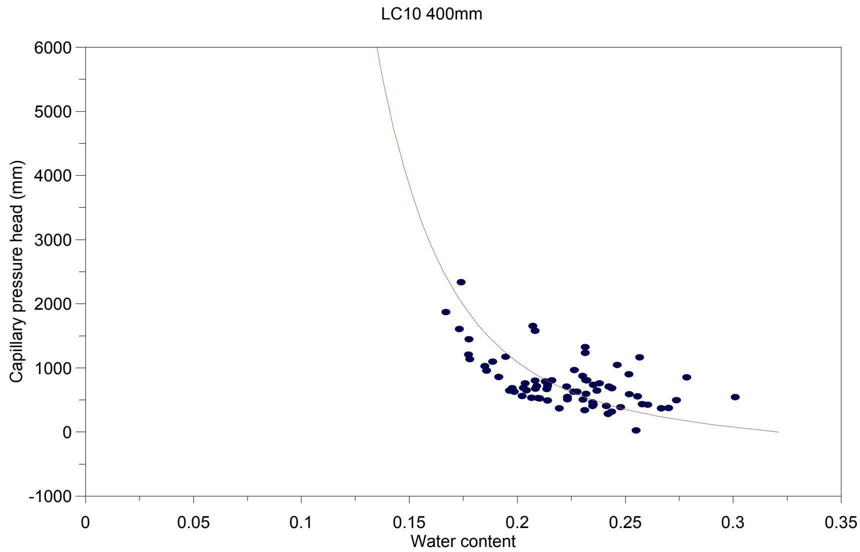

Figure C11 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 10 at 400mm showing curve fitted to laboratory data

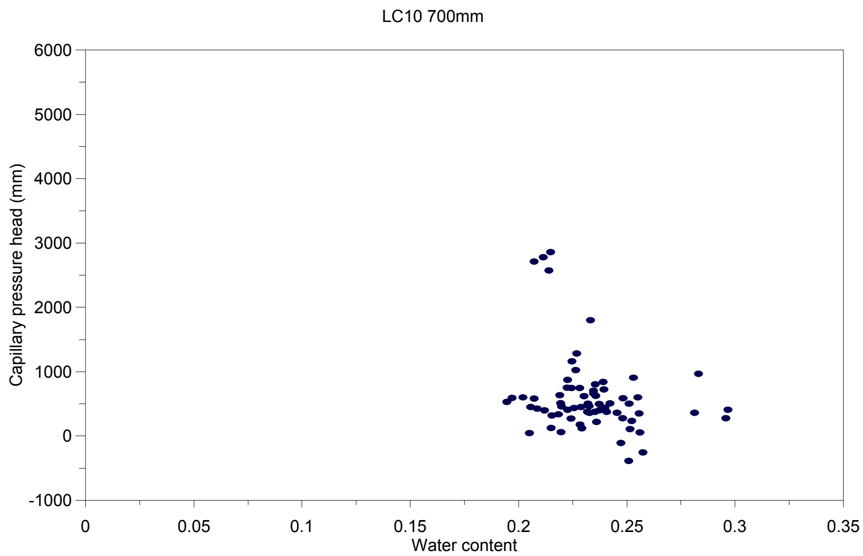

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Figure C12 Comparison of neutron probe (water content) and tensiometer (capillary pressure head) data for nest 10 at 700mm

Appendix D

In-situ and Laboratory Data of Soil Hydraulic Properties

Abbreviations:

Laboratory

Perm Ks	=	Saturated conductivity by laboratory permeameter
B-K D(θ)	=	Diffusivity vs water content by Bruce-Klute cell test
COC K(h)	=	Controlled Outflow Cell Hydraulic Conductivity Characteristic
COC h(θ)	=	Controlled Outflow Cell Water Retention Characteristic
BTC C(t)	=	Column Leach Test Break Through Characteristic
DUL	=	Drained Upper Limit at 0.1 bar of Water Retention Characteristic
WP	=	Wilting Point at 15 bar of Water Retention Characteristic

In-situ

K(h)	=	Unsaturated Hydraulic Conductivity By Tension Infiltrometer
Ks	=	Saturated Hydraulic Conductivity By Double Ring Infiltrometer
K(60)	=	Unsaturated Hydraulic Conductivity at 60mm Tension
K(150)	=	Unsaturated Hydraulic Conductivity at 150mm Tension

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
				Den.	Perm	B-K	COC	COC	BTC	K(h)	Ks
		(m)			Ks		K(h)	h(θ)	C(t)		
NECF	Avalon1100: Site LC1	0.00	y	y				y		y	y
	Avalon1100: Site LC1	0.30	y	y				y		y	y
	Avalon1100: Site LC1	0.50	y	y				y			
	Avalon1100: Site LC1	0.70	y								
	Avalon1100: Site LC1	0.90	y								
	Avalon1100: Site LC1	1.10	y								
	Pinedene1100: SiteLC2	0.00	y	y				y		y	y
	Pinedene1100: SiteLC2	0.20	y	y				y		y	y
	Pinedene1100: SiteLC2	0.40	y	y				y		y	y
	Pinedene1100: SiteLC2	0.60	y	y				y		y	y
	Pinedene1100: SiteLC2	0.80	y	y				y			
	Pinedene1100: SiteLC2	1.00	y	y				y			
	Pinedene1100: SiteLC2	1.40	y	y				y			
	Pinedene1100: SiteLC2	1.60	y								
	Pinedene1100: SiteLC2	1.80	y								
	Tukula2210: Site LC3	0.00	y							y	y
	Tukula2210: Site LC3	0.20	y							y	y
	Tukula2210: Site LC3	0.40	y								
	Tukula2210: Site LC3	0.50	y	y				y		y	y
	Tukula2210: Site LC3	0.70	y	y				y		y	y
	Tukula2210: Site LC3	1.00	y								
	Tukula2210: Site LC3	1.20	y								
	Tukula2210: Site LC3	1.50	y	y				y			
	Tukula2210: Site LC3	1.80	y								
	Tukula2210: Site LC3	2.10	y								
	Kroonstad2000: Site LC4	0.00	y							y	y
	Kroonstad2000: Site LC4	0.20	y	y				y		y	y
	Kroonstad2000: Site LC4	0.50	y	y				y		y	y
	Kroonstad2000: Site LC4	0.90	y								
	Kroonstad1000: Site LC7	0.00								y	y
	Kroonstad1000: Site LC7	0.20	y							y	y
	Kroonstad1000: Site LC7	0.80	y							y	y
	Kroonstad1000: Site LC7	2.00								y	y
	Katspruit1000: Site LC9	0.00								y	y
	Katspruit1000: Site LC9	0.20	y							y	
	Katspruit1000: Site LC9	0.80	y							y	
	Oakleaf2210: Site LC10	0.00								y	y
	Oakleaf2210: Site LC10	0.20	y							y	y
	Oakleaf2210: Site LC10	0.80	y							y	y
	Oakleaf2210: Site LC10	2.00								y	
	Site UC1	0.00								y	y
	Site UC1	0.20								y	y
	Site UC1	0.80								y	y
	Site UC1	2.00								y	y
	Site UC2	0.00								y	y
	Site UC2	0.20								y	y
	Site UC2	0.80								y	y

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
NECF	Katspruit1000: Site UC5	0.20	y	y				y		y	y
(cont.)	Katspruit1000: Site UC5	0.80	y	y				y			
	Katspruit1000: Site UC5	2.00									y
	Tukula2220: Site UC7	0.00								y	y
	Tukula2220: Site UC7	0.20	y	y						y	y
	Tukula2220: Site UC7	0.80	y	y						y	y
	Tukula2220: Site UC7	2.00								y	y
	Site UC8	0.00		y				y		y	y
	Site UC8	0.20		y				y		y	y
	Site UC8	0.80									y
	Site UC8	2.00									
	Oakleaf2120: Site UC9	0.00		y				y		y	y
	Oakleaf2120: Site UC9	0.20	y					y		y	y
	Oakleaf2120: Site UC9	0.80	y	y						y	y
	Oakleaf2120: Site UC9	2.00									y
De Hoek: V1H011	Clovelly 17 Site F1	0.00	y	y				y		y	y
	Clovelly 17 Site F1	0.25	y							y	
	Clovelly 17 Site F1	0.40	y								
	Clovelly 17 Site F1	0.60	y								
	Clovelly 17 Site F1	0.70	y								
	Clovelly 17 Site F1	0.00	y							y	y
	Clovelly 17 Site F1	0.25	y							y	
	Clovelly 17 Site F1	0.40	y								
	Clovelly 17 Site F2	0.60	y								
	Clovelly 17 Site F2	0.80	y								
	Clovelly 17 Site G1	0.00	y							y	y
	Clovelly 17 Site G1	0.30	y							y	
	Clovelly 17 Site G1	0.50	y								
	Clovelly 17 Site G1	0.70	y								
	Clovelly 17 Site G2	0.00	y							y	y
	Clovelly 17 Site G2	0.30	y							y	
	Clovelly 17 Site G2	0.50	y								
	Clovelly 17 Site G2	0.70	y								
	Clovelly 17 Site J1	0.00	y							y	y
	Clovelly 17 Site J1	0.30	y								
	Clovelly 17 Site J1	0.50	y								
	Clovelly 17 Site J1	0.70	y								
	Clovelly 17 Site S1	0.00	y							y	y
	Clovelly 17 Site S1	0.30	y								
	Clovelly 17 Site S1	0.50	y								
	Clovelly 17 Site S1	0.70	y								
	Kroonstad 10 Site H1	0.00	y							y	y
	Kroonstad 10 Site H1	0.30	y								
	Kroonstad 10 Site H1	0.50	y								
	Kroonstad 10 Site H1	0.70	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
De Hoek: V1H011	Kroonstad 10 Site H2	0.00	y							y	y
(cont.)	Kroonstad 10 Site H2	0.30	y								
	Kroonstad 10 Site H2	0.50	y								
	Kroonstad 10 Site H2	0.70	y								
	Clovelly 13 Site K1	0.00	y							y	y
	Clovelly 13 Site K1	0.30	y								
	Clovelly 13 Site K1	0.50	y								
	Clovelly 13 Site K1	0.70	y								
	Clovelly 13 Site K2	0.00								y	y
	Clovelly 17 Site L1	0.00								y	y
	Clovelly 17 Site L2	0.00								y	y
	Longlands 21 Site M1	0.00	y							y	y
	Longlands 21 Site M1	0.30	y								
	Clovelly 17 Site N2	0.00								y	y
	Avalon 26 Site P1	0.00	y							y	y
	Avalon 26 Site P1	0.30	y								
	Avalon 26 Site P1	0.50	y								
	Avalon 26 Site P1	0.70	y								
	Longlands 21 Site T1	0.00	y							y	y
	Longlands 21 Site T1	0.30	y								
	Longlands 21 Site T1	0.50	y								
	Longlands 21 Site T1	0.70	y								
	Clovelly 18 Site U1	0.00	y							y	y
	Clovelly 18 Site U1	0.30	y								
	Clovelly 18 Site U1	0.50	y								
	Clovelly 18 Site U1	0.70	y								
	Clovelly 38 Site X1	0.00								y	y
	Clovelly 38 Site X2	0.00								y	y
Cathedral Peak	Lysimeter site: downslope	0.00								y	y
	Lysimeter site: downslope	0.10	y	y						y	y
	Lysimeter site: downslope	0.30								y	y
Ntabamhlope	Wetland	0.00		y				y			
	Wetland	0.38		y				y			
	Wetland	0.78		y				y			
Wastech	Orange Bimodal sand			y				y			
	White sand			y				y			
Sabie: CSIR	Hutton: Frankfurt Upper 1	0.00								y	y
	Hutton: Frankfurt Upper 1	0.25	y	y						y	y

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
				Den.	Perm	B-K	COC	COC	BTC	K(h)	Ks
		(m)			Ks	D(θ)	K(h)	h(θ)	C(t)		
Sabie: CSIR	Hutton: Frankfurt Upper 1	0.60								y	y
(cont.)	Hutton: Frankfurt Upper 1	0.75	y	y							
	Hutton: Frankfurt Upper 1	0.90								y	y
	Hutton: Frankfurt Upper 1	1.50	y	y						y	y
	Hutton: Frankfurt Upper 1	3.00	y	y							
	Hutton: Frankfurt Upper 2	1.50	y	y							
	Hutton: Frankfurt Upper 2	3.00	y	y							
	Hutton: Frankfurt Upper 2	5.00	y	y							
	Hutton: Frankfurt Upper 3	0.25	y	y							
	Hutton: Frankfurt Upper 3	0.75	y	y							
	Hutton: Frankfurt Lower 1	0.00								y	y
	Hutton: Frankfurt Lower 1	0.25	y	y						y	y
	Hutton: Frankfurt Lower 1	0.60		y						y	y
	Hutton: Frankfurt Lower 1	0.75	y								
	Hutton: Frankfurt Lower 1	0.90								y	y
	Hutton: Frankfurt Lower 1	1.50	y	y				y		y	y
	Hutton: Frankfurt Lower 1	3.00	y	y							
	Hutton: Frankfurt Lower 1	5.00	y	y							
	Hutton: Frankfurt Lower 2	0.25	y	y							
	Hutton: Frankfurt Lower 2	0.75	y	y							
	Hutton: Frankfurt Lower 2	1.50	y	y							
	Hutton: Frankfurt Lower 2	3.00	y	y							
	Hutton: Frankfurt Lower 2	5.00	y	y							
	Hutton: Frankfurt Lower 3	0.25	y	y							
	Hutton: Frankfurt Lower 3	0.75	y								
	Hutton: Frankfurt Lower 3	1.50	y	y							
	Hutton: Frankfurt Lower 3	3.00	y	y							
	Hutton: Frankfurt Lower 3	5.00	y	y							
	Legogotte 1	0.00								y	y
	Legogotte 1	0.25	y	y						y	y
	Legogotte 1	0.75	y	y							
	Legogotte 1	0.90						y		y	y
	Legogotte 1	1.50	y	y				y		y	y
	Legogotte 1	3.00	y	y							
	Legogotte 1	5.00	y	y							
	Legogotte 2	0.25	y	y							
	Legogotte 2	0.75	y	y							
	Legogotte 2	1.50	y	y							
	Legogotte 2	3.00	y	y							
	Legogotte 2	5.00	y	y							
	Legogotte 3	0.25	y	y							

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
Sabie: CSIR (cont.)	Legogotte 3	0.75	y	y							
	Legogotte 3	1.50	y	y							
	Legogotte 3	3.00	y	y							
	Legogotte 3	5.00	y	y							
	Strand (50)	0.08								y	
	Strand (1)	0.50								y	
	Strand (9)	0.90								y	
	G R	0.50								y	
	R (forest)	0.50								y	
	R Forest	0.10								y	
	Grass	10								y	
	Grass	30								y	
	Forest R	0.30								y	
	Forest A	0.50								y	
	Forest R	0.70								y	
Kleinkopjes	Pivot Major (Ave 35 reps)	0.00								y	
	Major: Field Capacity	0.05		y				y		y	y
	Major: Field Capacity	0.55								y	y
	Major: Field Capacity	0.85		y		y		y		y	y
	Jacuzzi: Deficit	0.55								y	y
	Jacuzzi: Deficit	0.85								y	y
	Jacuzzi: Deficit - Spoil	1.20		y		y		y		y	y
	Jacuzzi: Leach Fraction	0.00								y	y
	Jacuzzi: Leach Fraction	0.15								y	y
	Jacuzzi: Leach Fraction	0.85								y	y
	Jacuzzi: Field Capacity	0.00		y		y		y		y	
	Jacuzzi: Field Capacity	0.05								y	
	Jacuzzi: Field Capacity	0.15								y	y
	Jacuzzi: Field Capacity	Spoil		y				y			
	Pivot Four	0.25							y		
	Tweefontein FC	0.00				y		y		y	y
	Tweefontein FC	0.55								y	y
	Tweefontein FC	0.75								y	y
BCL mine	Alluvium: Site 1	0.00						y		y	y
	Alluvium: Site 1	0.20						y		y	
	Alluvium: Site 1	1.50						y		y	

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
BCL mine	Hutton: Site 3	0.00						y		y	y
(cont.)	Hutton: Site 3	0.61								y	
	Hutton: Site 4	1.20								y	
	Hutton: Site 6	0.00	y								
	Hutton: Site 6	1.20	y					y			
	Hutton: Site 7	0.00	y					y		y	y
	Hutton: Site 7	0.20	y					y		y	
Richards Bay	Engineered cap	0.00		y						y	y
	Engineered cap	0.25		y						y	y
	Sample 1	0.25							y		
	Sample 2	0.25							y		
	Sample 3	0.25							y		
	Sample 4	0.25						y	y		
SASEX	Fernwood 1	0.25	y	y		y		y			
	Fernwood 2	0.25	y	y		y		y			
	Fernwood 3	0.25	y	y		y		y			
	Swartland 1	0.25	y	y		y		y			
	Swartland 2	0.25	y	y		y		y			
	Swartland 3	0.25	y	y		y		y			
	Hutton	0.25	y	y		y		y			
	Profile Yvonne: A Horizon		y								
	Profile Yvonne: B Horizon		y								
	Profile Yvonne: BSw Horizon		y								
	Profile Yvonne: Csd/sw Horizon		y								
	Profile Vicky: A Horizon		y								
	Profile Vicky: B Horizon		y								
	Profile Genovetta: Bs Horizon		y								
Sabie: Witklip	Hutton Crest: Site A	0.00	y	y				y			
	Hutton Crest: Site A	0.25	y								
	Hutton Crest: Site A	0.50	y								
	Hutton Crest: Site A	0.75	y	y				y			
	Hutton Crest: Site A	1.00	y								
	Hutton Crest: Site A	1.50	y	y				y			
	Hutton Crest: Site A	2.00	y								
	Hutton Crest: Site A	2.50	y	y				y			
	Hutton Midslope: Site C2	0.00	y								
	Hutton Midslope: Site C2	0.25	y								
	Hutton Midslope: Site C2	0.50	y								
	Hutton Midslope: Site C2	0.75	y								
	Hutton Midslope: Site C2	1.00	y	y		y		y			
	Hutton Midslope: Site C2	1.50	y								
	Hutton Midslope: Site C2	2.00	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk Density	Laboratory					In-situ	
		(m)			Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
Sabie: Witklip (cont.)	Hutton Midslope: Site C2	2.50	y	y		y		y			
	Hutton Forested: Site F1	0.00		y				y			
	Riparian: Site R1	0.00		y				y			
	Riparian: Site R1	1.00		y				y			
Willowfontein	Market garden profile 1	0.00		y				y		y	y
	Market garden profile 1	0.30		y						y	y
	Market garden profile 1	0.75		y				y		y	y
	Market garden profile 1	1.30		y				y		y	y
Taylors Halt	Market garden profile 1	0.00		y				y		y	y
	Market garden profile 1	0.89		y				y		y	y
	Market garden profile 1	1.06		y				y		y	y
Kruger National Park	Nwarhlangari: Site 1	0.00								y	
	Nwarhlangari: Site 1	0.15	y					y		y	
	Nwarhlangari: Site 1	0.35								y	
	Nwarhlangari: Site 1	0.65								y	
	Nwarhlangari: Site 2	0.00								y	
	Nwarhlangari: Site 2	0.35	y							y	y
	Nwarhlangari: Site 3	0.35								y	y
	Nwarhlangari: Site 3	0.50								y	y
	Nwarhlangari: Site 4	0.00									
	Nwarhlangari: Site 4	0.15									
	Nwarhlangari: Site 4	0.35	y					y			
	Nwarhlangari: Site 4	0.60	y					y			
	Nwarhlangari: Site 5	0.00	y	y				y			
	Nwarhlangari: Site 5	1.10	y					y			
	Phugwane 2: Site 1	0.00								y	y
	Phugwane 2: Site 1	0.20								y	y
	Phugwane 2: Site 1	0.50								y	
	Phugwane 2: Site 1	1.00								y	y
	Phugwane 2: Site 2	0.00								y	
	Phugwane 2: Site 2	0.20								y	
	Phugwane 2: Site 2	0.50								y	y
	Phugwane 2: Site 2	1.00								y	y
	Phugwane 2: Site 2	1.80								y	y
	Phugwane 2: Site 2	1.90								y	y
	Phugwane 2: Site 2	2.00								y	y
	Phugwane 2: Site 3	0.00								y	y
	Phugwane 2: Site 4	0.00								y	y
Forest/Grassland *	Clovelly1100: Eucalypt	0.00	y	y				y		y	y

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk Density	Laboratory					In-situ	
		(m)			Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
Forest/Grassland * (cont.)	Clovelly1100: Grass	0.00	y	y				y		y	y
	Kranskop1100: Eucalypt C.P	0.00	y	y				y		y	y
	Kranskop1100: Grass C.P	0.00	y	y				y		y	y
	Inanda1100: Eucalypt	0.00	y	y				y		y	y
Portnet	Marine sand	0.18	y	y			y	y		y	y
	Marine sand	0.68	y							y	
	Inanda1100: Grass	0.00	y	y				y		y	y
	Kranskop1100: Eucalypt	0.00	y	y				y		y	y
	Kranskop1100: Grass	0.00	y	y				y		y	y
	Wasbank1000: Eucalypt	0.00	y	y				y		y	y
	Wasbank1000: Grass	0.00	y	y				y		y	y
Seven Oaks Nursery	Bark chips growing medium	0.00		y	y			y			
SASOL	Rensburg: Grass site	0.10		y				y			
	Rensburg: Grass site	0.30						y			
	Rensburg: Grass site	0.50									
	Arcadia: Forest site	0.00								y	
	Arcadia: Forest site	0.30						y		y	
Newcastle	Coal discard: Uncompacted	0.00	y	y			y	y		y	y
	Coal discard: Compacted	0.00	y	y				y		y	y
	Coal discard: Uncompacted	0.00	y	y			y	y		y	y
	Avalon soil: Uncompacted	0.30	y	y			y	y		y	y
	Avalon soil: Compacted	0.50	y	y				y		y	y
	Estcourt soil: Compacted	0.70	y	y				y		y	y
	Avalon soil: Compacted	0.70	y	y			y	y		y	y
	Avalon soil: Uncompacted	0.70	y	y				y		y	y
KwaMbonambi	CII 1	0.00								y	
		0.50								y	
		1.00		y						y	
		1.50		y						y	
		2.00								y	
		2.50		y						y	
		3.00								y	
		3.50								y	
		4.00								y	
		2-3	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth (m)	Tex.	Bulk Density	Laboratory Perm Ks	Laboratory B-K D(θ)	Laboratory COC K(h)	Laboratory COC h(θ)	Laboratory BTC C(t)	In-situ K(h)	In-situ Ks
KwaMbonambi	CII 1	3- 4	y								
(cont.)		4- 5	y								
		7- 8	y								
		8- 9	y								
	CII 2	0.00	y	y						y	
		0.50		y						y	
		1.00								y	
		1.50		y						y	
		2.20								y	
		2.50								y	
		3.1		y						y	
		3.50								y	
		4.00								y	
		4.50		y						y	
		5.00								y	
		5.50								y	
		6.00		y						y	
		6.50		y						y	
		0- 1	y								
		1- 2	y								
		2- 3	y								
		3- 4	y								
		4- 5	y								
		6-7	y								
		7- 8	y								
		8- 9	y								
		9- 10	y								
		10- 11	y								
		11- 12	y								
		12- 13	y								
		15- 16	y								
		16- 17	y								
		18- 19	y								
		20- 21	y								
		21- 22	y								
		22- 23	y								
		23- 24	y								
		24- 25	y								
		25-26	y								
		26- 27	y								
		27- 28	y								
		28-29	y								
		29-30	y								
		31-10c	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk Density	Laboratory					In-situ	
					Perm	B-K	COC	COC	BTC	K(h)	Ks
		(m)			Ks	D(θ)	K(h)	h(θ)	C(t)		
KwaMbonambi	CII 3	0.00									
(cont.)		0.50									
		1.00		y							
		1.50									
		2.00		y							
		2.50									
		3.00		y							
		3.50		y							
		0- 1	y								
		1-2	y								
		2- 3	y								
		3- 4	y								
		4- 5	y								
		5- 6	y								
		6- 7	y								
		7- 8	y								
		8- 9	y								
		9- 10	y								
		10-11	y								
		11- 12	y								
		12- 13	y								
		13- 14	y								
		14- 15	y								
		17-18	y								
		19- 20	y								
	CII 4	0.00		y							
		0.70									
		1.00		y							
		1.50		y							
		2.80									
		3.00		y							
		3.50									
		4.00		y							
		4.50		y							
		5.00		y							
		5.50		y							
		6.00		y							
		6.50		y							
		0- 1	y								
		1-2	y								
		2- 3	y								
		3- 4	y								
		4- 5	y								
		5- 6	y								
		7- 8	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth (m)	Tex.	Bulk Den.	Laboratory					In-situ	
					Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
KwaMbonambi (cont.)	CII 4	8- 9	y								
		10-11	y								
		11- 12	y								
		12- 13	y								
		13- 14	y								
		14- 15	y								
		15- 16	y								
		16- 17	y								
		17- 18	y								
		18- 19	y								
		19- 20	y								
	CII 5	0.00		y							
		0.70									
		1.30									
		1.70									
		2.00		y							
		2.50		y							
		3.00		y							
		3.50		y							
		4.00		y							
		4.50		y							
		4.70		y							
		5.00		y							
		5.50		y							
		1- 2	y								
		2- 3	y								
		4- 5	y								
		5- 6	y								
		6- 7	y								
		8- 9	y								
		11- 12	y								
		12- 13	y								
		13- 14	y								
		14- 15	y								
	CII 6	0- 1	y								
		1- 2	y								
		2- 3	y								
		3- 4	y								
		5- 6	y								
		7- 8	y								
		8- 9	y								
		9 – 10	y								

List of Soil Characteristics Measurements

PROJECT	DESCRIPTOR	Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
KwaMbonambi	CII 6	10- 11	y								
(cont.)		11- 12	y								
		12- 13	y								
		13- 14	y								
		15- 16	y								
	CII 7	0		y						y	
		0.50		y						y	
		1.10		y						y	
		2- 3	y								
		4- 5	y								
		5- 6	y								
		6- 7	y								
		7- 8	y								
		8- 9	y								
		9- 10	y								
		10- 11	y								
		13- 14	y								
		14- 15	y								
		15- 16	y								
		16- 17	y								
		17- 18	y								
	CII 8	0.00		y						y	
		0.60								y	
		1.00		y						y	
		1.50								y	
		2.00		y						y	
		2.50		y						y	
		3.00		y						y	
		3.50								y	
		4.10		y						y	
		4.50								y	
		5.00								y	
		5.50								y	
		6.00		y						y	
		6.00								y	
		0- 1	y								
		1- 2	y								
		2- 3	y								
		3- 4	y								
		5- 6	y								
		6- 7	y								
		8- 9	y								
		11- 12	y								
		13- 14	y								
		14- 15	y								

List of Soil Characteristics Measurements

PROJECT		Depth	Tex.	Bulk	Laboratory					In-situ	
		(m)		Den.	Perm Ks	B-K D(θ)	COC K(h)	COC h(θ)	BTC C(t)	K(h)	Ks
KwaMbonambi		15- 16	y								
(cont.)		17- 18									
	CII 9	0		y							
		0.50		y							
		1.00									
		1.50		y							
		2.10		y							
		2.50		y							
		3.00		y							
		3.50		y							
		4.00		y							
Muden	Block 6 (nest2)	0(2)		y			y			y	y
	Block 6 (nest2)	0 (1)		y			y			y	y
	Block 6 (nest3)	0.58		y			y			y	y
Fernwood			y				y				
Mngeni Sand			y				y				
AECI	Bugweed	0.5		y			y				
	Fig	0		y			y				
		0.25		y			y				
		1		y			y				
		2		y			y				
	Grass	0		y			y				
		0.5		y			y				
		2		y			y				

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth	Texture	Density	Porosity	DUL	WP	Ks	Ks	K(60)	K(150)
		m		kg/m3	m/m	m/m	m/m	mm/h	mm/h	mm/h	mm/h
NECF	Avalon1100: Site LC1	0.00	SaLm	1436	0.458	0.280	0.160		367.56	1.24	0.20
	Avalon1100: Site LC1	0.30	SaLm	1640	0.381	0.200	0.090		1054.80	0.66	0.11
	Avalon1100: Site LC1	0.50	SaLm	1585	0.402	0.220	0.100				
	Avalon1100: Site LC1	0.70	SaLm								
	Avalon1100: Site LC1	0.90	SaLm								
	Avalon1100: Site LC1	1.10	SaLm								
	Pinedene1100: SiteLC2	0.00	SaLm	1746	0.341	0.240	0.050		388.08	2.20	0.75
	Pinedene1100: SiteLC2	0.20	SaLm	1672	0.369	0.209	0.088		39.68	1.85	
	Pinedene1100: SiteLC2	0.40	SaLm	1757	0.337	0.260	0.140		39.68	61.19	11.19
	Pinedene1100: SiteLC2	0.60	SaLm	1775	0.330	0.200	0.050				
	Pinedene1100: SiteLC2	0.80	SaLm	1850	0.302	0.213	0.048				
	Pinedene1100: SiteLC2	1.00	SaLm	1850	0.302	0.213	0.048				
	Pinedene1100: SiteLC2	1.40	SiClLm	1842	0.305						
	Pinedene1100: SiteLC2	1.60	SiClLm								
	Pinedene1100: SiteLC2	1.80	SiClLm								
	Tukula2210: Site LC3	0.00	Lm						329.40	6.48	1.05
	Tukula2210: Site LC3	0.20	SaLm						39.68	3.58	1.28
	Tukula2210: Site LC3	0.40	Lm								
	Tukula2210: Site LC3	0.50	SaLm	1791	0.324	0.210	0.020		39.68	0.72	0.29
	Tukula2210: Site LC3	0.70	SaLm	1760	0.336	0.226	0.030				
	Tukula2210: Site LC3	1.00	SaLm								
	Tukula2210: Site LC3	1.20	SaLm								
	Tukula2210: Site LC3	1.50	Lm	1871	0.294	0.252	0.095				
	Tukula2210: Site LC3	1.80	SaLm								
	Tukula2210: Site LC3	2.10	ClLm								
	Kroonstad2000: Site LC4	0.00	SaLm						292.41	15.38	4.61
	Kroonstad2000: Site LC4	0.20	Lm	1892	0.286	0.244	0.050			10.68	2.29
	Kroonstad2000: Site LC4	0.50	Lm	1717	0.352	0.224	0.100			5.92	1.29
	Kroonstad2000: Site LC4	0.90	SiCl								
	Kroonstad1000: Site LC7	0.00							6.65	1.40	0.10
	Kroonstad1000: Site LC7	0.20	SiLm						0.40	0.43	
	Kroonstad1000: Site LC7	0.80	ClLm						0.11	0.27	0.04
	Katspruit1000: Site LC9	0.00							1.99	0.12	0.01
	Katspruit1000: Site LC9	0.20	Lm							0.60	0.23
	Katspruit1000: Site LC9	0.80	Lm							1.03	0.14
	Oakleaf2210: Site LC10	0.00							1.65	1.43	0.66
	Oakleaf2210: Site LC10	0.20	SaLm						1.38	1.24	0.27
	Oakleaf2210: Site LC10	0.80	SaClLm						5.21	1.10	0.20
	Oakleaf2210: Site LC10	2.00							0.11		
	Site UC1	0.00							3.18	0.00	0.00
	Site UC1	0.20							5.88	1.37	0.74
	Site UC1	0.80							11.39	8.01	2.52
	Site UC1	2.00							0.42	0.90	0.12
	Site UC2	0.00							7.79	4.24	0.99
	Site UC2	0.20							0.55	0.09	0.00
	Site UC2	0.80							18.80	0.42	0.26
	Site UC2	2.00							0.48	0.53	0.12
	Katspruit1000: Site UC4	0.00		1410	0.468	0.350					
	Katspruit1000: Site UC4	0.20	ClLm	1516	0.428	0.362					
	Katspruit1000: Site UC5	0.00							16.78	1.09	0.31
	Katspruit1000: Site UC5	0.20	Lm	1712	0.354	0.251			7.81	0.46	0.18
	Katspruit1000: Site UC5	0.80	Lm	1720	0.351	0.280					
	Katspruit1000: Site UC5	2.00							0.13		
	Tukula2220: Site UC7	0.00							6.89	1.93	0.26

Soil Characteristics Data

PROJECT	DESCRIPTOR	Depth m	LABORATORY Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	IN-SITU Ks mm/h	K(60) mm/h	K(150) mm/h
NECF	Tukula2220: Site UC7	0.20	SaLm						5.29	1.87	0.74
(cont.)	Tukula2220: Site UC7	0.80	SaLm						18.72	3.48	0.76
	Tukula2220: Site UC7	2.00							1.10	0.36	0.18
	Site UC8	0.00		1680	0.366	0.300			5.25	3.99	0.98
	Site UC8	0.20		1799	0.321	0.260			5.71	0.50	0.22
	Site UC8	0.80							5.28		
	Oakleaf2120: Site UC9	0.00		1818	0.314	0.313			6.12	3.07	0.66
	Oakleaf2120: Site UC9	0.20	Lm						2.30	0.36	0.26
	Oakleaf2120: Site UC9	0.80	Cl	1410	0.468	0.347			11.32	4.35	1.22
	Oakleaf2120: Site UC9	2.00							0.26		
De Hoek:	Clovelly 17 Site F1	0.00	ClLm	1378	0.480	0.330	0.200		41.04	3.96	0.35
V1H028	Clovelly 17 Site F1	0.25	Lm						41.63	15.72	
	Clovelly 17 Site F1	0.40	ClLm								
	Clovelly 17 Site F1	0.60	ClLm								
	Clovelly 17 Site F1	0.70	ClLm								
	Clovelly 17 Site F2	0.00	Lm						53.05	6.67	0.73
	Clovelly 17 Site F2	0.25	ClLm						41.63	9.41	
	Clovelly 17 Site F2	0.40	ClLm								
	Clovelly 17 Site F2	0.60	ClLm								
	Clovelly 17 Site F2	0.80	ClLm								
	Clovelly 17 Site G1	0.00	Lm						40.63	4.68	0.40
	Clovelly 17 Site G1	0.30	Lm								
	Clovelly 17 Site G1	0.50	Lm								
	Clovelly 17 Site G1	0.70	Lm								
	Clovelly 17 Site G2	0.00	Lm						40.63	5.80	
	Clovelly 17 Site G2	0.30	Lm							29.36	
	Clovelly 17 Site G2	0.50	Lm								
	Clovelly 17 Site G2	0.70	ClLm								
	Clovelly 17 Site J1	0.00	ClLm								
	Clovelly 17 Site J1	0.30	ClLm								
	Clovelly 17 Site J1	0.50	ClLm								
	Clovelly 17 Site J1	0.70	ClLm								
	Clovelly 17 Site S1	0.00	ClLm						6.18	4.81	
	Clovelly 17 Site S1	0.30	ClLm								
	Clovelly 17 Site S1	0.50	Cl								
	Clovelly 17 Site S1	0.70	ClLm								
	Kroonstad 10 Site H1	0.00	Lm						48.76	11.75	
	Kroonstad 10 Site H1	0.30	Lm								
	Kroonstad 10 Site H1	0.50	Lm								
	Kroonstad 10 Site H1	0.70	ClLm								
	Kroonstad 10 Site H2	0.00	Lm						199.77	26.33	2.73
	Kroonstad 10 Site H2	0.30	Lm								
	Kroonstad 10 Site H2	0.50	Lm								
	Kroonstad 10 Site H2	0.70	Lm								
	Clovelly 38 Site I1	0.00	Cl						68.02	4.35	0.95
	Clovelly 38 Site I1	0.30	Cl								
	Clovelly 38 Site I1	0.50	Cl								
	Clovelly 38 Site I1	0.70	Cl								
	Clovelly 13 Site K1	0.00	ClLm						348.66	3.24	

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth	Texture	Density	Porosity	DUL	WP	Ks	Ks	K(60)	K(150)
		m		kg/m3	m/m	m/m	m/m	mm/h	mm/h	mm/h	mm/h
De Hoek:	Clovelly 13 Site K1	0.30	ClLm								
V1H028	Clovelly 13 Site K1	0.50	ClLm								
(cont.)	Clovelly 13 Site K1	0.70	ClLm								
	Clovelly 13 Site K2	0.00							66.54	4.05	0.54
	Clovelly 17 Site L1	0.00							79.12	3.53	
	Clovelly 17 Site L2	0.00							315.64	28.32	2.90
	Longlands 21 Site M1	0.00	SaLm						23.67	33.39	
	Longlands 21 Site M1	0.30	SaLm								
	Longlands 21 Site M1	0.50	SaLm								
	Longlands 21 Site M1	0.70	SaLm								
	Clovelly 17 Site N1	0.00							14.60	1.87	
	Clovelly 17 Site N2	0.00							3.10	2.60	
	Avalon 26 Site P1	0.00	Lm						62.21	3.46	0.36
	Avalon 26 Site P1	0.30	Lm								
	Avalon 26 Site P1	0.50	Lm								
	Avalon 26 Site P1	0.70	Lm								
	Longlands 21 Site T1	0.00	Lm						59.60	14.70	2.40
	Longlands 21 Site T1	0.30	Lm								
	Longlands 21 Site T1	0.50	Lm								
	Longlands 21 Site T1	0.70	Lm								
	Clovelly 18 Site U1	0.00	ClLm						204.69	9.45	1.08
	Clovelly 18 Site U1	0.30	ClLm								
	Clovelly 18 Site U1	0.50	Cl								
	Clovelly 18 Site U1	0.70	Cl								
	Clovelly 38 Site X1	0.00							117.27	5.62	0.79
	Clovelly 38 Site X2	0.00							53.45	10.00	1.16
Cathedral											
Peak	Lysimeter site: downslope	0.00							586.39	255.93	69.61
	Lysimeter site: downslope	0.10	Lm	868	0.673	0.592			122.10	128.41	17.67
	Lysimeter site: downslope	0.30								31.27	0.77
Ntabam.	Wetland	0.00		578	0.782	0.536	0				
	Wetland	0.38		933	0.648	0.549	0				
	Wetland	0.78		1277	0.518	0.364	0				
Wastech	Orange Bimodal sand			424	0.840	0.360	0.000				
	White sand			1566	0.409	0.070	0.000				
Sabie: CSIR	Hutton: Frankfurt Upper 1	0.00							350.24	0.51	0.070
	Hutton: Frankfurt Upper 1	0.25	SaClLm	1149	0.566				13.62	7.63	2.21
	Hutton: Frankfurt Upper 1	0.60							13.85	3.99	0.054
	Hutton: Frankfurt Upper 1	0.75	SaClLm	1173	0.557						
	Hutton: Frankfurt Upper 1	0.90							15.90	3.80	0.75
	Hutton: Frankfurt Upper 1	1.50	SaClLm	1187	0.552				19.91	19.86	0.57
	Hutton: Frankfurt Upper 1	3.00	SaClLm	1352	0.490						
	Hutton: Frankfurt Upper 1	5.00	Lm	1311	0.505						
	Hutton: Frankfurt Upper 2	0.25	SaLm	1131	0.573						
	Hutton: Frankfurt Upper 2	0.75	Lm	1302	0.509						

Soil Characteristics Data

PROJECT	DESCRIPTOR	Depth m	LABORATORY Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	IN-SITU Ks mm/h	K(60) mm/h	K(150) mm/h
Sabie: CSIR	Hutton: Frankfurt Upper 2	1.50	Lm	1290	0.513						
(cont.)	Hutton: Frankfurt Upper 2	3.00	SaLm	1250	0.528						
	Hutton: Frankfurt Upper 2	5.00	Lm	1371	0.483						
	Hutton: Frankfurt Upper 3	0.25	SaClLm	1296	0.511						
	Hutton: Frankfurt Upper 3	0.75	SaClLm	1242	0.531						
	Hutton: Frankfurt Upper 3	1.50	SaLm	1277	0.518						
	Hutton: Frankfurt Upper 3	3.00	SaLm	1499	0.434						
	Hutton: Frankfurt Upper 3	5.00	Lm	1304	0.508						
	Hutton: Frankfurt Lower 1	0.00							105.33	0.15	0.058
	Hutton: Frankfurt Lower 1	0.25	ClLm	1205	0.545				8.27	0.62	0.28
	Hutton: Frankfurt Lower 1	0.60		1334	0.497				109.24	1.06	0.31
	Hutton: Frankfurt Lower 1	0.75	ClLm								
	Hutton: Frankfurt Lower 1	0.90							6.00	0.30	0.056
	Hutton: Frankfurt Lower 1	1.50	Lm	1321	0.501	0.433	0.365		43.91	0.11	
	Hutton: Frankfurt Lower 1	3.00	Lm	1340	0.494						
	Hutton: Frankfurt Lower 1	5.00	SaLm	1358	0.488						
	Hutton: Frankfurt Lower 2	0.25	SaClLm	1191	0.550						
	Hutton: Frankfurt Lower 2	0.75	SaClLm	1045	0.606						
	Hutton: Frankfurt Lower 2	1.50	Lm	1271	0.521						
	Hutton: Frankfurt Lower 2	3.00	Lm	1179	0.555						
	Hutton: Frankfurt Lower 2	5.00	SaLm	1091	0.588						
	Hutton: Frankfurt Lower 3	0.25	SaClLm	1080	0.592						
	Hutton: Frankfurt Lower 3	0.75	SaLm								
	Hutton: Frankfurt Lower 3	1.50	ClLm	1108	0.582						
	Hutton: Frankfurt Lower 3	3.00	Lm	1182	0.554						
	Hutton: Frankfurt Lower 3	5.00	SaLm	1283	0.516						
	Legogotte 1	0.00							424.48	0.18	0.005
	Legogotte 1	0.25	SaClLm	1275	0.519				105.25	0.49	0.40
	Legogotte 1	0.75	ClLm	1311	0.505						
	Legogotte 1	0.90			0.517	0.270	0.209		297.67	0.05	0.023
	Legogotte 1	1.50	ClLm	1251	0.528	0.431	0.365		74.43		
	Legogotte 1	3.00	Lm	1378	0.480						
	Legogotte 1	5.00	SaLm	1439	0.457						
	Legogotte 2	0.25	SaClLm	1406	0.469						
	Legogotte 2	0.75	ClLm	1120	0.577						
	Legogotte 2	1.50	SaLm	1435	0.458						
	Legogotte 2	3.00	SaLm	1320	0.502						
	Legogotte 2	5.00	SaLm	1520	0.426						
	Legogotte 3	0.25	SaClLm	1358	0.488						
	Legogotte 3	0.75	Cl	1200	0.547						
	Legogotte 3	1.50	Cl	1422	0.463						
	Legogotte 3	3.00	ClLm	1292	0.513						
	Legogotte 3	5.00	SaLm	1411	0.468						
Kleinkopjes	Pivot Major (Ave 35 reps)	0.00								12.6	7.2
	Major: Field Capacity	0.00		1813	0.316	0.107	0.000		271.11	60.36	18.27
	Major: Field Capacity	0.05		1728	0.348	0.235	0.000		116.47	31.64	1.83

Soil Characteristics Data

PROJECT	DESCRIPTOR	Depth m	LABORATORY Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	IN-SITU Ks mm/h	K(60) mm/h	K(150) mm/h
Kleinkopjes	Major: Field Capacity	0.55							583.59	20.72	6.38
(cont.)	Major: Field Capacity	0.85		1609	0.393	0.210	0.000			8.59	4.01
	Major: Plinthite	1.80		1813	0.316	0.295	0.200				
	Jacuzzi: Deficit	0.00		1558	0.412	0.218	0.130		71.70	34.43	23.58
	Jacuzzi: Deficit	0.15							43.78	5.79	3.85
	Jacuzzi: Deficit	0.55							6.84	3.44	3.33
	Jacuzzi: Deficit	0.85							5.03	2.48	1.34
	Jacuzzi: Deficit - Spoil	1.20		1765	0.334	0.312	0.000		0.91	4.94	1.46
	Jacuzzi: Leach Fraction	0.00							8.36	1.96	0.09
	Jacuzzi: Leach Fraction	0.15							5.14	5.26	0.60
	Jacuzzi: Leach Fraction	0.85							3.22	8.14	0.68
	Jacuzzi: Field Capacity	0.00		1346	0.492	0.260	0.000			4.96	0.32
	Jacuzzi: Field Capacity	0.05								4.85	0.99
	Jacuzzi: Field Capacity	0.15							3.16	22.01	1.46
	Jacuzzi: Field Capacity	Spoil		2048	0.227	0.202	0.000				
	Pivot Four	0.25									
	Tweefontein FC	0.00							91.98	12.42	1.70
	Tweefontein FC	0.55							34.83	8.06	1.80
	Tweefontein FC	0.75							13.80	3.05	1.62
BCL mine	Alluvium: Site 1	0.00							42.50	0.50	0.22
	Alluvium: Site 1	0.20							72.06	0.50	0.22
	Alluvium: Site 1	1.50								1.15	0.29
	Hutton: Site 3	0.00			0.374	0.228	0.000		55.06	5.69	2.43
	Hutton: Site 3	0.61								59.14	23.67
	Hutton: Site 4	1.20								55.25	16.71
	Hutton: Site 6	0.00	SaClLm								
	Hutton: Site 6	1.20	SaLm								
	Hutton: Site 7	0.00	SaLm		0.362	0.140	0.075		7.12	1.51	0.68
	Hutton: Site 7	0.20	SaClLm		0.418	0.135	0.056			7.76	5.53
Richards	Engineered cap	0.00		1736	0.345	0.150	0.000		180.36	1.79	1.67
Bay	Engineered cap	0.25		1200	0.547	0.250	0.000		10.80	4.99	2.49
	Sample 4	0.25			0.474	0.087	0.000				
SASEX	Fernwood 1	0.25	Sa	1441	0.456	0.110	0.030				
	Fernwood 2	0.25	Sa	1420	0.464	0.130	0.052				
	Fernwood 3	0.25	Sa	1333	0.497	0.049	0.016				
	Swartland 1	0.25	SaClLm	1329	0.507	0.300	0.205				
	Swartland 2	0.25	SaCl	1061	0.600	0.276	0.175				
	Swartland 3	0.25	SaCl	1193	0.550	0.275	0.150				
	Hutton	0.25	LmSa	1305	0.508	0.167	0.120				
Dundee	Coal discard dump	0.00									
Mkomazi	Erosion gulley: Edge	0.00								11.59	2.48

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Mkomazi	Erosion gulley: Floor	0.00								44.89	11.36
	Erosion gulley: Top	0.00								13.50	0.97
	Profile Y: A Horizon		Lm								
	Profile Y: B Horizon		SiLm								
	Profile Y: BSw Horizon		Lm								
	Profile Y: Csd/sw Horizon		ClLm								
	Profile V: A Horizon		Lm								
	Profile V: B Horizon		ClLm								
	Profile G: Bs Horizon		ClLm								
Sabie:	Hutton: Crest: Site A	0.00	Lm	1276	0.519	0.380					
Witklip	Hutton: Crest: Site A	0.25	SaClLm								
	Hutton: Crest: Site A	0.50	SaClLm								
	Hutton: Crest: Site A	0.75	SaLm	1534	0.421	0.290					
	Hutton: Crest: Site A	1.00	Lm								
	Hutton: Crest: Site A	1.50	SaLm	1327	0.499	0.185					
	Hutton: Crest: Site A	2.00	SaLm								
	Hutton: Crest: Site A	2.50	SaLm	1353	0.489	0.280					
	Hutton: Midslope: Site C	0.00	SaClLm								
	Hutton: Midslope: Site C	0.25	SaClLm								
	Hutton: Midslope: Site C	0.50									
	Hutton: Midslope: Site C	0.75	ClLm								
	Hutton: Midslope: Site C	1.00	ClLm	1375	0.481	0.365					
	Hutton: Midslope: Site C	1.50	SaClLm								
	Hutton: Midslope: Site C	2.00	SaClLm								
	Hutton: Midslope: Site C	2.50	SaLm	1503	0.433	0.353					
	Hutton Forested: Site F	0.00		965	0.636						
	Riparian: Site R	0.00		1312	0.505						
	Riparian: Site R	1.00		1969	0.257						
Willowfontei	Profile 1	0.00		1332.95	0.497	0.360	0.310		24.59	12.60	4.68
	Profile 1	0.30							12.66	8.96	6.12
	Profile 1	0.75		1476.05	0.443	0.350	0.280		12.66	8.64	2.52
	Profile 1	1.30		1582	0.403	0.300	0.157		9.54	2.45	1.04
Taylors Halt	Profile 1	0.00		898	0.661	0.475	0.290		13.17	5.04	2.88
	Profile 1	0.89		739	0.721	0.540	0.300		12.66	6.05	3.89
	Profile 1	1.06		1219	0.540	0.410	0.200		7.93	2.95	1.15
Kruger National Park	Nwarhlangari: Site 1	0.00								6.07	1.29
	Nwarhlangari: Site 1	0.15	Lm							13.92	1.09
	Nwarhlangari: Site 1	0.35								32.64	5.62
	Nwarhlangari: Site 1	0.65								22.33	6.92
	Nwarhlangari: Site 2	0.00								10.07	1.75
	Nwarhlangari: Site 2	0.35	ClLm						125.72	40.39	7.42
	Nwarhlangari: Site 2	0.60								40.67	4.42

Soil Characteristics Data

PROJECT	DESCRIPTOR	Depth	LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Kruger	Nwarhlangari: Site 3	0.00	ClLm						259.74	17.67	2.14
National	Nwarhlangari: Site 3	0.15	Cl						56.53	8.46	1.49
Park	Nwarhlangari: Site 3	0.35							86.58	29.84	4.57
(cont).	Nwarhlangari: Site 3	0.50							95.60	73.22	11.96
	Nwarhlangari: Site 4	0.00									
	Nwarhlangari: Site 4	0.15									
	Nwarhlangari: Site 4	0.35	Cl								
	Nwarhlangari: Site 4	0.60	Cl								
	Nwarhlangari: Site 5	0.00	Cl	917	0.654	0.489					
	Nwarhlangari: Site 5	1.10	Cl								
	Phugwane 2: Site 1	0.00									
	Phugwane 2: Site 1	0.20									
	Phugwane 2: Site 1	0.50									
	Phugwane 2: Site 1	1.00									
	Phugwane 2: Site 2	0.00									
	Phugwane 2: Site 2	0.20									
	Phugwane 2: Site 2	0.50									
	Phugwane 2: Site 2	1.00									
	Phugwane 2: Site 2	1.80									
	Phugwane 2: Site 2	1.90									
	Phugwane 2: Site 2	2.00									
	Phugwane 2: Site 3	0.00									
	Phugwane 2: Site 4	0.00									
Forest/	Clovelly1100: Euc. T.B	0.00	SaCl	1216	0.541	0.259	0.174		390.60	0.36	0.18
Grassland	Clovelly1100: Gr. T.B	0.00	SaCl	1311	0.505	0.293	0.187		375.00	14.40	1.08
	Kranskop1100: Euc.C.P	0.00	Cl	806	0.696	0.325	0.254		581.40	18.00	2.88
	Kranskop1100: Gr. C.P	0.00	Cl	796	0.700	0.405	0.252		714.00	36.00	7.20
	Inanda1100: Euc. B.H	0.00	Cl	790	0.702	0.286	0.202		1373.40	0.36	0.11
	Inanda1100: Gr. B.H	0.00	Cl	882	0.667	0.341	0.194		1014.60	39.60	3.60
	Kranskop1100: Euc.G.H	0.00	Cl	700	0.736	0.357	0.245		1202.40	1.15	0.61
	Kranskop1100: Gr. G.H	0.00	Cl	832	0.686	0.385	0.279		644.40	5.40	0.90
	Wasbank1000: Euc. C	0.00	LmSa	1191	0.551	0.106	0.038		1770.60	5.04	0.43
	Wasbank1000: Gr. C	0.00	LmSa	1474	0.444	0.155	0.062		342.60	21.60	1.44
Seven Oaks Nursery	Bark chips grow med.	0.00		254	0.780	0.475	0.344	3910			
SASOL	Rensburg: Grass site	0.00		1603	0.395	0.316					
	Rensburg: Grass site	0.30		1518	0.427	0.34					
	Arcadia: Forest site	0.00							15.30	0.51	0.10
	Arcadia: Forest site	0.30		1383	0.478	0.350			1.70	1.27	0.011
	Arcadia: Forest site	0.50		1137	0.571	0.476					
	Arcadia: Forest site	0.70		1359	0.487	0.472			10.76	4	0.48

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
SASOL											
(cont.)	Arcadia: Forest site	0.80							3.60	1.94	0.50
Portnet	Marine sand	0.18	Sa	1601	0.396	0.091	0.000		85.18	42.59	
	Marine sand	0.68	Sa						439.10	601.25	132.90
Newcastle	Coal discard: Uncompact	0.00	Sa	986	0.330	0.140	0.040		113.76	30.38	3.22
	Coal discard: Compacted	0.00	Sa	1063	0.300	0.150	0.020		203.04	4.61	2.12
	Coal discard: Uncompact	0.00	Sa	1066	0.250	0.110	0.070		72.36	11.34	3.89
	Avalon soil: Uncompacted	0.30	ClLm	1539	0.393	0.310	0.015		114.12	2.04	1.74
	Avalon soil: Compacted	0.50	ClLm	1644	0.342	0.330	0.230		11.52	0.81	0.11
	Estcourt soil: Compacted	0.70	SaClLm	1776	0.301	0.300	0.250		0.54	0.35	0.012
	Avalon soil: Compacted	0.70	SaClLm	1694	0.345	0.350	0.000		10.80	1.81	0.85
	Avalon soil: Uncompacted	0.70	ClLm	1663	0.338	0.310	0.000		116.28	0.84	0.55
Kwa	CII 1	0.00									
Mbonambi		0.50	Si								
		1.00	Si	1644							
		1.50	Si	1880				7.730			
		2.00	SiLm								
		2.50		1892				2.820			
		3.00	SiLm								
		3.50	SiLm	1830	0.308	0.231	0.080	5.940			
		4.00		1820	0.315	0.203	0.120	0.045			
		2-3	Si								
		3- 4	SiLm								
		4- 5	Si								
		7- 8	Si								
		8- 9	Si								
	CII 2	0.00	Si	1474							
		0.50	Si	1570				2.540			
		1.00	Si								
		1.50									
		2.20	SiLm	1660	0.375	0.245	0.130				
		2.50		1700	0.359	0.185	0.053				
		3.1	SiLm								
		3.50									
		4.00									
		4.50		1528				82.93			
		5.00									
		5.50									
		6.00		1796				7.07			
		6.50	Si	1580				12.69			
		0- 1	Si								
		1- 2									
		2- 3	SiLm								
		3- 4									
		4- 5	Si								
		6-7									
		7- 8	SiLm								
		8- 9	SiLm								
		9- 10	SiLm								

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Kwa	CII 2	10- 11	SiLm								
Mbonambi		11- 12	SiLm								
(cont.)		12- 13	SiLm								
		15- 16	SiLm								
		16- 17									
		18- 19									
		20- 21									
		21- 22	SiLm								
		22- 23									
		23- 24									
		24- 25									
		25-26									
		26- 27									
		27- 28									
		28-29	Si								
		29-30	Si								
		31-10c									
	CII 3	0.00	Si								
		0.50	Si								
		1.00		1421				8.600			
		1.50		1450	0.454	0.160	0.061				
		2.00		1607				18.060			
		2.50	SiLm								
		3.00	SiLm	1643				43.420			
		3.50	SiLm	1541				9.110			
		0- 1									
		1-2	Si								
		2- 3	Si								
		3- 4	SiLm								
		4- 5	SiLm								
		5- 6									
		6- 7									
		7- 8									
		8- 9									
		9- 10									
		10-11									
		11- 12									
		12- 13									
		13- 14									
		14- 15									
		17-18	SiLm								
		19- 20	Si								
	CII 4	0.00		1376							
		0.70	Si	1530	0.421	0.410	0.050				
		1.00	Si	1417							
		1.50	Si								
		2.80									
		3.00	Si	1706							
		3.50									
		4.00	SiLm	1659							
		4.50	Si	1612				8.680			
		5.00	Si	1669							

Soil Characteristics Data

PROJECT			LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Kwa	CII 4	5.50		1564				17.230			
Mbonambi		6.00		1587				29.880			
(cont.)		6.50	Si	1501				23.300			
		0- 1									
		1-2									
		2- 3									
		3- 4	Si								
		4- 5									
		5- 6									
		7- 8									
		8- 9									
		10-11									
		11- 12									
		12- 13									
		13- 14	SiLm								
		14- 15									
		15- 16									
		16- 17	SiLm								
		17- 18									
		18- 19									
		19- 20	SiLm								
	CII 5	0.00		1345							
		0.70	Si								
		1.30	Si								
		1.70	Si								
		2.00	Si					45.530			
		2.50	Si					50.010			
		3.00	Si					22.850			
		3.50	Si	1571				26.890			
		4.00	SiLm	1561				19.950			
		4.50	SiLm					0.010			
		4.70						0.003			
		5.00		1313				0.007			
		5.50		1303				0.005			
		1- 2									
		2- 3									
		4- 5									
		5- 6									
		6- 7									
		8- 9									
		11- 12									
		12- 13									
		13- 14									
		14- 15									
	CII 6	0- 1									
		1- 2									
		2- 3									
		3- 4									
		5- 6									
		7- 8									
		8- 9									

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Kwa Mbonambi (cont.)	CII 6	9- 10									
		10- 11									
		11- 12									
		12- 13									
		13- 14									
		15- 16									
	CII 7	0	SiLm	1289							
		0.50	Si	1526				13.180			
		1.10	SiLm	1525				6.400			
		2- 3									
		4- 5									
		5- 6									
		6- 7									
		7- 8									
		8- 9									
		9- 10									
		10- 11									
		13- 14									
		14- 15									
		15- 16									
		16- 17									
		17- 18									
	CII 8	0.00		1263							
		0.60									
		1.10		1556							
		1.50	SiLm								
		2.00	Si					8.350			
		2.50	SiLm	1682							
		3.00	SiLm					11.260			
		3.50	Si								
		4.10	SiLm					25.050			
		4.50	Si								
		5.00	SiLm								
		5.50									
		6.00						6.130			
		6.00						23.240			
		0- 1									
		1- 2									
		2- 3									
		3- 4									
		5- 6									
		6- 7									
		8- 9									
		11- 12									
		13- 14									
		14- 15									
		15- 16									
		17- 18									
	CII 9	0	Si								
		0.50		1434							

Soil Characteristics Data

PROJECT	DESCRIPTOR		LABORATORY						IN-SITU		
		Depth m	Texture	Density kg/m3	Porosity m/m	DUL m/m	WP m/m	Ks mm/h	Ks mm/h	K(60) mm/h	K(150) mm/h
Kwa Mbonambi (cont.)	CII9	1.00									
		1.50	SiLm	1448							
		2.10		1493							
		2.50	Si								
		3.00	SiLm	1638							
		3.50									
		4.00	SiLm	1550							
Muden	Block 6 (nest2)	0(2)		1533	0.421	0.394	0.100			62.05	8.29
	Block 6 (nest2)	0 (1)		1538	0.419	0.396	0.090			54.460	7.920
	Block 6 (nest3)	0.58		1546	0.417	0.390	0.073				
AECI	Bugweed	0.5		548	0.789	0.713					
	Fig	0		509	0.804	0.615					
		0.25		546	0.794	0.585					
		1		444	0.822	0.803					
		2		401	0.846	0.846					
	Grass	0		525	0.798	0.786					
		0.5		492	0.811	0.690					
		2		416	0.840	0.834					

Soil Hydraulic Characteristics
van Genuchten Model Parameters

PROJECT	DESCRIPTOR	Depth m	Texture	MODEL PARAMETERS Density kg/m3	THETAS m/m	THETAR m/m	ALPHA mm-1	n	Ks mm/h	RATING
NECF	Avalon1100: Site LC1	0.00	SaLm	1436	0.378	0.000	0.02040	1.426	368.00	6
	Avalon1100: Site LC1	0.30	SaLm	1640	0.374	0.000	0.01680	1.2078	1543.00	6
	Avalon1100: Site LC1	0.50	SaLm	1585	0.413	0.000	0.01324	1.246		8
	Pinedene1100: SiteLC2	0.00	SaLm	1746	0.375	0.000	0.00229	1.4475	5.73	6
	Pinedene1100: SiteLC2	0.20	SaLm	1672	0.289	0.150	0.02700	2.156	39.68	6
	Pinedene1100: SiteLC2	0.40	SaLm	1757	0.262	0.000	0.00070	1.316	66.44	7
	Pinedene1100: SiteLC2	0.60	SaLm	1775	0.343	0.000	0.09370	1.303		8
	Pinedene1100: SiteLC2	0.80	SaLm	1850	0.260	0.000	0.00093	1.257		9
	Pinedene1100: SiteLC2	1.40	SiClLm	1842	0.546	0.000	0.41500	1.073		8
	Tukula2210: Site LC3	0.50	SaLm	1791	0.317	0.000	0.00312	1.256	5.12	8
	Tukula2210: Site LC3	0.70	SaLm	1760	0.322	0.000	0.10000	1.076		7
	Tukula2210: Site LC3	1.50	Lm	1871	0.302	0.000	0.00068	1.511		8
	Kroonstad2000: Site LC4	0.20	Lm	1892	0.296	0.000	0.00068	1.563	9.20	6
	Kroonstad2000: Site LC4	0.50	Lm	1717	0.326	0.000	0.01740	1.138	869.77	7
	Katspruit1000: Site UC4	0.00		1410	0.480	0.000	0.05570	1.076		7
	Katspruit1000: Site UC4	0.20	ClLm	1516	0.429	0.000	0.06210	1.039		7
	Katspruit1000: Site UC5	0.20	Lm	1712	0.354	0.234	0.01650	1.674	8.90	8
	Katspruit1000: Site UC5	0.80	Lm	1720	0.351	0.265	0.02000	1.688		7
	Site UC8	0.00		1680	0.316	0.000	0.00033	1.191	8.89	6
	Site UC8	0.20		1799	0.321	0.000	0.00608	1.118	28.01	8
	Oakleaf2120: Site UC9	0.00		1818	0.326	0.000	0.00054	1.106	20.63	7
	Oakleaf2120: Site UC9	0.80	Cl	1410	0.468	0.171	0.00630	1.855	1.63	9
De Hoek : V1H028	Clovelly 17 Site F1	0.00	ClLm	1378	0.484	0.254	0.01230	1.519	41.16	7
Portnet	Marine sand	0.18	Sa	1601	0.349	0.000	0.00176	2.933	133.00	7
Newcastle	Coal discard: Uncompacted	0.00	Sa	986	0.330	0.040	0.00402	1.570	1.80	8
	Coal discard: Compacted	0.00	Sa	1063	0.300	0.020	0.00251	1.608	3.60	8
	Coal discard: Uncompacted	0.00	Sa	1066	0.300	0.070	0.00900	1.650	25.20	8
	Avalon soil: Uncompacted	0.30	ClLm	1539	0.393	0.015	0.00377	1.122	3.60	8
	Avalon soil: Compacted	0.50	ClLm	1644	0.342	0.230	0.00300	1.400	1.08	8
	Estcourt soil: Compacted	0.70	SaClLm	1776	0.301	0.250	0.00010	2.000	0.01	8
	Avalon soil: Compacted	0.70	SaClLm	1694	0.345	0.000	0.00077	1.069	1.08	7
	Avalon soil: Uncompacted	0.70	ClLm	1663	0.338	0.000	0.00080	1.120	5.40	8
Cathedral Peak	Lysimeter site: downslope	0.10	Lm	868	0.643	0.420	0.00391	1.232	15.90	9

Soil Hydraulic Characteristics
van Genuchten Model Parameters

PROJECT	DESCRIPTOR	Depth	Texture	MODEL PARAMETERS						RATING
		Depth	Texture	Density	THETAS	THETAR	ALPHA	n	Ks	
		m		kg/m3	m/m	m/m	mm-1		mm/h	
Ntabamhlope	Wetland	0.00		578	0.753	0.000	0.10420	1.07		8
	Wetland	0.38		933	0.656	0.000	0.00418	1.106		8
	Wetland	0.78		1277	0.491	0.175	0.00691	1.242		9
Wastech	Orange Bimodal sand			424	0.700	0.367	0.00378	8.144		9
	White sand			1566	0.413	0.000	0.00470	2.137		9
Sabie: CSIR	Hutton: Frankfurt Lower 1	1.50	Lm	1321	0.506	0.380	0.01670	1.391	44.00	7
	Legogotte 1	0.90		1280	0.380	0.000	1.60300	1.042	298.00	6
	Legogotte 1	1.50	ClLm	1251	0.452	0.000	0.31900	1.067	74.48	6
Kleinkopjes	Major: Topsoil	0.00		1807	0.318	0.000	0.08575	1.235		6
	Major: Topsoil	0.05		1746	0.341	0.000	0.00400	1.236		8
	Major: Field Capacity	1.00		1564	0.410	0.000	0.00527	1.361	1.32	5
	Major: Plinthite	1.80		1794	0.323	0.200	0.00082	1.971	0.40	5
	Jacuzzi: Deficit	0.00		1558	0.412	0.130	0.00350	2.467	1.00	8
	Jacuzzi: Deficit - Spoil	1.20		2056	0.224	0.000	0.00740	1.043	0.10	5
	Jacuzzi: Field Capacity	0.00		1182	0.554	0.000	0.00225	1.772	235.00	8
	Tweefontein: Field Capacity	0.00		1410	0.468	0.000	0.00380	1.336	138.00	7
BCL mine	Alluvium: Site 1	0.00		1447	0.454	0.100	0.00051	1.392	45.28	6
	Alluvium: Site 1	0.20		1481	0.441	0.000	0.01710	1.201	138.14	8
	Alluvium: Site 1	1.50		1317	0.503	0.000	0.00790	1.141	53.04	8
	Hutton: Site 3	0.00		1659	0.374	0.000	0.00390	1.286	55.19	9
	Hutton: Site 7	0.00	SaLm	1691	0.362	0.075	0.00819	1.73	7.13	8
	Hutton: Site 7	0.20	SaClLm	1542	0.418	0.056	0.00941	1.601	71.86	8
Richards Bay	Engineered fill	0.25		1394	0.474	0.041	0.00300	3.051		10
SASEX	Fernwood 1	0.25	Sa	1441	0.456	0.000	0.11680	1.272	142.00	4
	Fernwood 2	0.25	Sa	1420	0.464	0.000	0.01310	1.467	327.70	6
	Fernwood 3	0.25	Sa	1333	0.497	0.000	0.00350	3.031	185.70	6
	Swartland 1	0.25	SaClLm	1306	0.507	0.150	0.00208	2.731	5.53	5
	Swartland 2	0.25	SaCl	1061	0.600	0.000	0.00581	1.416	799.40	5
	Swartland 3	0.25	SaCl	1193	0.550	0.000	0.00318	1.703	500.00	7
	Hutton	0.25	LmSa	1305	0.597	0.070	0.06370	1.227	981.00	5
Seven Oaks Nursery	Bark chips growing medium	0.00		254	0.780	0.371	0.00153	1.533	3910.00	10
SASOL	Rensburg: Grass site	0.00		1603	0.395	0.000	0.01020	1.0909		9
	Rensburg: Grass site	0.30		1518	0.427	0.285	0.01140	1.45		9
	Arcadia: Forest site	0.30		1383	0.478	0.000	0.01330	1.557		7
	Arcadia: Forest site	0.50		1137	0.571	0.180	0.87840	1.0418		8
	Arcadia: Forest site	0.70		1359	0.487	0.000	0.00018	1.9714		8

Soil Hydraulic Characteristics
van Genuchten Model Parameters

PROJECT	DESCRIPTOR			MODEL PARAMETERS						RATING
		Depth m	Texture	Density kg/m3	THETAS m/m	THETAR m/m	ALPHA mm-1	n	Ks mm/h	
Sabie: Witklip	Hutton Crest: Site A	0.00	Lm	1276	0.519	0.279	0.10900	1.18		6
	Hutton Crest: Site A	0.75	SaLm	1534	0.421	0.276	0.00501	4.851		8
	Hutton Crest: Site A	1.50	SaLm	1327	0.435	0.000	0.03070	1.232		9
	Hutton Crest: Site A	2.50	SaLm	1353	0.489	0.162	0.00621	1.537		7
	Hutton Midslope: Site C2	1.00	ClLm	1375	0.455	0.142	0.00674	1.156		7
	Hutton Midslope: Site C2	2.50	SaLm	1503	0.433	0.346	0.00510	16.11		7
	Hutton Forested: Site F1	0.00		965	0.636	0.236	0.00097	3.733		9
	Riparian: Site R1	0.00		1312	0.505	0.300	0.00563	2.142		9
	Riparian: Site R1	1.00		1969	0.257	0.143	0.01730	1.133		8
Willowfontein	Profile 1: Market garden	0.00		1332.95	0.497	0.293	0.00386	1.769	24.60	8
	Profile 1: Market garden	0.30		1476.05	0.443	0.310	0.00329	2.265	12.53	7
	Profile 1: Market garden	0.75		1476.05	0.443	0.276	0.00070	2.691	12.60	6
	Profile 1: Market garden	1.30		1582	0.403	0.000	0.00346	1.228	18.20	7
Taylors Halt	Profile 1: Market garden	0.00		898	0.661	0.260	0.00253	1.513	13.51	8
	Profile 1: Market garden	0.89		739	0.721	0.405	0.00242	1.640	12.58	7
	Profile 1: Market garden	1.06		1219	0.540	0.368	0.00678	1.967	7.91	8
Kruger National Park	Nwarhlangari: Site 1	0.15	Lm	1034	0.634	0.000	0.00201	1.180	100.00	5
	Nwarhlangari: Site 2	0.60		1299	0.510	0.000	0.00037	4.055	15.08	5
	Nwarhlangari: Site 3	0.00	ClLm	1163	0.561	0.000	0.00090	1.268	64.00	6
	Nwarhlangari: Site 3	0.15	Cl	1073	0.595	0.310	0.00515	1.588	24.08	6
	Nwarhlangari: Site 4	0.35	Cl	1113	0.580	0.000	0.13400	1.042		6
	Nwarhlangari: Site 4	0.60	Cl	1060	0.600	0.327	0.00450	1.201		8
	Nwarhlangari: Site 5	0.00	Cl	917	0.660	0.000	0.01800	1.108		8
	Nwarhlangari: Site 5	0.35		1036	0.609	0.371	0.00812	2.008		8
	Nwarhlangari: Site 5	0.50		1034	0.610	0.291	0.00707	1.855		7
	Nwarhlangari: Site 5	0.60		1007	0.620	0.000	0.00389	1.121		7
	Nwarhlangari: Site 5	1.10	Cl	1060	0.600	0.442	0.00427	1.397		7
Forest/ Grassland *	Clovelly1100: Eucalypt T.B	0.00	SaCl	1216	0.541	0.228	0.00540	2.525	0.27	9
	Clovelly1100: Grass T.B	0.00	SaCl	1311	0.505	0.239	0.00776	1.694	14.76	9
	Kranskop1100: Eucalypt C.P	0.00	Cl	806	0.696	0.234	0.01065	1.449	75.60	9
	Kranskop1100: Grass C.P	0.00	Cl	796	0.700	0.271	0.00432	1.470	38.88	9
	Inanda1100: Eucalypt B.H	0.00	Cl	790	0.702	0.206	0.00567	1.918	0.72	9

Soil Hydraulic Characteristics
van Genuchten Model Parameters

PROJECT	DESCRIPTOR	Depth m	Texture	MODEL PARAMETERS Density kg/m3	THETAS m/m	THETAR m/m	ALPHA mm-1	n	Ks mm/h	RATING
Forest / Grassland (cont.)	Inanda1100: Grass B.H	0.00	Cl	882	0.667	0.250	0.00941	1.501	129.24	9
	Kranskop1100: Eucalypt G.H	0.00	Cl	700	0.736	0.220	0.00410	1.650	2.16	9
	Kranskop1100: Grass G.H	0.00	Cl	832	0.686	0.288	0.00544	1.578	8.28	9
	Wasbank1000: Eucalypt C	0.00	LmSa	1191	0.551	0.038	0.01186	1.730	7.92	9
	Wasbank1000: Grass C	0.00	LmSa	1474	0.444	0.038	0.00520	1.533	23.11	9

Soil Hydraulic Characteristics
Modified van Genuchten Model Parameters

PROJECT	DESCRIPTOR	Depth	Texture	MODEL PARAMETERS								RATING
		Depth	Texture	THETAS	THETAR	ALPHA	n	Ks	Km	ALPHA2	n2	
		m		m/m	m/m	mm-1		mm/h	mm/h	mm-1		
NECF	Pinedene1100: SiteLC2	0.00	SaLm	0.375	0.000	0.0023	1.45	5.73	388	0.700	3.0	6
Forest/Grassland *	Clovelly1100: Eucalypt T.B	0.00	SaCl	0.541	0.228	0.0054	2.53	0.27	392	0.750	3.0	9
	Clovelly1100: Grass T.B	0.00	SaCl	0.505	0.239	0.0078	1.69	14.76	374	0.700	2.5	9
	Kranskop1100: Eucalypt C.P	0.00	Cl	0.696	0.234	0.0107	1.45	75.60	583	0.500	1.8	9
	Kranskop1100: Grass C.P	0.00	Cl	0.700	0.271	0.0043	1.47	38.88	713	0.500	2.0	9
	Inanda1100: Eucalypt B.H	0.00	Cl	0.702	0.206	0.0057	1.92	0.72	1375	0.700	4.0	9
	Inanda1100: Grass B.H	0.00	Cl	0.667	0.250	0.0094	1.50	129.24	1015	0.400	2.0	9
	Kranskop1100: Eucalypt G.H	0.00	Cl	0.736	0.220	0.0041	1.65	2.16	1202	0.700	3.0	9
	Kranskop1100: Grass G.H	0.00	Cl	0.686	0.288	0.0054	1.58	8.28	644	0.700	3.0	9
	Wasbank1000: Eucalypt C	0.00	LmSa	0.551	0.038	0.0119	1.73	7.92	1771	0.700	3.0	9
	Wasbank1000: Grass C	0.00	LmSa	0.444	0.038	0.0052	1.53	23.11	34	0.650	3.0	9
Newcastle	Coal discard: Uncompacted	0.00	Sa	0.330	0.040	0.0040	1.57	1.80	108	0.020	2.0	9
	Coal discard: Compacted	0.00	Sa	0.300	0.020	0.0025	1.61	3.60	198	0.200	2.4	9
	Coal discard: Uncompacted	0.00	Sa	0.300	0.070	0.0090	1.65	25.20	54	1.000	3.0	9
	Avalon soil: Uncompacted	0.30	ClLm	0.393	0.015	0.0038	1.12	3.60	119	5.000	10.0	9
	Avalon soil: Compacted	0.50	ClLm	0.342	0.230	0.0030	1.40	1.08	11	5.000	5.0	9
	Estcourt soil: Compacted	0.70	SaClLm	0.301	0.250	0.0001	2.00	0.01	0	0.030	4.0	8
	Avalon soil: Compacted	0.70	SaClLm	0.345	0.000	0.0008	1.07	1.08	11	0.020	3.0	9
	Avalon soil: Uncompacted	0.70	ClLm	0.338	0.000	0.0008	1.12	5.40	108	0.300	3.0	9

Soil Hydraulic Characteristics
Brooks-Corey Model Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS								RATING
		Depth M	Texture	Density kg/m3	THETAS m/m	THETAR m/m	hd mm	lamda	Ks mm/h		
NECF	Avalon1100: Site LC1	0.00	SaLm	1436	0.367	0.000	87.7	0.246	139.67		6
	Avalon1100: Site LC1	0.30	SaLm	1640	0.446	0.000	2.4	0.108	1054.00		6
	Avalon1100: Site LC1	0.50	SaLm	1585	0.403	0.000	73.4	0.200			8
	Pinedene1100: SiteLC2	0.00	SaLm	1746	0.336	0.000	392.2	0.381	2.20		6
	Pinedene1100: SiteLC2	0.20	SaLm	1672	0.369	0.100	1.0	0.208	39.68		6
	Pinedene1100: SiteLC2	0.40	SaLm	1757	0.272	0.000	214.6	0.148	60.00		6
	Pinedene1100: SiteLC2	0.60	SaLm	1775	0.330	0.000	440.5	0.230			9
	Pinedene1100: SiteLC2	0.80	SaLm	1850	0.254	0.000	497.5	0.172			9
	Pinedene1100: SiteLC2	1.40	SiClLm	1842	0.447	0.000	277.8	0.130			8
	Tukula2210: Site LC3	0.50	SaLm	1791	0.319	0.000	101.4	0.158	1.00		7
	Tukula2210: Site LC3	0.70	SaLm	1760	0.320	0.000	6.1	0.067			6
	Tukula2210: Site LC3	1.50	Lm	1871	0.294	0.000	719.4	0.332			9
	Kroonstad2000: Site LC4	0.20	Lm	1892	0.286	0.000	787.4	0.393	5.00		6
	Kroonstad2000: Site LC4	0.50	Lm	1717	0.314	0.000	87.0	0.147	7.20		7
	Katspruit1000: Site UC4	0.00		1410	0.468	0.000	21.6	0.074			7
	Katspruit1000: Site UC4	0.20	ClLm	1516	0.428	0.000	12.4	0.037			7
	Katspruit1000: Site UC5	0.20	Lm	1712	0.248	0.228	177.0	2.525	2.87		8
	Katspruit1000: Site UC5	0.80	Lm	1720	0.351	0.264	30.4	0.562			7
	Site UC8	0.00		1680	0.306	0.000	909.1	0.063	2.64		6
	Site UC8	0.20		1799	0.321	0.000	19.7	0.032	1.39		7
	Oakleaf2120: Site UC9	0.00		1818	0.318	0.000	476.2	0.035	2.35		6
	Oakleaf2120: Site UC9	0.80	Cl	1410	0.468	0.180	416.7	2.450	11.32		9
De Hoek : V1H028	Clovelly 17 Site F1	0.00	ClLm	1378	0.432	0.000	192.3	0.145	41.16		9
Portnet	Marine sand	0.18	Sa	1601	0.349	0.000	349.7	1.303	125		7
Newcastle	Coal discard: Uncompacted	0.00	Sa	986	0.413	0.050	65.0	0.470	113.76		9
	Coal discard: Compacted	0.00	Sa	1063	0.401	0.000	80.0	0.390	203.04		8
	Coal discard: Uncompacted	0.00	Sa	1066	0.367	0.075	68.0	0.650	72.36		9
	Avalon soil: Uncompacted	0.30	ClLm	1539	0.393	0.050	70.0	0.100	114.12		8
	Avalon soil: Compacted	0.50	ClLm	1644	0.342	0.200	800.0	0.400	11.52		8
	Estcourt soil: Compacted	0.70	SaClLm	1776	0.301	0.220	700.0	0.250	0.54		7
	Avalon soil: Compacted	0.70	SaClLm	1694	0.345	0.220	400.0	0.450	10.80		8
	Avalon soil: Uncompacted	0.70	ClLm	1663	0.338	0.070	400.0	0.110	116.28		9

Soil Hydraulic Characteristics
Brooks-Corey Model Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS							RATING
		Depth M	Texture	Density kg/m3	THETAS m/m	THETAR m/m	hd mm	lamda	Ks mm/h	
Cathedral Peak	Catchment 6: n. lysimeter site	0.10	Lm	868	0.666	0.300	21.8	0.076	15.90	9
Ntabamhlope	Wetland	0.00		578	0.753	0.000	4.3	0.057		8
	Wetland	0.38		933	0.656	0.000	129.9	0.084		8
	Wetland	0.78		1277	0.491	0.000	71.9	0.108		9
Wastech	Orange Bimodal sand			424	0.700	0.330	211.9	2.560		9
	White sand			1566	0.413	0.000	157.0	0.924		9
Sabie: CSIR	Hutton: Frankfurt Lower 1	1.50	Lm	1321	0.495	0.270	7.8	0.075	43.91	7
	Legogotte 1	0.90		1280	0.38	0.000	0.7	0.042	299.00	7
	Legogotte 1	1.50	ClLm	1251	0.480	0.000	0.1	0.049	74.40	6
Kleinkopjes Colliery	Major: Topsoil	0.00		1807	0.266	0.000	120.8	0.403		6
	Major: Topsoil	0.05		1746	0.337	0.000	147.1	0.189		9
	Major: Field Capacity	1.00		1564	0.410	0.000	167.2	0.332	1.32	5
	Major: Plinthite	1.80		1794	0.382	0.000	480.8	0.377	0.41	8
	Jacuzzi: Deficit	0.00		1558	0.412	0.065	114.7	0.390	1.00	8
	Jacuzzi: Deficit - Spoil	1.20		2056	0.318	0.180	144.9	1.018	0.10	7
	Jacuzzi: Field Capacity	0.00		1182	0.554	0.000	200.0	0.509	184.00	8
	Tweefontein: Field Capacity	0.00		1410	0.466	0.000	185.2	0.334	35.80	8
BCL mine	Alluvium: Site 1	0.00		1441	0.456	0.323	104.0	0.637	34.43	7
	Alluvium: Site 1	0.20		1420	0.464	0.171	185.2	0.833	18.31	6
	Alluvium: Site 1	1.50		1333	0.497	0.000	29.3	0.086	5.00	7
	Hutton: Site 3	0.00		1659	0.374	0.000	193.8	0.273	16.93	6
	Hutton: Site 7	0.00	SaLm	1691	0.362	0.091	751.9	2.694	2.61	7
	Hutton: Site 7	0.20	SaClLm	1542	0.418	0.073	92.6	0.667	29.32	8
Richards Bay	Sample 4	0.25		1394	0.474	0.028	213.2	1.154		10
SASEX	Fernwood 1	0.25	Sa	1441	0.440	0.050	8.1	0.690	3032.00	6
	Fernwood 2	0.25	Sa	1420	0.464	0.000	36.2	0.392	926.70	8
	Fernwood 3	0.25	Sa	1333	0.470	0.000	9.3	0.341	4038.00	7
	Swartland 1	0.25	SaClLm	1329	0.507	0.000	182.1	0.284	12.10	9
	Swartland 2	0.25	SaCl	1061	0.600	0.000	109.6	0.367	328.00	8
	Swartland 3	0.25	SaCl	1193	0.550	0.000	147.3	0.366	479.20	9
	Hutton	0.25	LmSa	1305	0.508	0.000	161.3	0.446	512.00	7
Seven Oaks Nursery	Bark chips growing medium	0.00		254	0.780	0.344	452.5	0.407	3910	10
SASOL	Rensburg: Grass site	0.00		1603	0.395	0.207	135.3	0.272		8
	Rensburg: Grass site	0.30		1518	0.427	0.300	381.7	1.158		8
	Arcadia: Forest site	0.30		1383	0.478	0.292	41.2	0.341		6

Soil Hydraulic Characteristics
Brooks-Corey Model Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS								RATING
		Depth M	Texture	Density kg/m3	THETAS m/m	THETAR m/m	hd mm	lamda	Ks mm/h		
SASOL (cont.)	Arcadia: Forest site	0.50		1137	0.571	0.354	1.7	0.094			7
	Arcadia: Forest site	0.70		1359	0.487	0.000	729.9	0.082			6
Sabie: Witklip	Hutton Crest: Site A	0.00	Lm	1276	0.519	0.274	8.1	0.170			6
	Hutton Crest: Site A	0.75	SaLm	1534	0.421	0.268	119.2	1.113			9
	Hutton Crest: Site A	1.50	SaLm	1327	0.499	0.000	25.4	0.218			9
	Hutton Crest: Site A	2.50	SaLm	1353	0.489	0.019	58.3	0.197			8
	Hutton Midslope: Site C2	1.00	ClLm	1375	0.481	0.000	75.9	0.081			8
	Hutton Midslope: Site C2	2.50	SaLm	1503	0.433	0.345	119.8	2.614			8
	Hutton Forested: Site F1	0.00		965	0.636	0.212	735.3	1.501			9
	Riparian: Site R1	0.00		1312	0.505	0.288	101.6	0.675			9
	Riparian: Site R1	1.00		1969	0.257	0.044	27.1	0.052			8
Willowfontein	Profile 1: Market garden	0.00		1333	0.497	0.336	159.7	0.997	24.10		6
	Profile 1: Market garden	0.30		1476	0.443	0.314	139.5	0.841	9.25		7
	Profile 1: Market garden	0.75		1476	0.443	0.000	473.9	0.161	12.76		7
	Profile 1: Market garden	1.30		1582	0.373	0.000	396.8	0.226	3.54		7
Taylors Halt	Profile 1: Market garden	0.00		898	0.600	0.000	500.0	0.214	13.57		8
	Profile 1: Market garden	0.89		739	0.649	0.000	751.9	0.157	12.66		7
	Profile 1: Market garden	1.06		1219	0.532	0.000	344.8	0.133	7.93		6
Kruger National Park	Nwarhlangari: Site 1	0.15	Lm	1034	0.614	0.000	61.0	0.051	13.92		6
	Nwarhlangari: Site 2	0.60		1299	0.510	0.000	1282.1	0.459	40		5
	Nwarhlangari: Site 3	0.00	ClLm	1163	0.561	0.000	30.2	0.057	64.94		7
	Nwarhlangari: Site 3	0.15	Cl	1073	0.563	0.000	222.2	0.152	21.66		7
	Nwarhlangari: Site 4	0.35	Cl	1113	0.580	0.451	19.5	0.903			7
	Nwarhlangari: Site 4	0.60	Cl	1060	0.600	0.000	86.2	0.058			8
	Nwarhlangari: Site 5	0.00	Cl	917	0.654	0.000	33.9	0.096			8
	Nwarhlangari: Site 5	0.35		1036	0.595	0.366	79.4	0.743			8
	Nwarhlangari: Site 5	0.50		1034	0.610	0.278	94.3	0.629			7
	Nwarhlangari: Site 5	0.60		1007	0.620	0.000	137.7	0.099			7
	Nwarhlangari: Site 5	1.10	Cl	1060	0.600	0.127	78.1	0.065			7
Forest/ Grassland*	Clovelly1100: Eucalypt T.B	0.00	SaCl	1216	0.430	0.210	126.9	1.005	0.36		9
	Clovelly1100: Grass T.B	0.00	SaCl	1311	0.400	0.230	2371.0	1.005	6.48		9
	Kranskop1100: Eucalypt C.P	0.00	Cl	806	0.556	0.304	54.8	1.005	27		9

Soil Hydraulic Characteristics
Brooks-Corey Model Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS							RATING
		Depth M	Texture	Density kg/m3	THETAS m/m	THETAR m/m	hd mm	lamda	Ks mm/h	
Forest/ Grassland (cont.)	Kranskop1100: Grass C.P	0.00	Cl	796	0.551	0.318	243.9	1.005	12.6	9
	Inanda1100: Eucalypt B.H	0.00	Cl	790	0.606	0.232	107.5	1.005	0.504	9
	Inanda1100: Grass B.H	0.00	Cl	882	0.502	0.298	48.1	1.005	55.8	9
	Kranskop1100: Eucalypt G.H	0.00	Cl	700	0.592	0.250	248.9	1.005	1.08	9
	Kranskop1100: Grass G.H	0.00	Cl	832	0.532	0.342	68.1	1.005	5.04	9
	Wasbank1000: Eucalypt C	0.00	LmSa	1191	0.431	0.110	62.9	1.005	3.96	9
	Wasbank1000: Grass C	0.00	LmSa	1474	0.360	0.110	106.4	1.005	10.08	9

Soil Hydraulic Characteristics
Campbell Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS							RATING
		Depth	Texture	Density	THETAS	he	hi	b	Ks (measured)	
		m		kg/m3	m/m	mm	mm		mm/h	
NECF	Avalon1100: Site LC1	0.00	SaLm	1436	0.371	75.0	120.1	4.0	367.35	9
	Avalon1100: Site LC1	0.30	SaLm	1640	0.446	79.0	126.5	4.0	1054.00	7
	Avalon1100: Site LC1	0.50	SaLm	1585	0.403	12.0	19.3	5.0		7
	Pinedene1100: SiteLC2	0.00	SaLm	1746	0.336				388.08	
	Pinedene1100: SiteLC2	0.20	SaLm	1672	0.369	2.0	3.3	10.0	39.68	9
	Pinedene1100: SiteLC2	0.40	SaLm	1757	0.272	360.0	579.8	5.0	39.68	8
	Pinedene1100: SiteLC2	0.60	SaLm	1775	0.330	480.0	768.9	4.0		9
	Pinedene1100: SiteLC2	0.80	SaLm	1850	0.254	670.0	1079.0	5.0		9
	Pinedene1100: SiteLC2	1.40	SiClLm	1842	0.447	2.0	3.3	15.0		
	Tukula2210: Site LC3	0.50	SaLm	1791	0.319	140.0	225.5	5.0	39.68	9
	Tukula2210: Site LC3	0.70	SaLm	1760	0.320	18.0	28.8	4.0		10
	Tukula2210: Site LC3	1.50	Lm	1871	0.294	740.0	1175.1	3.0		9
	Kroonstad2000: Site LC4	0.20	Lm	1892	0.286	800.0	1262.0	2.5		10
	Kroonstad2000: Site LC4	0.50	Lm	1717	0.314					
	Katspruit1000: Site UC4	0.00		1410	0.468	22.0	35.9	13.0		8
	Katspruit1000: Site UC4	0.20	ClLm	1516	0.428	50.0	82.0	22.0		7
	Katspruit1000: Site UC5	0.20	Lm	1712	0.354	7.0	11.4	15.0		6
	Katspruit1000: Site UC5	0.80	Lm	1720	0.351	40.0	65.5	17.0		6
	Site UC8	0.00		1680	0.302	400.0	656.7	29.0	5.25	7
	Site UC8	0.20		1799	0.321	180.0	292.4	8.0	5.71	7
	Oakleaf2120: Site UC9	0.00		1818	0.314	900.0	1473.8	18.0	2.35	4
	Oakleaf2120: Site UC9	0.80	Cl	1410	0.468	80.0	129.7	7.0	11.32	7
De Hoek: V1H028	Clovelly 17 Site F1	0.00	ClLm	1378	0.484	50.0	81.2	8.0	41.04	9
Portnet	Marine sand	0.18	Sa	1601	0.349	4.0	6.2	2.0	85.18	5
Newcastle	Coal discard: Uncompacted	0.00	Sa	986	0.413	2.0	3.2	4.6	113.76	
	Coal discard: Compacted	0.00	Sa	1063	0.401	5.0	8.0	3.8	203.04	
	Coal discard: Uncompacted	0.00	Sa	1066	0.367	2.0	3.2	4.6	72.36	
	Avalon soil: Uncompacted	0.30	ClLm	1539	0.393	5.0	8.2	11.0	114.12	
	Avalon soil: Compacted	0.50	ClLm	1644	0.342	100.0	162.4	8.0	11.52	
	Estcourt soil: Compacted	0.70	SaClLm	1776	0.301	500.0	818.4	17.0	0.54	
	Avalon soil: Compacted	0.70	SaClLm	1694	0.345	100.0	163.5	15.0	10.80	
	Avalon soil: Uncompacted	0.70	ClLm	1663	0.338	10.0	16.4	16.0	116.28	

Soil Hydraulic Characteristics
Campbell Parameters

PROJECT	DESCRIPTOR		MODEL PARAMETERS							RATING
		Depth m	Texture	Density kg/m3	THETAS m/m	he mm	hi mm	b	Ks (measured) mm/h	
Cathedral Peak	Catchment 6: n. lysimeter site	0.10	Lm	868	0.666				122.10	
Ntabamhlope	Wetland	0.00		578	0.753	25.0	40.9	16.0		9
	Wetland	0.38		933	0.656	300.0	487.3	8.0		6
	Wetland	0.78		1277	0.491	24.0	39.1	11.0		8
Wastech	Orange Bimodal sand			424	0.700					
	White sand			1566	0.413					
Sabie: CSIR	Hutton: Frankfurt Lower 1	1.50	Lm	1321	0.495				43.91	
	Legogotte 1	0.90		1280	0.380				297.67	
	Legogotte 1	1.50	ClLm	1251	0.480				74.43	
Kleinkopjes Colliery	Major: Topsoil	0.00		1807	0.266					
	Major: Topsoil	0.05		1746	0.337					
	Major: Field Capacity	1.00		1564	0.410	30.0	48.3	5.0	1.32	7
	Major: Plinthite	1.80		1794	0.382	520.0	842.8	7.0	0.41	8
	Jacuzzi: Deficit	0.00		1558	0.412	35.0	56.4	5.0	1.00	9
	Jacuzzi: Deficit - Spoil	1.20		2056	0.318				0.10	
	Jacuzzi: Field Capacity	0.00		1182	0.554	35.0	56.4	5.0	184.00	8
	Tweefontein: Field Capacity	0.00		1410	0.466	40.0	64.4	5.0	35.80	8
BCL mine	Alluvium: Site 1	0.00		1441	0.456	60.0	97.7	10.0	34.43	6
	Alluvium: Site 1	0.20		1420	0.464	10.0	16.3	9.0	71.95	7
	Alluvium: Site 1	1.50		1333	0.497	60.0	97.7	10.0	5.00	9
	Hutton: Site 3	0.00		1659	0.374	120.0	192.2	4.0	16.93	6
	Hutton: Site 7	0.00	SaLm	1691	0.362	25.0	40.0	4.0	3.26	10
	Hutton: Site 7	0.20	SaClLm	1542	0.418	18.0	28.8	4.0	29.32	9
Richards Bay	Sample 4	0.25		1394	0.474					
SASEX	Fernwood 1	0.25	Sa	1441	0.440	10.0	15.9	3.0		9
	Fernwood 2	0.25	Sa	1420	0.464	17.0	27.0	3.0		9
	Fernwood 3	0.25	Sa	1333	0.470	10.0	15.6	2.0		7
	Swartland 1	0.25	SaClLm	1329	0.507	60.0	96.6	5.0		9
	Swartland 2	0.25	SaCl	1061	0.600	10.0	16.2	6.0		8
	Swartland 3	0.25	SaCl	1193	0.550	200.0	312.5	2.0		9
	Hutton	0.25	LmSa	1305	0.508	18.0	28.8	4.0		9
Seven Oaks Nursery	Bark chips growing medium	0.00		254	0.780					
SASOL	Rensburg: Grass site	0.00		1603	0.395	65.0	106.1	12.0		9
	Rensburg: Grass site	0.30		1518	0.427	60.0	98.0	13.0		8

Soil Hydraulic Characteristics
Campbell Parameters

PROJECT	DESCRIPTOR	Depth	MODEL PARAMETERS							RATING
			Texture	Density	THETAS	he	hi	b	Ks (measured)	
		m		kg/m3	m/m	mm	mm		mm/h	
SASOL (cont.)	Arcadia: Forest site	0.30		1383	0.478	30.0	49.0	13.0		8
	Arcadia: Forest site	0.50		1137	0.571	38.0	62.3	20.0		8
	Arcadia: Forest site	0.70		1359	0.487	280.0	458.3	17.0		4
Sabie: Witklip	Hutton Crest: Site A	0.00	Lm	1276	0.519	25.0	41.0	30.0		6
	Hutton Crest: Site A	0.75	SaLm	1534	0.421	80.0	130.1	9.0		7
	Hutton Crest: Site A	1.50	SaLm	1327	0.499	40.0	64.1	4.0		9
	Hutton Crest: Site A	2.50	SaLm	1353	0.489	80.0	128.8	5.0		9
	Hutton Midslope: Site C2	1.00	ClLm	1375	0.481	120.0	195.5	10.0		8
	Hutton Midslope: Site C2	2.50	SaLm	1503	0.433	9.0	14.8	27.0		7
	Hutton Forested: Site F1	0.00		965	0.636	50.0	78.1	2.0		7
	Riparian: Site R1	0.00		1312	0.505	18.0	29.4	11.0		8
	Riparian: Site R1	1.00		1969	0.257	50.0	82.0	21.0		9
Willowfontein	Profile 1: Market garden	0.00		1333	0.497	120.0	194.5	7.0	24.59	7
	Profile 1: Market garden	0.30		1476	0.443	60.0	97.9	12.0	12.66	7
	Profile 1: Market garden	0.75		1476	0.443	30.0	49.1	15.0	12.66	6
	Profile 1: Market garden	1.30		1582	0.403	100.0	162.1	7.0	9.54	8
Taylors Halt	Profile 1: Market garden	0.00		898	0.661	17.0	27.7	12.0	13.17	8
	Profile 1: Market garden	0.89		739	0.721	25.0	40.9	14.0	12.66	8
	Profile 1: Market garden	1.06		1219	0.540	5.0	8.2	14.0	7.93	8
Kruger National Park	Nwarhlangari: Site 1	0.15	Lm	1034	0.614	200.0	326.7	13.0		6
	Nwarhlangari: Site 2	0.60		1299	0.510	190.0	310.1	12.0		4
	Nwarhlangari: Site 3	0.00	ClLm	1163	0.561	46.0	75.1	12.0	259.74	7
	Nwarhlangari: Site 3	0.15	Cl	1073	0.600	45.0	73.3	10.0	56.53	7
	Nwarhlangari: Site 4	0.35	Cl	1113	0.580	260.0	423.5	10.0		5
	Nwarhlangari: Site 4	0.60	Cl	1060	0.600	370.0	603.3	11.0		7
	Nwarhlangari: Site 5	0.00	Cl	917	0.654	95.0	154.3	8.0		9
	Nwarhlangari: Site 5	0.35		1036	0.595	18.0	29.3	10.0		7
	Nwarhlangari: Site 5	0.50		1034	0.610	17.0	27.8	18.0		9
	Nwarhlangari: Site 5	0.60		1007	0.620	160.0	260.3	9.0		9
	Nwarhlangari: Site 5	1.10	Cl	1060	0.600	90.0	147.4	19.0		10

Appendix E

Capacity Building

WRC Project Finalisation

Project K5/1061 and K5/1086

Table 1 : Capacity Building *(Include a separate page with the capacity building initiatives that can not be entered in the table below)*

Qualification (degree)	Black		White		Total
	Male	Female	Male	Female	
Doctors: **Achieved**					
On course	2				2
Masters: **Achieved**			1		1
On course	2		1		3
Honours: **Achieved**					
On course					
Other: **Achieved**					
On course					
Total: **Achieved**			1		1
On course	4		1		5

(See separate page)

Table 2: Knowledge dissemination *(A list of the publications and papers with the titles and where they were presented will be more useful.)*

Medium	Number to date	Anticipated additional number
Refereed publications	1	2
Popular articles	1	1
Conference presentations	6	1
Workshops	1	
Other		

Table 3: Knowledge application *(Details of how and where the knowledge gained, results or recommendations made in this project were applied)*

Applications to date	**Anticipated future applications**
	Application to hydrology of the Mooi river catchment

Non-refereed Publications:

Lorentz, S. and Hickson, R. 2001. Applying Hillslope Hydrology Observations to Catchment Modelling in Molteno Formations. Proceedings of the Tenth South African National Hydrology Symposium: 26 B 28 September, 2001, Pietermaritzburg, South Africa.

Sihlophe, N. and Lorentz, S. 2001 Efficiency in Irrigation and Operation of Community Gardens in KwaZulu-Natal. Proceedings of the Tenth South African National Hydrology Symposium: 26 B 28 September, 2001, Pietermaritzburg, South Africa.

Lorentz, S.A. 2001. Hillslope Monitoring on Molteno Formations of the northern Eastern Cape, South Africa. Presented at the American Geophysical Union Chapman Conference on State-of-the-Art Hillslope Hydrology. October 8-12, 2001, Sunriver, Oregon, USA.

Lorentz, S.and Hickson, R. 2001. Applying Hillslope Hydrology Observations to Catchment Modelling in Molteno Formations. Tenth South African National Hydrology Symposium: 26 – 28 September, 2001, Pietermaritzburg, South Africa. pp15.

Jovanovic, N.Z., Annandale, J.G., Claassens, A.S., Lorentz, S.A., Tanner, P.D., Aken, M.E. & Hodgson, F.D.I., 2002. Commercial production of crops irrigated with gypsiferous mine water. SASCP and SASHS Combined Congress. January 2002, Cedara Agricultural College, South Africa.

Lorentz, S.A. 2003. Automated soil water potential monitoring in irrigation. South African Irrigation: Aug/Sept. 2003:20-21.

Refereed publications:

Boardman, J. and Lorentz, S. 2000. The GCTE Soil Erosion Network and Model Evaluation Studies. South African Geographical Journal 82(3):154-156.

Book chapters:

Lorentz, S.A., Hughes, G.O. and Schulze, R.E. 2003. Techniques for Estimating Groundwater Recharge at Different Scales in Southern Africa, in Xu, Y. and Beekman, H.E. (Eds), 2003. *Groundwater Recharge Estimation in Southern Africa*. UNESCO IHP Series No. 64:149-164, UNESCO Paris. ISBN 92-9220-000-3.

Capacity Building

Provided training in hydrometry and advise in irrigation practices to Amahlube Trust and relocating farmers at Ntabamhlope through collaboration with the INR.

Mr Goba is the soil and water laboratory technician and conducts the tests on the hydraulic characterisation of the soils. He sat in on the Hydrology Honours section on Soil Water and Solute Transport and learnt appropriate modelling techniques.

Four students from previously disadvantaged backgrounds were employed in field work, laboratory work and data analysis during the past report period. Mr Sylvester Moekena led the field crew in the intensive monitoring exercise. Mr Mfundo Jili was employed as an hourly laboratory and field assistant during 2002 and 2003, where he learned the measurement of physical and hydraulic characteristics of porous media. He has also learned to install, use and maintain numerous field monitoring and soil water sensing apparatus and sampling methods.

The soils laboratory and the field sites have been used to instruct third year hydrology students and fourth year honours students, many of whom are from disadvantaged backgrounds.