

**THE RELATIONSHIP BETWEEN SOIL WATER REGIME
AND SOIL PROFILE MORPHOLOGY IN THE
WEATHERLEY CATCHMENT, AN AFFORESTATION
AREA IN THE EASTERN CAPE**

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The relationship between soil water regime and soil profile
morphology in the Weatherley catchment, an afforestation area
in the Eastern Cape

Report to the
Water Research Commission

by

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CONTENTS

EXECUTIVE SUMMARY	vi
ACKNOWLEDGEMENTS	xii
LIST OF FIGURES	xiii
LIST OF TABLES	xxii
LIST OF SYMBOLS USED	xxiv
1 INTRODUCTION	1
1.1 Problem statement	1
1.2 Hypothesis	3
1.3 Objectives	4
2 LITERATURE REVIEW	5
2.1 Introduction	5
2.2 Soil colour and soil water content	5
2.3 Soil colour indices	6
2.4 Iron oxide mineralogy and soil water content	9
2.4.1 Origin	9
2.4.2 Minerals	10
2.4.3 Properties	13
2.4.3.1 Mineral surface structure	13
2.4.3.2 Surface charge	14
2.4.3.3 Ion adsorption	14
2.4.3.4 Adsorption of organic molecules	15
2.4.3.5 Aggregation and cementation	15
2.4.4 Iron oxides and micro organisms	16
2.4.5 Determination	18
2.5 Pedogenesis and water content	18
2.6 Colour models	21
2.6.1 Munsell	21
2.6.2 CIE	24
2.6.3 RGB	25
2.6.4 CMY	25
2.6.5 Application	26
2.7 Summary	27
3 GEOGRAPHY OF THE STUDY AREA	29
3.1 Introduction	29
3.2 Location	29
3.3 Relief	29
3.4 Geology	30
3.5 Soils	30
3.6 Climate	30
3.7 Hydrology	37
3.8 Summary	37
4 METHODOLOGY	39
4.1 Introduction	39
4.2 Selection of the study site	39
4.3 Field measurements	40
4.4 Calculation of degree of water saturation	42

4.4.1	Improving neutron water meter calibrations	43
4.4.1.1	Introduction	43
4.4.1.2	Bulk density determinations and use of the density probe	44
4.4.1.3	Procedure	46
4.4.1.4	Results and discussion	48
4.4.1.5	Conclusions	53
4.5	Laboratory Measurements	53
4.6	The soil water balance	54
4.6.1	The soil water balance equation	54
4.6.2	Rainfall	55
4.6.3	Runoff	55
4.6.4	Evapotranspiration	55
4.6.4.1	ET _o	56
4.6.4.2	ET/ET _o during a stress-free period	58
4.6.4.3	ET/ET _o during a stress period	60
4.6.4.4	Final daily ET calculations	63
4.6.4.5	Comparison of ET values estimated using the procedure described, and ET estimates obtained by other procedures	64
4.6.5	Drainage	67
4.6.6	Daily soil water content	68
4.6.6.1	Calculation procedure	68
4.6.6.2	Results	69
4.7	Digital photographs	73
4.8	Interpretation of digital photographs	77
4.9	Summary	80
5	SOIL PROFILE AND WATER REGIME CHARACTERIZATION	83
5.1	Introduction	83
5.2	P201 (Longlands 2000)	87
5.2.1	Morphology	87
5.2.2	Chemical properties	87
5.2.3	Physical properties	88
5.2.4	Hydrology	89
5.3	P202 (Pinedene 1100)	90
5.3.1	Morphology	90
5.3.2	Chemical properties	90
5.3.3	Physical properties	92
5.3.4	Hydrology	92
5.4	P203 (Tukulu 2100)	94
5.4.1	Morphology	94
5.4.2	Chemical properties	94
5.4.3	Physical properties	96
5.4.4	Hydrology	96
5.5	P204 (Longlands 2000)	97
5.5.1	Morphology	97
5.5.2	Chemical properties	98
5.5.3	Physical properties	99
5.5.4	Hydrology	100
5.6	P205 (Kroonstad 2000)	101
5.6.1	Morphology	101
5.6.2	Chemical properties	101
5.6.3	Physical properties	103
5.6.4	Hydrology	103

5.7	P206 (Kroonstad 1000)	104
5.7.1	Morphology	104
5.7.2	Chemical properties	105
5.7.3	Physical properties	106
5.7.4	Hydrology	107
5.8	P207 (Westleigh 1000)	108
5.8.1	Morphology	108
5.8.2	Chemical properties	108
5.8.3	Physical properties	110
5.8.4	Hydrology	110
5.9	P208 (Kroonstad 1000)	111
5.9.1	Morphology	111
5.9.2	Chemical properties	111
5.9.3	Physical properties	113
5.9.4	Hydrology	113
5.10	P209 (Katspruit 1000)	114
5.10.1	Morphology	114
5.10.2	Chemical properties	115
5.10.3	Physical properties	116
5.10.4	Hydrology	117
5.11	P210 (Bloemdal 1100)	118
5.11.1	Morphology	118
5.11.2	Chemical properties	118
5.11.3	Physical properties	120
5.11.4	Hydrology	121
5.12	P211 (Katspruit 1000)	122
5.12.1	Morphology	122
5.12.2	Chemical properties	122
5.12.3	Physical properties	123
5.12.4	Hydrology	124
5.13	P212 (Tukulu 1110)	124
5.13.1	Morphology	124
5.13.2	Chemical properties	125
5.13.3	Physical properties	127
5.13.4	Hydrology	127
5.14	P213 (Katspruit 1000)	128
5.14.1	Morphology	128
5.14.2	Chemical properties	128
5.14.3	Physical properties	129
5.14.4	Hydrology	130
5.15	P218 (Katspruit 1000)	130
5.15.1	Morphology	130
5.15.2	Chemical properties	131
5.15.3	Physical properties	132
5.15.4	Hydrology	133
5.16	P220 (Bloemdal 2100)	133
5.16.1	Morphology	133
5.16.2	Chemical properties	134
5.16.3	Physical properties	135
5.16.4	Hydrology	136
5.17	P221 (Hutton 2100)	137
5.17.1	Morphology	137
5.17.2	Chemical properties	137
5.17.3	Physical properties	139
5.17.4	Hydrology	139

5.18	P222 (Oakleaf 1210)	140
5.18.1	Morphology	140
5.18.2	Chemical properties	140
5.18.3	Physical properties	142
5.18.4	Hydrology	142
5.19	P225 (Longlands 1000)	143
5.19.1	Morphology	143
5.19.2	Chemical properties	143
5.19.3	Physical properties	145
5.19.4	Hydrology	145
5.20	P226 (Kroonstad 1000)	146
5.20.1	Morphology	146
5.20.2	Chemical properties	146
5.20.3	Physical properties	148
5.20.4	Hydrology	148
5.21	P229 (Kroonstad 1000)	149
5.21.1	Morphology	149
5.21.2	Chemical properties	149
5.21.3	Physical properties	151
5.21.4	Hydrology	151
5.22	P230 (Westleigh 1000)	152
5.22.1	Morphology	152
5.22.2	Chemical properties	152
5.22.3	Physical properties	154
5.22.4	Hydrology	154
5.23	P231 (Westleigh 2000)	155
5.23.1	Morphology	155
5.23.2	Chemical properties	155
5.23.3	Physical properties	157
5.23.4	Hydrology	157
5.24	P232 (Katspruit 1000)	158
5.24.1	Morphology	158
5.24.2	Chemical properties	158
5.24.3	Physical properties	160
5.24.4	Hydrology	160
5.25	P233 (Pinedene 2100)	161
5.25.1	Morphology	161
5.25.2	Chemical properties	161
5.25.3	Physical properties	163
5.25.4	Hydrology	163
5.26	P234 (Avalon 2100)	164
5.26.1	Morphology	164
5.26.2	Chemical properties	164
5.26.3	Physical properties	166
5.26.4	Hydrology	166
5.27	P235 (Katspruit 1000)	167
5.27.1	Morphology	167
5.27.2	Chemical properties	167
5.27.3	Physical properties	169
5.27.4	Hydrology	169
5.28	P236 (Katspruit 1000)	170
5.28.1	Morphology	170
5.28.2	Chemical properties	170
5.28.3	Physical properties	172
5.28.4	Hydrology	172

5.29	P237 (Westleigh 1000)	173
5.29.1	Morphology	173
5.29.2	Chemical properties	173
5.29.3	Physical properties	175
5.29.4	Hydrology	175
5.30	Summary	176
6	QUANTIFICATION OF SOIL COLOUR FROM DIGITAL IMAGES	179
6.1	Introduction	179
6.2	Incidence of diagnostic colours	179
6.3	Mean horizon colour	185
6.4	Colour correlations	186
6.5	Summary	187
7	DIAGNOSTIC HORIZON CHARACTERIZATION	189
7.1	Introduction	189
7.2	Orthic A horizons	193
7.3	E horizons	197
7.4	G horizons	199
7.5	Red apedal B horizons	200
7.6	Yellow-brown apedal B horizons	202
7.7	Neocutanic B horizons	203
7.8	Soft plinthic B horizons	205
7.9	Unspecified material with signs of wetness	207
7.10	Summary	209
8	CORRELATION OF SOIL CHARACTERISTICS WITH HYDROLOGICAL RESPONSE CHARACTERISTICS	211
8.1	Introduction	211
8.2	Catchment features camouflaging the correlation between soil and hydrological response characteristics	213
8.3	Upper eastern catchment	218
8.3.1	Topographical and hydropedological characteristics	218
8.3.2	Hydrological response characteristics	221
8.3.2.1	Hydrological response characteristics of selected soils in the UEC	221
8.3.2.2	Hydrological response of the UEC	223
8.4	Summary	227
9	SUMMARY AND RECOMMENDATIONS	229
9.1	Summary	229
9.2	Conclusions	231
9.3	Recommendations for future research	232
10	REFERENCES	235
10	APPENDICES	
A	Photograph, profile description, chemical and physical analyses and degree of water saturation for 28 profiles over 7 years	237
B	Annual duration, frequency and duration of $s > 0.7$ events 28 profiles over 7 years	294

EXECUTIVE SUMMARY

South Africa is a water poor country. Procedures for establishing the water yield of catchments are therefore important, and become increasingly so, as the demand for water increases. Any expansion of knowledge in this regard is therefore desirable.

Apart from the surface flow, all outflow from a catchment must have flowed through the soil at some point. The way in which this process has occurred in different locations in the catchment over thousands of years has played a major role in pedogenesis. These results have become expressed in a discernable way in the soil distribution pattern, in the morphology of the different soil horizons and profiles, and in their chemical and physical characteristics. It is the elucidation of this relationship between hydrology and pedology of the Weatherley catchment that has been the overall objective of this project. The hypothesis was that the general elucidation of the relationship between soil profile morphology and soil hydrology will contribute towards understanding hillslope hydrological processes and facilitate technology transfer between catchments. It is significant that the study of the relationship between hydrology and pedology was formally accentuated during 2004 by the international launching of a new subject called hydropedology, by a team of world leaders in hydrology, pedology and soil physics. They defined hydropedology as "The synergistic integration of classical pedology with soil physics, hydrology and other related bio- and geo-sciences".

The 160 ha Weatherley catchment near Maclear was selected in 1995 for a long-term study aimed at comparing hydrological conditions under natural grassland with those after afforestation on parts of the catchment. The study was initiated and executed by the School of Bioresources Engineering & Environmental Hydrology (SBEEH) of the University of KwaZulu-Natal in cooperation with North East Cape Forests and Mondi Forests, with additional funding provided by the Water Research Commission. The grassland monitoring phase started in November 1995 and continued over seven rain seasons. The planting of forest trees on approximately 82 ha, with three selected areas planted to three different species viz. *Eucalyptus nitens* (33 ha), *Pinus patula* (23 ha) and *Pinus eliottii* (26 ha), was done in September 2002.

Hydrological monitoring at the Weatherley catchment has been achieved by the installation of a wide range of appropriate instruments spread out over the catchment, including two flow measuring weirs. All results have been made available for this project. Measurements for this project commenced during June 2000.

The first objective of this project was to characterize and quantify the soil water regime and soil profile morphology in the Weatherley catchment. The soil water regime referred to here is that which occurred under natural grassland. The objective was reached by the following actions:

- a) Detail descriptions of 28 modal profiles located at different sites in the catchments.
- b) Detailed sampling of the different soil horizons of each of these profiles and subjecting them to detailed analyses.
- c) Digital colour photographs of each of the modal profiles and horizons and initiating the development of a computer aided process to quantify the colours in an objective manner.
- d) Installing piezometer pipes at selected profiles and extracting water samples from each of these at appropriate intervals to study the composition of the soil water.
- e) Employing neutron water meter (NWM) soil water content measurements, taken at a number of depths at each of the 28 modal profile sites, at approximately weekly intervals for the six year period July 1997 to June 2003, in a soil water balance modelling exercise to estimate the soil water content at each measurement point in each modal profile on a daily basis for the six year period.
- f) Making 86 bulk density determinations, in duplicate, by the core method, supported by determinations of bulk density using a gamma density probe at all NWM measurement points, in order to improve NWM calibration lines.

This objective was satisfactorily achieved. For the 28 profiles, detailed profile descriptions, analytical data, photographs and daily water regime data for the six years are available. Hydromorphic soils dominate in the catchment. Of the total area 25 % consists of marshland with mainly soils of the Katspruit and Kroonstad forms which remain close to saturation for most of the year. Eleven of the 28 modal profiles belong to these forms. Other fairly wet soils are those belonging to the Longlands and Westleigh forms, represented by three and five modal profiles respectively. Only one of the 28 modal profiles is freely drained (Hutton form). The remaining eight

belong to the Avalon, Pinedene, Tukulu and Bloemdal forms, all of which have freely drained characteristics in the upper portion of the profile overlying horizons with signs of wetness. These soils occur on the hill slopes surrounding the marsh.

Seven Katspruit, 5 Kroonstad, 4 Westleigh, 3 Longlands, 2 Bloemdal, 2 Pinedene, 2 Tukulu, 1 Avalon, 1 Hutton and 1 Oakleaf soil were identified during field investigations. The chemical data for the Weatherley soils can be summarised as follows:

Diagnostic horizon	Clay (%)	S	CEC _{soil}	CEC _{clay}	BS	OC	N	pH _{water}	pH _{KCl}	Fe	Mn
		(cmol _c kg ⁻¹)				(%)	(mg kg ⁻¹)			(mg kg ⁻¹)	
neocutanic B	18.6	2.0	4.6	20.1	45.1	0.35	343	5.22	4.31	9741	155.3
yellow-brown apedal B	13.6	1.2	4.4	28.0	28.3	0.22	187	5.18	3.99	5152	25.2
red apedal B	21.4	1.6	4.5	16.3	38.5	0.35	259	5.36	4.17	10338	144.6
orthic A	14.8	3.2	6.8	27.0	46.0	0.93	645	5.33	4.36	7586	46.6
soft plinthic B	17.6	3.2	6.0	32.7	52.5	0.19	249	5.79	4.31	6835	64.5
E	13.0	1.9	6.8	44.5	34.3	0.45	374	5.44	4.29	7924	16.8
unspecified material with signs of wetness	23.4	4.3	7.0	28.1	58.2	0.13	208	5.59	4.27	8669	115.4
G	28.2	6.9	10.5	35.3	64.2	0.20	306	6.15	4.44	9227	33.0

The second objective was to determine the relationship between soil water regime and soil profile morphology. This objective was achieved in the following ways:

A preliminary assumption was made that the degree of saturation (*s*) at which anaerobic conditions would be acute enough to cause redox reactions of sufficient intensity to produce visible signs of redox morphology was $s > 0.7$. In accordance with this assumption the daily soil water regime was used to obtain values for the following parameters for the diagnostic horizons for each modal profile:

$AD_{s>0.7}$ = the average duration in days year⁻¹ that *s* was above 0.7 of porosity.

$F_{s>0.7}$ = the average frequency of $s > 0.7$ events year⁻¹.

$D_{s>0.7}$ = the average duration of $s > 0.7$ events.

The results from all the profiles were pooled to give average values for the following diagnostic horizons: G (331 ± 10 days year⁻¹), unspecified material with signs of wetness (248 ± 37 days year⁻¹), E (202 ± 45 days year⁻¹), soft plinthic B (182 ± 25 days year⁻¹), orthic A (148 ± 19 days year⁻¹), red apedal B (80 ± 58 days year⁻¹), yellow-brown apedal B (75 ± 25 days year⁻¹) and neocutanic B horizons (37 ± 24 days year⁻¹).

The third objective was to develop a procedure, in collaboration with hydrologists, to correlate diagnostic and non-diagnostic soil characteristics with hydrological response characteristics in the landscape. The following procedure was followed to achieve this objective:

- a) Identification of the portion of the hydrograph expected to provide the most information about the soils of the catchment – necessary because the hydrological response characteristics of a catchment are reflected in the shape of the hydrograph. Peaks in the hydrograph are due to surface runoff, and the baseflow line is determined by flow from the soil water table and the lower vadose zone. It was therefore decided that the curved portion between these two would be the most useful for our purposes. It should reflect the hydrographical response caused mainly by water which had entered the soil (upper vadose zone) and flowed laterally to the stream bed at a fairly rapid rate compared to the water flowing laterally at greater depths.
- b) Determination of the amount and rate of interflow water released from a small sub-catchment at the end of the rain season and correlating it with the hydrological characteristics of the soils in the sub-catchment.
- c) Identification of important preliminary steps in a procedure to be adopted to correlate soil characteristics and hydrological response characteristics in a particular catchment.

Results to test the hypothesis presented under (a) were obtained by comparing typical autumn, rain free period, hydrographs for Weatherley (160 ha) and Cathedral Peak Catchment VI (68 ha). The total outflow, presumably mainly from interflow (i.e. excluding baseflow) from the two catchments during these periods was 4 362 and 52 093 m³ for Weatherley and Cathedral Peak VI respectively. This large difference, accentuated by the differences in sizes of the catchments, is attributed mainly to two soil-related factors viz. (a) far larger marsh area at Weatherley (40 ha) compared to Cathedral Peak VI (6 ha); (b) far larger water storage capacity of the deep, high organic matter content, low bulk density, high clay content apedal soils on the hillslopes of the Cathedral Peak catchment. The value of the "interflow" portion of the hydrograph was therefore demonstrated.

Results of action (b) were obtained for the sub-catchment represented by the toposequence P201 to P204 from which water flows out over the sandstone shelf during the rainy season and stops in autumn. The estimated total flow during a selected late-summer/autumn period in 2001 was 453 m³. The drainable water capacity, i.e. the amount of water available for interflow, in the soils of the sub-catchment was estimated to be 1 889 m³. There are many factors which could have contributed to the poor agreement between the two values. These were identified. The value of the exercise was in the determination of an approximate procedure for such a study.

Action (c) resulted in the formulation of the following initial steps in a procedure to correlate soil characteristics with hydrological response characteristics in a particular landscape or catchment. First, construct detailed large-scale topographical, geological and soil survey maps. Secondly, collect the data that will make it possible to estimate the total drainable water capacity of the upper vadose zone, and if possible also the lower vadose zone. Thirdly, obtain reliable ET data for the vegetation of the catchment; this is an important step since small errors in this value have a large influence on the water balance, especially for the "interflow" portion of the hydrograph.

Diagnostic horizons can be used to infer hydrological and other soil properties. Since this study was concerned mainly with soils that have developed in siliceous parent material, the effect of different parent materials on Fe supply, and hence soil colour should be researched further. The same is true for climate – mainly rainfall and temperature. Similar studies should therefore be carried out under different climatic conditions. The predictive value of diagnostic horizon and soil form characterization in relation to hydrology should also be evaluated by verification against other profiles in other catchments.

Technology transfer has taken place through four refereed articles, nine conference presentations and three other publications. Capacity building took place within the research group, through two students appointed as co-workers, two Ph.D. students and one Hons. B.Sc. Agric. student.

The possibilities of digital photograph interpretation holds great promise and should be investigated further. It is especially the effect of different cameras and lighting conditions, the relationship between Munsell and RGB colour notation and meaningful differentiation between diagnostic red, yellow and grey colours, as well as the interpretation of soil photographs in the dry and wet states should be investigated further.

The results of a comparison between the Weatherley catchment and Cathedral Peak catchment VI showed that the curved portion of the hydrograph during a rain-free period, and following a high rainfall period which filled the catchment, was correlated with the soil distribution pattern and soil characteristics of the catchment. Three important initial steps – discussed above – were identified in the procedure to correlate soil characteristics with hydrological characteristics in a catchment. Future research at Weatherley should focus on (a) the continuation of measuring and processing neutron water meter measurements and improving the relationship between these and other continuous water monitoring procedures; (b) changes in the water regimes of specific soils caused by specific tree species; (c) changes in ET caused by afforestation (d) intensive studies regarding soil redox reactions; and (e) the formulation of appropriate wetness classes for South African soils.

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LIST OF FIGURES

Figure 2.1	The Munsell color solid (Fujihara Industry Company, 1967). Note that colours further from the centre of the solid are further from one another.	7
Figure 2.2	The reaction of surface Fe in oxides with water through two steps: hydroxylation (step 1) and hydration (step 2) (Schwertmann & Taylor, 1989).	14
Figure 2.3	Adsorption and desorption of H^+ on Fe oxides, resulting in a pH dependent charge (Schwertmann & Taylor, 1989).	14
Figure 2.4	The partition of value and chroma along the 10Y – 10PB axis (Fujihara Industry Company, 1967). Note that the chromas differ at different values and hues.	23
Figure 2.5	The division of hues in the Munsell Color System (Fujihara Industry Company, 1967).	23
Figure 2.6	The CIE colour space (Anon., 2003a).	26
Figure 2.7	Examples of additive (RGB) and subtractive {CMY(K)} colour spaces (Anon., 2003a).	26
Figure 2.8	The RGB colour space (Anon., 2003a).	27
Figure 3.1	The location of the Weatherley catchment, 4 km south of Maclear on the road to Ugie (Chief Director of Surveys and Mapping, 1993).	32
Figure 3.2	Planting strategy in the Weatherley catchment (BEEH, 2003).	33
Figure 3.3	Geography of the Weatherley catchment, including the location of neutron water meter sampling sites.	34
Figure 3.4	Simplified geology of the Weatherley catchment (De Decker, 1981).	35
Figure 3.5	Generalised soil patterns, using Soil Classification Working Group (1991) and FSD (1995) classification, according to	36
Figure 3.6	Hydrograph, showing runoff at the lower weir in the Weatherley catchment (BEEH, 2003).	37
Figure 4.1	Calibration equations of orthic A horizons for CPN 3411, used at Weatherley.	49
Figure 4.2	Calibration equations of red apedal (re), yellow-brown apedal (ye) and neocutanic (ne) B horizons, and E (gs) horizons for CPN 3411, used at Weatherley.	50
Figure 4.3	Calibration equations of G (gh), soft plinthic B (sp), unspecified material with signs of wetness (on), and saprolite (so) for CPN 3411, used at Weatherley.	50
Figure 4.4	Calibration equations of the orthic A (ot), red (re) and G (gh) horizon groups, for CPN instrument 3411, used at Weatherley.	53

Figure 4.5	Regression equations for ETo values of Weatherley vs. surrounding stations. Data obtained from ARC-ISCW climate database (L. Maritz, personal communication, 2004).	57
Figure 4.6	ET/ETo as a function of degree of saturation (s) between FMS and LL.	63
Figure 4.7	Bowen ratio measured ET (BR ET), estimated ET at P218 (Est. ET), reference ET (ETo) and rainfall (P) data for Weatherley for 40 non-consecutive days during the second half of 2001.	66
Figure 4.8	Flow diagram for estimating daily soil water content.	70
Figure 4.9	Comparison of measured and estimated θ values during the period July 1997 to June 2003, for the five diagnostic horizons at soil profile P202.	72
Figure 4.10	The relationship between calculated and photographed Red, Green and Blue values of the 7.5YR Munsell hue.	75
Figure 4.11	The relationship between calculated and photographed Red values of the 7.5YR Munsell hue, in different light sources.	75
Figure 4.12	The relationship between calculated and photographed Green values of the 7.5YR Munsell hue, in different light sources.	76
Figure 4.13	The relationship between calculated and photographed Blue values of the 7.5YR Munsell hue, in different light sources.	76
Figure 4.14	The relationship between calculated and scanned Red, Green and Blue values of the 7.5YR Munsell hue.	77
Figure 4.15	The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991), when plotted against Red and Green (RGB notation). The two lines are used to differentiate between the grey and yellow-brown and between yellow-brown and red colour classes.	78
Figure 4.16	The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991) plotted against Blue and Green (RGB notation).	79
Figure 4.17	The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991) plotted against Red and Blue (RGB notation).	79
Figure 4.18	Result (right) of the application of equations 4.23 and 4.24 to classify a digital photograph (left) of a soft plinthic B horizon, using ArcView SpatialAnalyst (ESRI, 2000).	80
Figure 5.1	pH _{Water} and pH _{KCl} for P201 (Longlands 2000).	87
Figure 5.2	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P201 (Longlands).	88
Figure 5.3	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P201 (Longlands 2000).	88
Figure 5.4	Particle size distribution of the fine earth fraction of P201 (Longlands 2000).	89

Figure 5.5	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the three measuring depths at P201 (Longlands 2000).	89
Figure 5.6	pH_{Water} and pH_{KCl} for P202 (Pinedene 1100).	91
Figure 5.7	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P202 (Pinedene 1100).	91
Figure 5.8	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P202 (Pinedene 1100).	92
Figure 5.9	Texture of the fine earth in P202 (Pinedene 1100).	92
Figure 5.10	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the six measuring depths at P202 (Pinedene 1100).	93
Figure 5.11	pH_{Water} and pH_{KCl} for P203 (Tukulu 2100).	95
Figure 5.12	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P203 (Tukulu 2100).	95
Figure 5.13	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P203 (Tukulu 2100).	96
Figure 5.14	Texture of the fine earth in P203 (Tukulu 2100).	96
Figure 5.15	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the six measuring depths at P203 (Tukulu 2100).	97
Figure 5.16	pH_{Water} and pH_{KCl} for P204 (Longlands 2000).	98
Figure 5.17	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P204 (Longlands 2000).	98
Figure 5.18	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P204 (Longlands 2000).	99
Figure 5.19	Texture of the fine earth in P204 (Longlands 2000).	100
Figure 5.20	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P204 (Longlands 2000).	100
Figure 5.21	pH_{Water} and pH_{KCl} for P205 (Kroonstad 2000).	102
Figure 5.22	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P205 (Kroonstad 2000).	102
Figure 5.23	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P205 (Kroonstad 2000).	103
Figure 5.24	Texture of the fine earth in P205 (Kroonstad 2000).	103
Figure 5.25	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P205 (Kroonstad 2000).	104
Figure 5.26	pH_{Water} and pH_{KCl} for P206 (Kroonstad 1000).	105
Figure 5.27	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P206 (Kroonstad 1000).	105

Figure 5.28	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P206 (Kroonstad 1000).	106
Figure 5.29	Texture of the fine earth in P206 (Kroonstad 1000).	107
Figure 5.30	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P206 (Kroonstad 1000).	107
Figure 5.31	pH_{Water} and pH_{KCl} for P207 (Westleigh 1000).	108
Figure 5.32	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P207 (Westleigh 1000).	109
Figure 5.33	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P207 (Westleigh 1000).	109
Figure 5.34	Texture of the fine earth in P207 (Westleigh 1000).	110
Figure 5.35	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the two measuring depths at P207 (Westleigh 1000).	111
Figure 5.36	pH_{Water} and pH_{KCl} for P208 (Kroonstad 1000).	112
Figure 5.37	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P208 (Kroonstad 1000).	112
Figure 5.38	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P208 (Kroonstad 1000).	113
Figure 5.39	Texture of the fine earth in P208 (Kroonstad 1000).	113
Figure 5.40	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P208 (Kroonstad 1000).	114
Figure 5.41	pH_{Water} and pH_{KCl} for P209 (Katspruit 1000).	115
Figure 5.42	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P209 (Katspruit 1000).	115
Figure 5.43	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P209 (Katspruit 1000).	116
Figure 5.44	Texture of the fine earth in P209 (Katspruit 1000).	117
Figure 5.45	Mean $AD_{s>0.7}$ value based on estimated daily soil water contents, for the two measuring depths at P209 (Katspruit 1000).	117
Figure 5.46	pH_{Water} and pH_{KCl} for P210 (Bloemdal 1100).	119
Figure 5.47	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P210 (Bloemdal 1100).	119
Figure 5.48	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P210 (Bloemdal 1100).	120
Figure 5.49	Texture of the fine earth in P210 (Bloemdal 1100).	120
Figure 5.50	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P210 (Bloemdal 1100).	121

Figure 5.51	pH _{Water} and pH _{KCl} for P211 (Katspruit 1000).	122
Figure 5.52	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P211 (Katspruit 1000).	123
Figure 5.53	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P211 (Katspruit 1000).	123
Figure 5.54	Texture of the fine earth in P211 (Katspruit 1000).	124
Figure 5.55	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P211 (Katspruit 1000).	124
Figure 5.56	pH _{Water} and pH _{KCl} for P212 (Tukulu 1110).	125
Figure 5.57	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P212 (Tukulu 1110).	126
Figure 5.58	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P212 (Tukulu 1110).	126
Figure 5.59	Texture of the fine earth in P212 (Tukulu 1110).	127
Figure 5.60	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P212 (Tukulu 1110).	127
Figure 5.61	pH _{Water} and pH _{KCl} for P213 (Katspruit 1000).	128
Figure 5.62	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P213 (Katspruit 1000).	129
Figure 5.63	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P213 (Katspruit 1000).	129
Figure 5.64	Texture of the fine earth in P213 (Katspruit 1000).	130
Figure 5.65	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P213 (Katspruit 1000).	130
Figure 5.66	pH _{Water} and pH _{KCl} for P218 (Katspruit 1000).	131
Figure 5.67	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P218 (Katspruit 1000).	132
Figure 5.68	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P218 (Katspruit 1000).	132
Figure 5.69	Texture of the fine earth in P218 (Katspruit 1000).	133
Figure 5.70	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P218 (Katspruit 1000).	133
Figure 5.71	pH _{Water} and pH _{KCl} for P220 (Bloemdal 2100).	134
Figure 5.72	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P220 (Bloemdal 2100).	135
Figure 5.73	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P220 (Bloemdal 1100).	135
Figure 5.74	Texture of the fine earth in P220 (Bloemdal 2100).	136
Figure 5.75	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P220 (Bloemdal 2100).	137

Figure 5.76	pH _{Water} and pH _{KCl} for P221 (Hutton 2100).	138
Figure 5.77	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P221 (Hutton 2100).	138
Figure 5.78	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P221 (Hutton 2100).	139
Figure 5.79	Texture of the fine earth in P221 (Hutton 2100).	139
Figure 5.80	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P221 (Hutton 2100).	140
Figure 5.81	pH _{Water} and pH _{KCl} for P222 (Oakleaf 1210).	141
Figure 5.82	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P222 (Oakleaf 1210).	141
Figure 5.83	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P222 (Oakleaf 1210).	142
Figure 5.84	Texture of the fine earth in P222 (Oakleaf 1210).	142
Figure 5.85	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P222 (Oakleaf 1210).	143
Figure 5.86	pH _{Water} and pH _{KCl} for P225 (Longlands 1000).	144
Figure 5.87	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P225 (Longlands 1000).	144
Figure 5.88	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P225 (Longlands 1000).	145
Figure 5.89	Texture of the fine earth in P225 (Longlands 1000).	145
Figure 5.90	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P225 (Longlands 1000).	146
Figure 5.91	pH _{Water} and pH _{KCl} for P226 (Kroonstad 1000).	147
Figure 5.92	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P226 (Kroonstad 1000).	147
Figure 5.93	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P226 (Kroonstad 1000).	148
Figure 5.94	Texture of the fine earth in P226 (Kroonstad 1000).	148
Figure 5.95	Mean AD _{s>0.7} values based on estimated daily soil water contents, for the five measuring depths at P226 (Kroonstad 1000).	149
Figure 5.96	pH _{Water} and pH _{KCl} for P229 (Kroonstad 1000).	150
Figure 5.97	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P229 (Kroonstad 1000).	150
Figure 5.98	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P229 (Kroonstad 1000).	151
Figure 5.99	Texture of the fine earth in P229 (Kroonstad 1000).	151

Figure 5.100	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P229 (Kroonstad 1000).	152
Figure 5.101	pH_{Water} and pH_{KCl} for P230 (Westleigh 1000).	153
Figure 5.102	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P230 (Westleigh 1000).	153
Figure 5.103	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P230 (Westleigh 1000).	154
Figure 5.104	Texture of the fine earth in P230 (Westleigh 1000).	154
Figure 5.105	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P230 (Westleigh 1000).	155
Figure 5.106	pH_{Water} and pH_{KCl} for P231 (Westleigh 2000).	156
Figure 5.107	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P231 (Westleigh 2000).	156
Figure 5.108	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P231 (Westleigh 2000).	157
Figure 5.109	Texture of the fine earth in P231 (Westleigh 2000).	157
Figure 5.110	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P231 (Westleigh 2000).	158
Figure 5.111	pH_{Water} and pH_{KCl} for P232 (Katspruit 1000).	159
Figure 5.112	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P232 (Katspruit 1000).	159
Figure 5.113	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P232 (Katspruit 1000).	160
Figure 5.114	Texture of the fine earth in P232 (Katspruit 1000).	160
Figure 5.115	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P232 (Katspruit 1000).	161
Figure 5.116	pH_{Water} and pH_{KCl} for P233 (Pinedene 2100).	162
Figure 5.117	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P233 (Pinedene 2100).	162
Figure 5.118	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P233 (Pinedene 2100).	163
Figure 5.119	Texture of the fine earth in P233 (Pinedene 2100).	163
Figure 5.120	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P233 (Pinedene 2100).	164
Figure 5.121	pH_{Water} and pH_{KCl} for P234 (Avalon 2100).	165
Figure 5.122	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P234 (Avalon 2100).	165

Figure 5.123	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P234 (Avalon 2100).	166
Figure 5.124	Texture of the fine earth in P234 (Avalon 2100).	166
Figure 5.125	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P234 (Avalon 2100).	167
Figure 5.126	pH_{Water} and pH_{KCl} for P235 (Katspruit 1000).	168
Figure 5.127	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P235 (Katspruit 1000).	168
Figure 5.128	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P235 (Katspruit 1000).	169
Figure 5.129	Texture of the fine earth in P235 (Katspruit 1000).	169
Figure 5.130	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P235 (Katspruit 1000).	170
Figure 5.131	pH_{Water} and pH_{KCl} for P236 (Katspruit 1000).	171
Figure 5.132	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P236 (Katspruit 1000).	171
Figure 5.133	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P236 (Katspruit 1000).	172
Figure 5.134	Texture of the fine earth in P236 (Katspruit 1000).	172
Figure 5.135	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P236 (Katspruit 1000).	173
Figure 5.136	pH_{Water} and pH_{KCl} for P237 (Westleigh 1000).	174
Figure 5.137	Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P237 (Westleigh 1000).	174
Figure 5.138	CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P237 (Westleigh 1000).	175
Figure 5.139	Texture of the fine earth in P237 (Westleigh 1000).	175
Figure 5.140	Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P237 (Westleigh 1000).	176
Figure 6.1	The relationship between two methods for determining soil colour.	186
Figure 7.1	Mean and standard error of mean the $AD_{s>0.7}$ values per diagnostic horizon group.	189
Figure 7.2	Clay content mean and standard error, per diagnostic horizon group.	190
Figure 7.3	Mean texture per diagnostic horizon group.	190
Figure 7.4	Organic carbon mean and standard error, per diagnostic horizon group.	190

Figure 7.5	Organic nitrogen (N) mean and standard error, per diagnostic horizon group.	191
Figure 7.6	CEC _{soil} and CEC _{clay} mean and standard error, per diagnostic horizon group.	191
Figure 7.7	Sum of basic cations (S) mean and standard error, per diagnostic horizon group.	191
Figure 7.8	Base saturation mean and standard error, per diagnostic horizon group.	192
Figure 7.9	pH _{Water} mean and standard error, per diagnostic horizon group.	192
Figure 7.10	pH _{KCl} mean and standard error, per diagnostic horizon group.	192
Figure 7.11	CBD extractable Fe and Fe:clay mean and standard error, per diagnostic horizon group.	193
Figure 7.12	CBD extractable Mn and Mn:clay mean and standard error of, per diagnostic horizon group.	193
Figure 8.1	The extent of the vadose zone in relation to the ground water (Lin, 2003).	212
Figure 8.2	The Weatherley catchment showing contours (2 mm interval), some convenient sub-catchments, hydrographical weirs, and NWM measuring sites.	213
Figure 8.3	Examples of quick runoff response to varying rainfall intensities as reported at the upper weir in February 1999 (BEEH, 2003).	215
Figure 8.4	Topographic map of Catchment VI showing the location of the various monitoring sites (Everson <i>et al.</i> , 1998).	217
Figure 8.5	Typical hydrographs for the Weatherley and Cathedral Peak (VI) catchments during a rain-free period at the end of the rain season, approximately up to the stage when base flow starts.	218
Figure 8.6	Map of the upper eastern catchment with its map units and 2 m interval contour lines. 201 to 204 (204 is at location B in Figure 8.8) are the sites of soil profiles, tensiometer nests and NWM access tubes. Soil map information obtained from Roberts <i>et al.</i> (1996).	220
Figure 8.7	Hydrological responses of different diagnostic horizons following isolated rainfall events.	222
Figure 8.8	Conceptual model of flow mechanisms in the Weatherley research catchment (Lorentz, 2001).	224
Figure 8.9	Changes in the degree of saturation (s) between 1 May and 12 May 2001 at P204, at 250 mm and 700 mm depths.	226

LIST OF TABLES

Table 2.1	General characteristics of iron oxide minerals (Schwertmann, 1985)	13
Table 2.2	Typical reduction reactions and their redox potentials in the soil (Bohn <i>et al.</i> , 1985)	17
Table 3.1	Yearly rainfall, measured at Weatherley (BEEH, 2003)	31
Table 3.2	Monthly mean rainfall and evaporation for Weatherley and temperature from a weather station roughly 4 km from the study area (Roberts <i>et al.</i> 1996)	31
Table 4.1	NWM calibration equations for Weatherley compiled in June 1997 by ARC-ISCW	44
Table 4.2	Calculated ET/ET ₀ for non-stressed veld grass during selected periods at profiles with freely drained 0-900 mm layers at Weatherley	59
Table 4.3	Calculated ET/ET ₀ for water-stressed veld grass during selected periods at profiles with freely drained 0-900 mm layers at Weatherley	62
Table 4.4	Weatherley total catchment water balance results for the period 30 June 1999 to 30 June 2003; and results partitioned into hillslope and marsh areas	65
Table 4.5	Example of daily soil water balance calculations in a worksheet	71
Table 4.6	Results of statistical test of model performance for θ at P202 for five horizons	73
Table 4.7	Bartlett's test results (Snedecor & Cochran, 1989), measuring the homogeneity of error variance in regression lines of calculated vs. photographed Red, Green and Blue, Y-intercepts and slopes	74
Table 4.8	Number of Munsell chips defined as diagnostic red, yellow-brown and grey class (Soil Classification Working Group, 1991) by calculation from RGB-values	80
Table 5.1	Mean annual duration of $s > 0.7$ ($AD_{s > 0.7}$), mean frequency of $s > 0.7$ ($F_{s > 0.7}$) and mean duration of $s > 0.7$ events ($D_{s > 0.7}$) for profiles 201 to 237, based on estimated daily soil water contents (section 4.6.6) from 01/07/1997 until 30/06/2003	84
Table 6.1	The occurrence of diagnostic red, yellow and grey colours (Soil Classification Working Group, 1991) as well as black determined from digital photographs taken per diagnostic horizon	180
Table 6.2	Results of Munsell colour calculation from RGB values determined from digital photographs	181
Table 6.3	The correlation (R^2) of mean photo Red, Green and Blue with mean $AD_{s > 0.7}$, mean duration and mean frequency of water saturation	187

Table 7.1	Classes of duration of the wet state (Soil Survey Division Staff, 1993)	195
Table 7.2	Classification of mean $AD_{s>0.7}$ values in orthic A horizons according to the wetness classes of Soil Survey Division Staff (1993)	196
Table 7.3	Classification of mean $AD_{s>0.7}$ values in E horizons (gs) using the wetness classes of the Soil Survey Division Staff (1993)	197
Table 7.4	Classification of mean $AD_{s>0.7}$ values in G horizons (gh) according to the wetness classes of Soil Survey Division Staff (1993)	200
Table 7.5	Classification of mean $AD_{s>0.7}$ values in red apedal B horizons (re), according to the wetness classes of Soil Survey Division Staff (1993)	201
Table 7.6	Classification of mean $AD_{s>0.7}$ values in yellow-brown apedal B horizons (ye), according to the wetness classes of Soil Survey Division Staff (1993)	203
Table 7.7	Classification of mean $AD_{s>0.7}$ values neocutanic B horizons (ne), according to the wetness classes of Soil Survey Division Staff (1993)	204
Table 7.8	Classification of mean $AD_{s>0.7}$ value in soft plinthic B horizons (sp), according to the wetness classes of Soil Survey Division Staff (1993)	206
Table 7.9	Classification of mean $AD_{s>0.7}$ values in unspecified material with signs of wetness (on) according to the wetness classes of Soil Survey Division Staff (1993)	208
Table 8.1	Soils in the UEC, areas they occupied, and their drainable water capacities	220
Table 8.2	Summary of flow mechanisms and their occurrence in the Weatherley catchment (first three columns, Lorentz, 2001) and correlation of flow mechanisms and pedology (fourth column)	225
Table 8.3	Soil water balance for the UEC during the period 23 March 2001 to 12 May 2001	227
Table 9.1	Means of selected soil properties in the Weatherley catchment, grouped per diagnostic horizon	230
Table 2	Profile description for profile 201 (Longlands 2000)	244
Table 3	Soil analyses for profile 201 (Longlands 2000)	244
Table 4	Profile description for profile 202 (Pinedene 1100)	246
Table 5	Soil analyses for profile 202 (Pinedene 1100)	246
Table 6	Profile description for profile 203 (Tukulu 2110)	248
Table 7	Soil analyses for profile 203 (Tukulu 2110)	248
Table 8	Profile description for profile 204 (Longlands 2000)	250

Table 9	Soil analyses for profile 204 (Longlands 2000)	250
Table 10	Profile description for profile 205 (Kroonstad 2000)	252
Table 11	Soil analyses for profile 205 (Kroonstad 2000)	252
Table 12	Profile description for profile 206 (Kroonstad 1000)	254
Table 13	Soil analyses for profile 206 (Kroonstad 1000)	254
Table 14	Profile description for profile 207 (Westleigh 1000)	256
Table 15	Soil analyses for profile 207 (Westleigh 1000)	256
Table 16	Profile description for profile 208 (Kroonstad 1000)	258
Table 17	Soil analyses for profile 208 (Kroonstad 1000)	258
Table 18	Profile description for profile 209 (Katspruit 1000)	260
Table 19	Soil analyses for profile 209 (Katspruit 1000)	260
Table 20	Profile description for profile 210 (Bloemdal 1100)	262
Table 21	Soil analyses for profile 210 (Bloemdal 1100)	262
Table 22	Profile description for profile 211 (Katspruit 1000)	264
Table 23	Soil analyses for profile 211 (Katspruit 1000)	264
Table 24	Profile description for profile 212 (Tukulu 1110)	266
Table 25	Soil analyses for profile 212 (Tukulu 1110)	266
Table 26	Profile description for profile 213 (Katspruit 1000)	268
Table 27	Soil analyses for profile 213 (Katspruit 1000)	268
Table 28	Profile description for profile 218 (Katspruit 1000)	270
Table 29	Soil analyses for profile 218 (Katspruit 1000)	270
Table 30	Profile description for profile 220 (Bloemdal 2100)	272
Table 31	Soil analyses for profile 220 (Bloemdal 2100)	272
Table 32	Profile description for profile 221 (Hutton 2100)	274
Table 33	Soil analyses for profile 221 (Hutton 2100)	274
Table 34	Profile description for profile 222 (Oakleaf 1210)	276
Table 35	Soil analyses for profile 222 (Oakleaf 1210)	276
Table 36	Profile description for profile 225 (Longlands 1000)	278
Table 37	Soil analyses for profile 225 (Longlands 1000)	278
Table 38	Profile description for profile 226 (Kroonstad 1000)	280
Table 39	Soil analyses for profile 226 (Kroonstad 1000)	280
Table 40	Profile description for profile 229 (Kroonstad 1000)	282
Table 41	Soil analyses for profile 229 (Kroonstad 1000)	282
Table 42	Profile description for profile 230 (Westleigh 1000)	284
Table 43	Soil analyses for profile 230 (Westleigh 1000)	284

Table 44	Profile description for profile 231 (Westleigh 2000)	286
Table 45	Soil analyses for profile 231 (Westleigh 2000)	286
Table 46	Profile description for profile 232 (Katspruit 1000)	288
Table 47	Soil analyses for profile 232 (Katspruit 1000)	288
Table 48	Profile description for profile 233 (Pinedene 2100)	290
Table 49	Soil analyses for profile 233 (Pinedene 2100)	290
Table 50	Profile description for profile 234 (Avalon 2100)	292
Table 51	Soil analyses for profile 234 (Avalon 2100)	292
Table 52	Profile description for profile 235 (Katspruit 1000)	294
Table 53	Soil analyses for profile 235 (Katspruit 1000)	294
Table 54	Profile description for profile 236 (Katspruit 1000)	296
Table 55	Soil analyses for profile 236 (Katspruit 1000)	296
Table 56	Profile description for profile 237 (Westleigh 1000)	298
Table 57	Soil analyses for profile 237 (Westleigh 1000)	298

LIST OF SYMBOLS USED

θ	volumetric soil water content (mm)
$AD_{s>0.7}$	annual duration of water saturation above 0.7 of porosity (days year ⁻¹)
Av	Avalon soil form (orthic A – yellow-brown apedal B – soft plinthic B)
Bd	Bloemdal soil form (orthic A – red apedal B – unspecified material with signs of wetness)
C_d	dry colour chroma
d	day
D	deep percolation (–) and capillary rise (+)
$D_{s>0.7}$	duration of degree of water saturation above 0.7 of porosity in a particular year (days event ⁻¹)
DUL	drained upper limit
E	evaporation
ET	evapotranspiration
ETo	reference evaporation determined by the FAO Penman-Monteith equation
f	porosity
fi Sat	field saturation
$F_{s>0.7}$	frequency of water saturation above 0.7 of porosity (events year ⁻¹)
gh	G horizon
gs	E horizon
H_d	dry colour hue
Hu	Hutton soil form (orthic A – red apedal B – unspecified)
I	irrigation
Ka	Katspruit soil form (orthic A – G)
Kd	Kroonstad soil form (orthic A – E – G)
LL	lower limit of plant available water (mm)
Lo	Longlands soil form (orthic A – E – soft plinthic B)
max	maximum
min	minimum
ne	neocutanic B horizon
NWM	neutron water meter
on	unspecified material with signs of wetness
ot	orthic A horizon
P	precipitation
Pn	Pinedene soil form (orthic A – yellow-brown apedal B – unspecified material with signs of wetness)
R	run-off (–) and run-on (+)
re	red apedal B horizon

ro	rock
s	degree of saturation (volume of water per volume of pores)
s>0.7	degree of water saturation above 0.7 of porosity
so	saprolite
SOC	soil organic carbon
sp	soft plinthic B horizon
std	standard deviation
T	transpiration
Tu	Tukulu soil form (orthic A – neocutanic B – unspecified material with signs of wetness)
ud	unconsolidated material without signs of wetness
V _d	dry colour value
We	Westleigh soil form (orthic A – soft plinthic B)
ye	yellow-brown apedal B horizon
ΔW	Change in soil water content (mm)

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1 INTRODUCTION

This report describes a project that researched the relationship between soil morphology and duration of water saturation to aid hydrological modelling. The project built on current and previous research done by Lorentz, Van Zyl and others in the Weatherley catchment in the northern Eastern Cape Province. This project also followed a one-year WRC project (K8/419) that initiated soil water sampling in the catchment (Van Huyssteen *et al.* 2002).

1.1 Problem statement

South Africa is a water poor country. Procedures for establishing the water yield of catchments are therefore important, and become increasingly so as the demand for water increases. Any expansion of knowledge in this regard is therefore desirable. This led to the establishment of an intensively measured catchment on the farm Weatherley in the northern Eastern Cape Province. Various Water Research Commission (WRC) funded, and other projects have been conducted in this catchment (Lorentz & Hickson, 2001; Lorentz *et al.*, 2001; Van Huyssteen *et al.*, 2002; 2003a). The relationship between soil water regime and soil profile morphology has, however, up to now received very little attention. Soil water regime refers to the state and availability of water in soil (Van der Watt & Van Rooyen, 1995) and is used in this research to refer to the degree of wetness of a soil, with the critical parameter mean $AD_{\theta > 0.7}$, defined as the mean annual duration of water saturation above 0.7 of porosity, expressed in days year⁻¹.

There is a close relationship between the water regime of a soil profile and its morphology, since water plays a primary role in soil genesis. The quantity and quality of water available during pedogenesis is reflected in the morphology of the profile. The hydrological characteristics of soil can either be determined quantitatively by regular measurements, or qualitatively by inference from the soil properties such as colour, exchangeable bases, occurrence of mottles and concretions. Soil colour is the most common morphological soil property used to predict the water regime of soil. The major soil classification systems of the world apply soil colours as distinguishing criteria at various levels. The South African system applies it at the highest level to distinguish between diagnostic horizons, and

thus soil forms. The definitions for colour defined horizons (Soil Classification Working Group, 1991) were compiled to differentiate between horizons with differing hydrological characteristics. The hypothesis is that red apedal B horizons are freely drained, yellow-brown apedal B horizons are well drained, and E horizons are poorly drained (Le Roux *et al.*, 1999). This conforms to the hypothesis that degree of wetness determines the quantity and type of iron oxide minerals present and hence the soil colour (Schwertmann, 1993).

In a paper titled "Hydrology and Soil Science", Amerman (1973) concludes that hydrologists need an improved understanding of the hydrology of soils, and that they are looking to soil scientists for assistance. This need has up to now received relatively little attention in South Africa. Schwertmann wrote in 1985 that: "Studies in which soil temperature and soil moisture regimes are measured and directly related to the pedogenic Fe oxides would thus be very desirable." The importance of this relationship was accentuated by Lin *et al.* (2004), launching the new subject termed *hydropedology*.

Improved understanding of the relationship between the water regimes of soil profiles and their morphology will improve soil classification. This will lead to improved understanding of landscape hydrology and improved definitions of hydrological response units (Flugel, 1993), and similarly ecotopes (MacVicar *et al.*, 1974). This will contribute to improved pedotransfer and performance of models such as ACRU (Schulze, 1995) and SWAMP (Bennie *et al.*, 1998).

An experiment conducted in the Weatherley catchment, close to Maclear, to monitor and model total catchment hydrology. The study has been in operation since 1995 and other soil water relationships were studied thoroughly. The development of pedotransfer functions from these results, for application to other catchments, will be enhanced if the relationship between soil water regime and soil morphology is better understood. The relationship between soil properties and soil water regime has been studied in South Africa (Donkin & Fey, 1991; Van Huyssteen, 1995; Le Roux, 1996) and in other countries (Blavet *et al.*, 2000; 2002).

1.2 Hypothesis

Both the genesis of soil and its suitability for common land uses (agricultural, ecological and engineering purposes) depend to a large extent on the soil water regime. The soil water regime can either be determined by regular long-term measurements of soil water content or by inference from soil properties such as soil colour, exchangeable bases, and the occurrence of mottles and concretions. Soil colour has always been regarded as the best tool to predict the water status of soil (Cutler, 1983). The major soil classification systems of the world apply soil colour as distinguishing criteria. For example Soil Taxonomy (Soil Survey Staff, 1975) rates soil colours with a chroma equal to or less than two as indicators of a significant time of water saturation in that horizon per year. The frequency and / or duration of a specific degree of water saturation are, however, not specified. On the other hand it has been stated that the importance of soil colour is somewhat overrated, since plant roots are colour-blind and the value of colour interpretation is often questioned (Evans & Franzmeier, 1986; Cogger & Kennedy, 1992).

In the South African soil classification system the definitions for colour defined diagnostic horizons were compiled to differentiate, amongst other things, between horizons with differing water regimes (Soil Classification Working Group, 1991). Distinguishing definitions for colour ranges were established by long term experience of field observations (Lambrechts, 1994, personal communication). These colour definitions form the basis of definitions for the diagnostic red apedal B, yellow-brown apedal B, soft plinthic B, E and G horizons and unspecified material with signs of wetness. Colour is also applied to differentiate between the families of several soil forms. The differentiation between families with yellow and grey E horizons is an example. It is speculated that yellow E horizons are somewhat better drained than grey E horizons. This is in line with the hypothesis of Schwertmann (1993) that water saturation impacts on the quantity and type of Fe oxide minerals, and therefore soil colour.

The relationship between soil morphology and soil water regime is used to delineate wetlands (Land-Use and Wetland/Riparian Habitat Working Group, 2000), because soils in wetlands typically have morphology associated with long periods of water

saturation. Soil water content data for the Weatherley catchment may contribute towards quantifying this relationship.

Improved knowledge of the relationship between soil water regimes and soil morphology will improve technology transfer between catchments. Soil morphological features could thus be used to interpret the hydrology of catchments under similar climatic and geological conditions.

It is hypothesized that elucidation of the relationship between soil profile morphology and soil hydrology will contribute towards understanding hillslope hydrological processes.

1.3 Objectives

- a) To characterize and quantify the soil water regime and soil profile morphology in the Weatherley catchment.
- b) To determine the relationship between soil water regime and soil profile morphology in the Weatherley catchment.
- c) To develop a procedure, in collaboration with hydrologists, to correlate diagnostic and non-diagnostic soil characteristics with hydrological response characteristics in the landscape.

The original third objective was changed to its current formulation and the original fourth objective was deleted during the inaugural meeting of the steering committee held on 29 May 2002 at the Royal Hotel in Maclear. The third objective originally read: "To develop a new model, using the above-mentioned data, which will facilitate in the assessment of the hydrological characteristics of catchments where soil water measurements are limited or absent." The fourth objective read: "To calibrate the above-mentioned model."

The first objective is discussed in chapters 4 and 5, the second objective in chapter 6 and the third objective in chapter 7.

2 LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature on the relationship between soil colour and soil water regime, especially colour indices. It also focuses on iron oxide minerals in soil as well as soil forming processes where excess soil water influences soil morphology.

2.2 Soil colour and soil water content

The major soil classification systems of the world (Soil Survey Staff, 1975 and FAO, 1998b) also use low soil chroma (< 2) as an indicator of long term water saturation for part of the year.

In South Africa Henning & Von Harmse (1993) found that soil saturation can be detected by hydromorphic properties such as the presence of grey matrix colours, mottles, and the presence of diagnostic and non-diagnostic soft plinthic and G horizons. MacVicar (1978) also stated that the formation of soft plinthic B horizons is the result of current profile hydromorphy and not translocation of pre-weathered material. He suggests that the presence of water tables in these soils is consistent with red-yellow-grey vertical profile morphology, and the red-yellow-grey catenas found over vast areas of the country. In his opinion these features support the contention that plinthic soils are a result of current pedogenesis.

Van Huyssteen (1995) studied red apedal B, yellow-brown apedal B, yellow E and grey E horizons for one year on three catenas in the Grabouw district. He found that duration of free water was 1.3 % in red apedal B, 18.8 % in yellow-brown apedal B, 42.2 % in yellow E and 54.4 % in grey E horizons. [Duration of free water was defined as the period that free water was measured in each horizon, expressed in days year⁻¹ as a percentage.] Coarse silt, fine silt, clay and CEC as well as Fe and Al oxides decreased from red apedal B to yellow-brown apedal B to yellow E to grey E horizons. Total Fe oxides correlated with duration of free water ($R^2 = 0.41$), while amorphous Fe ($R^2 = 0.37$) and fine crystalline Fe ($R^2 = 0.40$) were mainly correlated with dry soil colour chroma. Van Huyssteen (1995) also stated that dry soil colour is a good indicator ($R^2 = 0.59$) of duration of free water and developed the following

equation to predict duration of free water in red apedal B, yellow-brown apedal B, yellow E and grey E horizons:

$$\text{Duration of free water (\%)} = 2.35 \times \text{hue}_{gy} + 5.79 \times \text{value}_{gy} - 7.31 \times \text{chroma}_{gy} - 27.89 \quad (2.1)$$

He concluded that the present colour definitions for red apedal B, yellow-brown apedal B and E horizons (Soil Classification Working Group, 1991) distinguish satisfactorily between these horizons with respect to duration of free water.

Le Roux (1996) studied published data on plinthite soils to determine the variation in environments where these soils occur and to relate the environmental factors to the nature of these soils. He constructed a phase diagram using aridity index and a soil index defined as $\{(\text{Si} + \text{Cl}) : \text{depth of occurrence}\}$. The phase diagram indicated that plinthite soils are in harmony with their present environment. He concluded that the conditions during soil formation correlate well with the current environment. Either the climate has not changed in pedogenic terms or it is now again similar to the conditions of formation. These results therefore support the conclusions drawn by MacVicar (1978) in this regard.

2.3 Soil colour indices

The main challenge, when attempting to use colour in mathematical equations, is to present colour differences in some numerical format. Various authors have proposed different colour indices in an attempt to attain this goal.

Godlove (1951) proposed a colour difference equation (ΔE), which accounts for the difference in value and chroma scales:

$$\Delta E = \sqrt{2C_1C_2[1 - \cos(3.6 \times \Delta H)] + (\Delta C)^2 + (4\Delta V)^2} \quad (2.2)$$

Where C_1 and C_2 are the chroma units of two colours, separated by ΔC chroma units, ΔH hue units and ΔV value units. Two sets of different colours can therefore have the same colour difference, due to the fact that the Munsell colour system comprises a three dimensional space (Figure 2.1).

Evans & Franzmeier (1988) studied soils formed from loess in north-central Indiana, with the aim of devising a numerical index to predict wetness, based on soil morphology. They developed two colour indices: $C1_h$ is based on chroma alone, while $C2_h$ is based on numeric hue + chroma. The colour indices had the following basic format:

$$C1_h = \frac{(A_m \times C1_m) - \{(A_1 \times C1_1) - (A_2 \times C1_2) - \dots - (A_n \times C1_n)\} - (A_t \times C1_t)}{1 - A_t} \quad (2.6)$$

Where:

- A_m = abundance of matrix with colour index C_m
- = $1 - (A_1 + A_2 + \dots + A_n)$
- $A_1, A_2 \dots A_n$ = abundance of different sized and coloured mottles with colour index $C1_1, C1_2 \dots C1_n$
- A_t = abundance of clay cutans with colour index C_t
- C_1 = chroma

Evans & Franzmeier (1988) found correlation coefficients between -0.62 and -0.92 ($R^2 = 0.38$ to 0.85), depending on the depth of the soil horizon and the temperature during saturation. They defined saturation as the presence of a water table, measured in 14-day intervals using piezometers. For practical purposes, they found no marked difference in correlation coefficients between $C1_h$ and $C2_h$.

Mokma & Cremeens (1991) studied the relationship between soil colour patterns, depth and duration of water tables, and developed a horizon colour index (CI_h) based on matrix colour, size and colour of mottles and continuity and colour of clay films:

$$CI_h = C_m + \{(S_1 \times C_1) - (S_2 \times C_2) - \dots - (S_n \times C_n)\} + (C_{cl} \times CI_{cl}) \quad (2.7)$$

Where:

- C_m = colour index of the soil matrix
- = numeric hue + (8 - chroma)
- $S_1, S_2 \dots S_n$ = size of mottles with colour index $C_1, C_2 \dots C_n$
- C_{cl} = continuity of clay cutans with colour index C_{cl}

They found a good correlation ($R^2 = 0.76$) with duration of water saturation, when temperature is above 5 °C. The equation used to predict duration of water saturation (Sat) from the horizon colour index is given by:

$$\text{Sat} = -52.9 + 7.3 \text{ Cl}_h \quad (R^2 = 0.76) \quad (2.8)$$

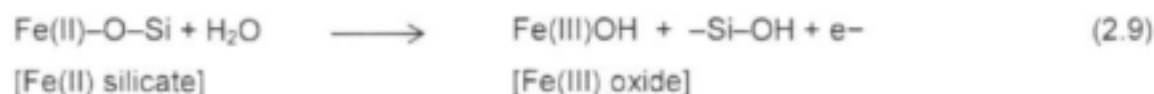
Blavet *et al.* (2000) found a significant relationship between the duration of waterlogging (%), mean angular hue ($R^2 = 0.52$) and mean redness rating ($R^2 = 0.52$) as defined by Torrent *et al.* (1980 and 1983). Blavet *et al.* (2000) also concluded that waterlogging is rare in materials redder than 10YR and is almost permanent in materials greener than 2.5Y. This suggests that colour limits could be defined, when constructing relationships between soil morphology and the duration of water saturation. Blavet *et al.* (2000) employed sigmoidal functions to describe the relationship. These relationships were, unfortunately, not reported. The lack of correlation between chroma and duration of water saturation is related to the fact that chroma only measures the saturation of a colour. The low correlation between Munsell value and duration of water saturation ($R^2 = 0.12$) is explained by the fact that value is masked by the presence of organic matter (Schulze *et al.*, 1993 as cited by Blavet *et al.* 2000).

2.4 Iron oxide mineralogy and soil water content

2.4.1 Origin

According to Fitzpatrick (1980), iron is found in most igneous rocks. It is found in several minerals, for example olivine (61 % FeO), biotite (22 % FeO), augite (20 % FeO) and hornblende (13 % FeO). Iron-bearing minerals include pyrite (FeS_2), pyrrhotite (FeS), magnetite (Fe_3O_4), chromite (FeCr_2O_4) and ilmenite (FeTiO_3).

In magmatic rocks divalent iron is bound by silicate. This iron is released from the silicate minerals through protolysis or oxidation:



This reaction is irreversible and can therefore be used to estimate the degree of weathering. This can easily be done by expressing the dithionite-soluble Fe as a fraction of the total Fe (Schwertmann, 1985).

The released iron has a strong tendency to hydrolyse and form the oxides hematite (Fe_2O_3) and goethite (FeOOH) where the soil pH is in excess of 3. Below this pH, iron is normally present in the reduced form. The formation of Fe^{3+} oxides is due to the high affinity of Fe^{3+} for the OH ligand and the ready polymerisation of Fe^{3+} as hydrolysis proceeds. The Fe^{3+} oxides consequently have low solubility constants ($K_{sp} = 10^{-39}$ to 10^{-44}) and the dissolution of iron oxides by protolysis is therefore improbable, because the soil pH is seldom low enough to permit this reaction.

Iron can, however, easily be mobilised through a reductive reaction:



This reaction takes place whenever reducing conditions occur, caused by the reduction in O_2 content by microbial and / or root respiration, normally under conditions of water saturation. The ferrous iron (Fe^{2+}) produced by this reaction can be re-oxidised or transported. New mineral phases can be formed during oxidation. The type and properties of the neo-formed minerals depend on the pedo-environment. The ferrous iron can be transported over very short to long distances, giving rise to spatial redistribution as mottles, concretions in the form of horizons within the soil profile or in the landscape. The removal of iron ultimately results in a grey colour – a result of the remaining soil matrix commonly consisting of quartz and clay minerals. The grey colours are manifested as mottles, cutans or horizons.

2.4.2 Minerals

Goethite ($\alpha\text{-FeOOH}$) has a needle-like crystal structure. The crystal structure may vary considerably – to such an extent that it cannot be used for identification. The needle length varies from 50 to 100 nm, but may be as small as 20 nm. The surface area varies between 60 000 and 200 000 $\text{m}^2 \text{ kg}^{-1}$ (Schwertmann *et al.*, 1985; Schwertmann & Taylor, 1989). A high rate of Al substitution for Fe is observed in tropical soils and saprolite. Lower substitution of Al is prevalent in weakly acid soils and in redoximorphic soils (Fitzpatrick & Schwertmann, 1982).

The important soil factors that determine the relationship between goethite and hematite are temperature, water activity, pH and organic matter (Schwertmann, 1985).

Goethite or hematite is formed from the dehydration of ferrihydrite ($5\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$). Hematite is favoured as the temperature increases. Goethite does not dehydrate to form hematite. With a decrease in relative humidity and therefore soil water content, there is a drastic decrease in the transformation of iron oxides. Hematite is, however, still formed in preference to goethite (Torrent *et al.*, 1982). It therefore seems that hematite formation is influenced more by temperature fluctuation than by the soil water content (Schwertmann, 1985).

The goethite : (goethite + hematite) ratio is a handy tool to correlate soil colour with Fe mineralogy. If the ratio is close to one, goethite is dominant and if the ratio approaches zero, then hematite predominates (Schwertmann, 1985). From the above it should be clear that pedo-environments that favour the preservation of carbon (i.e. cool and moist conditions) also favour the formation of goethite relative to hematite. It also seems that organic matter inhibits the formation of ferrihydrite and therefore also hematite. The formation of goethite from ferrihydrite also seems to be favoured as the pH decreases from 8 to 4. In warmer climates, the dominance of temperature favours the preferential formation of hematite from ferrihydrite.

Hematite ($\alpha\text{-Fe}_2\text{O}_3$) gives soils a bright red colour (5YR and redder). Due to its high pigmenting power, it can mask the yellow colour of goethite that may occur in higher concentrations. There is a significant correlation between the redness of a soil and its hematite content (Torrent *et al.*, 1983). An increase in crystal size leads to a purple colour (Torrent & Schwertmann, 1987). Hematite has a hexagonal crystal shape. The crystal size varies between 20 and 50 nm and the surface area varies between 50 000 and 120 000 $\text{m}^2 \text{kg}^{-1}$. Al substitution for Fe is only half of that observed in goethite. The substitution of Al gives hematite a lighter colour (Barrón & Torrent, 1984 as cited by Schwertmann & Taylor, 1989).

Lepidocrocite (γ -FeOOH) is a polymorph of goethite and has an orange colour. It is widespread in redoximorphic soil, where it occurs as mottles, bands, pipe stems and concretions. The crystals usually form elongated plates or laths with serrated ends. Where lepidocrocite is formed by rapid oxidation, as is the case in root channels or at the soil's surface, the crystals tend to be very poorly developed and only a few layers thick. Al substitution is not common in lepidocrocite. It may be that small amounts of Al lead to the formation of goethite, instead of lepidocrocite (Taylor & Schwertmann, 1978).

Lepidocrocite should not be stable in pedo-environments, because goethite is kinetically more stable. It forms in hydromorphic soils when Fe^{2+} is oxidised and is usually better crystallised than goethite. This may, however, vary depending on the rate of oxidation. Lepidocrocite precipitates inside structure units where the rate of Fe^{2+} and O_2 supply is low. Under these conditions it will be well crystallised. Inside macro pores and root channels the rate of Fe^{2+} and air supply will be faster and less crystalline oxides will form. Less crystalline lepidocrocite is more reddish in colour (Schwertmann, 1985).

Lepidocrocite is found in association with goethite, but not with hematite. This may be because goethite and lepidocrocite form as a result of competitive processes. Goethite is formed preferentially as the CO_2 concentration increases. Goethite would thus be found closer to macro pores and root channels, where the CO_2 concentration is higher, and lepidocrocite would be found some distance away. It has been shown in laboratory experiments (Taylor & Schwertmann, 1978) that > 10 mole % Al completely suppresses the formation of lepidocrocite. This will influence the occurrence of lepidocrocite in strongly acid, hydromorphic soils (Blume, 1968 as cited by Schwertmann, 1985).

Magnetite (Fe_3O_4) occurs as black grains in soil and is inherited from the parent material. Magnetite converts to hematite during pedogenesis. Fine-grained magnetite can also easily oxidise to maghemite, which contains Fe^{2+} and Fe^{3+} (Schwertmann, 1985).

Maghemite ($\gamma\text{-Fe}_2\text{O}_3$) occurs in many soils of the tropics and subtropics. It has a reddish-brown colour. Substitution of Al for Fe is possible. Maghemite is similar in structure to magnetite and is a dimorph of hematite (Schwertmann, 1985).

Ferrihydrite ($5\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$) is widespread and is characteristic of young Fe accumulations. It typically precipitates during the oxidation of Fe-containing water as well as in podzol horizons. The colour of ferrihydrite is redder than goethite, but less so than hematite. It forms spherical particles, 3 to 7 nm in diameter, with a surface area of 200 000 to 500 000 $\text{m}^2 \text{kg}^{-1}$ (Table 2.1). It therefore possesses the ability to adsorb silicate, phosphate and organic molecules. Ferrihydrite is almost completely soluble in ammonium oxalate (Schwertmann, 1985).

Table 2.1 General characteristics of iron oxide minerals (Schwertmann, 1985)

Mineral	Hematite	Goethite	Lepidocrocite	Ferrihydrite	Maghemite	Magnetite
Composition	$\alpha\text{-Fe}_2\text{O}_3$	$\alpha\text{-FeOOH}$	$\gamma\text{-FeOOH}$	$5\text{Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$	$\gamma\text{-Fe}_2\text{O}_3$	Fe_3O_4
Density (kg m^{-3})	5 260	4 260	4 090	3 960	4 870	5 180
Colour	bright red	yellowish-brown	orange	redder than goethite	reddish-brown	black
	5R – 2.5YR	7.5YR – 2.5Y	5YR – 7.5YR	5YR – 7.5YR		
Size (nm)	10 to 20	50 to 100		3 to 7		
Surface area ($\times 10^3 \text{ m}^2 \text{ kg}^{-1}$)	50 to 120	60 to 200		200 to 500		

2.4.3 Properties

2.4.3.1 Mineral surface structure

The Fe ions at the surface of an oxide complete its ligand shell by hydroxylation in the presence of water. This is followed by the adsorption of water molecules through hydrogen bonding (Figure 2.2). The amount of water that is bound in a monomolecular layer increases with increasing surface area, but generally ranges between 0.3 and 0.4 mg m^{-2} . This water seems to be tightly bound and can only be driven off at 200 °C (Schwertmann & Taylor, 1989).

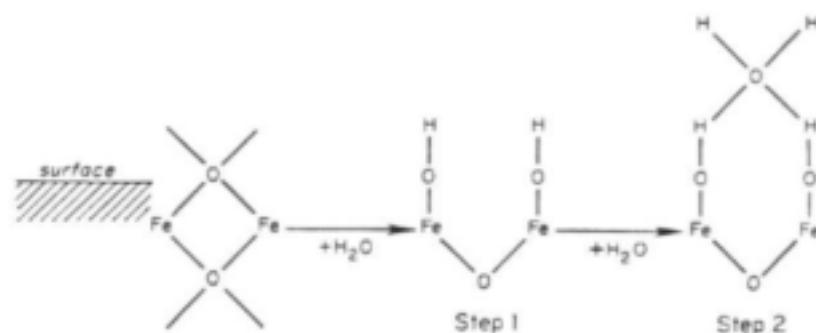


Figure 2.2 The reaction of surface Fe in oxides with water through two steps: hydroxylation (step 1) and hydration (step 2) (Schwertmann & Taylor, 1989).

2.4.3.2 Surface charge

A positive or negative charge can be created at the hydroxylated or hydrate surface by the adsorption of H^+ (Figure 2.3). The charge can therefore vary, depending on the soil pH. The pH at which the net surface charge equals zero is called the point of zero charge. The point of zero charge varies between 7 and 9, but is normally lower in soil ($pH < 7$) due to the adsorption of anions (Schwertmann & Taylor, 1989).

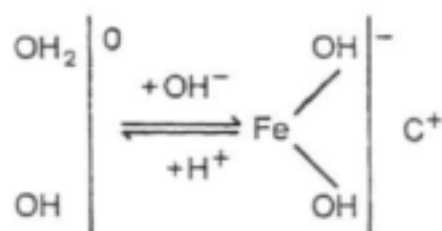


Figure 2.3 Adsorption and desorption of H^+ on Fe oxides, resulting in a pH dependent charge (Schwertmann & Taylor, 1989).

2.4.3.3 Ion adsorption

The positive or negative charge on Fe oxides are balanced by anions or cations, held in an outer diffuse double layer. Cations and anions can also chemically bind to the Fe oxide surface, thus increasing or decreasing the charge.

Heavy metals can be adsorbed by Fe oxides. The extent of adsorption is determined by the pH, due to its influence on the pH dependent charge. Heavy metals are adsorbed in the order $Cu > Pb > Zn > Cd > Co > Ni > Mn$ (Schwertmann & Taylor, 1989).

Anions such as phosphate, silicate, molybdate, arsenate, selenate, sulfate and organic anions can also be adsorbed on Fe oxides. Borggaard (1983), for example, found that there is a correlation between adsorbed phosphate and the amount of oxalate extractable Fe. This can severely impact on P fertilization.

2.4.3.4 Adsorption of organic molecules

Humic acid and fulvic acid are found concentrated with Fe oxides in podzol horizons. The amount of fulvic and humic acid adsorbed on the surface of the Fe oxides increases as the pH decreases from 8 to 3. Simple organic acids and herbicides behave in a similar manner to humic and fulvic acids (Schwertmann & Taylor, 1989).

2.4.3.5 Aggregation and cementation

Finely divided Fe oxides can act as binding agents between individual soil particles, binding them into larger units. This results in aggregation or cementation (Schwertmann & Taylor, 1989).

Cementation is a process whereby Fe oxides fill the pores between the particles – through crystal growth – to form nodules and ferricretes. These are often quite large, although they may also be small. Cementation can inhibit root and water movement, while at the same time immobilising nutrients.

Aggregation takes place when the positively charged Fe oxides form bridges between the negatively charged silicate clays. This process is pH dependent, because the positive charge on Fe oxides is pH dependent. It can therefore be expected that aggregation by Fe oxides will increase with an increase in Fe oxide content as well as a reduction in pH. The amount of Fe oxides required for aggregation is much lower than that required for cementation, although all intergrades are possible (Shadfan et al., 1985). The lower the Fe oxide crystallinity and the higher the oxalate extractable fraction, the higher the aggregation effect. There also seem to be examples where Fe oxides do not affect aggregation (Borggaard, 1983; Deshpande *et al.*, 1964; 1968; Schwertmann & Kämpf, 1985). The aggregation effect of Fe oxides therefore seems to vary with the amount and

nature of Fe oxides as well as the nature of the pedo-environment during their formation.

2.4.4 Iron oxides and micro organisms

Although Fe oxides are highly insoluble, they can easily be mobilised through reduction by micro organisms. Reduction of Fe occurs whenever oxygen is deficient, and micro organisms use other electron acceptors during the oxidation of organic matter substrate. Reduction of Fe^{3+} takes place when O_2 becomes deficient and the redox potential (Eh) has been lowered to approximately +100 mV (Bohn *et al.*, 1985).

The micro-organisms in the soil respire. This means that they use oxygen as final electron acceptor in a long range of chemical reactions in order to extract energy from the organic material they use as a food source. The use of oxygen as final electron acceptor ensures that the highest amount of energy can be released from the organic matter. Some micro organisms can use other electron acceptors in this process in the absence of oxygen, as is the case in soils saturated with water. These other elements are used in order of decreasing redox potential. This ensures that the most energy is always released by the reaction. There are therefore three prerequisites for a decrease in the redox potential of the soil. The first is the presence of micro organisms, second is the presence of organic matter food substrate, and third a restricted oxygen supply. Data for this study suggests that organic matter is present throughout the profile, although it diminishes with depth (see for example Table 2 in Appendix A).

Various micro organism species, mainly anaerobic bacteria, can utilise Fe in this process (Ottow & Glathe, 1971; Schwertmann *et al.*, 1985). The Fe^{2+} produced by this reaction is soluble and enters the soil solution. It can therefore be leached or it can move to a zone with a higher Eh, where it will be re-oxidised. The activity of Fe^{2+} in the soil solution will therefore increase with a decrease in the Eh and pH. At a given Eh and pH the activity of Fe^{2+} will increase with a decrease in the solubility of the Fe^{3+} oxide (Schwertmann, 1985).

Typical reduction reactions (Bohn *et al.*, 1985) and their redox potentials in the soil are presented in Table 2.2. From these reactions it is clear that reduction will take

place in the sequence: $\text{NO}_3^- - \text{MnO}_2 - \text{FeOOH} - \text{SO}_4^{2-} - \text{H}^+$, due to the decreasing redox potential and therefore energy supply, of each reaction.

Table 2.2 Typical reduction reactions and their redox potentials in the soil (Bohn *et al.*, 1985)

Half reaction	Redox potential measured in soil (mV)
$\text{O}_2 + 4 \text{e}^- + 4 \text{H}^+ \rightarrow 2 \text{H}_2\text{O}$	600 to 400
$\text{NO}_3^- + 2 \text{e}^- + 2 \text{H}^+ \rightarrow \text{NO}_2^- + \text{H}_2\text{O}$	500 to 200
$\text{MnO}_2 + 2 \text{e}^- + 4 \text{H}^+ \rightarrow \text{Mn}^{2+} + 2 \text{H}_2\text{O}$	400 to 200
$\text{FeOOH} + \text{e}^- + 3 \text{H}^+ \rightarrow \text{Fe}^{2+} + 2 \text{H}_2\text{O}$	300 to 100
$\text{SO}_4^{2-} + 6 \text{e}^- + 9 \text{H}^+ \rightarrow \text{HS}^- + 4 \text{H}_2\text{O}$	0 to -150
$2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{H}_2$	-150 to -220
$2 \text{CH}_2\text{O} \rightarrow \text{CO}_2 + \text{CH}_4$	-150 to -220

The products formed during anaerobic respiration are, however, not stable in soil and quickly oxidise in the presence of oxygen. Fe and Mn also play an important role in soil, because they act as colouring agents. Fe and Mn are immobile in their oxidised states. Reduction and redistribution or removal of these agents causes distinct colour patterns that can be associated with the water regime in soils, due to the above-mentioned relationships.

From the above one can expect that the redox potential will be lowest in soils with the longest duration of water saturation. This relation is clear from the redox potential data in Table 2.2.

There is an inverse relationship between redox potential (mV) and pH in soil. This is because H^+ is used in the reduction reactions during the oxidation of organic matter (Table 2.2). This causes a decrease in the H^+ concentration, resulting in an increased pH. It can be expected that horizons not saturated for long periods, have extracted soil water pH values closer to the measured soil pH, and that soils with longer durations of saturation have higher pH values in the extracted soil water.

Ferrihydrite can be dissolved and reprecipitated within a few days, even under mildly reducing conditions. On the other hand coarse crystalline hematite will resist reduction even under long term reduced conditions (Schwertmann, 1985).

2.4.5 Determination

Iron oxides can be identified and quantified by their mineral-specific colour, differential dissolution, and X-ray diffraction analysis (XRD).

Dithionite-citrate-bicarbonate (CBD) extracts practically all secondary Fe oxides (Fe_d) i.e. Fe not part of the clay lattice (Mehra & Jackson, 1960; McKeague et al., 1971). Acid ammonium oxalate extracts poorly crystalline and organic complexed Fe oxides (Fe_o). Pyrophosphate extracts organic complexed Fe oxides (Fe_p). The amorphous Fe oxide (mainly ferrihydrite) content (Fe_a) can therefore be calculated as $Fe_o - Fe_p$. The crystalline Fe oxide content (Fe_c) can be calculated as $Fe_d - Fe_o$, while the ratio of oxalate (Fe_o) to dithionite (Fe_d) extractable iron quantifies the active iron fraction in the soil (Mehra & Jackson, 1960; Schwertmann, 1985; McKeague et al., 1971).

X-ray diffraction analysis is used for identification of the various crystalline phases (Brindley & Brown, 1980). Detection of Fe by these techniques is hampered by the low concentration of Fe. Concentration techniques can be used to overcome this. Particle size separation (Fe is usually found in the finer fractions), magnetic separation (Schulze & Dixon, 1979), and a 5 M NaOH treatment which dissolves silicate clay minerals (Norrish & Taylor, 1961), can be used as concentration techniques.

2.5 Pedogenesis and water content

Iron plays a prominent role in four processes of soil formation. Brinkman (1979) proposes two processes (cheluviation and ferrolysis) for the genesis of a bleached horizon. In ferrugination and gleying, the presence of oxidized iron is responsible for the reddish and grey colouring of soils respectively (Buol, Hole & McCracken, 1989).

Cheluviation is the result of Al^{3+} removal by chelating agents. This results in the dissolution of Al-rich minerals e.g. chlorites, and eventually montmorillonite. The removal of the weathering products ultimately results in a pure quartz matrix. Accumulation and liberation of Al^{3+} from the chelates can cause the precipitation of an aluminium hydroxide, Al-interlayering in 2:1 clay minerals, or synthesis of new clay minerals. Where these processes are dominant, soils will have a higher CEC_{clay} in

the A and E horizons than in the underlying B or C horizons. The clay fraction of the E horizon will also contain more montmorillonite and less chlorite, kaolinite and Fe oxides, compared to the lower horizons.

Ferrollysis relies on alternate reduced and oxidised conditions. During saturation, reduction takes place, consuming H^+ and releasing of Fe^{2+} . The dissolved Fe^{2+} distorts the cation ratio and is adsorbed on the clay complex, releasing the exchangeable bases. Exchangeable bases, Al^{3+} and Fe^{2+} are leached, leading to Al-interlayering between the 2:1 clay minerals and ultimately the formation of 1:1 clays. Some Fe oxides may be trapped in the interlayer spaces during this process. This lowers the CEC and increases the Fe content of the clay fraction. During oxidation the Fe^{2+} concentration in the soil solution decreases and exchangeable Fe^{2+} is released to the outer soil solution where it is oxidised, with the associated release of H^+ , leading to an acid environment and the formation of H^+ saturated clay. This leads to clay decomposition, releasing Al and Mg that leads to the formation of Al and Mg saturated clays. The process is more rapid in smectite and vermiculite soils, than in chlorite and kaolinite soils. Horizons subjected to ferrollysis therefore have less smectite and vermiculite, more interlayered clays, a lower CEC and a higher Fe oxide content than the underlying horizons.

Ferrugination (Buol, Hole & McCracken, 1989) is the process of soil reddening in upland soils, resulting in dispersion and oxidation of Fe oxides throughout the profile. Gleying on the other hand is the reduction of Fe oxides, its segregation into mottles or concretions and / or its removal from the gleyed horizon.

Eluviation and leaching (Buol, Hole & McCracken, 1989) are analogous, in the sense that both refer to the dissolution and removal of material (colloids and / or elements). Eluviation is the removal of suspended colloids while leaching refers to the removal of dissolved elements. Both processes require mobilisation and translocation of the material in question.

Illuviation and enrichment are analogous in the sense that both require the interruption of translocation, resulting in immobilisation and accumulation of the

transported material in a horizon or solum. Illuviation refers to the accumulation of clay minerals while enrichment refers to the accumulation of soluble elements.

The transformation of hematite to goethite is closely related to a change in the organic matter content of a soil, which is in turn determined by the climate (Schwertmann, 1971). Increased availability of organic matter results in increased reduction and / or complexing of Fe. Reprecipitation upon oxidation usually results in the formation of goethite. The hematite to goethite ratio therefore reflects the carbon regime of a soil, which in turn reflects the climate. Warm, dry conditions favouring the mineralisation of organic matter will therefore favour the formation and persistence of hematite. On the other hand, wet and cool conditions will favour the dissolution of hematite and the precipitation of goethite (Schwertmann, 1971).

Fey (1981) amended the theory of Schwertmann (1971) by proposing that the greater stability of goethite relative to hematite results in the preferential dissolution of the latter. This leads to the removal of the red colouring agent while the yellow goethite remains. The yellowing of soils will therefore be determined by the initial Fe content of the parent material, the extent of Al substitution, the availability of an organic substrate and the soil redox status. Fey (1981) concluded that "the intensity and duration of reducing conditions reflected by pedogenic yellowing will probably vary widely" and that "once it is possible to identify more quantitatively the soil conditions reflected by yellowing in its various forms, it should become possible to predict the extent to which chemical transformations such as denitrification and manganese reduction will manifest themselves as agronomic problems...".

McCarthy & Bremner (1992) supported the hypothesis of lower rates of reduction at lower levels of organic carbon deeper down in the soil. They found that denitrification of nitrate in subsoils is not due to a lack of denitrifying bacteria, but due to a lack of organic carbon substrate. De Villiers (1965) found that lepidocrocite is active (hematite and goethite are absent) in yellow-brown horizons where the organic mobilization of Fe is active, while hematite and goethite predominate in the deeper, red horizons.

In reduced soils Fe is mobilised through reduction, leading to an increase in exchangeable Fe, which replaces exchangeable bases on the exchange complex. This results in the mobilisation of Fe and exchangeable bases. For example, Tarekegne (2001) found that ammonium extractable nutrients increased with increasing severity of waterlogging and postulated that the damaging effects of waterlogging were not due to Mn, Fe, or Na toxicity, but rather decreased nutrient (P & Zn) uptake due to O₂ deficiency. The concentration of Mn and Fe greatly increased in the soil due to waterlogging.

Fiedler *et al.* (2002) determined that redox conditions and an abundance of chelating agents are the main factors that lead to the mobilization of cations, Fe, Mn and clay. They found that redox conditions in the mid-catena zones led to the depletion of Fe and Mn, while accumulation of Fe, Mn and organic carbon took place lower down in the catena. They concluded that taxonomic soil type (Soil Survey Staff, 1975; FAO, 1998b) reflects pedogenic soil processes and soil material dynamics, but that these dynamics are not adequately represented for the low lying soils.

2.6 Colour models

Sight and the perception of colour is probably an individual's greatest gift. We are able to distinguish different shapes and are able to associate different colours to that shape. This ability of man is also applied in soil classification, with nearly all diagnostic criteria reliant on visual soil properties. Colour of the soil is especially useful in this regard. The big challenge is, however, to be able to note soil colour in a standardised manner. With this in mind, the USDA adopted the Munsell color charts as a colour reference system (Soil Survey Staff, 1975). New technology, e.g. digital cameras, scanners and image processing software, however, opens new avenues to analyse images of soil profiles. The challenge now shifts to finding correlations between the following different platforms: reality vs. captured image vs. computer analysis.

2.6.1 Munsell

During 1975 the Soil Survey Staff adopted the Munsell Soil Color Charts as standard soil colour referencing system (Soil Survey Staff, 1975). This was done in an attempt

to standardise soil colour representation. Until then colour was noted in a freestyle manner.

The Munsell Soil Color Charts (Munsell Color Company, 1975) are extracts from the more comprehensive Munsell Book of Color (Munsell Color Company, 1980). The system takes the shape of a colour ball, where the central (vertical) axis denotes the "value" (Figure 2.4). The value ranges from zero at the bottom of the axis to ten at the top. Value denotes the darkness of a colour, where one is the darkest (absolute black) and nine is the lightest (absolute white). Absolute achromatic colours, where the chroma is zero, do therefore not have a hue and are designated as neutral. The letter "N" takes the place of the hue designation.

Looking from the top of the colour ball (Figure 2.5), the "hue" forms radians from the central axis. The hue is defined in terms of five major colours: red, yellow, green, blue and purple. Complementary colours (yellow-red, yellow-green, blue-green, purple-blue and red-purple) are arranged between these major colours. Each colour ranges from zero to ten. The zero value coincides with the ten value of the previous colour. The hues are arranged on a circular scale. This configuration gives rise to 100 hues, each separated by a 3.6 degree angle. Only the 2.5, 5, 7.5 and 10 hues are represented in the Munsell Soil Color charts. The separation between hue pages in the Munsell Soil Color Charts is therefore nine degrees (Melville & Atkinson, 1985).

Chroma ranges from zero for the neutral grey colours to about twenty (Figure 2.1). Chroma expresses the strength of a colour, or its departure from neutral at the same lightness. Not all chromas are found in soil and some are therefore excluded from the Munsell Soil Color Charts. The chromas in the Munsell Soil Color Charts normally range from zero to eight.

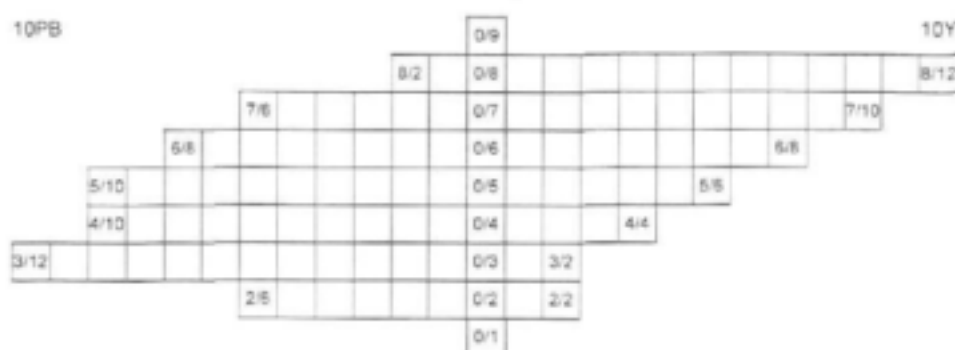


Figure 2.4 The partition of value and chroma along the 10Y – 10PB axis (Fujihara Industry Company, 1967). Note that the chromas differ at different values and hues.

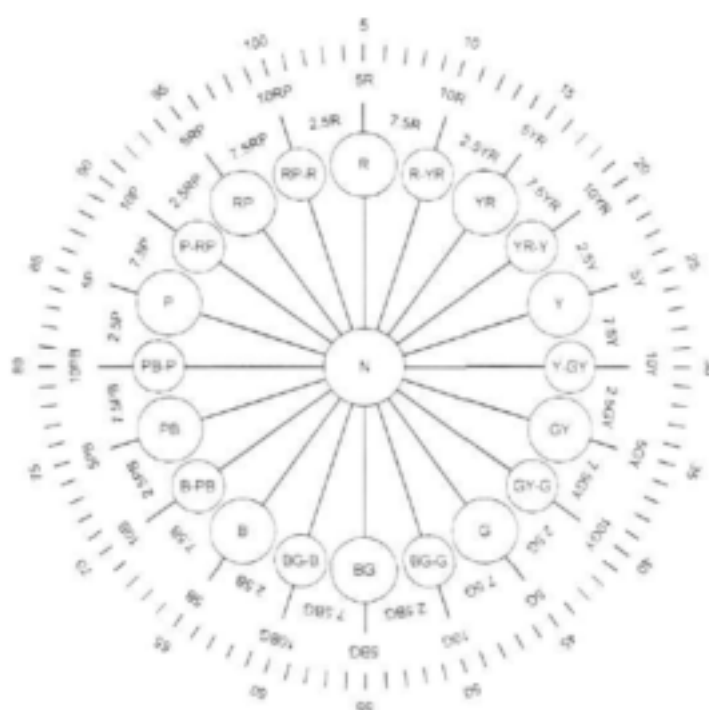


Figure 2.5 The division of hues in the Munsell Color System (Fujihara Industry Company, 1967).

The Munsell Color System is a decimal system i.e. there exist intermediaries between the different hues, values and chromas. These intermediaries are expressed as decimals e.g. 2.5YR3.2/4.8. The colours depicted in the Munsell Color System were selected to represent equal steps of visual colour perception (Melville & Atkinson, 1985). There are therefore discrete steps when the Munsell colour values are plotted against any other colour system.

Melville and Atkinson (1985) list the following main advantages of the Munsell Color System:

- a) The system is not limited by present day colour production techniques, but can be expanded as production technology develops.
- b) The colour chips are produced to very stringent tolerances.
- c) Equal steps in visual perception and spacing exist between each of the colour co-ordinates.

"Few color systems are nearly as good in this respect; the Munsell system is the standard to which other systems are compared." (Billmeyer & Saltzman, 1981 as cited by Melville and Atkinson, 1985)

2.6.2 CIE

In 1931 the Commission Internationale de l'Eclairage (CIE), or the international commission on light, developed a system for specifying colour stimuli using tristimulus values for three imaginary primaries (Poynton, 1999). The CIE system works by weighting the spectral power distribution of an object in terms of three colour matching functions. These functions are the sensitivities of a standard observer to light of different wavelengths. The weighting is performed over the visual spectrum, from around 360nm to 830nm in 1nm intervals. This process produces three CIE tri-stimulus values, XYZ, which describe the colour. The main advantage of the CIE XYZ system is that it is completely device independent. The main disadvantage with CIE based colour spaces is the complexity of implementing them; in addition some are not user intuitive (Poynton, 1999). An example of the CIE colour space is given in Figure 2.6.

Conversion from RGB to CIE XYZ can be done with the following matrix (Poynton, 1999):

$$X = 0.412411 \times \text{Red} + 0.357585 \times \text{Green} + 0.180454 \times \text{Blue} \quad (2.11)$$

$$Y = 0.212649 \times \text{Red} + 0.715169 \times \text{Green} + 0.072182 \times \text{Blue} \quad (2.12)$$

$$Z = 0.019332 \times \text{Red} + 0.119195 \times \text{Green} + 0.950390 \times \text{Blue} \quad (2.13)$$

2.6.3 RGB

RGB (Red-Green-Blue) is an additive colour system (Figure 2.7) based on trichromatic theory. RGB colour notation is commonly used in television cameras, computer graphics, etc. It is easy to implement, non linear, device dependent and unintuitive. Red, Green and Blue are also known as additive primary colours, because a colour is produced by adding different quantities of the three components, red, green, and blue (Poynton, 1999). The values of RGB range from 0 to 255, which also define the colour space (Figure 2.8).

To convert between RGB and CMY, the following equations can be used, provided the RGB values are expressed as a fraction:

RGB to CMY

$$\text{Red} = 1 - \text{Cyan} \quad (0 \leq \text{Cyan} \leq 1) \quad (2.14)$$

$$\text{Green} = 1 - \text{Magenta} \quad (0 \leq \text{Magenta} \leq 1) \quad (2.15)$$

$$\text{Blue} = 1 - \text{Yellow} \quad (0 \leq \text{Yellow} \leq 1) \quad (2.16)$$

CMY to RGB

$$\text{Cyan} = 1 - \text{Red} \quad (0 \leq \text{Red} \leq 1) \quad (2.17)$$

$$\text{Magenta} = 1 - \text{Green} \quad (0 \leq \text{Green} \leq 1) \quad (2.18)$$

$$\text{Yellow} = 1 - \text{Blue} \quad (0 \leq \text{Blue} \leq 1) \quad (2.19)$$

The algorithm for conversion from RGB to Munsell colour notation is proprietary (Poynton, 1999). In this study a computer program, which allows for conversion between all the major colour notation systems, was used (Anon, 2003b). Look-up tables can also be used with equal success (Travis, 1991 as cited by Adderley et al., 2002).

2.6.4 CMY

CMY (Cyan-Magenta-Yellow). CMY are known as subtractive colours (Figure 2.7), because the colour is generated by subtracting different quantities of cyan, magenta and yellow from white. It is used in printing and photography. Printers often include a fourth (black) component to improve the colour range, to improve black colours, to save money and for speeding drying (because there is less ink to dry). CMY is fairly

easy to implement but it is difficult to transfer properly from RGB – sometimes resulting in colour differences between those visible on screen and printed in documents. CMY is device dependent, non-linear and unintuitive (Poynton, 1999).

2.6.5 Application

Adderley *et al.* (2002) described a method for determining the colour of thin sections and converting it to Munsell color notation. They used a three-chip video camera to obtain HLS images (576 pixels x 760 pixels) through a polarizing microscope. CIE was calculated from the HLS images (Harrington, 1997 as cited by Adderley *et al.*, 2002), which was then converted to Munsell color notation using look-up tables (Travis, 1991 as cited by Adderley *et al.*, 2002).

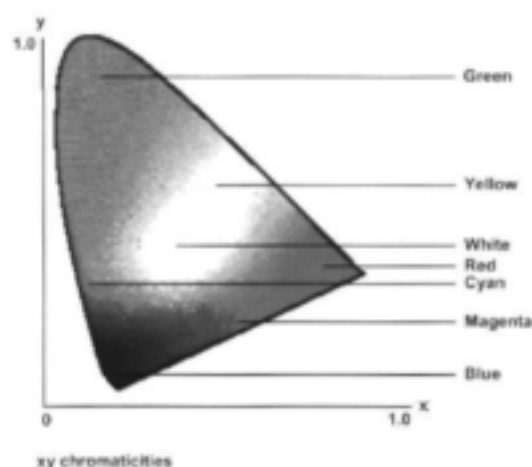


Figure 2.6 The CIE colour space (Anon., 2003a).

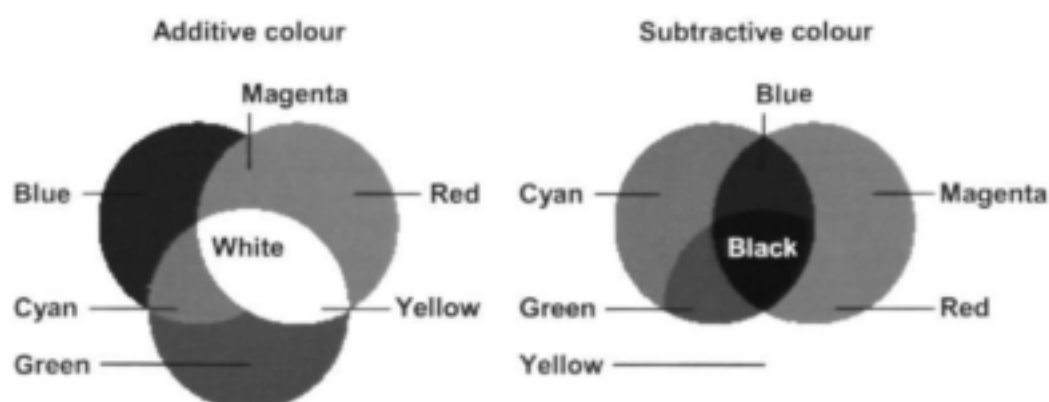


Figure 2.7 Examples of additive (RGB) and subtractive {CMY(K)} colour spaces (Anon., 2003a).

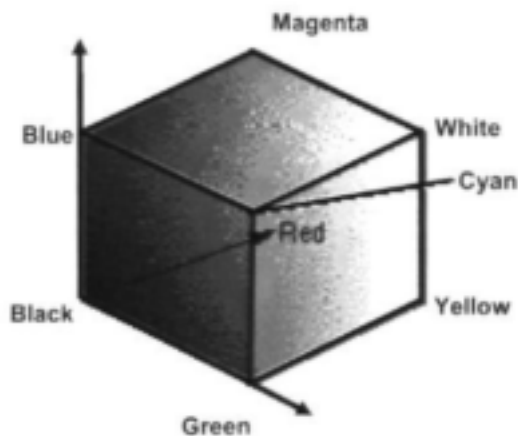


Figure 2.8 The RGB colour space (Anon., 2003a).

2.7 Summary

Due to their striking colour Fe oxides play an important role in soil morphology. They can be reduced, leached, eluviated, illuviated and oxidised. Fe oxides are therefore the main colouring agents responsible for the red and yellow colours in soil. Lack of Fe oxides on the other hand causes uncovering of the grey soil matrix, resulting in the predomination of these colours. It is mainly the redox status of a soil that determines the fate of Fe oxide, because it is not soluble or mobile in the oxidised state. The presence and distribution of Fe oxides can therefore be used to infer soil redox status, and therefore degree of wetness.

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3 GEOGRAPHY OF THE STUDY AREA

3.1 Introduction

The Weatherley study area is situated in one of the most picturesque areas of South Africa, on the footslopes of the Drakensberg mountain range (Figure 3.1). The climate is cool and wet, with warm wet summers and cold dry winters. This region has only recently been deemed suitable for forestry and has been planted since 1989. Weatherley escaped this development and only received attention during 1995 when it was decided to utilise this catchment to monitor the impact of forestry on catchment water yield. Pitting in the Weatherley catchment was done during 9 to 18 April 2002. Partial planting of the catchment was done from 2 to 13 September 2002 (Figure 3.2).

3.2 Location

The study catchment is located in the north-eastern part of the Eastern Cape Province. It occupies approximately 160 ha and constitutes most of the farm Weatherley. It is situated 4 km south-west of Maclear, on the road to Ugie (Figure 3.1). The study area is covered by the 1:50 000 sheet 3128AB Maclear (Chief Director of Surveys and Mapping, 1993).

3.3 Relief

The study area is the upper-most catchment of one of the very small tributaries of the Mooi River (Figure 3.1). There is therefore no inflow of water into the catchment (Figure 3.3), which makes it highly attractive for hydrological studies. It drains in a north-easterly direction and is therefore closed on the eastern, southern and western slopes.

The eastern and southern slopes have prominent shelves at approximately 1 320 m above mean sea level. This is largely due to the resistance of Elliot sandstone against weathering.

The highest point in the catchment, at 1 352 m, occurs in the south western corner of the catchment. The stream runs in a north easterly direction and occurs at a height of between 1 254 and 1 286 m.

Moles and earthworms are very active in the catchment. This is probably due to the moist conditions that predominate in the soils. It leads to the formation of many surface mounds, to such an extent that walking becomes difficult. It is possible that macro faunal activity is associated with changing water regimes in the soil. Moles and earthworms will move to drier soil in summer when it rains and back to the wetter soils in the dry winter months.

3.4 Geology

Elliot sandstone and mudstone are found above approximately 1 300 m above mean sea level (Figure 3.4). This covers the upper slopes on the Eastern and Southern slopes. Both sandstone and mudstone of the Molteno Formation predominates below 1 300 m above mean sea level. There are two dolerite dykes in the catchment (Figure 3.4), both running roughly in a north-south direction, one in the south western corner and one in the north eastern corner. The former creates a natural sub catchment in the south western part of the catchment.

3.5 Soils

Due to the high rainfall and the siliceous lithology, the soils in the catchment are highly acidic. The soils also have a very low cation exchange capacity. A soil survey was done by Roberts *et al.* (1996), using Soil Classification – A Taxonomic System for South Africa (Soil Classification Working Group, 1991). The soils range from very wet (Katspruit soil form) to very dry (Hutton and Oakleaf forms). Most of the soils do, however, show clear signs of water saturation. These signs range from faint mottles to grey zones characterised by clay depletion, often referred to as silans or skeletans (Le Roux *et al.*, 2003; Soil Science Society of America, 2001). Strongly structured Sepane soils also occur on the northwest facing slopes in the southern part of the catchment (Figure 3.5).

3.6 Climate

Two automatic weather stations were installed in the catchment on 1 January 1996 by the ARC-ISCW and were operated by NECF (BEEH, 2003). Mean annual rainfall is given in Table 3.1. A rain and mist gauge is also located at the eastern edge of the catchment (close to P201; Figure 3.3). A Bowen ratio apparatus, for the

measurement of evapotranspiration, was installed and operated by the CSIR-Environmentek, from 13 July 2001 to 9 December 2001, just north of the upper-catchment weir. The best long-term climate data available is that recorded at Maclear, roughly 4 km from the Weatherley catchment (Table 3.2).

The study area has moderately high rainfall, which occurs mainly in summer. The mean annual aridity index (P/ET) is 0.50 and the value for the period December to March is 0.84. The summer is hot, with mean maximum temperatures of 25 °C. Winters are cold and snow is common, especially on the surrounding higher lying areas. Mean winter minimum temperatures are 4 °C.

Table 3.1 Yearly rainfall, measured at Weatherley (BEEH, 2003)

Year	Rainfall (mm)
1996	1 196
1997	952
1998	1 187
1999	956
2000	1 304
2001	1 092
2002	896
2003	714
2004	1 005
Mean	1 013

Table 3.2 Monthly mean rainfall and evaporation for Weatherley and temperature from a weather station roughly 4 km from the study area (Roberts *et al.* 1996)

Month	Rainfall (mm)	Evaporation (A-pan) (mm)	P/ETo	Temperature (°C)		
				Maximum	Minimum	Mean
January	195.3	142.1	1.37	25	14	20
February	154.3	120.6	1.28	25	14	20
March	140.4	116.9	1.20	24	12	18
April	61.6	97.1	0.63	24	11	18
May	30.3	84.2	0.36	21	7	14
June	24.9	71.6	0.35	18	4	11
July	15.2	73.5	0.21	19	4	11
August	28.8	98.2	0.29	19	6	11
September	36.6	111.4	0.33	21	8	14
October	65.2	134.0	0.49	21	10	15
November	131.3	137.0	0.96	24	12	18
December	180.5	141.6	1.27	24	13	19
Total	1064.3	1328.1	0.80			

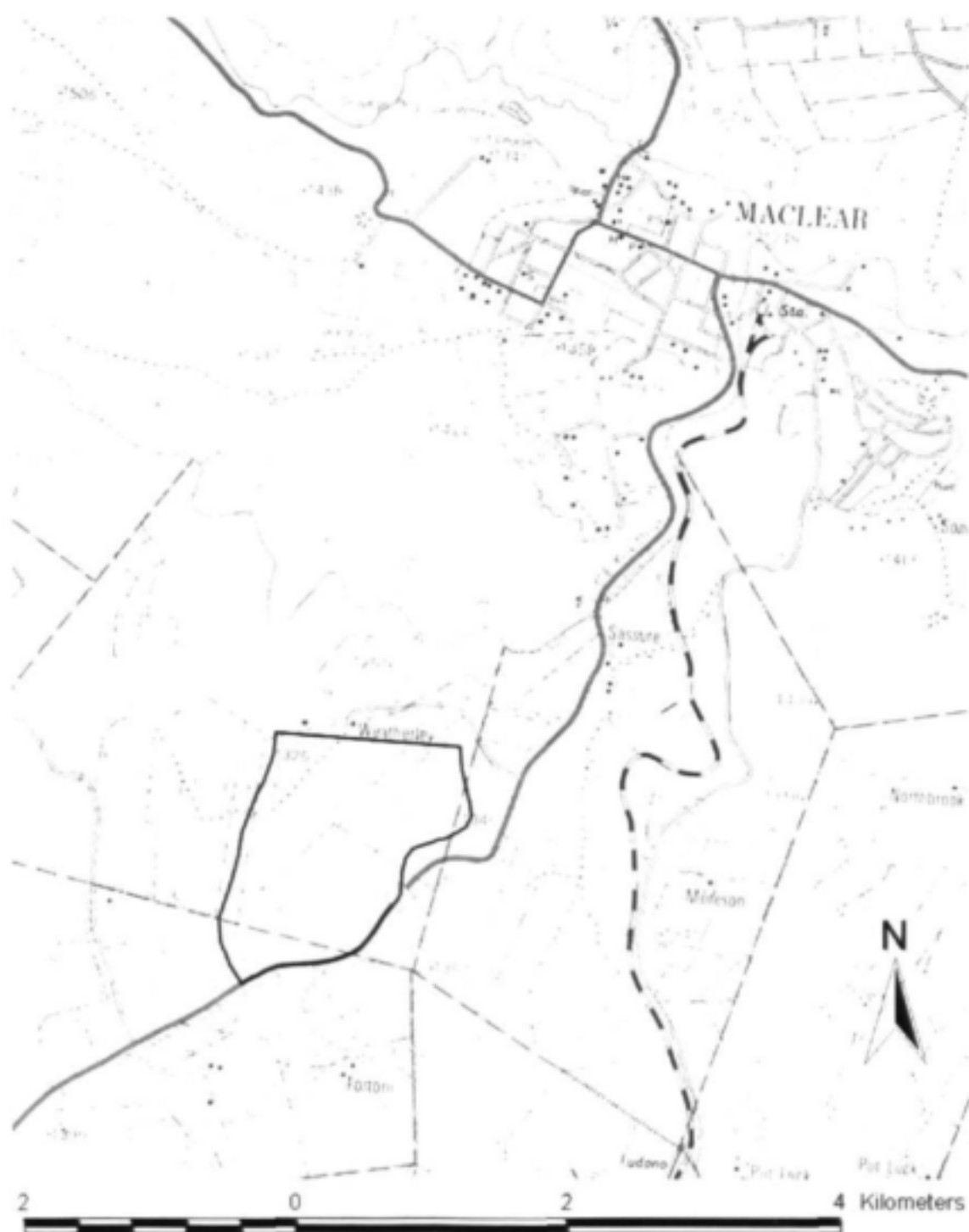


Figure 3.1 The location of the Weatherley catchment, 4 km south of Maclear on the road to Ugie (Chief Director of Surveys and Mapping, 1993).

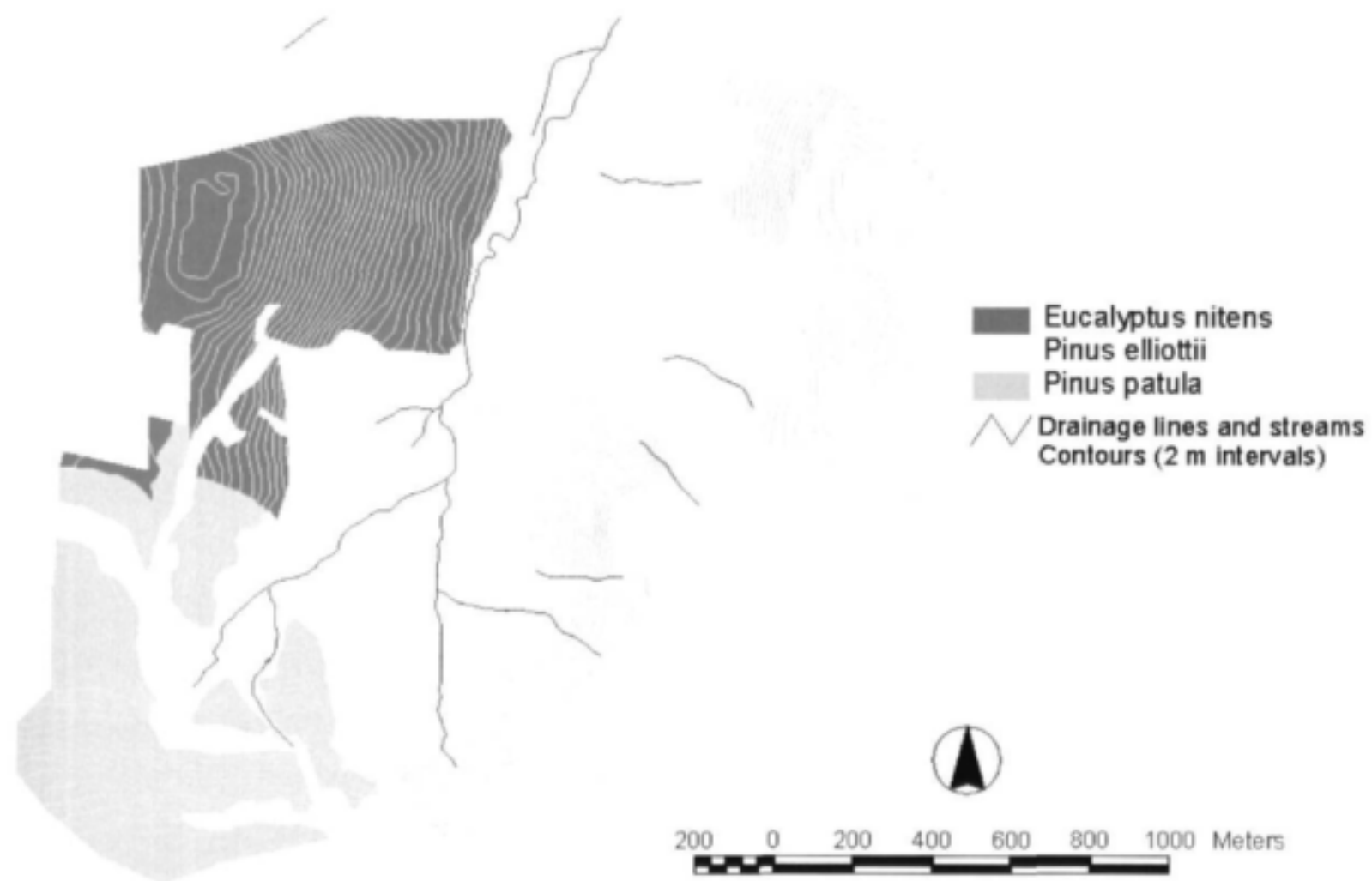


Figure 3.2 Planting strategy in the Weatherley catchment (BEEH, 2003).

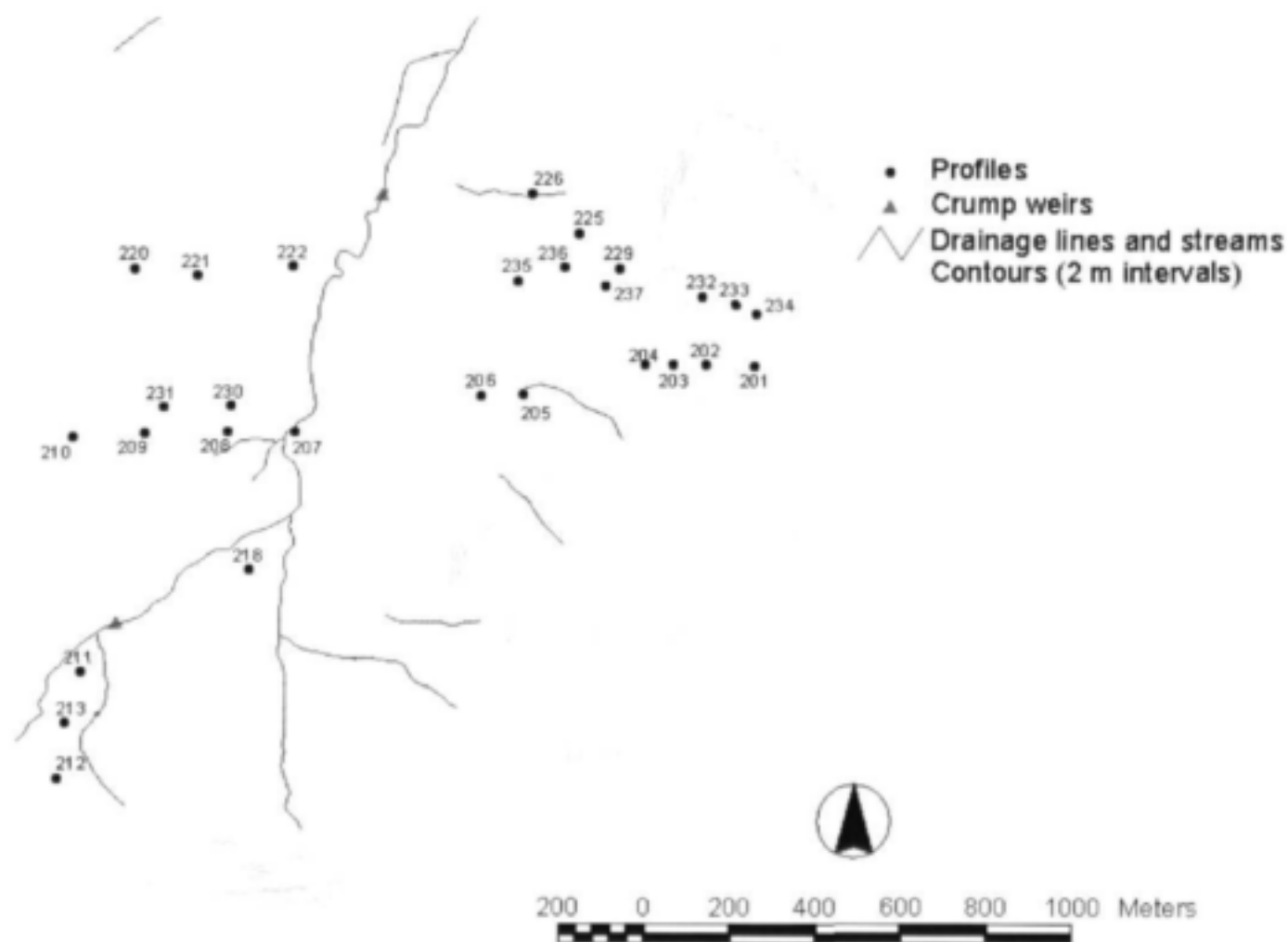


Figure 3.3 Geography of the Weatherley catchment, including the location of neutron water meter sampling sites.

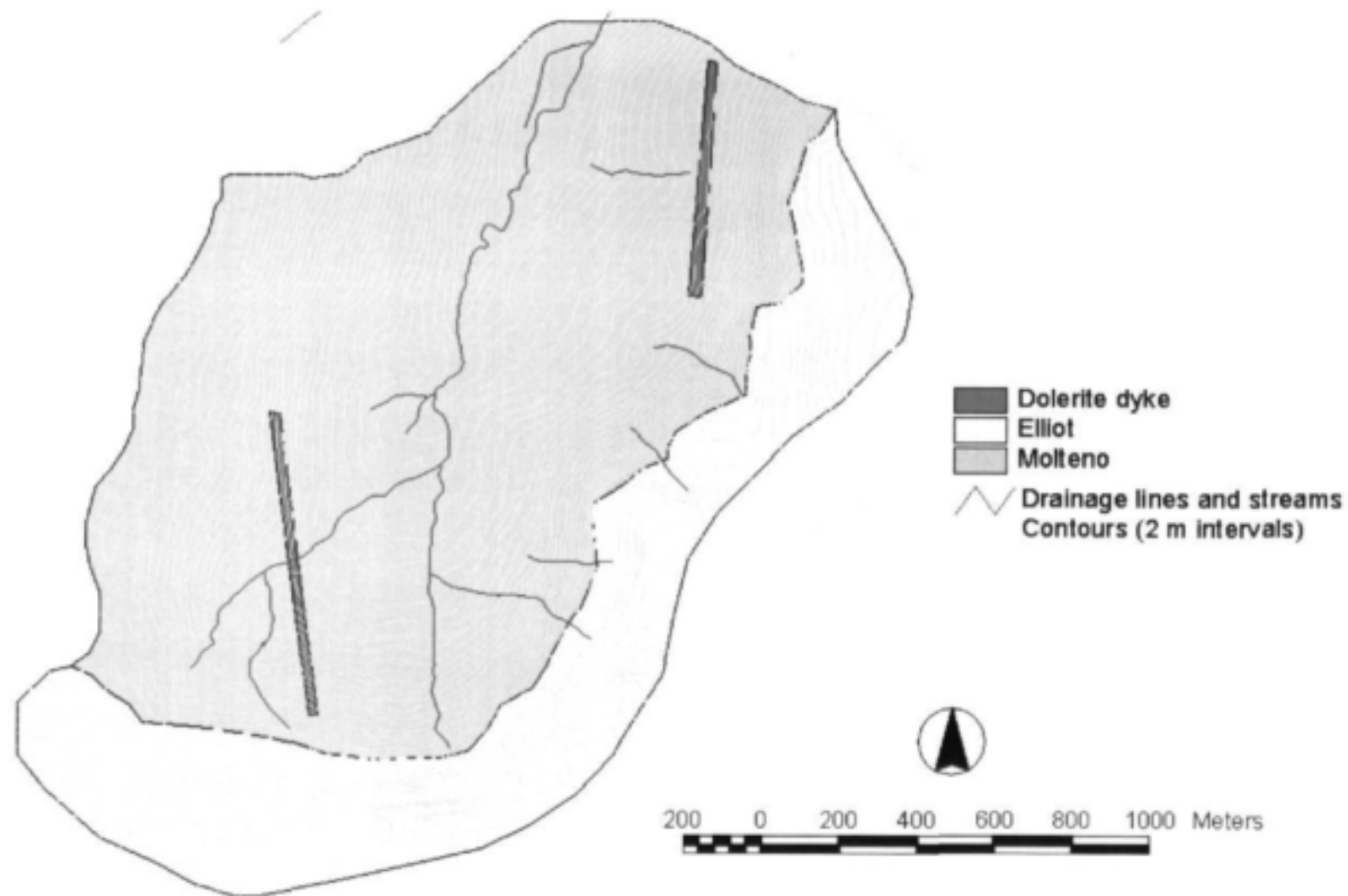


Figure 3.4 Simplified geology of the Weatherley catchment (De Decker, 1981).

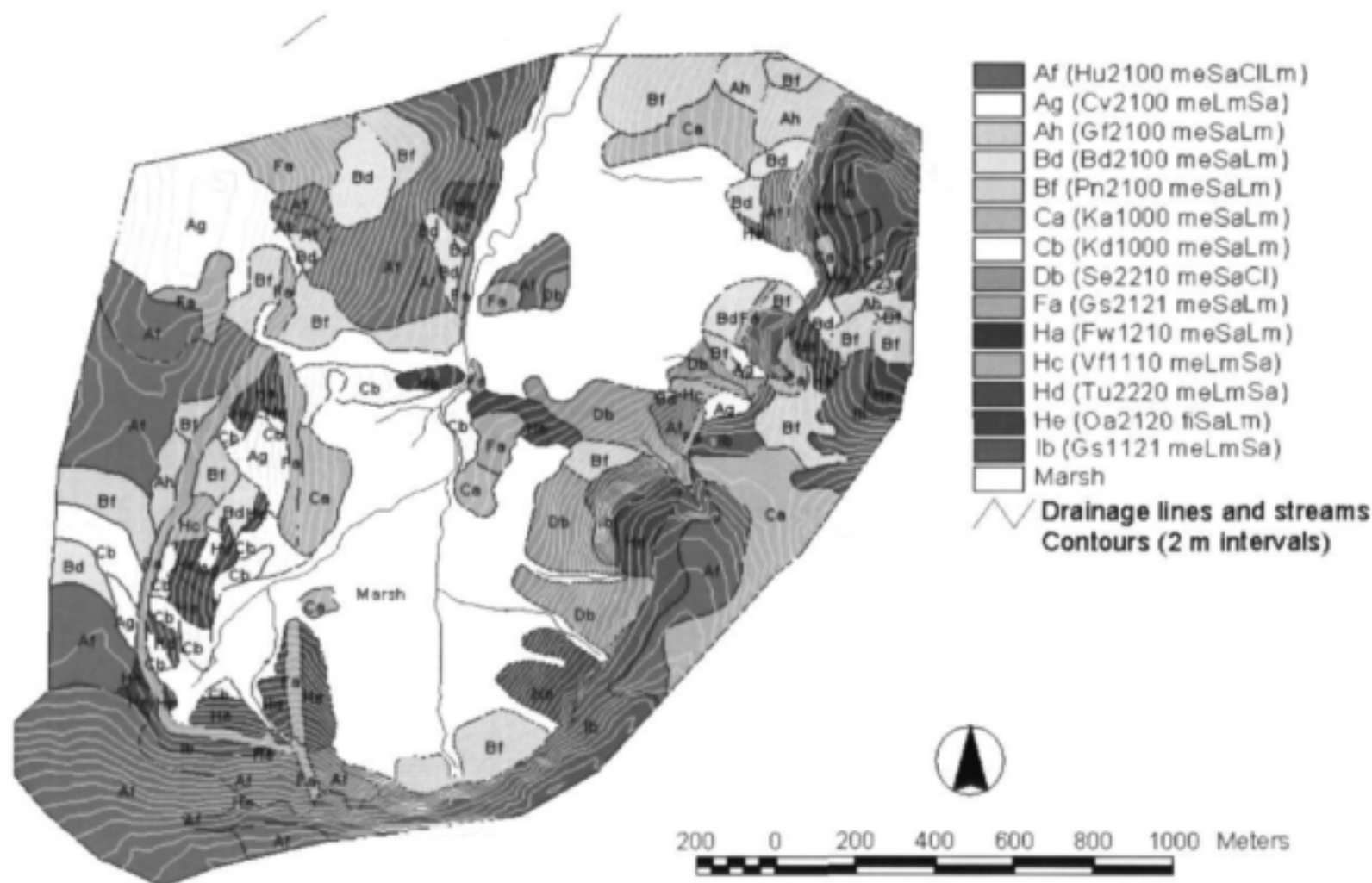


Figure 3.5 Generalised soil patterns, using Soil Classification Working Group (1991) and FSD (1995) classification, according to Roberts *et al.* (1996).

3.7 Hydrology

Runoff is measured at two crump weirs in the Weatherley catchment (Figure 3.3). Some data for the lower weir is given in Figure 3.6. It is clear that runoff is concentrated in the first quarter of the year and that runoff normally occurs as peaks, presumably after large rain storms. The large variation in annual runoff is also apparent in the graph.

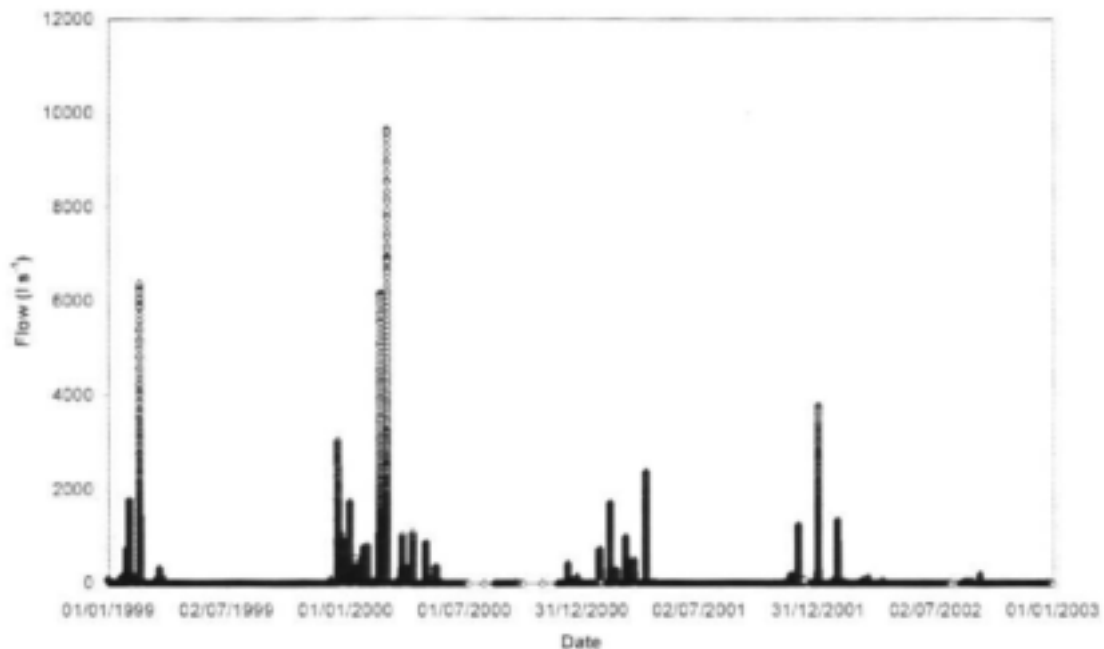


Figure 3.6 Hydrograph, showing runoff at the lower weir in the Weatherley catchment (BEEH, 2003).

3.8 Summary

The Weatherley catchment was selected mainly because a vast amount of work has been, and is continuously being done at this site. It therefore offers the opportunity to build on previous research whilst at the same time creating the opportunity to make valuable contributions to future research. Lithology in the Weatherley catchment is mainly Elliot and Molteno sandstone, with two dolerite dykes bisecting it. The summers are wet and hot, while the winters are cold and dry. The mean annual aridity index is 0.50. Soils in the Weatherley catchment are characterized by varying degrees of hydromorphy. This complicates the study, but also provides ample opportunity to study water saturation in these highly leached and sometimes permanently saturated soils.

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4 METHODOLOGY

4.1 Introduction

The aim of data accumulation during this study was to measure those soil properties that would shed more light on the processes that influence soil morphology. In this regard, soil water content formed the backbone of the data accumulation phase. Bulk density, through its influence on volumetric water content and degree of saturation was further deemed to be very important. Soil profiles were described, classified, photographed and analysed to illustrate soil morphology and the soil chemical and physical environment as well as possible.

4.2 Selection of the study site

Defining the relationship between soil profile morphology and soil water regime is generally difficult due to the lack of sufficient quantitative and qualitative soil water data. This is not the case at Weatherley. The available information includes the following:

- a) Detailed hydrological measurements over six years at 28 strategic sites and continuous tensiometer readings at selected sites.
- b) Bulk density, hydraulic conductivity and matric suction curves for important horizons at selected sites.
- c) Detailed soil survey data (28 modal profiles, with 427 soil auger observations by Roberts *et al.* (1996).
- d) Data from two automatic weather stations (BEEH, 2003).
- e) Hydrological data from two crump weirs, sited to allow for detailed process-based hydrological modelling (BEEH, 2003).
- f) Runoff measurements from two runoff plots, situated on the western and eastern sides of the catchment (BEEH, 2003).
- g) Evapotranspiration measurements from a Bowen ratio apparatus, located to measure integrated evaporation within the catchment (BEEH, 2003).

Research in the catchment has also resulted in the publication of various reports, theses and conference contributions:

- a) Four WRC project reports (Lorentz, 2001; Lorentz *et al.*, 2001; Van Huyssteen *et al.*, 2002; Van Huyssteen *et al.*, 2003a; Van Zyl & Lorentz, 2003).
- b) Two M.Sc. (Hydrology) theses (Esprey, 1997; Hickson, 2000).
- c) Various conference papers (Lorentz & Esprey, 1998; Lorentz & Hickson, 2001; Le Roux *et al.*, 2003; Van Huyssteen *et al.*, 2003b; Van Huyssteen *et al.*, 2003c).

The Weatherley catchment was chosen for this study because of the vast amount of data that has been collected for the catchment. It further provided the opportunity to work across established research boundaries.

4.3 Field measurements

Neutron water meter measuring sites were selected by a hydrologist to elucidate hillside water movement. At that time there was no thought that these measuring sites would be used to relate soil profile morphology with soil hydrology. Because of all the measurements available now, the results can, however, also be used beneficially for the latter purpose. This is true in spite of some profiles being located in sites which are transitional or non-representative from a pedological point of view *e.g.* P204 (Longlands) and P207 (Westleigh), as shown in Figure 3.3.

The profiles (Figure 3.3) were sited so as to occur close to current neutron water meter access tubes and tensiometer nests, while keeping a distance of 2 m between the in-field instrumentation and the profile pits. Initial pedological field measurements were done during the last two weeks of June 2001. During this period soil profiles were dug, profiles were described, and soil samples and bulk density samples were taken. Soil profile morphology was described in detail, using the methods proposed by Turner (1991). Additional features were noted and included in the descriptions. Special attention was given to colour variations and the occurrence of mottles.

The three dominant dry and wet matrix colours were described, using new Munsell Soil Color Charts (Munsell Color Company, 1975). An estimate of the occurrence (area percentage) of each colour was also made. The colour, size, shape,

occurrence, boundary and cause of mottles were also described. Colours were described by a number of people, to eliminate personal bias.

Representative soil samples were taken per diagnostic horizon at 100 mm intervals throughout the solum. Intervals were varied to accommodate morphological variation and were increased to 200 or 300 mm in the lower part of the solum. Soil samples were air dried and crushed with a rubber pestle in a ceramic mortar. Samples were sieved through a 2 mm sieve to remove the gravel. The soil and gravel were weighed and stored.

Digital photographs of each profile and individual horizons were taken. These photographs were analysed, using GIS techniques, to quantitatively determine soil matrix colour and the colour, size, shape and quantity of mottles. Photographs were taken in direct sunlight.

The lithology of the parent material was described for each soil profile. Special attention was given to soil profiles with more than one parent material. Samples of the rock and saprolite were taken for analysis.

Soil water contents were measured using a neutron water meter. Three CPN instruments (2022, 3411 and 8550) were used to collect the data used in this study. Details regarding calibration of the instruments are presented in section 4.4.1. The instruments were calibrated against each other, using standard high density plastic tubes (Reginato & Nakayama, 1987). Data is stored in a Microsoft Access database. This data was extracted and the volumetric soil water contents calculated. Volumetric soil water contents and degree of water saturation were calculated from the neutron water measurements. Calculations are described in section 4.4. Although neutron water meter (NWM) measurements were started on 9 November 1995, only data for nine measurements are available up to the end of 1996. Fairly regular measurements were taken during the ensuing years. Measuring depths were kept at standard 300 mm intervals. Although every effort was made to do regular measurements, the mean duration between measurements was 8.7 days, while the median duration between measurements is 7.0 days. Measurements were made 353 times at the relevant access tubes between 1 January 1997 and 21 February 2005.

4.4 Calculation of degree of water saturation

The degree of water saturation (Hillel, 1980) was calculated as:

$$s = \frac{V_w}{V_f} \quad (4.1)$$

Where:

- s = degree of saturation (as a fraction)
- V_w = water content ($\text{mm}^3 \text{ mm}^{-3}$)
- V_f = total pore volume ($\text{mm}^3 \text{ mm}^{-3}$)

The degree of saturation measures the volume of water relative to the total pore volume. It ranges from zero in dry soil to unity (one) when all soil pores are filled with water. Complete saturation is seldom reached, because some air is almost always trapped by the water in wet soil (Hillel, 1980). In soil with a small pore volume a small amount of water will lead to saturation, while in a soil with a larger pore volume, more water will be required to reach saturation.

The porosity (f) was calculated as follows:

$$f = 1 - \frac{\rho_d}{\rho_s} \quad (4.2)$$

Where:

- ρ_d = bulk density (Mg m^{-3})
- ρ_s = particle density (Mg m^{-3}), assumed to be 2.65 Mg m^{-3}

The term "annual duration of degree of water saturation above 0.7 of porosity" ($AD_{s>0.7}$) is defined here to be very specific for the following reasons: First, the redox system that was studied is a complex one. Soil water content, pore size distribution within each porosity class, soil water O_2 content, microbial factors, soil Fe content, and soil carbon content are probably the main, but not necessarily all, the factors that determine the redox conditions in a soil. Secondly, these factors are further influenced by landscape position, climate, parent material and living organisms. The choice of 70 % of porosity as a lower threshold for the onset of significant reduction is

therefore a first approximation, based on the motivation presented in section 4.4.1. It is further likely that this value will be different for different horizons and soil profiles, due to the complex nature of the system, as specified above. Because of these factors it would be advantageous if more detailed research could be done regarding the degree of saturation where reduction would set in and the impact of bulk density on this value. The unit used for $AD_{s>0.7}$ in this study is days year^{-1} . This is based on the fact that $D_{s>0.7}$ was calculated on an annual basis. Instead of days year^{-1} one could simply express the period as a fraction of a year. This is, however, considered to be undesirable as it may invite the reader to apply it on a monthly or weekly basis, which would be erroneous.

The mean value of $s>0.7$ events for a particular year were calculated as the yearly duration divided by the frequency events during that year:

$$F_{s>0.7} = \text{number of times per year that } s \text{ increases above } 0.7 \text{ (events year}^{-1}\text{)} \quad (4.3)$$

$$D_{s>0.7} = \frac{AD_{s>0.7}}{F_{s>0.7}} \quad (4.4)$$

Where:

$$\begin{aligned} AD_{s>0.7} &= \text{duration of } s>0.7 \text{ (days year}^{-1}\text{)} \\ F_{s>0.7} &= \text{frequency (events year}^{-1}\text{)} \\ D_{s>0.7} &= \text{mean duration of } s>0.7 \text{ events (days event}^{-1}\text{)} \end{aligned}$$

4.4.1 Improving neutron water meter calibrations

4.4.1.1 Introduction

Data was initially collected for this purpose in a combined effort by NECF and the ARC-ISCW when the 28 access tubes were inserted in November 1995. It consisted of NWM readings with CPN instrument serial No. 8550 and concomitant gravimetric soil water content (θ_m) measurements at most of the tubes. Additional relevant data was collected by Esprey (1997) and Lorentz *et al.* (2001) in their hydrological studies. This consisted of bulk density determinations at some of the NWM measuring sites. In March 1997 a large amount of additional data was collected by ARC-ISCW. This consisted of NWM readings with CPN instrument serial No. 3411 at 16 access tubes,

concomitant θ_m measurements, and readings with CPN density probe serial No. 9547. All the data described above was processed to produce the first detailed set of calibration equations in June 1997 (Table 4.1).

Table 4.1 NWM calibration equations for Weatherley compiled in June 1997 by ARC-ISCW

Calibration equation	Horizon group	Instrument No.	a (Slope)	b (intercept)	R ²
1	A horizons	8550	15.872	-0.940	0.96
		3411	16.570	-1.003	
2	B horizons	8550	17.157	-5.920	0.92
		3411	17.912	-5.989	
3	C and E horizons	8550	21.272	-12.665	0.79
		3411	22.208	-12.750	
4	G horizons	8550	14.543	+2.801	0.71
		3411	15.183	+2.743	

Because it is known that there are fundamental differences in the properties of different kinds of horizons, separate calibration equations were developed for the groups recorded in Table 4.1. The R² values for the A and B horizons are satisfactory, and those for the last two groups less satisfactory. An important reason for the latter is that one can seldom obtain dry θ_v values for C, E and G horizons. This reduces the range of values available for the regression analysis, and therefore mitigates against good correlation. In the operating manual supplied with the NWM it is stated that the relationship between the NWM count ratio and volumetric water content is linear over "the most commonly used moisture range". It is also stated that for "moisture contents higher than this, it is necessary to have a special calibration that covers the intended range of use". The need for this special calibration at the wet end has been confirmed in practice over a long period. Note that there are no special "wet end" calibration equations in Table 4.1. The data available at that time proved to be inadequate for this refinement.

4.4.1.2 Bulk density determinations and use of the density probe

Because volumetric water content (θ_v) is obtained by multiplying θ_m by bulk density (Db), reliable Db values are of fundamental importance for reliable NWM calibration. Because of the time and cost involved in determining bulk density at all depths by the core method, the first set of calibration equations was based on a minimum number

of core determinations. All other D_b values for the initial set of calibrations were obtained by using the CPN density probe. This instrument employs gamma photons, emitted by a cesium source, to determine the density of the material in a sphere around the source. As the cylindrical probe part of the instrument has the same diameter as the NWM, it is lowered down the same access tubes as those used for θ_v determinations.

If suitably calibrated and under certain conditions, a density probe provides a method for making rapid and reliable D_b determinations over a wide range of depths (Reginato, 1974; Erbach 1987). It does, however, have weaknesses which need to be taken into account when interpreting results. A description of the procedure will reveal these, and at the same time provide the necessary background against which to describe the measures taken to moderate these weaknesses as far as possible, while exploiting the advantages of the procedure.

The density meter measures the density of the total matrix, i.e. mineral material, organic material and water. Since most Weatherley soils are low in organic matter, complications due to this factor are not important in the present discussion, but θ_v at the time of measurement is very important. Equation 4.5 was used for calculation of density with the CPN density probe.

$$DWp = -b \times \ln\left(\frac{CR - c}{A}\right) \quad (4.5)$$

Where:

- | | | |
|---------|---|---|
| DWp | = | probe value of wet density, i.e. the density of the solid matrix and the water (g cm^{-3}) |
| CR | = | count ratio obtained with the instrument |
| b, c, A | = | coefficients specific for the instrument. |

Values for b, c and A are obtained by calibrating the particular instrument in three large blocks of known density ranging from 2.62 to 1.50 Mg m^{-3} . This can be done at the CSIR in Pretoria. It needs to be repeated every few years because of the relatively short half-life of the radio active source. The relevant calibration of the instrument used at Weatherley was carried out at the CSIR in 1999 and early in 2003.

The probe value for dry density (DDp) is obtained by subtracting the water content, expressed in g cm^{-3} , from the DWp value:

$$\text{DDp} = \text{DWp} - \theta_v (\text{g cm}^{-3}) \quad (4.6)$$

It is therefore imperative to have a reliable θ_v value obtained at the same time as the DWp value. Studies at Weatherley and elsewhere have shown that the relationship between DDp values and Db values obtained by the core method is different for different kinds of soil. For this study it has been assumed that this relationship will be constant for a particular diagnostic horizon or group of similar diagnostic horizons. A further necessary step towards improving the NWM calibration equations was therefore to define these relationships for the main diagnostic horizons found at Weatherley.

For this discussion to be fully meaningful it is necessary to expose a fundamental problem in connection with studies involving soil Db. It revolves around the relatively large variation of this parameter in natural soils. This is due to the influence of a number of factors, e.g. spatial variation in organic matter content, unevenly distributed voids in the soil caused by faunal activity and/or old root channels, spatial variation in texture (a few small stones in one specific sample could for example produce an extraneous value). These problems are best overcome by using fairly large cores replicated as many times as possible. Spatial variation also has a detrimental influence when comparing results obtained by the core method with those obtained with the density probe. This is because different volumes of soil are being sampled. In view of the basic problems it is not surprising to generally find poor correlations associated with studies involving Db (Lorentz *et al.*, 2001; Kaur *et al.*, 2002).

4.4.1.3 Procedure

It has been found convenient in this project to express θ_v as a fraction of porosity (f). This is advantageous for two reasons. First, it normalizes the data and therefore facilitates comparisons between different horizons within a particular profile, and

between different profiles. Secondly, it presents the data in a form that is meaningful with regard to the redox reactions which influence soil colour and therefore soil morphology. This is because of the fact that significant redox reactions can only be expected to occur when soils are relatively wet, which they are at θ_v values > 0.7 , the first approximation threshold value chosen for this project. Since $f = 1 - D_b/2.65$ the importance of reliable D_b values is again accentuated.

Data collection actions to improve the NWM calibration equations were undertaken during June 2001 and June 2003. Concomitant measurements of θ_m , θ_v by NWM, and D_b using the density meter, were included at all of the 28 measuring sites to a depth of at least 1500 mm. Eighty six D_b determinations by the core method (Blake & Hartge, 1986), in duplicate, were also made. The cores had a radius of 50.5 mm and height of 116.5 mm *i.e.* a volume of 933 000 mm³. This relatively large size was chosen to increase the volume sampled and therefore decrease the influence of spatial variation. Undisturbed core samples with a volume of 644 000 mm³ were also taken in case they might be needed for later studies concerned with the shape of the matric suction curves. These D_b values were used to convert θ_m to θ_v . The θ_v values made it possible to obtain DDp values using equation 4.6 where concomitant density probe and θ_m measurements had been made. This provided a valuable set of DDp values for horizons for which equivalent core determined D_b values were also available, and therefore made it possible to calculate a regression of D_b on DDp. The need to define this relationship is referred to in the paragraph below equation 4.6.

Since starting neutron water meter measurements at Weatherley in November 1995 a number of different instruments have been used. To avoid data collection problems arising from instrument failure, each time a new instrument was used it was standardised by making measurements in plastic standards as described by Reginato and Nakayama (1987). These measurements made it possible to make reliable calibration graph conversions between instruments. The instrument which has been longest in service at Weatherley is 3411. For this reason it has been used to provide the basis for the improved calibration lines. The equivalent lines for the other instruments were obtained by using the inter-instrument relationships obtained via

the plastic standards. That is the reason why the R^2 values for correlation between the count ratios of the different instruments and water content are therefore the same. The correlation between the count ratios of the different instruments are given below:

$$CR_{3411} = 0.958 CR_{8850} + 0.004 \quad (4.7)$$

$$CR_{3411} = 1.069 CR_{2022} + 0.017 \quad (4.8)$$

The coefficient of variance (CV) values associated with each of the improved calibration lines are as follows:

orthic A horizons: dry portion:	27%
wet portion:	16%
re, ye, ne, gs group of horizons:	34%
gh, sp, on, so group of horizons:	21%

4.4.1.4 Results and discussion

Separate Db vs. DDP regressions were computed for the following groups of horizons: the first group – orthic A horizons (ot); the second group – red apedal (re), yellow-brown apedal (ye) and neocutanic (ne) B horizons, and E (gs) horizons; the third group included the following horizons – gley (gh), soft plinthic (sp), unspecified material with signs of wetness (on), and saprolite (so). Computation of the Db vs. DDP regressions for each of these groups revealed a number of values which were clearly extraneous and which therefore needed to be excluded. The data was also relatively scattered with R^2 values surprising low, especially for the re group. Possible contributing factors are: the natural relatively large spatial variability of Db; possibly some inherent weakness of the density probe for measuring Db in the range present here; the fact that many of the DWp readings were made in relatively wet soils which could have impaired the accuracy of the DDP results obtained using equation 4.6 (since there is inevitably a certain amount of error in the θ_v value). For convenience all the DDP readings obtained during the three data collections were expressed in terms of the 2003 data set. The following equations were obtained for the three groups, using the symbol for the first horizon in each group for identification:

Db (ot)	=	$0.647 (DDp_{(03)}) + 0.396$	$n = 37$	$R^2 = 0.76$	(4.9)
Db (re)	=	$0.322 (DDp_{(03)}) + 1.030$	$n = 34$	$R^2 = 0.39$	(4.10)
Db (gh)	=	$0.450 (DDp_{(03)}) + 0.822$	$n = 68$	$R^2 = 0.83$	(4.11)

Equations 4.9, 4.10 and 4.11 were used to estimate Db values of all horizons at the 28 sites where Db had not been determined by the core method. The complete set of Db values is presented in Appendix A. Mean values (Mg m^{-3}) for the three groups are as follows: ot = 1.57; re = 1.65; gh = 1.71. The values are all significantly different from each other at the 1% level. These results made it possible to calculate reasonably reliable θ_v values for all θ_m measurements. These, together with the concomitant NWM measurements provided the information needed to compute the NWM calibration equations. Because of the known differences between diagnostic horizons, separate calibration equations were developed for each of the groups represented by equations 4.9, 4.10 and 4.11. The calibrations for the three CPN instruments of orthic A horizons are presented in Figure 4.1, of red apedal B, yellow-brown apedal B and neocutanic B, and E horizons in Figure 4.2 and for G and soft plinthic B horizons as well as unspecified material with signs of wetness, and saprolite in Figure 4.3. For computational convenience an exponential equation has been used to describe the calibration line for the re group.

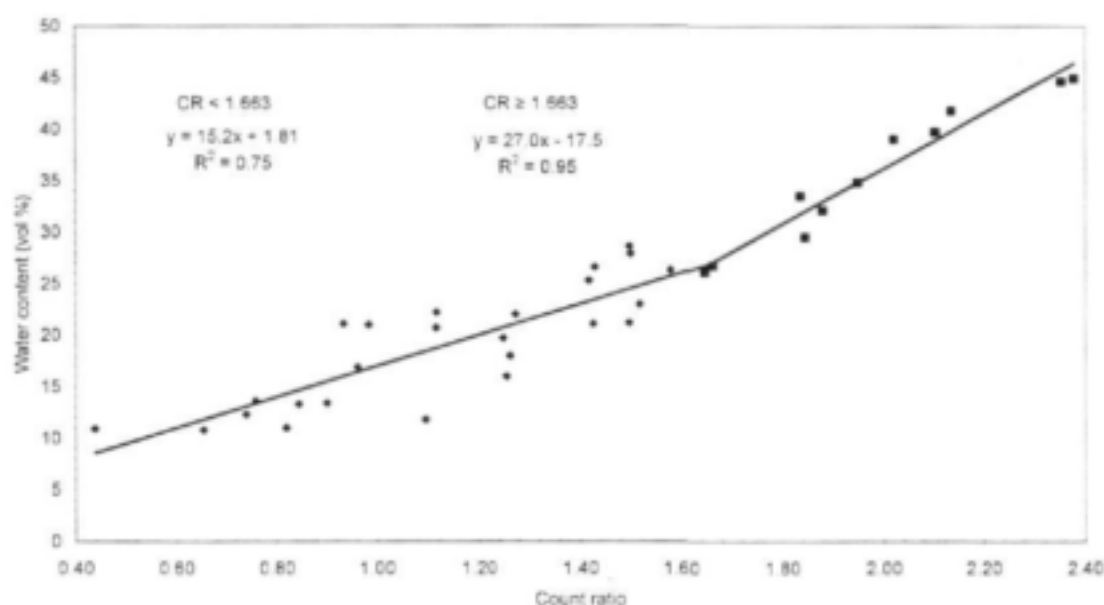


Figure 4.1 Calibration equations of orthic A horizons for CPN 3411, used at Weatherley.

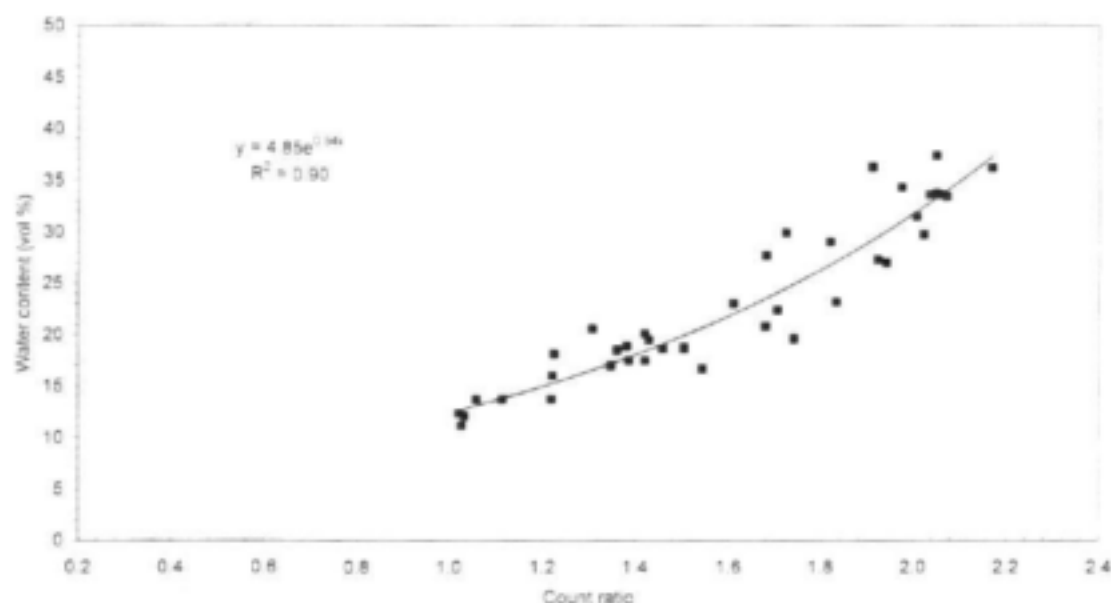


Figure 4.2 Calibration equations of red apedal (re), yellow-brown apedal (ye) and neocutanic (ne) B horizons, and E (gs) horizons for CPN 3411, used at Weatherley.

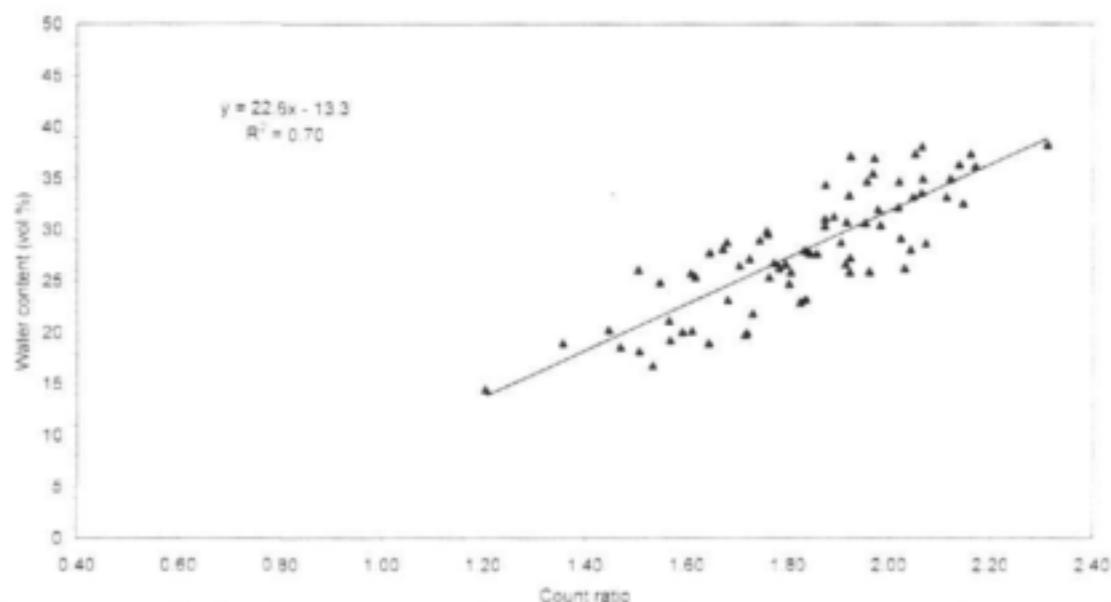


Figure 4.3 Calibration equations of G (gh), soft plinthic B (sp), unspecified material with signs of wetness (on), and saprolite (so) for CPN 3411, used at Weatherley.

Evaluation of the calibrations is facilitated by considering relevant results obtained by other scientists. Excellent research work in this connection was done at Stellenbosch and published between 1960 and 1975 (Marais & Smit, 1960; Marais & Smit 1962; Karsten & Haasbroek, 1973; Karsten *et al.*, 1975). They showed that, "variation in bulk density causes a parallel shift in the calibration curve, but differences in soil type

present a more complex problem since both intercept and slope of the calibration curve are affected" (Karsten *et al.* 1975). One of these "complex problems" was shown to be the amount of water contained in the crystal structure of the clay minerals, which they called "structural water". It is released above 105°C when a soil sample is heated to 700°C, i.e. a loss on ignition determination. In a soil low in organic matter this water provides the main contribution to the size of the negative value of the intercept. It is therefore true that the higher the content of smectites in a soil the larger the negative intercept is expected to be. Holmes (1966), working in Australia, came to conclusions similar to those of the Stellenbosch researchers, and concluded that "there appears to be no alternative to individual calibration of each soil intended for investigations". It was considered to be an advantage in this study to develop separate calibration lines for groups of soil horizons with fairly similar properties, e.g. Db value and CEC (as an index of smectite content), in preference to determining separate calibration lines for different groups of soils.

Figure 4.1 shows that for a CR₃₄₁₁ reading of 2.1 in an orthic A horizon the 1997 calibration gives a water content of 5.1% less than the improved one. This is a significant difference, especially considering that it is in the θ_v range > 0.7 . Validity of the improved calibration line is shown by the fact that it passes close to what is expected to be the maximum θ_v value ($\approx 0.9S$), as determined by the mean Db (1.57 Mg m⁻³), and therefore mean porosity (40.7%) of these horizons, at the maximum CR₃₄₁₁ (≈ 2.1). The slightly flatter slope of the new "dry end" line is according to expectation. This is because the deficiency of wet end data for the 1997 line resulted in some of it being included with the drier values to give a single line with a steeper slope.

Although the horizon grouping for the 1997 and new calibration lines is slightly different, since the main contributors are the same in both cases, it is considered useful to make the relevant comparisons. Figure 4.2 shows that the improvement of the new calibration line over the 1997 one is similar to that in Figure 4.1. At the maximum CR₃₄₁₁ value of around 2.1 the 1997 line gives a θ_v value of 3.3% less than the new value. The validity of the new line is confirmed by its close proximity at CR₃₄₁₁ around 2.1, to 0.9 s as defined by the mean Db value for these horizons of

1.65 Mg m⁻³, and therefore a mean porosity of 37.7%. The two lines are almost identical over the drier range below 0.7 s.

The horizons included in Figure 4.3 are naturally almost always fairly wet. It was therefore not possible, and also not necessary, to obtain sufficient θ_v values for a dry end line. It is considered that the additional measurements made during 2001 and 2003 have improved this calibration considerably in spite of there being no improvement in the R^2 value. In accordance with an expected fairly large amount of "structural water", the new line has a negative intercept of 13.3 whereas the 1997 line has a positive intercept of 2.7.

The three new calibration lines, for CPN instrument 3411, are plotted together in Figure 4.4. Only the linear lines are shown for the re group as the line described by the exponential equation becomes spurious when extrapolated. The fact that the ot line is above the other two is in accordance with the findings of Marais & Smit (1962) and Karsten *et al.* (1975), that an increase in Db causes a parallel displacement of the calibration line to give a higher NWM count at the same θ_v value. Although there is little difference between the calibration lines for the re and gh groups, they nevertheless correctly reflect known differences in the characteristics of these two groups of horizons. First, the lower porosity of the gh group is reflected by the lower θ_v value at the maximum CR₃₄₁₁ of around 2.1. Secondly, comparing the intercepts of the two lines reflects the difference in water held in the crystal structures of the clay minerals (Karsten *et al.*, 1975). Whereas the intercept of the gh line is - 13.3, causing the line to be relatively steep and indicating a considerable amount of water held between 105°C and 700°C, the intercept of the re line is + 0.119. Theoretically this value should be negative as there must also be some "structural water" in these horizons. The deviation is presumably due to sampling error and too small a number of samples. Both pedology logic and chemical analyses provide support for the contention that the gh group is richer in smectites than the re group. The mean CEC_{soil} values for the two groups are around 8 and 5 respectively.

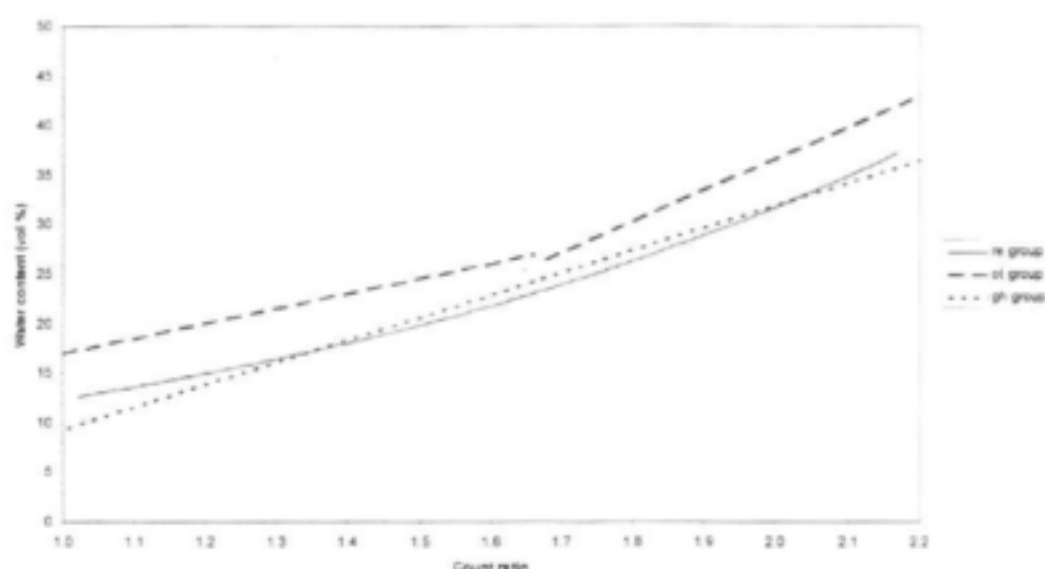


Figure 4.4 Calibration equations of the orthic A (ot), red (re) and G (gh) horizon groups, for CPN instrument 3411, used at Weatherley.

4.4.1.5 Conclusions

Karsten *et al.* (1975) have proposed a procedure for obtaining a single calibration line for a range of different soils. The procedure involves introducing correction factors for differences in Db and loss on ignition. Although they obtained very good results, which are also very valuable from a theoretical point of view, it needs to be kept in mind that they worked under laboratory conditions. The 10 different soils they used were contained in drums packed to produce different Db values. The natural factors causing much spatial variation in Db were therefore absent. Therefore, although their procedure is attractive, it is not certain that it would be worthwhile to try to implement it for this Weatherley project. The extent to which data processing has been simplified by computers neutralises to some extent earlier urges to try to reduce the number of calibration lines being used.

Considerable effort has been expended to improve the calibration lines to ensure that reliable θ_v values are obtained. The results presented indicate that this objective has been satisfactorily achieved.

4.5 Laboratory Measurements

All chemical analyses were done according to standard methods (The Non-Affiliated Soil Analysis Work Committee, 1990). Soil samples were analysed for particle size

distribution (7 fractions), pH (H₂O and KCl), exchangeable cations, cation exchange capacity (CEC), organic carbon, nitrogen, as well as dithionite-citrate-bicarbonate, pyrophosphate and oxalate extractable Fe and Mn.

The results of pyrophosphate and oxalate extraction of Fe and Mn yielded disappointing results, to such an extent that no attempt was made to interpret them. This is also supported by the findings of Loeppert & Inskeep (1996). They stated that: "... the pyrophosphate extract, following high-speed centrifugation includes microcrystalline iron oxide particles ..." and that "the pyrophosphate extractable Fe cannot be designated as organically bound Fe".

Due to the very low clay content in some of the horizons, the CEC_{clay} was calculated by subtracting the CEC_{organic matter} from the CEC_{soil}. This was then divided by the clay content to yield the CEC_{clay}. The organic matter content was calculated as 1.74 * organic carbon content and the CEC_{organic matter} was taken as 200 cmol_c kg⁻¹ organic matter (Brady & Weil, 1996).

4.6 The soil water balance

4.6.1 The soil water balance equation

The data presented in previous reports on this project was based on neutron water meter (NWM) measurements made at approximately weekly intervals. To provide more accurate information it is desirable that estimates on a daily basis be obtained. The procedure to achieve this is described in the following subsections.

It is necessary that it be clearly understood that this is a point study and therefore volumes of water are not under consideration. The water balance equation for a particular point on a particular day can be described by equation 4.12.

$$\theta_i = \theta_{i-1} + P \pm R \pm D_v \pm D_l - ET \quad (4.12)$$

Where:

θ_i	=	soil water content on day i (mm)
θ_{i-1}	=	soil water content on day i-1 (mm)
P	=	rainfall on day i (mm)
R	=	runoff on day i (mm)
D	=	vertical (D _v) and lateral (D _l) drainage on day i (mm)
ET	=	evapotranspiration on day i (mm)

Equation 4.12 was solved on a daily basis for the soil water content of each layer based on the NWM data, which provided the θ_{i-1} term of equation 4.12 for days on which measurements were made. Determination of the other terms in equation 4.12 is described in the following sections.

4.6.2 Rainfall

Daily rainfall data is needed to solve equation 4.12. This data was obtained from the Weatherley database version 1 (BEEH, 2003) for the period 26 November 1997 to 08 July 2003, which had missing values for the period 02 December 2001 to 21 January 2002. The data gap was filled with daily rainfall generated from regression ($R^2 = 0.82$) between daily rainfall data obtained from a nearby farm (Mr. Coetzee, personal communication, 2004) and daily Weatherley rainfall for the months of December and January of 2000 to 2003.

4.6.3 Runoff

In this report runoff refers to overland flow, due to the wide use thereof in Soil Science. The two terms should therefore be seen as synonyms. Lorentz and Hickson (2001) analyzed the runoff data collected at their runoff plots located on the mid slopes of the Weatherley catchment. They concluded that surface runoff, that reaches the stream, is generally negligible within the catchment. Water generally flows only 20 m on the soil's surface before it infiltrates or enters a stream. Runoff from one part of the catchment would therefore be run-on at another part of the catchment. Equation 4.12 could therefore be simplified to equation 4.13, where all the terms are as defined in equation 4.12.

$$\theta_i = \theta_{i-1} + P \pm D_v \pm D_l - ET \quad (4.13)$$

4.6.4 Evapotranspiration

Measured evapotranspiration (ET) for the veld grass in the Weatherley catchment was not available for this study. It was therefore necessary to make an estimate of this parameter in order to solve equation 4.13. Estimation of ET was carried out in several steps. First, daily FAO Penman-Monteith reference evapotranspiration (ET_o)

data was compiled, as described below. Then ET/ET_o ratios were established from NWM soil water contents at appropriate sites during suitable periods. Finally daily ET was generated from the ET/ET_o and daily P data.

4.6.4.1 ET_o

Reference evapotranspiration (ET_o) is defined by Allen *et al.* (1998) as that which occurs from a hypothetical extensive surface of green, well watered, actively growing grass of 0.12 m height, a fixed surface resistance of 70 s m⁻¹, and albedo of 0.23. The standard method for its computation from meteorological data is carried out using the FAO Penman-Monteith equation (equation 4.14):

$$ET_o = \frac{0.408\Delta(R_n - G)}{\Delta + \gamma(1 + 0.34u_2)} + \frac{\gamma u_2(e_s - e_a)(900/(T + 273))}{\Delta + \gamma(1 + 0.34u_2)} \quad (4.14)$$

Where:

ET _o	=	reference evapotranspiration (mm d ⁻¹)
Δ	=	slope of vapour pressure curve at mean air temperature (kPa °C ⁻¹)
R _n	=	net radiation at the crop surface (MJ m ⁻² day ⁻¹)
G	=	soil heat flux density (MJ m ⁻² day ⁻¹)
γ	=	psychrometric constant (kPa °C ⁻¹)
T	=	mean daily air temperature at 2 m height (°C)
u ₂	=	wind speed at 2 m height (m s ⁻¹)
e _s	=	saturation vapour pressure (kPa)
e _a	=	actual vapour pressure (kPa)
e _s - e _a	=	saturation vapour pressure deficit (kPa)

For this study, limited daily ET_o data for Weatherley and surrounding stations was obtained from the ARC-ICSW (L. Maritz, personal communication, 2004). The stations and the periods of reported data include:

Weatherley (31.1000 S, 28.3333 E), from 01 June 1997 to 28 February 2001;
Somerton (31.1567 S; 28.3843 E) from 01 January 1997 to 3 August 2003;
Wildebees (31.2000 S; 28.2167 E) from 25 March 1997 to 28 February 2001; and
Tsolo (31.3000 S; 28.7667 E) from 3 December 1997 to 6 January 2004.

The ET_o data from all of the above stations contains many missing values. In order to fill the data gaps at Weatherley, ET_o for Weatherley was regressed on those of

each of the surrounding stations (Figure 4.5). The resulting scatter plots and the regression equations indicate that Somerton ETo, followed by Tsolo ETo matched Weatherley ETo fairly well. Wildebees ETo showed slight scatter, specifically for ETo values exceeding 4 mm day⁻¹. Missing daily Weatherley ETo data were therefore estimated using the resulting regression equations in the following order of preference: Somerton, Tsolo, and Wildebees.

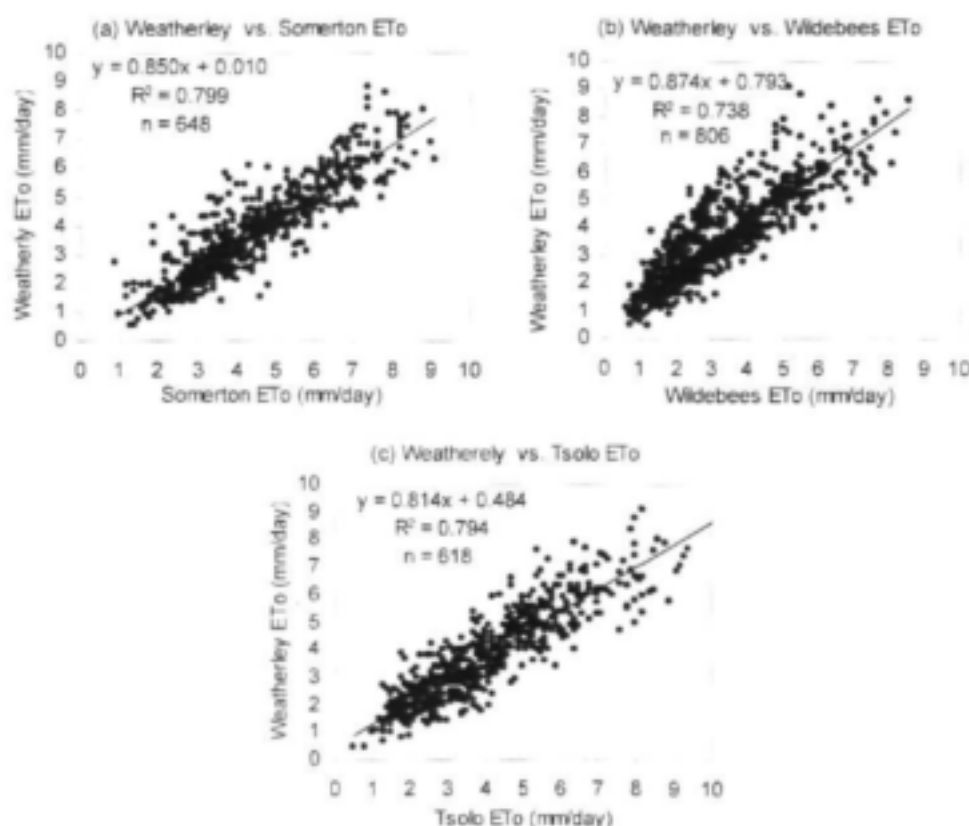


Figure 4.5 Regression equations for ETo values of Weatherley vs. surrounding stations. Data obtained from ARC-ISCW climate database (L. Maritz, personal communication, 2004).

An appropriate ET/ETo relationship is necessary to estimate actual daily grass ET from the daily ETo data. Such a relationship was developed for Weatherley by solving equation 4.12 for selected profiles during selected periods, for both water stressed and stress-free soil water conditions.

The following assumptions were made:

- The effective root zone for the veld grass is 0-900 mm.
- Drained upper limit (DUL) for a freely drained layer is at $s = 0.6$ (s is degree of saturation)
- Stress-free ET occurs at water contents above first material stress (FMS). FMS is defined as the water content of the root zone at the onset of stress (Hensley, 1980). In this case the onset of stress is approximated by the value halfway between DUL and the lower limit of plant available water (LL).
- At soil water contents below FMS, ET decreases linearly with decreasing soil water content (*i.e.* with increasing stress level). Although the relationship is in fact curvilinear, this assumption is considered to be acceptable in view of the very small amounts of water involved, and the extent to which computations are affected. This assumption is similar to the procedure employed in ACRU (Smithers & Schulze, 1995).
- Small amounts of rainfall ($\Sigma P \leq 5$ mm) in a period of approximately one week are lost rapidly by ET and therefore do not influence θ in equation 4.12, but are nevertheless considered as contributing to ET (Table 4.2). This is based on Ritchie (1972).

4.6.4.2 *ET/ET₀ during a stress-free period*

A suitable stress-free period for this study was defined as one in which the soil water content was between DUL+5 mm, and FMS, and in which there was little or no cumulative rainfall ($\Sigma P \leq 5$ mm). During such a period R and D_v can be considered negligible, and soil water availability is such that ET can take place without significant stress. Solving equation 4.13 for ET during such a period also requires selection of soils where the root zone (0-900 mm) is freely drained, *i.e.* D_i is negligible. The suitable periods and soil profiles selected for this purpose are presented in Table 4.2. The profiles were: P202 (Pinedene), P203 (Tukulu), P210 (Bloemdal), P212 (Tukulu), P220 (Bloemdal), P221 (Hutton), and P234 (Avalon). Although the whole profiles of most of these soils are not freely drained, a study of their morphology shows that to consider the 0-900 mm layer as freely drained is a reasonable assumption.

Table 4.2 Calculated ET/ET_o for non-stressed veld grass during selected periods at profiles with freely drained 0-900 mm layers at Weatherley

Profile No.	Period			Measured water loss (mm) per layer depth (mm)			Period P (mm)	Period ET (mm)	Daily ET (mm)	Period ET _o (mm)	Period ET/ET _o
	Start date	End date	Length (days)	0-300	300-600	600-900					
P202	28-Oct-99	4-Nov-99	7	12.5	4.7	0.5	0.6	18.3	2.61	40.1	0.46
P202	24-Mar-03	2-Apr-03	9	16.0	7.6	4.2	2.4	30.2	3.36	37.1	0.82
P203	18-Jun-97	26-Jun-97	8	5.5	3.9	0.2	0.0	9.6	1.21	22.9	0.42
P203	1-Apr-99	8-Apr-99	7	10.3	2.1	0.0	0.0	12.3	1.76	26.3	0.47
P203	21-Sep-00	29-Sep-00	8	8.8	2.8	0.0	0.0	11.6	1.44	37.4	0.31
P203	28-Feb-01	7-Mar-01	7	12.2	1.4	3.2	0.8	17.6	2.52	34.7	0.51
P203	16-Apr-02	23-Apr-02	7	8.7	3.0	1.5	0.2	13.4	1.91	23.9	0.56
P203	10-Jan-03	15-Jan-03	5	8.7	2.0	1.1	1.2	13.0	2.60	28.2	0.46
P210	6-Aug-97	14-Aug-97	8	9.3	3.4	0.0	0.0	12.7	1.59	27.9	0.46
P210	15-Oct-97	23-Oct-97	7	15.5	9.2	5.2	0.0	29.8	4.26	35.1	0.85
P210	2-Apr-98	9-Apr-98	7	12.9	4.5	2.2	0.8	20.4	2.91	26.6	0.77
P210	1-Apr-99	8-Apr-99	7	7.6	3.7	0.3	0.0	11.7	1.67	26.3	0.44
P210	13-Oct-00	19-Oct-00	6	6.4	2.0	0.7	0.2	9.3	1.55	30.5	0.30
P210	10-Oct-02	16-Oct-02	6	10.6	4.9	2.8	0.4	18.7	3.11	31.6	0.59
P210	10-Jan-03	15-Jan-03	5	8.1	3.7	1.1	1.2	14.1	2.82	28.2	0.50
P210	24-Mar-03	2-Apr-03	9	10.5	8.1	4.9	2.4	26.0	2.89	37.1	0.70
P212	4-Mar-97	12-Mar-97	8	7.3	6.4	2.7	4.0	20.5	2.56	31.4	0.65
P212	10-Jan-03	15-Jan-03	5	8.4	2.1	0.6	1.2	12.4	2.47	28.2	0.44
P220	30-Oct-97	6-Nov-97	7	11.5	2.0	1.1	0.0	14.7	2.09	40.7	0.36
P220	10-Oct-02	16-Oct-02	6	10.9	3.8	1.3	0.4	16.4	2.74	31.6	0.52
P221	6-Aug-97	14-Aug-97	8	13.4	0.6	0.0	0.0	14.0	1.75	27.9	0.50
P221	16-Oct-97	23-Oct-97	7	17.6	8.9	2.6	0.0	29.0	4.15	35.1	0.83
P221	2-Apr-98	9-Apr-98	7	11.7	4.5	0.6	0.8	17.6	2.52	26.6	0.66
P221	29-Sep-00	8-Oct-00	9	10.0	6.2	4.6	4.6	25.5	2.83	33.5	0.76
P234	17-Jul-97	24-Jul-97	7	11.3	0.5	1.3	2.5	15.7	2.24	19.0	0.82
P234	2-Apr-98	9-Apr-98	7	13.4	4.0	1.2	0.8	19.4	2.78	26.6	0.73
P234	1-Apr-99	8-Apr-99	7	15.0	5.7	2.4	0.0	23.1	3.30	26.3	0.88
Layer fractions (I _i)				0.65	0.25	0.10				Mean ET/ET _o	0.58

The soil water loss during the selected periods was computed and together with the small rainfall amounts, considered as ET. Total ETo data was also computed for each of the selected periods. The values were used to calculate ET/ETo for each of the selected periods.

As shown in Table 4.2, a mean ET/ETo of 0.58 was obtained. This value enables the computation of daily ET from ETo during stress-free periods. The ET values obtained in this way describe the evapotranspiration rate of the veld grass under optimum conditions, *i.e.* minimum stress, and therefore provide the best available approximation of the evapotranspiration rate that would occur under such conditions.

Another necessary parameter revealed by the data in Table 4.2 is the fraction of ET provided by each 300 mm layer. It is clearly indicated in the results that the average layer fraction (I_1) values, during a stress-free period, are 65%, 25% and 10% of ET for the 0-300, 300-600, and 600-900 mm layers respectively. These values proved valuable for modelling the soil hydrology of each layer on a daily basis for the different soils at Weatherley.

4.6.4.3 *ET/ETo during a stress period*

For dry periods the ET/ETo values determined in the previous section are not valid since the veld grass may be stressed to varying degrees, causing ET to be suppressed. After the onset of stress the ET/ETo ratio is expected to decrease as a function of θ . The value of 0.58 obtained during stress free periods is thus clearly too high for these drier conditions. Another ET/ETo ratio was therefore necessary to estimate ET from ETo during periods when θ drops below FMS. To estimate ET/ETo under such conditions a similar procedure was followed as for the stress-free periods.

A suitable stress period was defined as one in which ET occurs below optimum. At the extreme lower end of such a period the soil water content (θ) would typically be around LL. Several such periods were identified at the end of winter. Soil water loss ($\Delta\theta$) was computed from the weekly NWM measurements at suitable soil profiles during these periods. The soils selected for this purpose were: P202 (Pinedene), P203 (Tukulu), P210 (Bloemdal), P221 (Hutton), and P234 (Avalon). A mean ET/ETo of 0.19 was obtained (Table 4.3). The mean percentages of ET provided by

each 300 mm layer, *i.e.* the layer fraction values (l_2) in this case were 51%, 33% and 16% for the 0-300 mm, 300-600 mm and 600-900 mm depths, respectively. Compared to the fractions during stress-free periods, there is a clear increase in extraction with increasing depth. This is expected because, as the top layers become drier, the roots would normally be forced to extract more water from the deeper layers.

To estimate the ET/ET_o values between the stress-free rate and the minimum rate, *i.e.* during periods having soil water contents below FMS, a linear relationship was assumed to exist between the ET/ET_o and θ . In this case θ was expressed in terms of degree of saturation (s) in order to eliminate the effect of variation in the water holding capacities between different layers in the different soils. The s value for each layer of the selected profiles was calculated both at FMS and at LL. The mean s value at FMS for the profiles selected for the stress-free ET/ET_o was found to be 0.51, and the mean ET/ET_o ratio above this s value was 0.58. Near the dry end of the soil water spectrum, the mean s value at LL for the profiles selected for this purpose was found to be 0.36, and the ET/ET_o was 0.19. These two points have been designated as A and B in Figure 4.6.

Table 4.3 Calculated ET/ET_o for water-stressed veld grass during selected periods at profiles with freely drained 0-900 mm layers at Weatherley

No.	Beginning date	End date	Length (days)	Layer depth (mm)			P (mm)	ET (mm)	ET (mm)	ET _o (mm)	ET/ET _o
				0-300	300-600	600-900					
P202	25-Sep-97	1-Oct-97	6	5.5	1.7	0.0	3.0	10.1	1.69	28.3	0.36
P202	9-Sep-99	16-Sep-99	7	1.2	0.0	2.2	0.4	3.8	0.54	34.5	0.11
P202	17-Aug-01	23-Aug-01	6	1.1	1.7	1.5	0.0	4.3	0.72	22.3	0.19
P202	16-Oct-02	24-Oct-02	8	1.9	6.0	2.2	1.8	11.9	1.49	43.9	0.27
P203	25-Sep-97	1-Oct-97	6	5.7	1.8	0.0	3.0	10.6	1.76	28.3	0.37
P203	9-Sep-99	16-Sep-99	7	0.5	0.1	0.0	0.4	1.0	0.14	34.5	0.03
P203	17-Aug-01	23-Aug-01	6	0.5	0.5	0.0	0.0	1.0	0.17	22.3	0.04
P203	16-Oct-02	24-Oct-02	8	7.8	2.5	1.1	1.8	13.3	1.66	43.9	0.30
P210	17-Aug-01	23-Aug-01	6	0.4	0.7	1.8	0.0	2.9	0.48	22.3	0.13
P221	25-Sep-97	1-Oct-97	6	5.3	3.6	0.0	3.0	11.8	1.97	28.3	0.42
P221	17-Aug-01	23-Aug-01	6	0.0	1.1	0.0	0.0	1.1	0.18	22.3	0.05
P234	9-Sep-99	16-Sep-99	7	1.3	0.5	1.2	0.4	3.4	0.48	34.5	0.10
P234	17-Aug-01	23-Aug-01	6	1.2	1.0	0.4	0.0	2.7	0.45	22.3	0.12
Layer fraction (I ₂)				0.51	0.33	0.16	Mean ET/ET _o				0.19

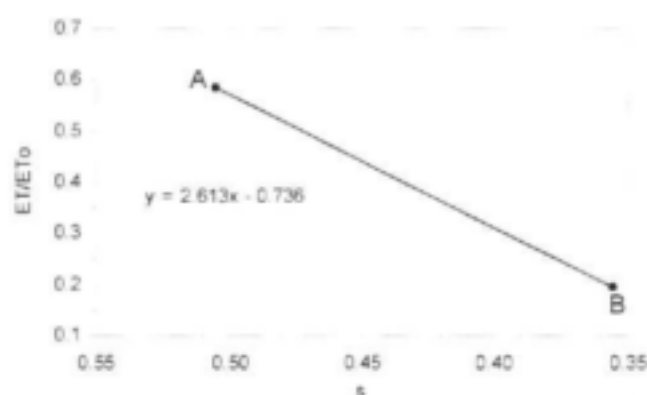


Figure 4.6 ET/ETo as a function of degree of saturation (s) between FMS and LL.

The equation for the straight line connecting points A and B in Figure 4.6 (equation 4.15) was used to estimate ET/ETo from s at water contents below FMS.

$$ET/ET_o = 2.613 s - 0.736 \quad (4.15)$$

Where:

s = degree of saturation

4.6.4.4 Final daily ET calculations

From the discussion above it follows that ET/ETo can be taken to be a constant value of 0.58 when the soil s is at FMS or above, and decreasing linearly with the decreasing values of s below FMS. During very wet periods, however, ET/ETo should be considerably higher than 0.58. Ritchie (1972) considered that during the initial stage of evaporation (for example, following significant rainfall events) ET is equal to the potential rate, or in our case, ETo. Therefore, ET values for each day during the period of daily soil water balance calculations were determined using a logical procedure which endeavours to simulate the maximum ET during very wet days (Figure 4.8). The calculated ET (ETa) is the ET value for a certain day computed as a fraction of the day's ETo (from ET/ETo ratios described in previous sections). If ETo during a particular day exceeds that day's $P+ETa$ then ET is considered to be equal to $P+ETa$, otherwise ET is considered to be equal to ETo.

To estimate the ET for each layer (ET_i in Figure 4.8) from the total profile ET the layer fractions in Figure 4.3 (l_1) and Figure 4.4 (l_2) were used, depending on the value of s . The ET calculation was carried out in a spiral manner on a daily basis. The

calculation exercise started one day after a day of NWM measurement. On this starting day, the measured value (θ_{i-1}) was used to determine the degree of saturation (s) in order to choose the correct ET/ET_o ratio for calculating ET. Then the ET calculated from this ratio, and the adjustments discussed in the previous paragraph, were used to contribute to the solution of equation 4.13 for θ_i . After θ_i had been calculated (section 3.6.6) its value was, in turn, used to determine s for calculating ET on the next day. The calculation continued in this manner for the period of six years, from 01 July 1997 to 30 June 2003.

4.6.4.5 Comparison of ET values estimated using the procedure described, and ET estimates obtained by other procedures

Daily ET values were calculated at 3 measurement depths for 28 sites in Weatherley for the six year period (Table 4.5). The resulting mean ET values for the six years ranged from 1.4 mm/day (40% of ET_o) at the driest site (P212) to 2.6 mm/day (71% of ET_o) at the marsh (P218).

A whole catchment water balance calculation was carried out for four years for Weatherley in order to obtain an estimate of the total ET during this period (ET_t), based on measured stream flow data at the lower weir (R_t) and total rainfall (P_t). A volumetric version of equation 4.13 was solved for total ET during the four year period between 30 June 1999 and 30 June 2003, as described in equation 4.16. Results are presented in Table 4.5.

$$ET_t = (P_t \pm \Delta\theta) - (R_t + D) \quad (4.16)$$

Where:

ET _t	=	total grass evapotranspiration for the whole Weatherley catchment in four years (m ³)
P _t	=	total rainfall for the whole Weatherley catchment in four years (m ³)
R _t	=	total stream flow at the lower weir in four years (m ³)
Δθ	=	difference in stored soil water at the beginning and at the end of the four years period (m ³)
D	=	deep drainage at the base of the Weatherley catchment (m ³)

In order to keep the change in soil water content (Δθ) at a minimum the calculation was carried out for the period 30 June 1999 to 30 June 2003. The soil water

contents at both the starting and ending dates were nearly the same, as these were during winter. Because of this $\Delta\theta$ is negligibly small compared to P_t and R_t and can therefore be ignored. Because of the geology of the catchment it is reasonable to assume that deep drainage beyond the base of the catchment (D) is negligible. Equation 4.16 therefore simplifies to equation 4.17.

$$ET_t = P_t - R_t \quad (4.17)$$

Results are presented in Table 4.4. The catchment water loss due to ET during the four years was 66% of the total ET_o .

Table 4.4 Weatherley total catchment water balance results for the period 30 June 1999 to 30 June 2003; and results partitioned into hillslope and marsh areas

Parameter	Value
Hillslope area (m^2)	1200195
Marsh area (m^2)	400065
Total area (m^2)	1600260
Total reference evapotranspiration, ET_o (m^3)	8350797
Total rainfall, P_t (m^3)	6731153
Total stream flow, R_t (m^3)	1210544
Total evapotranspiration, $ET_t = P_t - R_t$ (m^3)	5520609
ET_t/ET_o from catchment water balance	0.66
ET_t/ET_o from P202	0.59
ET_t/ET_o from P218	0.72
Weighted mean of ET_t/ET_o at P202 and 218	0.62

The estimated ET during this period was 59% of ET_o at P202 and 72% of ET_o at P218. Assuming that the ET at P202 represents that of the hillslopes (*i.e.* 75% of the total area of Weatherley), and the ET at P218 represents that of the marsh area (*i.e.* 25% of the total area), the weighted mean of the two is 62% of ET_o . This is slightly less than the 66% obtained by the catchment water balance. The discrepancy could mainly be due to errors inherent in estimating ET using the catchment water balance. Everson *et al.* (1998) describe this method as, "... not precise enough to enable accurate predictions of water yield from hydrological models."

Daily ET values, measured using the Bowen ratio energy balance method from the marsh area in Weatherley, were obtained for 40 non-consecutive days during the period 13 July 2001 to 09 December 2001 (Everson & Jarman, 2004). These data,

together with the estimated ET at P218, ETo and P data for the days on which Bowen ratio data was reported, are presented in Figure 4.7.

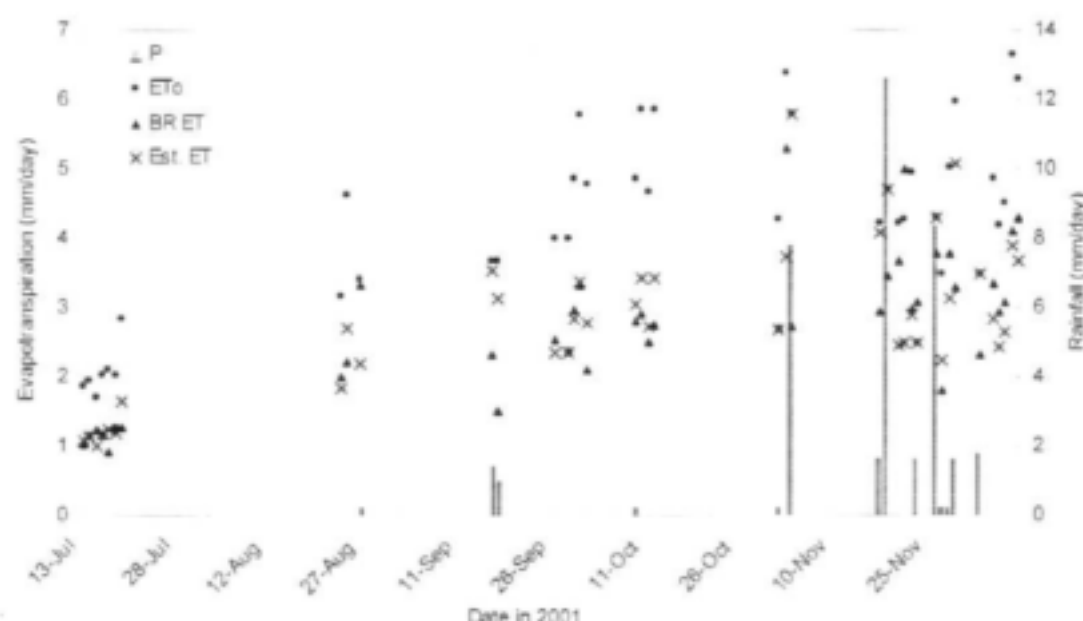


Figure 4.7 Bowen ratio measured ET (BR ET), estimated ET at P218 (Est. ET), reference ET (ETo) and rainfall (P) data for Weatherley for 40 non-consecutive days during the second half of 2001.

The Bowen ratio ET data was collected mainly from the marsh area of the catchment, as the apparatus was installed at the northern end of the marsh, facing down the valley in an approximately NNE direction. The estimated ET at P218 was selected because this site is also located in the marsh and fairly close to the Bowen ratio site (Figure 3.3). The mean Bowen ratio ET reported was 2.7 mm/day, which is practically the same as our estimated mean ET of 2.8 mm/day at P218 for the same set of days. For most days there is reasonably good agreement between the two sets of values. Wide variations occur, however, on rain days, e.g. on 03, 18, 26, and 29 November. This may well be due to the procedure adopted for estimating ET on these days (section 3.6.4.4). Although this procedure appears to be logical, similar results are not reflected by the Bowen ratio measurements. The R^2 between the daily estimated ET and Bowen ratio ET during the 40 days was 0.36. This fairly low agreement on a daily basis could also be due to estimation errors of the two methods and spatial variations between the sites. These errors, however, tend to balance out with time, as indicated by the mean values.

The lower ET/ET₀ values for the hillsides, compared to the values for the marsh, presented in Table 4.4 are in agreement with similar results obtained by Everson *et al.* (1998) for the Cathedral Peak catchment (VI). They found that ET from their marsh area amounted to 120 mm more than that from the adjacent hillside over a period of 1 year.

4.6.5 Drainage

After daily ET had been estimated, the unknown parameters required to solve equation 4.13 for daily θ were only D_v and D_i . It is difficult to differentiate between these two based on the available weekly NWM measurements. More frequent readings are required to construct reliable drainage curves. An estimate of daily values of D_v and D_i was nevertheless made based on θ_{i-1} , P , ET, and certain soil properties (Figure 4.8). Daily D_v out of a 300 mm layer was estimated by solving equation 4.13 for θ_i and comparing the result with the DUL of the layer. If θ did not exceed DUL then D was considered to be 0. If on the other hand θ exceeded DUL a certain fraction (c) of the excess water was allowed to drain to the underlying layer. The value of c was determined based on the degree of saturation of the underlying layer on the previous day (s_{i-1}). If s_{i-1} was small (say $s_{i-1} < 0.7f$, f being total porosity), indicating relatively drier underlying soil conditions, then a relatively larger value (c_2) was adopted compared to c_1 where s_{i-1} was above $0.7f$. Thus one of the two coefficients (c_1 or c_2), ranging between 0 and 1.0, was used depending on the value of s_{i-1} of the underlying layer.

An algorithm was written to empirically choose on each day between c_1 and c_2 for a soil layer. Initial values between 0 and 1.0 were given to c_1 and c_2 to temporarily calculate θ_{i-1} . The final values for each soil layer were then determined at the end of the whole soil water balance exercise. This was carried out by studying the overall agreement between the weekly measured and estimated θ values over the six year period during which daily θ was calculated. The values of c_1 and c_2 were repeatedly changed until the best possible level of agreement was reached (Figure 4.9). These coefficients were therefore used to "calibrate" the soil water balance procedure for each soil layer.

The following additional points were considered during the calculation procedure:

- (i) For all layers below 300 mm the D out of the overlying layer, instead of P , was used as input.
- (ii) ET was considered negligible below the root zone (900 mm).
- (iii) For the lowermost layer it was assumed that the underlying material is fairly impermeable, suppressing deep drainage. Therefore only C_1 was used for this layer.
- (iv) During days on which measured soil water content (θ_m) data was available any excess in the estimated soil water content (θ_c) was considered to be deep drainage loss (i.e. when $\theta_c > \theta_m$, and $\theta_c > \text{DUL}$).

An estimate of D_i was made empirically for each soil horizon at the end of the modelling procedure. As part of the model calibration exercise, any general tendency to overestimate θ_i was considered to be due to unaccounted for water loss by D_i to downslope soils, and so it was removed from the estimated θ_i . On the other hand, any general tendency to underestimate θ_i was considered to be due to unaccounted for addition by D_i from upslope soils, and so it was added to the estimated θ_i . D_i can be distinguished from D_v because D_i does not normally cascade vertically; it is a net loss, or sometimes net gain, to the water balance of a soil profile.

4.6.6 Daily soil water content

4.6.6.1 Calculation procedure

The final step and the purpose of the soil water balance calculations was estimation of daily θ . This was carried out by solving equation 4.13 for θ_i for each 300 mm layer for which weekly NWM data was reported. In order to obtain measured θ_{i-1} as an input, the calculation procedure was started on a day following a day of NWM measurement. The estimated θ_i value was then used as input for subsequent calculation on the next day. This practice continued each day until the day when the next NWM reading was reported. The same exercise was then repeated during the next week, and so on. The calculation procedure is described using the flow diagram in Figure 4.8. An intermediate value (θ_{c1}) was first calculated from θ_{i-1} , P , and ET. If this value was smaller than the DUL for that layer, then it was taken to be θ_i for the layer. If the value was larger than DUL, however, it was corrected for D_v and D_i . The

corrected value is referred to as θ_{c2} in Figure 4.8. Finally θ_{c2} was compared to 0.9f for this layer, and θ_i was taken to be equal to the smaller of the two values.

The 0.9f value was assumed to be the upper limit of the soil water content in all cases, since complete saturation in the field by water entry from above is generally not possible due to the presence of small air pockets in the soil. The θ_i calculation procedure was the same in all the relevant layers in a profile, with the exception that D_v from the overlying layer was used as an input, instead of P , in all layers below the top one.

4.6.6.2 Results

Daily θ data was generated using the procedure described above for each 300 mm soil layer, for six years from 01 July 1997 to 30 June 2003, for all the 28 measuring sites at Weatherley. A sample of the calculation worksheet is presented in Table 4.5. Possible estimation errors of the procedure were 'reset' using measured NWM data on days when the latter was reported. The estimated θ values during days when measured θ values were reported were compared to the latter to test the output of the procedure. A quick test of the agreement between the measured and estimated values over the six year period was carried out by studying the R^2 values, the alignment and closeness of the least squares line to the 1:1 line, and the spread of the data along the 1:1 line. If necessary, the estimation was then improved by repeatedly changing the drainage coefficients described in section 3.6.5. A scatter plot between the measured and estimated values at P202 is presented in Figure 4.9.

A statistical test of model performance, according to Willmott (1982), was carried out on estimated vs. measured θ values at P202. The following parameters were calculated: Index of agreement (D-index), mean absolute error (MAE), root mean square error (RMSE), systematic RMSE (RMSEs) and unsystematic RMSE (RMSEu). The statistical results (Table 4.6) indicate that the procedure for estimated daily soil water contents worked well at P202. According to Willmott (1982), a good model D-index should approach 1.0, while the RMSEs should approach 0, as a large RMSEs indicates bias. For P202 the mean D-index was 0.91 and the mean RMSEs was 22% of the mean RMSE. A similar performance was obtained for most of the other soil profiles. Values of R^2 sometimes exceeded 0.9. It is therefore concluded

that the procedure adopted gave predictions of daily soil water contents that are satisfactory for the purposes of this study.

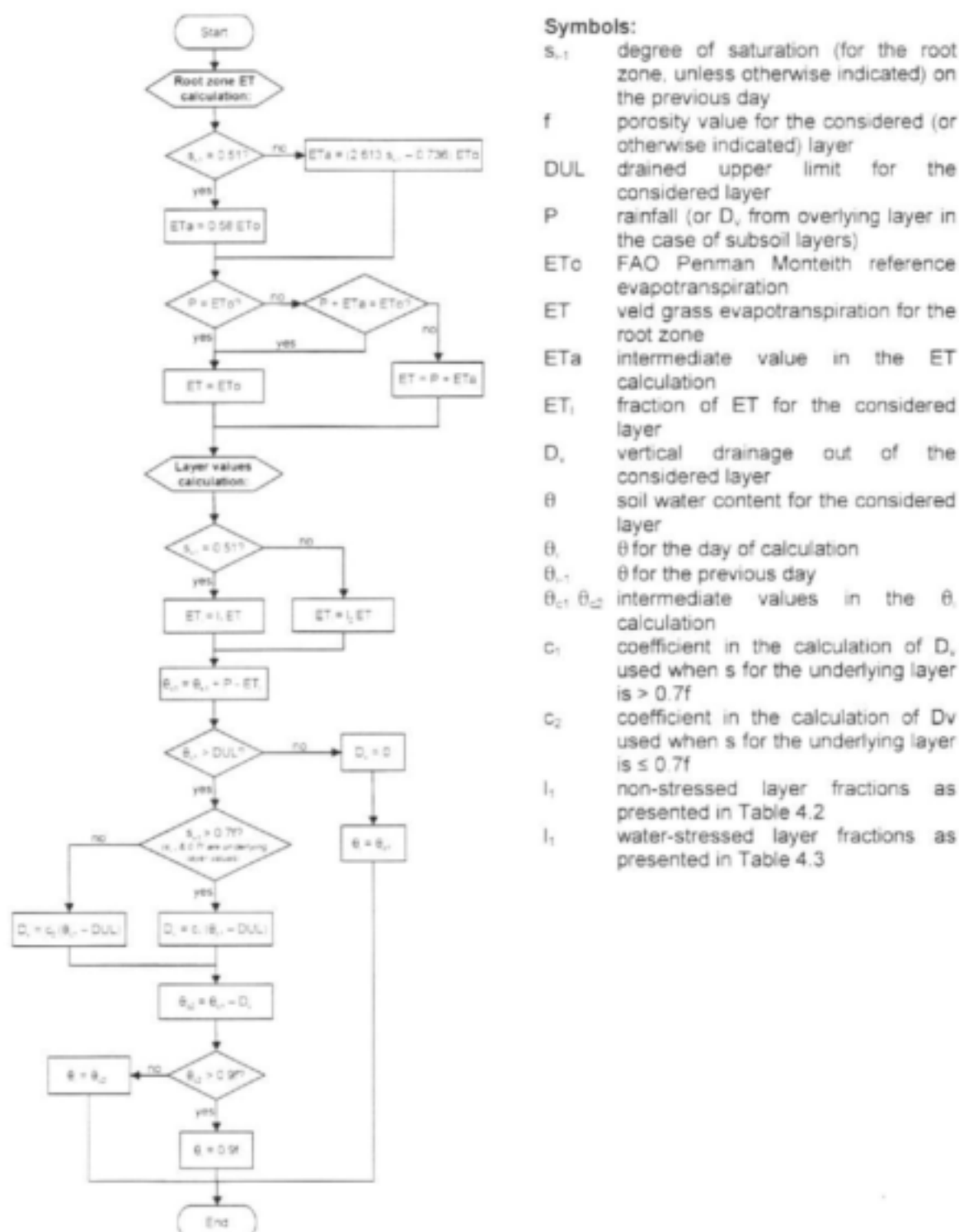


Figure 4.8 Flow diagram for estimating daily soil water content.

Table 4.5 Example of daily soil water balance calculations in a worksheet

Site data					190 mm depth					490 mm depth					790 mm depth					1090 mm depth					1390 mm depth					Mean s
Diagnostic horizon					ol					ye					ye					on					on					
BD (Mg m ⁻³)					1.68					1.61					1.72					1.71					1.72					
f (mm)					109.8					117.7					105.3					106.4					105.3					
0.9f (%)					98.8					106.0					94.8					95.8					94.8					
0.7f (mm)					76.9					82.4					73.7					74.5					73.7					
DUL (mm)					69.2					67.1					90.5					93.6					88.4					
Date	P mm	ET _o mm	ET _a mm	ET mm	ET mm	D _v mm	θ _m mm	θ _{c1} mm	θ mm	ET mm	D _v mm	θ _m mm	θ _{c1} mm	θ mm	ET mm	D _v mm	θ _m mm	θ _{c1} mm	θ mm	ET mm	D _v mm	θ _m mm	θ _{c1} mm	θ mm	ET mm	D _v mm	θ _m mm	θ _{c1} mm	θ mm	
					c ₁ = 0.7	c ₂ = 0.9			D _v = 0	c ₁ = 0.7	c ₂ = 0.9			D _v = 0	c ₁ = 0.4	c ₂ = 0.8			D _v = 0	c ₁ = 0.2	c ₂ = 0.5			D _v = 0	c ₁ = 0.3			D _v = 0		
29-Dec-00	0	5.0	2.9	2.9	1.9	0	69.0	0	69.0	0.7	0	65.3	0	65.3	0.3	0.1	94.8	0	94.8	0	0.4	94.8	0	94.8	0	0	94.5	0	94.5	0.69
30-Dec-00	0	5.2	3.0	3.0	2.0	0	67.0	67.0	0.8	0	64.6	64.6	0.3	1.6	94.5	92.9	0	1.2	96.4	95.2	0	2.2	96.4	95.2	0	2.2	95.6	93.5	0.68	
31-Dec-00	0	4.4	2.6	3.0	1.9	0	65.1	65.1	0.7	0	63.8	63.8	0.3	0.8	92.6	91.8	0	0.5	96.0	95.6	0	1.7	96.0	95.6	0	1.7	94.0	92.3	0.67	
01-Jan-01	24	2.2	1.3	2.2	1.4	15.8	86.7	70.9	0.5	8.4	79.1	70.7	0.2	3.8	99.9	94.8	0	1.1	99.3	95.8	0	1.5	99.3	95.8	0	1.5	93.4	91.9	0.72	
02-Jan-01	3	2.7	1.6	2.7	1.8	1.7	71.1	69.4	0.7	3.2	71.7	68.5	0.3	2.9	97.7	94.8	0	1.0	98.6	95.8	0	1.4	98.6	95.8	0	1.4	92.9	91.6	0.70	
03-Jan-01	0	5.0	2.9	2.9	1.9	0	67.5	67.5	0.7	0.5	67.8	67.3	0.3	1.8	94.9	93.2	0	0.8	97.5	95.8	0	1.2	97.5	95.8	0	1.2	92.4	91.2	0.69	
04-Jan-01	0	5.6	3.3	3.3	2.1	0	65.3	65.3	0.8	0	66.5	66.5	0.3	0.9	92.8	91.9	0	0.6	96.7	95.8	0	1.0	96.7	95.8	0	1.0	91.8	90.8	0.68	
05-Jan-01	0	5.7	3.3	3.3	2.2	0	63.2	63.2	0.8	0	65.7	65.7	0.3	0.4	91.6	91.2	0	0.5	96.2	95.7	0	0.9	96.2	95.7	0	0.9	91.3	90.4	0.67	
06-Jan-01	0	7.3	4.3	4.3	2.8	0	60.4	60.4	1.1	0	64.6	64.6	0.4	0.1	90.7	90.7	0	0.4	95.7	95.3	0	0.7	95.7	95.3	0	0.7	90.9	90.1	0.65	
07-Jan-01	0	5.2	3.0	3.0	2.0	0	59.2	58.4	59.2	0.8	0	56.2	63.9	56.2	0.3	0	91.9	90.3	91.9	0	0.3	92.8	95.0	92.8	0	0.6	85.5	89.9	85.5	0.63
08-Jan-01	20	3.6	2.1	3.6	2.3	5.6	75.4	69.8	0.9	0	60.9	60.9	0.4	0.4	91.5	91.1	0	1.3	93.2	93.2	0	1.4	93.2	93.2	0	1.4	86.9	86.9	0.67	
09-Jan-01	6	4.8	2.8	4.8	3.1	1.4	70.7	69.3	1.2	0	61.1	61.1	0.5	0	90.6	90.6	0	0	93.2	93.2	0	0	93.2	93.2	0	0	86.9	86.9	0.67	
10-Jan-01	0	4.1	2.4	2.4	1.6	0	67.8	67.8	0.6	0	60.5	60.5	0.2	0	90.3	90.3	0	0	93.2	93.2	0	0	93.2	93.2	0	0	86.9	86.9	0.66	
11-Jan-01	0	3.8	2.2	2.2	1.4	0	66.3	66.3	0.5	0	59.9	59.9	0.2	0	90.1	90.1	0	0	93.2	93.2	0	0	93.2	93.2	0	0	86.9	86.9	0.66	
12-Jan-01	0	7.8	4.6	4.6	3.0	0	67.1	63.4	67.1	1.1	0	60.4	58.8	60.4	0.5	0	94.8	89.6	94.8	0	0	94.8	93.2	94.8	0	0	90.7	86.9	90.7	0.67
13-Jan-01	25	6.2	3.6	6.2	4.0	14.8	85.7	70.8	1.5	4.6	73.7	69.1	0.6	3.3	98.8	94.8	0	0.9	98.1	95.8	0	1.0	98.1	95.8	0	1.0	91.6	90.7	0.71	
14-Jan-01	3	2.4	1.4	2.4	1.6	1.7	71.1	69.4	0.6	2.2	70.2	68.0	0.2	2.4	96.7	94.2	0	0.9	98.2	95.8	0	0.9	98.2	95.8	0	0.9	91.6	90.6	0.70	
15-Jan-01	0	4.3	2.5	2.5	1.6	0	67.7	67.7	0.6	0.2	67.4	67.2	0.3	1.5	94.2	92.7	0	0.7	97.2	95.8	0	0.9	97.2	95.8	0	0.9	91.4	90.5	0.69	
16-Jan-01	0	4.5	2.6	2.6	1.7	0	66.0	66.0	0.6	0	66.6	66.6	0.3	0.8	92.4	91.7	0	0.6	96.5	95.8	0	0.8	96.5	95.8	0	0.8	91.1	90.3	0.68	
17-Jan-01	0	4.0	2.3	2.3	1.5	0	64.5	64.5	0.6	0	66.0	66.0	0.2	0.4	91.4	91.1	0	0.5	96.1	95.6	0	0.7	96.1	95.6	0	0.7	90.8	90.1	0.67	
18-Jan-01	11	7.2	4.2	7.2	4.7	0	68.0	68.0	1.8	0	64.2	64.2	0.7	0	90.3	90.3	0	0.4	95.6	95.2	0	0.6	95.6	95.2	0	0.6	90.5	89.9	0.67	
19-Jan-01	5	4.6	2.7	4.6	3.0	0	66.0	67.7	66.0	1.1	0	56.8	63.1	56.8	0.5	0	90.6	89.9	90.6	0	0.3	90.7	94.9	90.7	0	0.5	85	89.7	85.0	0.65

Symbols:

BD bulk density
f porosity
DUL drained upper limit
P rainfall
ET_o FAO Penman Monteith reference
evapotranspiration
ET veld grass evapotranspiration

ET_a intermediate value in the ET calculation
D_v vertical drainage
θ_m measured soil water content
θ daily measured/estimated soil water content
θ_{c1} intermediate value in the θ calculation (when
θ_m is reported θ_{c1} is replaced by the final θ
estimate which is used for comparison to θ_m)

s degree of saturation for the root zone
c₁ coefficient in the D_v calculation used when s
for the underlying layer is > 0.7f
c₂ coefficient in the D_v calculation used when s
for the underlying layer is ≤ 0.7f.

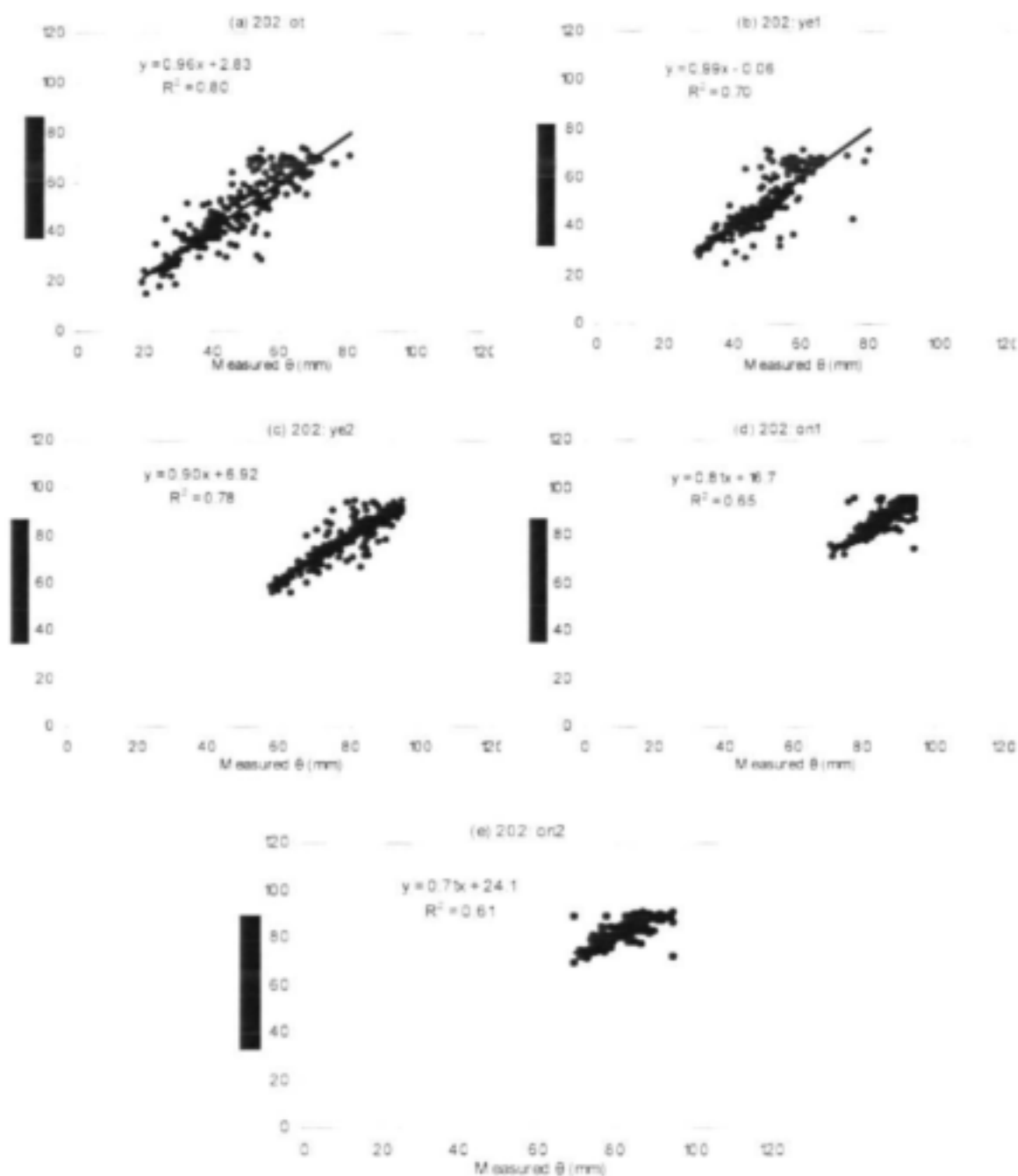


Figure 4.9 Comparison of measured and estimated θ values during the period July 1997 to June 2003, for the five diagnostic horizons at soil profile P202.

Table 4.6 Results of statistical test of model performance for θ at P202 for five horizons

Parameter	Measuring depth (mm)				
	190	490	790	1090	1390
n	234	234	234	234	234
D-index	0.95	0.89	0.94	0.90	0.89
MAE (mm)	4.80	4.56	3.03	2.13	2.07
RMSE (mm)	6.67	6.94	4.67	3.26	3.24
RMSEs (mm)	0.08	0.51	0.84	1.51	1.16
RMSEu (mm)	6.62	6.92	4.60	2.89	3.02
R ²	0.80	0.70	0.78	0.65	0.61

4.7 Digital photographs

Digital colour photographs were taken of each profile and master horizon, with a Sony MVC-FD83 digital camera. Photographs were cropped to remove shaded areas, the measuring tape, grass and other foreign matter from the photo. This photographic "sample" of each horizon was used in further calculations.

An attempt was made to classify the digital photograph into diagnostic red, yellow and grey colours (Soil Classification Working Group, 1991). Analyses of colour photographs were done using ArcView's SpatialAnalyst extension (ESRI, 2000). Digital photographs, however, use RGB notation (Poynton, 1999), while soil colour definitions are in Munsell colour notation (Soil Classification Working Group, 1991). The transformation between Munsell and RGB is discussed in section 2.6.

Calculated RGB values did, however, not correspond to the actual RGB values of a photographed Munsell hue sheet. There does, however, exist a good correlation ($R^2 = 0.99$) between calculated and actual RGB values for the 7.5YR Munsell hue sheet (Figure 4.10).

$$\text{Red} = 0.9238x - 37.24 \quad R^2 = 0.99 \quad (4.18)$$

$$\text{Green} = 0.9975x - 38.96 \quad R^2 = 0.99 \quad (4.19)$$

$$\text{Blue} = 0.9841x - 35.74 \quad R^2 = 0.99 \quad (4.20)$$

Bartlett's test (Snedecor & Cochran, 1989) was done to determine the difference between the regression lines of Red, Green and Blue, determined by calculation and photography. The values are significantly higher than 3.12 – indicating that the lines

differ at the 95 % confidence level (Table 4.7). The slopes and the Y-intercept also differ for the three equations.

Table 4.7 Bartlett's test results (Snedecor & Cochran, 1989), measuring the homogeneity of error variance in regression lines of calculated vs. photographed Red, Green and Blue, Y-intercepts and slopes

	Red	Green	Blue
regression lines	24.68	20.61	3.22
y-intercept	15.88	39.68	6.30
slope	13.18	17.12	7.51

Lighting influences the colour of the object (Melville & Atkinson, 1985), but for all three colours this correlation seemed to be independent of lighting source when indirect indoor sunlight, direct sunlight, shaded sunlight and neon light were tested (Figure 4.11, Figure 4.12 and Figure 4.13). It is therefore proposed that analyses of digital photographs can be compared, irrespective of the lighting conditions. It is, however, imperative to correct the Munsell colour co-ordinates for instrument deviations from the calculated values, using the above equations.

There exists an exponential relationship between scanned and calculated RGB values for the 7.5YR hue sheet (Figure 4.14). It is not certain why this is, but it should be clear that there would be different results between the analyses of digital photographs and scanned optical photographs. This relationship was not studied in more detail, because all photographs in this study were made with a digital camera.

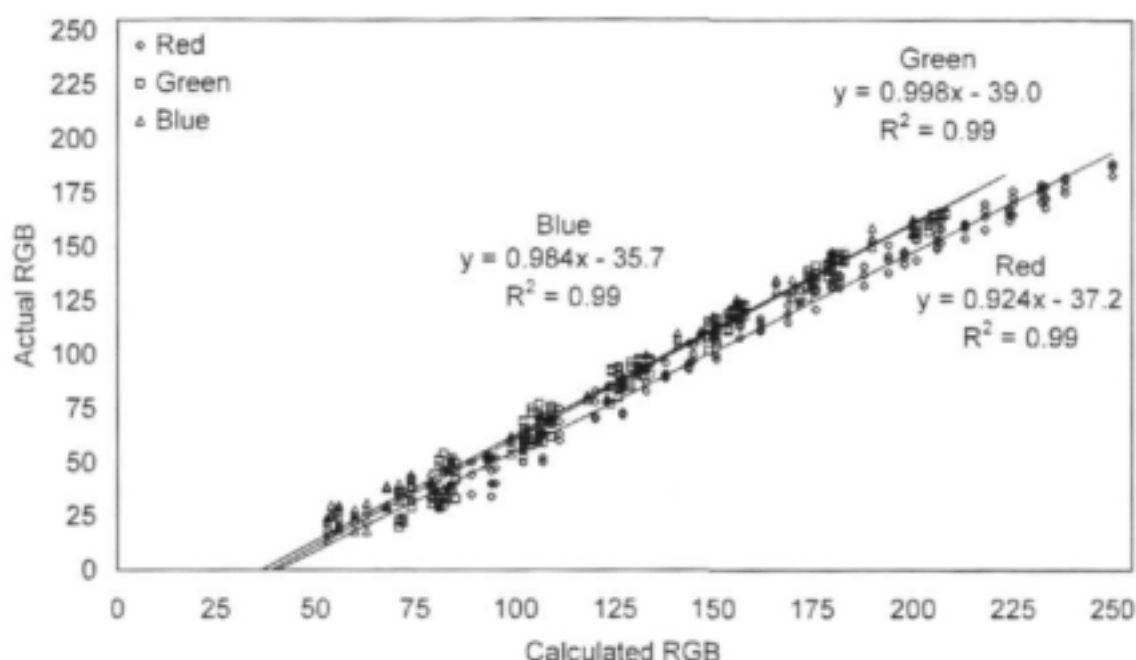


Figure 4.10 The relationship between calculated and photographed Red, Green and Blue values of the 7.5YR Munsell hue.

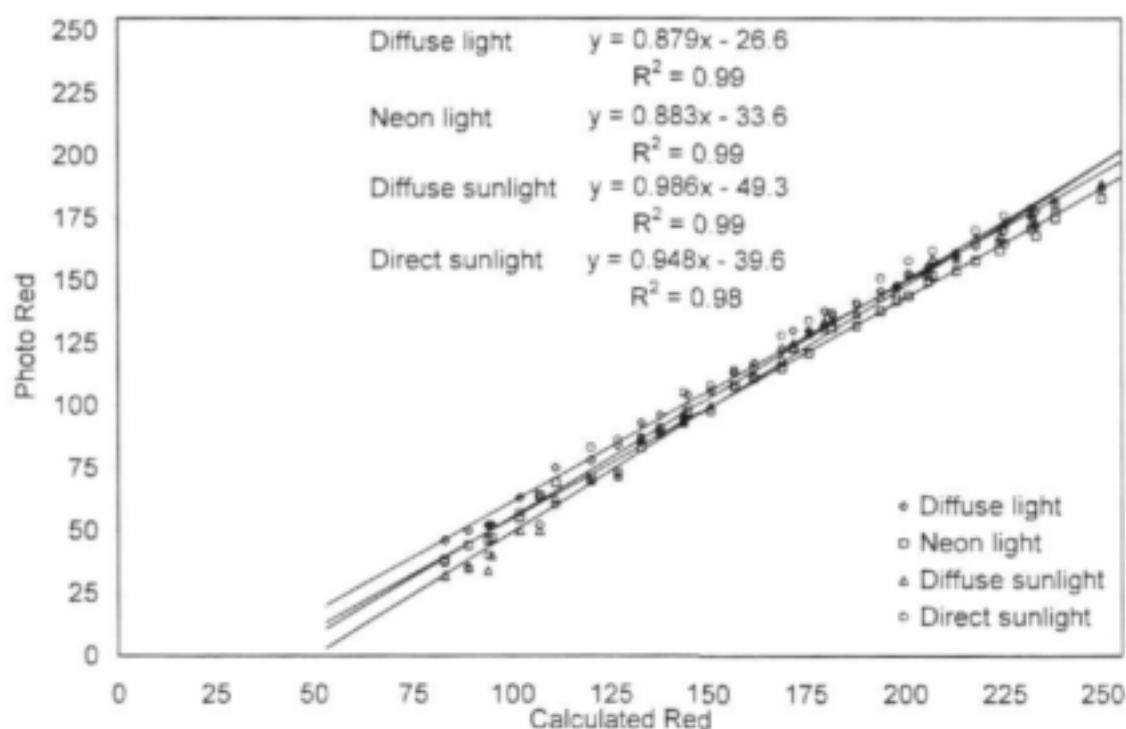


Figure 4.11 The relationship between calculated and photographed Red values of the 7.5YR Munsell hue, in different light sources.

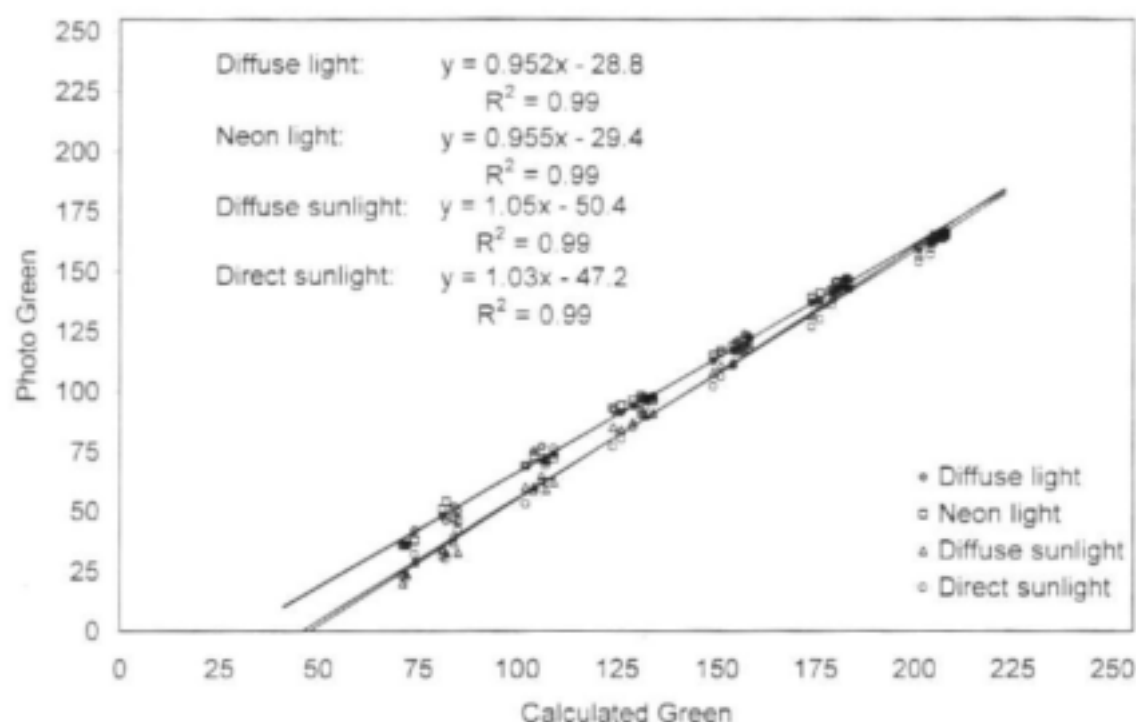


Figure 4.12 The relationship between calculated and photographed Green values of the 7.5YR Munsell hue, in different light sources.

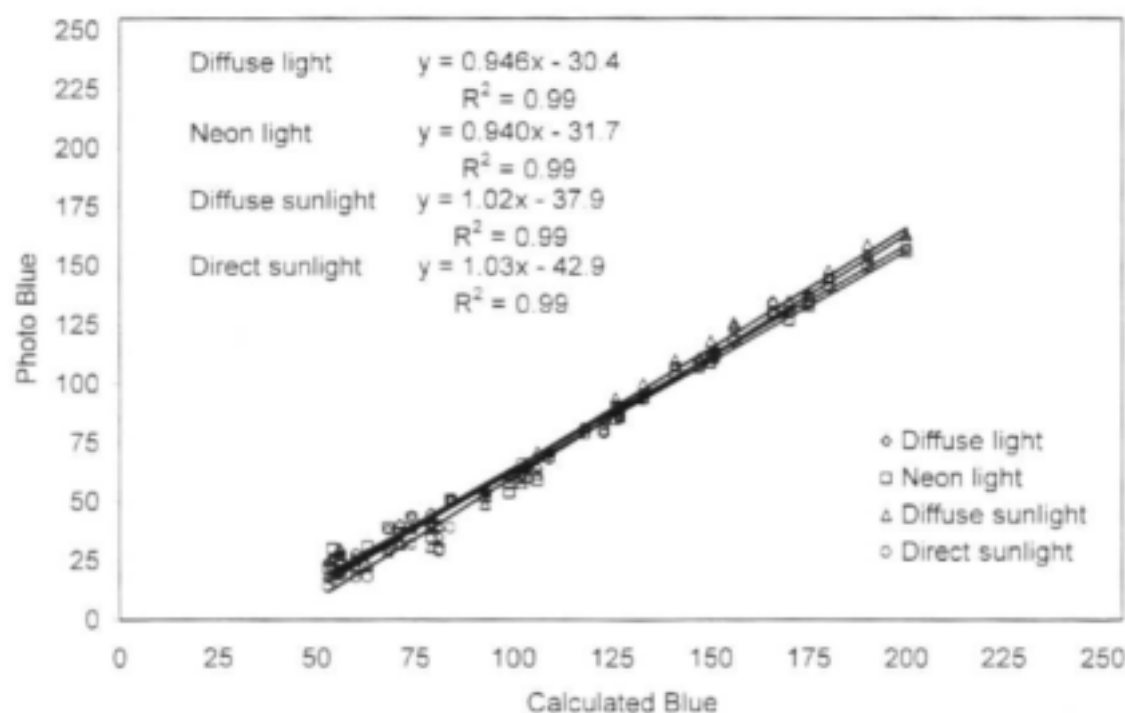


Figure 4.13 The relationship between calculated and photographed Blue values of the 7.5YR Munsell hue, in different light sources.

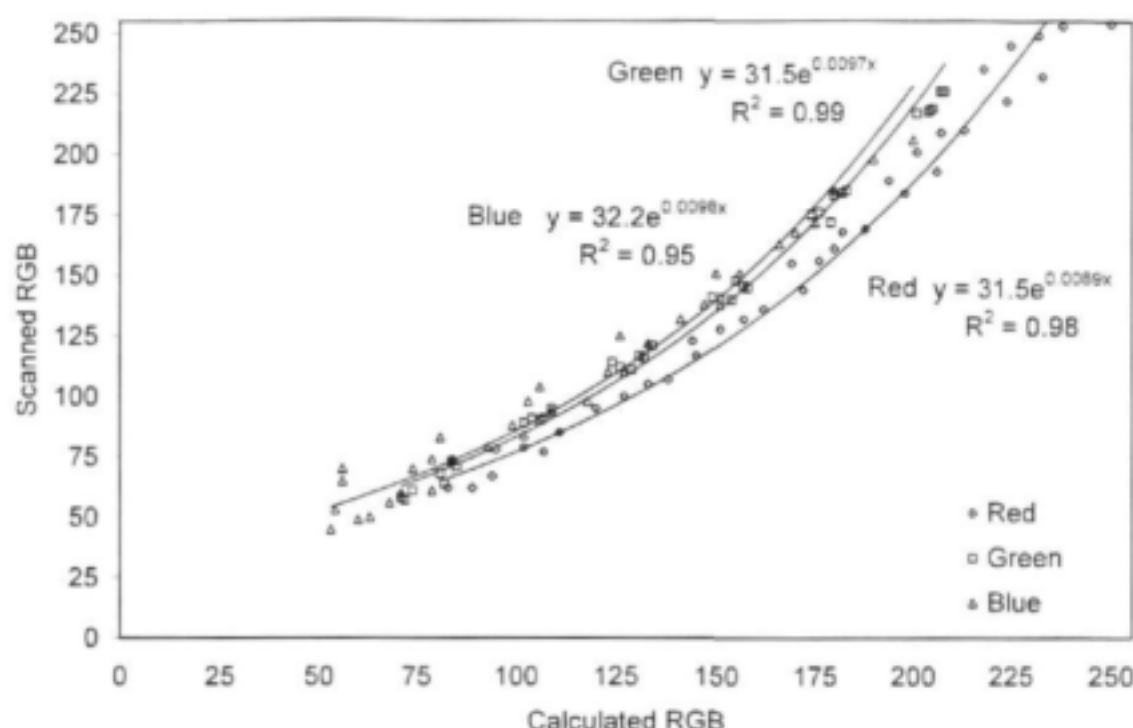


Figure 4.14 The relationship between calculated and scanned Red, Green and Blue values of the 7.5YR Munsell hue.

4.8 Interpretation of digital photographs

The biggest challenge in interpreting digital photographs is the difference in colour notation systems. As discussed previously, digital photographs are in RGB notation. This results in three values that need to be evaluated to determine the eventual colour. Furthermore, there exists an overlapping relationship between RGB and the diagnostic colour definitions of the Soil Classification Working Group (1991).

The distribution of diagnostic red, yellow-brown and grey colour classes as defined for the red apedal B, yellow-brown apedal B and E horizons (Soil Classification Working Group, 1991), plotted against Red and Green (RGB notation) are given in Figure 4.15, Figure 4.16 and Figure 4.17. Only Red and Green gave a meaningful differentiation between the diagnostic red, yellow-brown and grey classes. Two empirical lines were drawn to differentiate between grey and yellow and between yellow and red (Figure 4.15). The equations are listed below.

$$\text{Between grey and yellow: } \text{Green} = 0.88 * \text{Red} - 5 \quad (4.21)$$

$$\text{Between yellow and red: } \text{Green} = 0.79 * \text{Red} - 11 \quad (4.22)$$

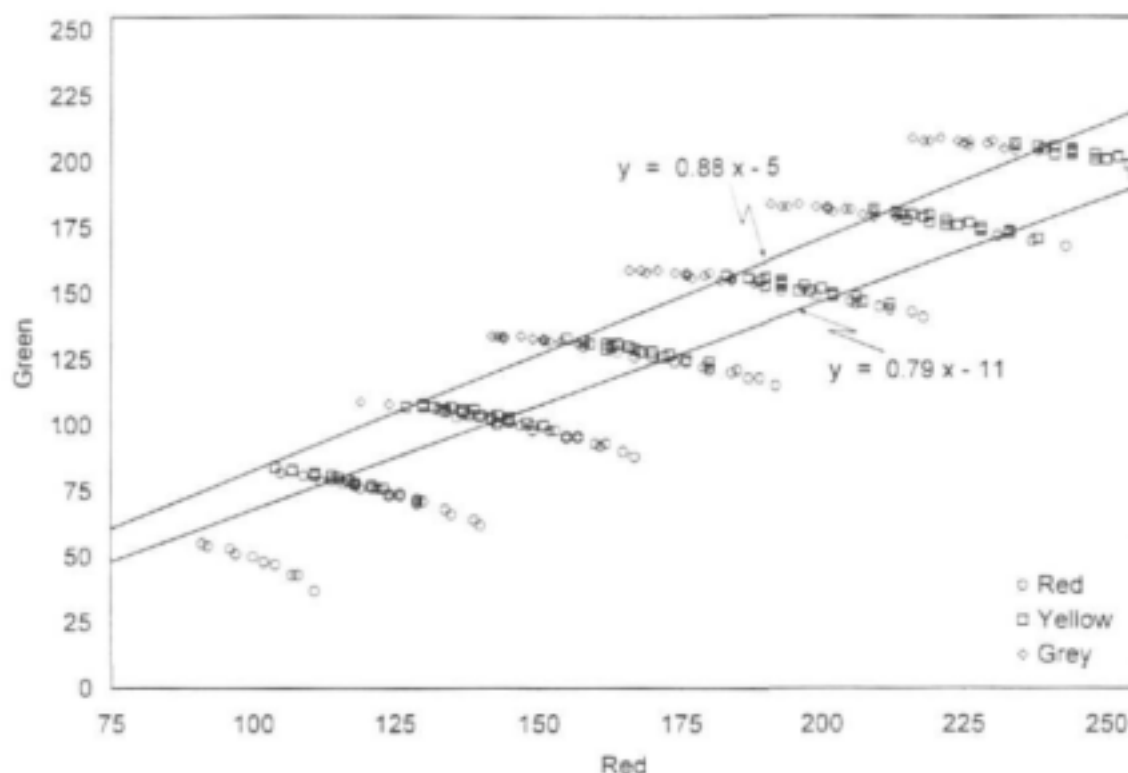


Figure 4.15 The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991), when plotted against Red and Green (RGB notation). The two lines are used to differentiate between the grey and yellow-brown and between yellow-brown and red colour classes.

Because there is not a 1:1 relationship between calculated RGB and photo RGB values (section 4.7), equations 4.23 and 4.24 can now be derived by substitution of equations 4.18 and 4.19 into equations 4.21 and 4.22:

$$\text{Photo Green} = 0.95 * \text{Photo Red} - 3.7 \quad (4.23)$$

$$\text{Photo Green} = 0.85 * \text{Photo Red} - 9.7 \quad (4.24)$$

Black was calculated as those cells which had Red and Green values less than 75. These included shaded areas as well as manganese mottles and concretions. This is unfortunate, but unavoidable at this stage. Black was eliminated to remove the effect of shadows on the photograph.

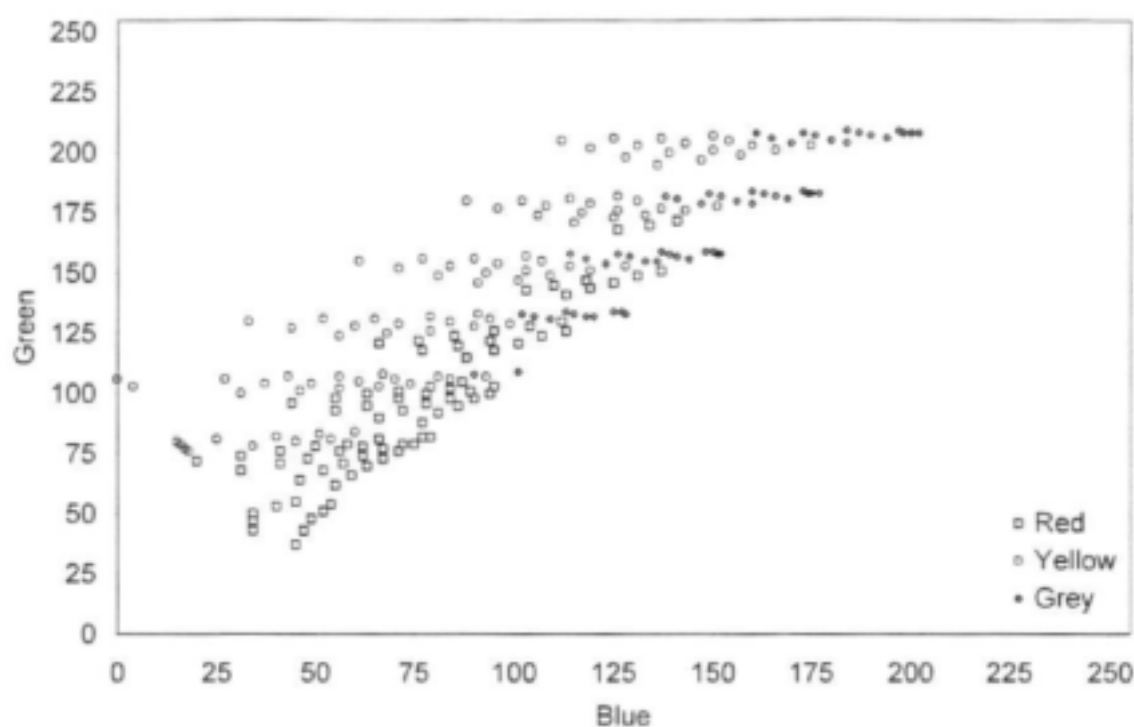


Figure 4.16 The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991) plotted against Blue and Green (RGB notation).

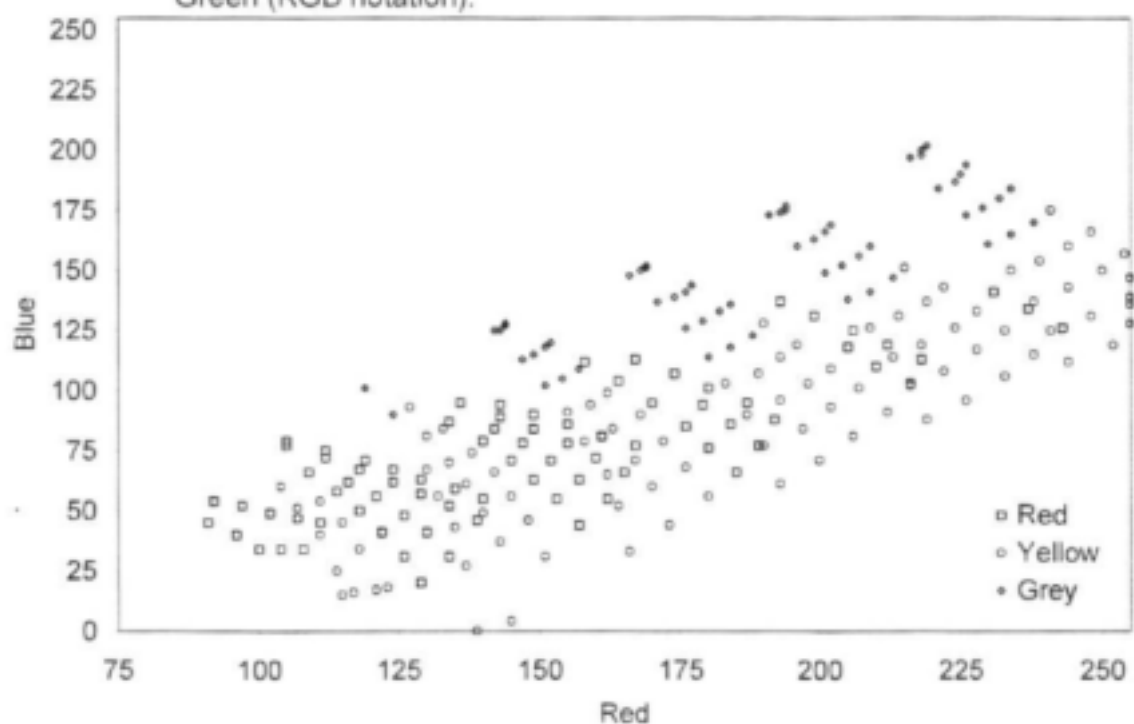


Figure 4.17 The distribution of diagnostic red, yellow-brown and grey colour classes (Soil Classification Working Group, 1991) plotted against Red and Blue (RGB notation).

Using equations 4.23 and 4.24 to classify RGB colours into diagnostic red, yellow-brown and grey classes resulted in an 18.7% (44 out of 235) miscalculation of the Munsell chips defined by the Soil Classification Working Group (1991). The classification is, however, a significant improvement over visual determinations, as human perceptions of colour can greatly differ (Melville & Atkinson, 1985). There was, however, little change in the amount classified into the diagnostic red, yellow-brown or grey classes (Table 4.8). Only photographs taken in the dry state were used in the calculations. The result of the application of equations 4.23 and 4.24 to classify a digital photograph of the soft plinthic B horizon of P229 is given in Figure 4.18.

Table 4.8 Number of Munsell chips defined as diagnostic red, yellow-brown and grey class (Soil Classification Working Group, 1991) by calculation from RGB-values

	Defined	Calculated
Red	82	81
Yellow	95	97
Grey	58	57
Total	235	235

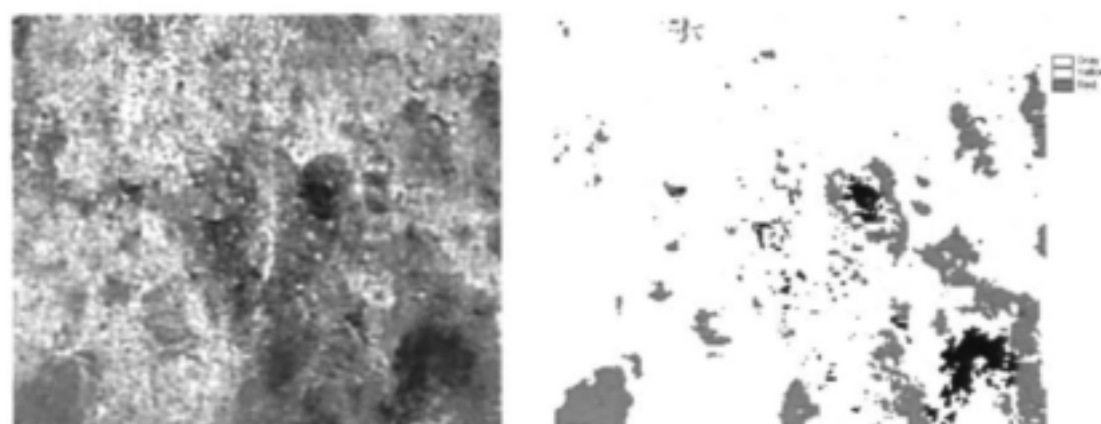


Figure 4.18 Result (right) of the application of equations 4.23 and 4.24 to classify a digital photograph (left) of a soft plinthic B horizon, using ArcView SpatialAnalyst (ESRI, 2000).

4.9 Summary

The study site was selected mainly due to the availability of a large quantity of relevant data. Methods used were kept standard, except for the development of the photograph interpretation procedure.

Daily soil water contents can be calculated, using the soil water balance equation and weekly neutron water meter measurements. This served to improve the estimations of the annual durations of water saturation.

These initial results show promise for the use of digital photographs to be used as a versatile, reproducible, objective, quantitative, reliable and unintuitive tool for the analysis and interpretation of soil colour. The technology to do this is not yet refined and requires substantial user input. It does, however, enable users to objectively analyse and interpret soil colour features. The following equations can be used to differentiate between diagnostic grey, yellow-brown and red:

$$\text{Photo Green} = 0.95 * \text{Photo Red} - 3.7 \quad (4.25)$$

$$\text{Photo Green} = 0.85 * \text{Photo Red} - 9.7 \quad (4.26)$$

Initial results indicated a 19 % misclassification, but represented a significant improvement when compared to visual methods. Camera and lighting differences as well as the relationship between colour notation systems should receive further investigation. Results of this technique, applied for each horizon, tested against published techniques and correlation with soil water regime are discussed in chapter 6.

5 SOIL PROFILE AND WATER REGIME CHARACTERIZATION

5.1 Introduction

The aim of this chapter is to describe the morphological, chemical and physical characteristics of the 28 soil profiles. The profile descriptions and analytical data for each profile are presented in Appendix A.

Soil redox reactions are driven by the presence or absence of water. In an aerated environment there is normally sufficient oxygen available to supply the respiratory demand of microorganisms. As the soil becomes increasingly more saturated, a point is reached where insufficient oxygen is available for microorganism respiration. Some microorganisms then utilize other electron acceptors (e.g. Mn^{4+} , Fe^{3+}) during respiration. This causes the reduction of these elements, their mobilization and redistribution, and an associated reduction in the redox potential of the soil. These elements have a marked and clearly visible influence on soil colour. The influence on soil colour is also dependant on their state of oxidation. The long term soil water regime is therefore important in any study aiming to relate soil water content to soil morphology. The aim of this chapter is to characterize the long term soil water contents of the profiles studied.

The soil was deemed to be sufficiently saturated, for redox reactions to occur, if the degree of saturation was above 0.7 of porosity. This fraction was chosen as a first approximation, based on the following observations. First, experience has shown that the drained upper limit (DUL) of a soil is generally around 0.6 of porosity (Hensley, 2002 personal communication). Since it is reasonable to expect that reduction reactions will only occur to a significant extent above DUL, the critical value for this study needs to be > 0.6 of porosity. Secondly, a study of the degree of water saturation *versus* time graphs in Appendix A provides the following evidence that 0.7 of porosity is a reasonable first approximation: (a) in horizons that are known to drain rapidly, e.g. the first two horizons in profiles 201 and 210, the water content only exceeds 0.7 of porosity for very short times and normally occur during periods of heavy rainfall; (b) the inflection point in the "water loss" (i.e. drainage + ET) curves of these rapidly drying horizons is always well below 0.7 of porosity, indicating that DUL is < 0.7 of porosity; (c) in horizons that are known to be very wet, e.g. G

horizons in profiles 204, 206, 208 and 209, the water content exceeds 0.7 of porosity for long periods.

A summary of mean $AD_{s>0.7}$, $F_{s>0.7}$ and $D_{s>0.7}$ values are given in Table 5.1. Annual values for $AD_{s>0.7}$, frequency of saturation above 0.7 of porosity ($F_{s>0.7}$) and annual and mean duration of saturation events above 0.7 of porosity ($D_{s>0.7}$) are given in Appendix B. Measuring depths frequently deviate from the original sequence of 150, 450, 750 mm etc. because the access tubes penetrate slightly deeper into the soil over time due to frequent readings with the fairly heavy neutron water meter.

Table 5.1 Mean annual duration of $s>0.7$ ($AD_{s>0.7}$), mean frequency of $s>0.7$ ($F_{s>0.7}$) and mean duration of $s>0.7$ events ($D_{s>0.7}$) for profiles 201 to 237, based on estimated daily soil water contents (section 4.6.6) from 01/07/1997 until 30/06/2003

Profile No.	Depth (mm)	Diagnostic horizon	$AD_{s>0.7}$ days year ⁻¹	$F_{s>0.7}$ events year ⁻¹	$D_{s>0.7}$ * days event ⁻¹
201	160	ot	4	1	3
	460	gs	24	5	5
	760	sp	83	3	32
202	190	ot	1	1	1
	490	ye	2	4	1
	790	ye	234	2	130
	1090	on	365	1	318
	1390	on	365	1	321
203	190	ot	1	1	1
	490	ne	5	4	1
	790	ne	6	5	1
	1090	on	135	4	33
	1390	on	100	6	17
204	220	ot/gs	94	3	29
	520	sp	124	3	37
	820	gh	251	2	143
	1120	gh	365	1	365
205	230	ot	31	6	5
	530	gs	47	5	10
	830	gh	244	3	87
	1130	gh	365	1	286
	1430	gh	365	1	334
206	170	ot	313	11	30
	470	gs	365	1	304
	770	gs	365	1	316
	1070	gh	365	1	365
207	180	ot	197	9	22
	480	sp	230	2	97

Profile No.	Depth (mm)	Diagnostic horizon	$AD_{S \geq 0.7}$ days year ⁻¹	$F_{S \geq 0.7}$ events year ⁻¹	$D_{S \geq 0.7}^*$ days event ⁻¹
208	205	ot	180	2	86
	505	gs	133	6	21
	805	gh	166	6	30
	1105	gh	365	1	365
	1405	gh	365	1	365
209	230	ot	213	5	43
	530	ot/gh	285	2	178
210	190	ot	1	1	1
	490	ot	46	6	8
	790	re	109	7	15
	1090	re	357	2	171
	1390	on	170	3	57
211	200	ot/gh	215	7	29
	500	gh	363	2	227
	800	gh	357	1	297
	1100	gh	365	1	365
212	200	ot	3	2	1
	500	ne	0	0	0
	800	ne	1	2	1
	1100	ne	1	2	1
	1400	on	4	6	1
213	180	ot	171	13	13
	480	ot	218	7	32
	780	gh	205	5	43
	1080	gh	323	2	209
	1380	gh	358	2	236
218	200	ot	201	5	44
	500	gh	292	7	40
	800	gh	360	2	236
	1100	gh	365	1	365
	1400	gh	365	1	365
220	175	ot	81	10	8
	475	ot	152	16	10
	775	re	0	0	0
	1075	on	7	1	11
	1375	on	300	4	67
221	140	ot	99	11	9
	440	re	1	1	1
	740	re	0	0	2
	1040	re	11	1	17
	1340	on	10	1	13
222	180	ot	171	11	15
	480	ne	80	7	12
	780	ne	164	5	34
	1080	on	365	1	334
225	220	ot	38	9	4
	520	gs	155	3	49
	820	gs	121	2	49
	1120	sp	220	3	73
	1420	so	255	2	149

Profile No.	Depth (mm)	Diagnostic horizon	AD ₅₋₁₀₋₇ days year ⁻¹	F ₅₋₁₀₋₇ events year ⁻¹	D ₅₋₁₀₋₇ * days event ⁻¹
226	190	ot	268	4	71
	490	gs	360	2	170
	790	gh	352	1	253
	1090	gh	365	1	365
	1390	gh	365	1	365
229	225	ot	234	3	77
	525	ot/gs	359	2	215
	825	gs	362	2	234
	1125	gh	365	1	365
230	150	ot	196	11	18
	450	sp	82	5	18
	750	gh	312	2	131
	1050	gh	365	1	365
	1350	gh	365	1	365
231	150	ot	191	7	28
	450	sp	215	5	40
	750	gh	215	5	46
	1050	gh	365	1	365
	1350	gh	365	1	365
232	230	ot	87	6	15
	530	gh	165	5	36
	830	gh	203	3	65
	1130	gh	365	1	286
	1430	gh	365	1	335
233	190	ot	10	3	3
	490	ye	20	6	3
	790	on	365	1	334
	1090	on	365	1	365
	1390	on	365	1	365
234	210	ot	24	7	3
	510	ot	26	7	4
	810	ye	44	9	5
	1110	sp	287	2	155
	1410	on	322	1	229
235	185	ot	178	6	28
	485	ot	365	2	232
	785	ot	365	1	287
	1085	gh	365	1	365
	1385	gh	365	1	365
236	190	ot	156	4	36
	490	ot	266	3	88
	790	gh	365	1	323
	1090	gh	365	1	365
	1390	gh	365	1	365
237	210	ot	53	8	7
	510	sp	100	2	40
	810	sp	196	2	97
	1110	on	365	1	333
	1410	on	365	1	365

* D₅₋₁₀₋₇ (days event⁻¹) was calculated as (days year⁻¹) / F₅₋₁₀₋₇ (events year⁻¹). Because these values represent averages calculated over six years and have been rounded to whole numbers, F₅₋₁₀₋₇ x D₅₋₁₀₋₇ does not always equal AD₅₋₁₀₋₇.

5.2 P201 (Longlands 2000)

5.2.1 Morphology

The profile is situated in an upper midslope position, with a slope of 10 % (Figure 3.3). It has a coarse sandy loam texture throughout the profile. The clay content increases and then decreases from 9 – 12 – 13 – 11 % from the A to the E, B and C horizons. The profile description and analytical data for this profile are given in Appendix A, Tables 1 and 2. The profile can be classified as Albic Hypodistric Arenosol (ferric) (FAO, 1998b) or Aeric Endoaquents (Soil Survey Staff, 1999). The brown (10YR4/4) orthic A horizon (0–430 mm) overlies slightly lighter, redder dull orange (7.5YR6/4) E (430–730 mm) and soft plinthic B horizons (730–980 mm) on light yellow orange (10YR8/4) to light brownish grey (7.5YR 7/2) to brown (10YR4/8) saprolite.

5.2.2 Chemical properties

pH_{Water} and pH_{KCl} are somewhat constant throughout the profile, decreasing slightly from 4.73 and 4.54 in the topsoil to 4.14 and 4.52 in the bottom of the profile (Figure 5.1). pH_{Water} and pH_{KCl} differ only slightly from one another, indicating very little reserve acidity (Brady & Weil, 1996) in this profile.

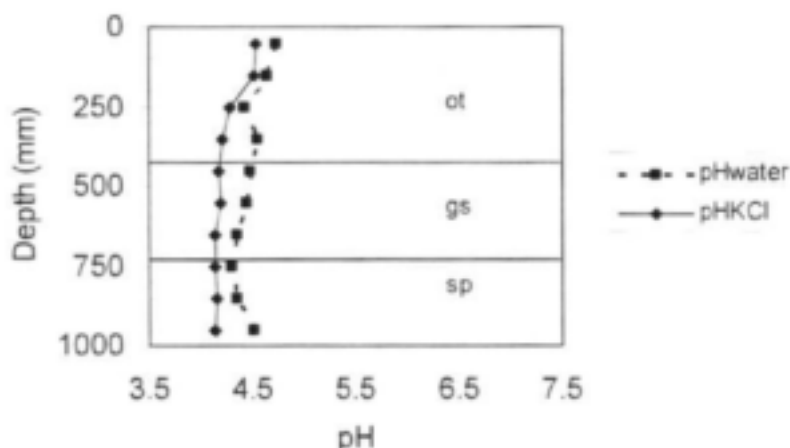


Figure 5.1 pH_{Water} and pH_{KCl} for P201 (Longlands 2000).

Base saturation (BS) decreases from 44 % in the topsoil to 15 % in the E and then increases to 25 % in the lower soft plinthic B horizon (Figure 5.2). The decrease is associated with a continuous decrease in sum of bases (S) with depth in the profile.

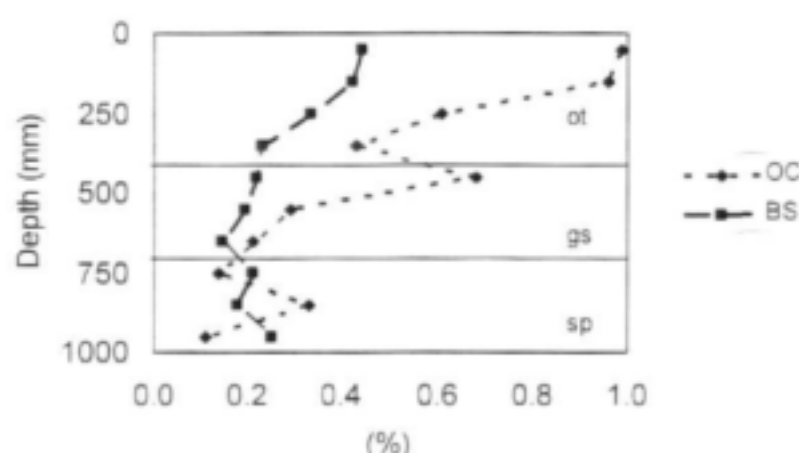


Figure 5.2 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P201 (Longlands).

Total Fe content (CBD extractable Fe) is fairly constant at 4 510 to 6 875 mg kg^{-1} throughout the profile (Figure 5.3). The peak occurs in the lower part of the E horizon, just above the soft plinthic B. It therefore seems that maximum Fe accumulation in the soil matrix (excluding concretions >2 mm), is not in the soft plinthic B, but rather just above it (Figure 5.3).

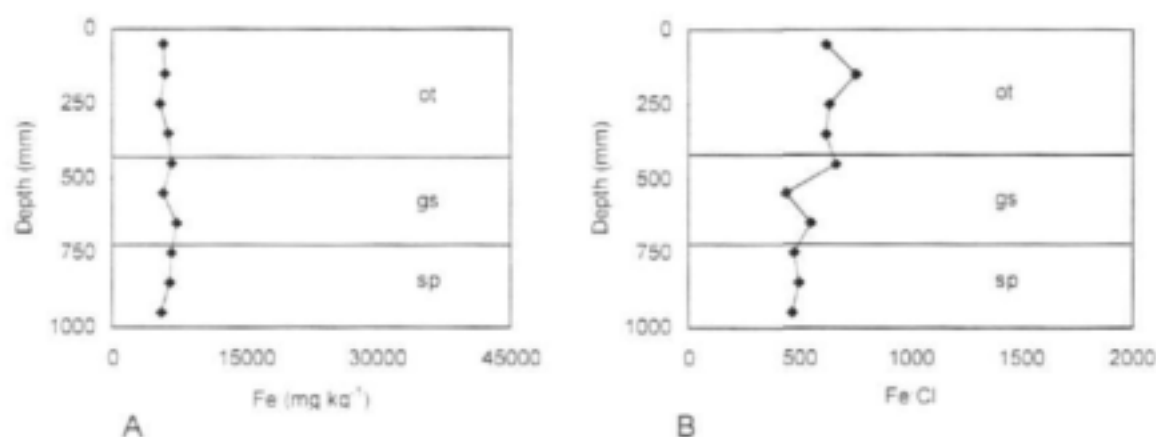


Figure 5.3 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P201 (Longlands 2000).

5.2.3 Physical properties

There is a systematic increase in clay content from 7 to 14 %, with depth throughout the profile (Figure 5.4). A slight decrease occurs at 100 to 300 mm in the A horizon. If a uniform parent material is assumed more clay removal has taken place from the A than from the E, or luviation played an important role in the genesis of the profile.

This hypothesis supports the borderline colour of the E horizon as being a borderline E / yellow-brown apedal B horizon. There is a marked decrease in silt content at the boundary between the A and the E horizon. This probably indicates a lithological discontinuity, as the sand content increases correspondingly.

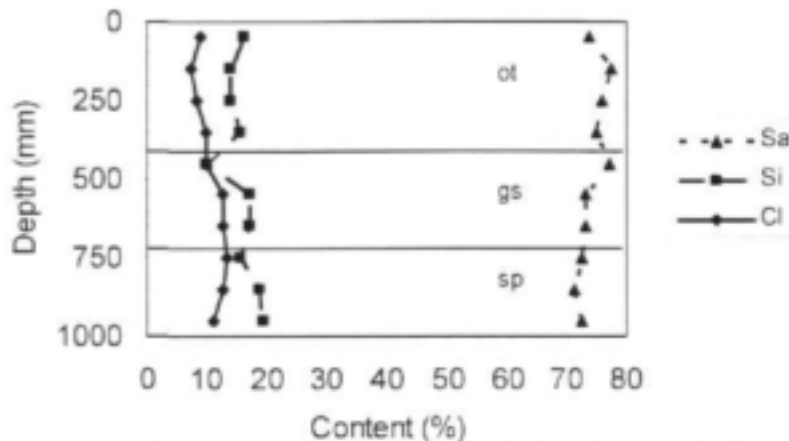


Figure 5.4 Particle size distribution of the fine earth fraction of P201 (Longlands 2000).

5.2.4 Hydrology

Mean $AD_{s>0.7}$ values increase with depth (Figure 5.5). On average, for the E horizon (430–730 mm) $s>0.7$ events occurred 5 times during the year, with each event lasting 5 days. The mean $AD_{s>0.7}$ value is 24 days year⁻¹. It ranged from 0 days in 2002/03 to 142 days in 1999/2000, when the highest annual rainfall during the measuring period was recorded.

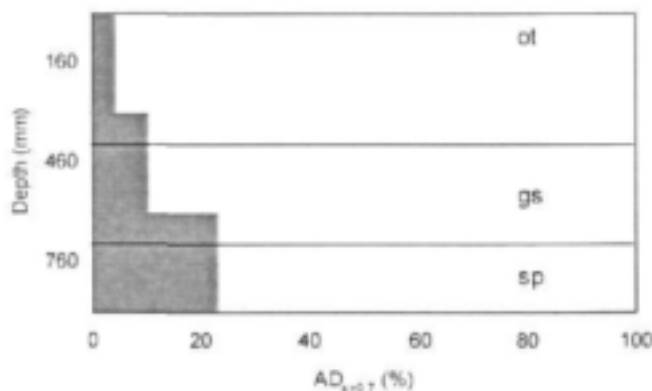


Figure 5.5 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the three measuring depths at P201 (Longlands 2000).

In the soft plinthic B horizon (730–980 mm) $s > 0.7$ events were less frequent (3 times year⁻¹), but for a much longer total mean duration of 32 days per event. The total duration of the $s > 0.7$ is therefore longer (83 days) than in the E horizon (24 days). The longer $s > 0.7$ events in the soft plinthic B can be expected, given the presence of the underlying relatively impermeable saprolite, which impedes further vertical drainage. Although no water measurements are available for the saprolite horizon, it is expected that the horizon is saturated for longer periods than the soft plinthic B horizon.

The results indicate adequate hydraulic conductivity in the profile. The underlying saprolite, however, forms an impervious layer, resulting in accumulation of water in the overlying horizons, resulting in redox conditions, leading to the formation of Fe mottles. Rapid lateral drainage in the E horizon results in these being fewer and less prominent than in the underlying horizon. Slower lateral drainage from the soft plinthic B horizon results in increased saturation and reduction, leading to the redistribution of Fe and Mn and the formation of many prominent Fe oxide mottles.

5.3 P202 (Pinedene 1100)

5.3.1 Morphology

The profile is situated in an upper midslope position, with a slope of 17 % (Figure 3.3). It has a medium sandy loam texture in the A and B horizons, with a fine sandy loam texture in the two C horizons. The clay content increases systematically (10 – 16 – 20 – 25 %) down the profile. The profile description and analytical data for this profile are given in Appendix A, Tables 3 and 4. The profile can be classified as Gleyic Orthi-distic Cambisol (FAO, 1998b) or Aquic Ustipsamments (Soil Survey Staff, 1999). The orthic A horizon (0–400 mm) has a dull yellowish brown (10YR4/3) colour. The yellow-brown apedal B horizon (400–820 mm) is brighter and lighter (bright brown, 7.5YR5/6) in colour. The unspecified material with signs of wetness is light grey, 10YR8/2 in the C1 (820–990 mm) and pinkish white (2.5YR8/2) in the C2 (990–1500 mm). Soil colour therefore becomes paler (value increases) with depth.

5.3.2 Chemical properties

pH_{Water} and pH_{KCl} are constant throughout the profile (Figure 5.6). pH_{Water} ranges between 4.44 and 4.67, while pH_{KCl} ranges between 4.00 and 4.25. The difference

between pH_{Water} and pH_{KCl} (almost half a unit) indicates more residual acidity in this profile, than was the case with P201 (Longlands 2000).

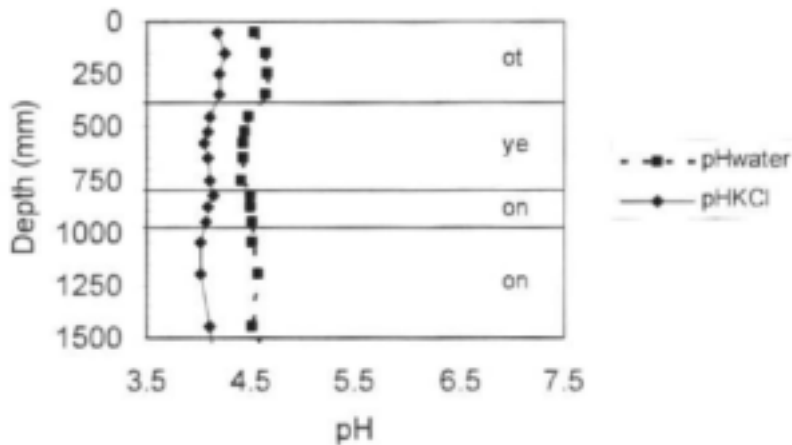


Figure 5.6 pH_{Water} and pH_{KCl} for P202 (Pinedene 1100).

Base saturation increases from 35 % in the A horizon to 74 % in the lower unspecified material with signs of wetness (Figure 5.7). This is associated with an increase in basic cation concentration that more or less follows the increase in CEC_{soil} and a small increase in the clay content.

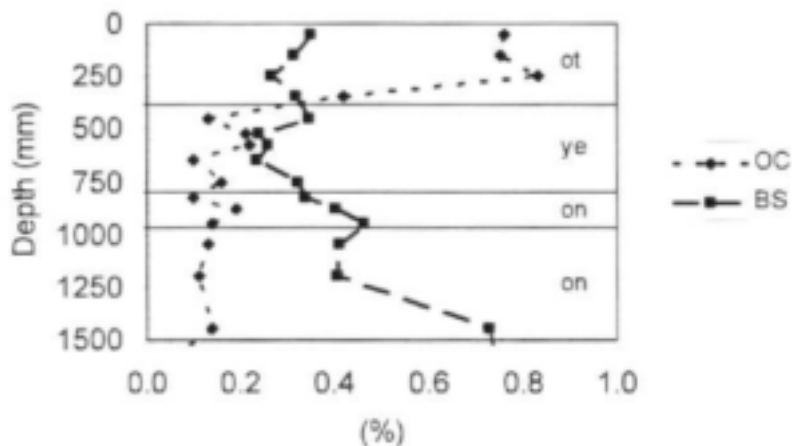


Figure 5.7 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P202 (Pinedene 1100).

Total Fe content increases from $4\,372\text{ mg kg}^{-1}$ in the A horizon to $7\,045\text{ mg kg}^{-1}$ in the B horizon (Figure 5.8). It then increases sharply to $15\,600\text{ mg kg}^{-1}$ in the upper unspecified material with signs of wetness, before dropping to $6\,347\text{ mg kg}^{-1}$ in the

lower half. It is therefore an indication of active Fe accumulation in the upper unspecified material with signs of wetness (Figure 5.8).

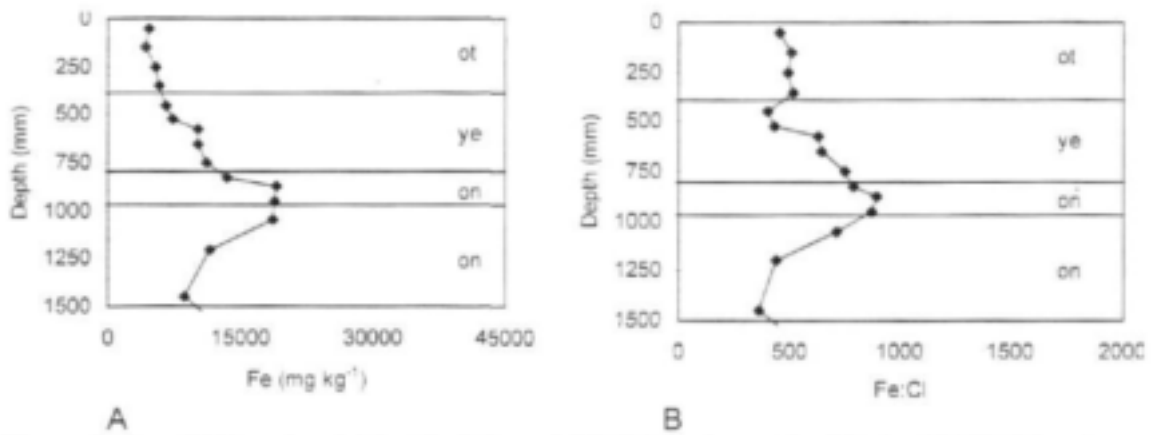


Figure 5.8 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P202 (Pinedene 1100).

5.3.3 Physical properties

Clay content (Figure 5.9) in the A (10 %) is much less than in the B horizon (16 %). The B horizon qualifies as a luvic B. The clay content increases further from the B to the C1 (20 %) and C2 (25 %) horizons. There is also a marked increase in silt content from the B to the C1 horizon. The increase in clay and silt content probably results in decreased hydraulic conductivity, promoting reducing conditions.

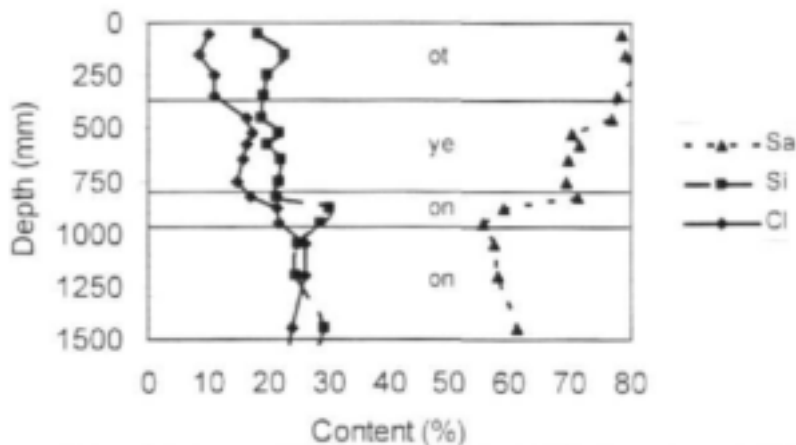


Figure 5.9 Texture of the fine earth in P202 (Pinedene 1100).

5.3.4 Hydrology

This profile is characterized by a very dry orthic A horizon, dry to variable degree of saturation in the yellow-brown apedal B, and almost constant $s > 0.7$ conditions in the

unspecified material with signs of wetness (Figure 5.10). Very few $s > 0.7$ events were recorded in the A horizon. It therefore seems that short durations (< 7 days) of $s > 0.7$ events are responsible for the grey colour in the orthic A horizon. This is probably as a result of the high organic carbon content, which gave rise to reduced conditions, even at short periods of wetness. Two NWM measuring depths (450 mm and 750 mm) are located within the yellow-brown apedal B horizon. At 450 mm the mean $AD_{s>0.7}$ value is 2 days year^{-1} .

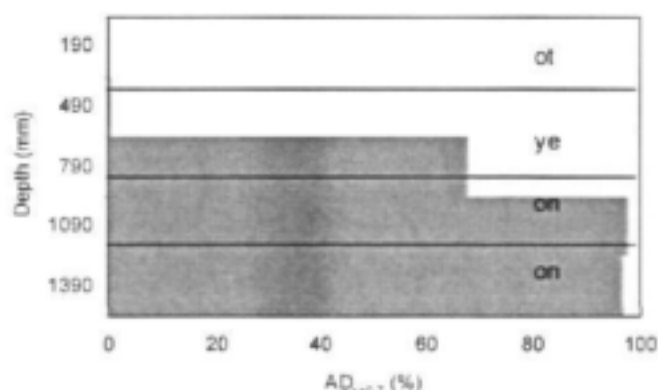


Figure 5.10 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the six measuring depths at P202 (Pinedene 1100).

At 750 mm the yellow-brown apedal B horizon had a mean $AD_{s>0.7}$ value of 234 days year^{-1} . The $AD_{s>0.7}$ varied from 194 days in 1999/2000 to 361 days in 2000/01. The frequency of $s > 0.7$ events is therefore low (2 times year^{-1}). One third of the NWM measuring volume at 750 mm lies within the upper part of the C1 horizon. It can therefore be expected that water content will be over estimated as far as the yellow-brown apedal B is concerned; mean $AD_{s>0.7}$ also corresponds much better to that of the underlying C horizons. If the measurement is assumed to be correct it would indicate that horizons situated deeper in the soil profile (less organic matter and possibly less micro organisms) can be saturated for longer periods before it impacts on the morphology. This is possibly due to the lower organic carbon contents in these horizons, providing less substrate for microorganisms and therefore resulting in less reduced conditions, even at longer periods of $AD_{s>0.7}$.

In the unspecified material with signs of wetness (1 050, 1 350 and 1 650 mm reading depths) $s > 0.7$ was almost continuous, giving a mean $AD_{s>0.7}$ value of 365 days year^{-1} , and mean $F_{s>0.7}$ of less than once per year.

This profile is characterized by an almost continuous $s > 0.7$ in the horizons deeper than 600 mm. There are no $s > 0.7$ events in the A, and minimal (2 days year^{-1}) in the B1 horizon. The increase in $AD_{s>0.7}$ corresponds to an increase in Munsell colour value, clay content and a decrease in the medium and fine sand fractions. It is postulated that water drains fast laterally above the C horizons and that the C horizons drain very slowly due to their high clay content and high bulk density. This is supported by the pH and base saturation that is lower in the yellow-brown apedal B horizon and higher in the unspecified material with signs of wetness.

5.4 P203 (Tukulu 2100)

5.4.1 Morphology

The profile is situated in an upper midslope position, with a slope of 14 % (Figure 3.3). It has a coarse sandy loam texture, except for the B horizon which has a medium sandy loam texture. The clay content increases (10 – 13 – 14 – 28 %) down the profile. The profile description and analytical data for this profile are given in Appendix A, Tables 5 and 6. The profile can be classified as Gleyic Hyperdistric Arenosol (FAO, 1998b) or Aquic Ustipsamments (Soil Survey Staff, 1999). The orthic A (0–380 mm) has a dull yellowish brown (10YR5/3) colour. The neocutanic B horizon and the upper unspecified material with signs of wetness (C1) have a dull orange (7.5YR7/4) colour. The lower unspecified material with signs of wetness (C2) has a light grey (7.5YR8/2) colour.

5.4.2 Chemical properties

pH_{Water} increases slightly from 4.25 in the topsoil to 4.82 in the subsoil, while pH_{KCl} increases from 4.06 to 4.17 (Figure 5.11). The increase in pH as well as the increased difference between pH_{Water} and pH_{KCl} is most probably linked to the increase in base saturation down the profile. The mean pH in this profile is similar to that in the previous two profiles.

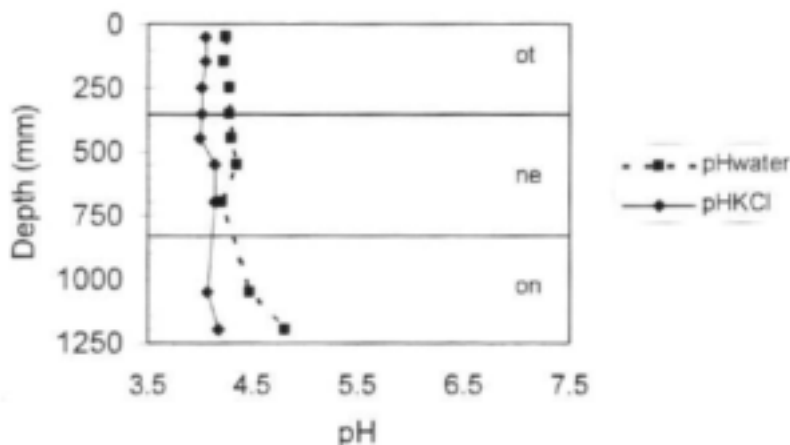


Figure 5.11 pH_{Water} and pH_{KCl} for P203 (Tukulu 2100).

Base saturation increases from 23 % in the upper A horizon to 41 % in the lower A horizon (Figure 5.12). It then decreases to 19 % in the B horizon and increases to 69 % in the lower unspecified material with signs of wetness. This pattern is determined by the CEC_{soil} distribution in the profile, rather than the sum of basic cations which is constant at approximately $1.0 \text{ cmol}_c \text{ kg}^{-1}$ in the profile, only increasing to 4.1 in the lower unspecified material with signs of wetness (Figure 5.18).

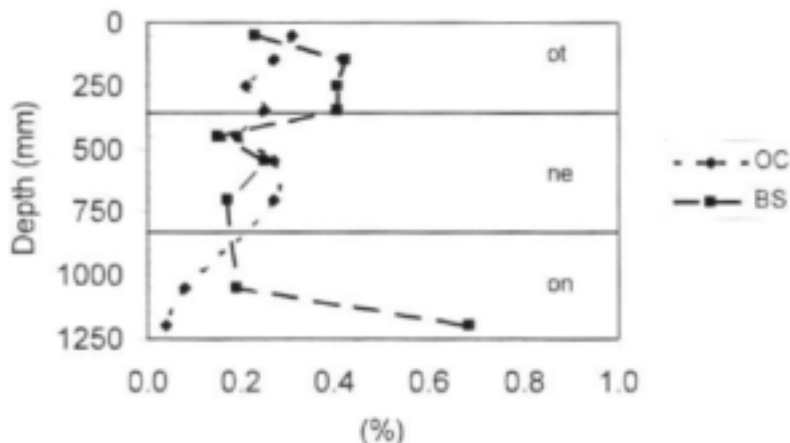


Figure 5.12 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P203 (Tukulu 2100).

Total Fe content increases from $4\,839 \text{ mg kg}^{-1}$ in the topsoil to $8\,100 \text{ mg kg}^{-1}$ in the subsoil (Figure 5.13). There is a slight accumulation of Fe in the middle of the neocutanic B horizon, indicating some plinthisation in the horizon (Figure 5.13).

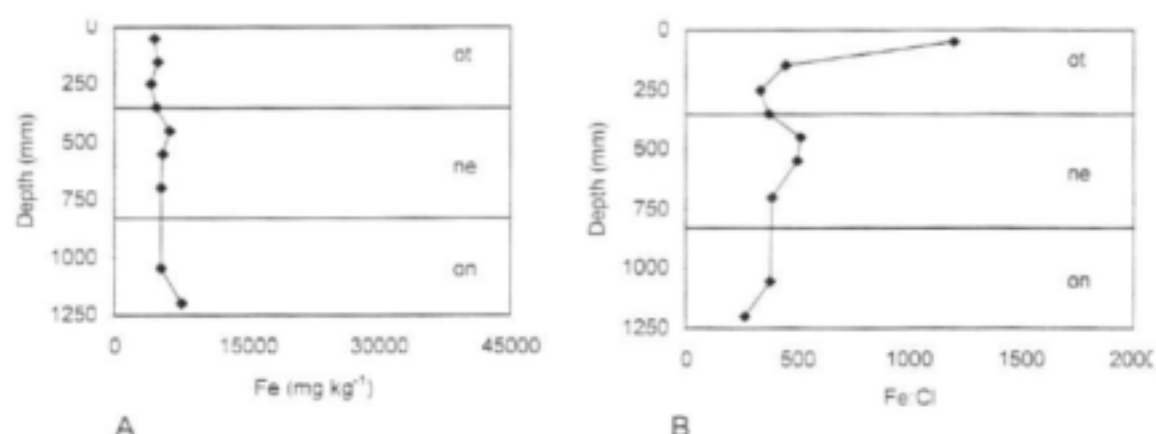


Figure 5.13 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P203 (Tukulu 2100).

5.4.3 Physical properties

The clay content stays fairly constant ($\pm 11\%$) throughout the A and B horizon, except for the very low (3.7 %) clay contents over the first 100 mm (Figure 5.14). This is probably due to the desert pavement-like feature observed on the surface of the first four profiles, situated on the upper Elliott sandstone shelf. The clay content then sharply increases to the C, which has 28 % clay. There is a marked decrease in silt content at 350 mm, corresponding with an increase in the sand (primarily medium and coarse sand) content. This might indicate a lithological discontinuity.

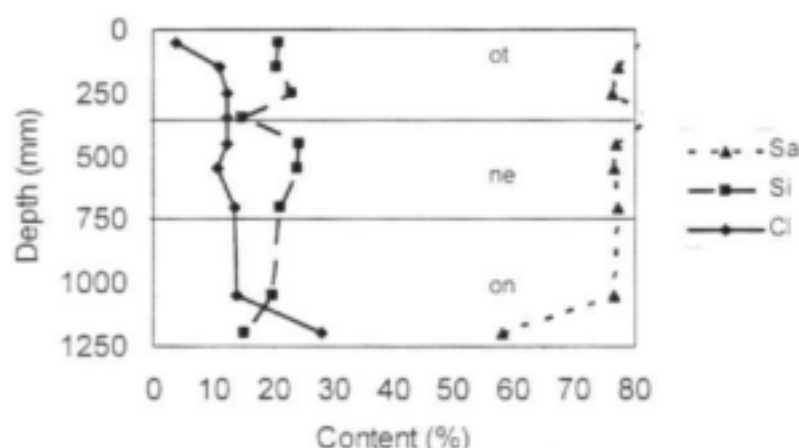


Figure 5.14 Texture of the fine earth in P203 (Tukulu 2100).

5.4.4 Hydrology

An average of one $s > 0.7$ event per year (Figure 5.15) were recorded at the orthic A horizon (190 mm), and four events per year at the orthic A / neocutanic B transition (490 mm). At 790 mm (in the middle of the neocutanic B) the mean $AD_{s>0.7}$ value

was 6 days year⁻¹. The $AD_{s>0.7}$ values ranged from 1 day in 1997/98 to 20 days in 1999/2000. These occurred as 5 $s>0.7$ events, lasting 1 day each. In the unspecified material with signs of wetness at 1 090 mm the mean $AD_{s>0.7}$ value was 135 days year⁻¹. These took place in 4 $s>0.7$ events, and lasted 33 days each. In the unspecified material with signs of wetness (1 390 mm) the mean $AD_{s>0.7}$ value was 100 days year⁻¹.

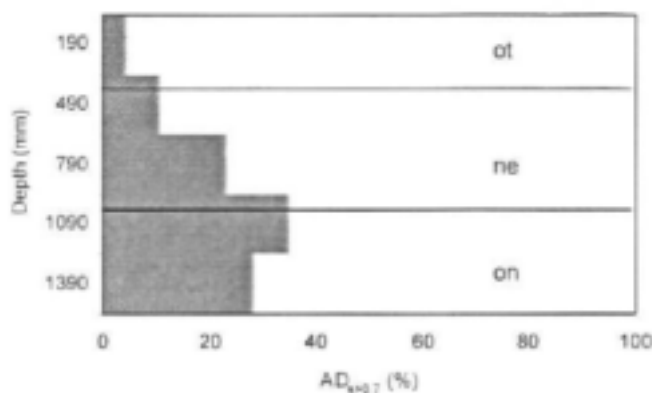


Figure 5.15 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the six measuring depths at P203 (Tukulu 2100).

The high clay content and high bulk density in the C2 probably restricted vertical water movement, causing a high $AD_{s>0.7}$ value in the C1 horizon. This wetness probably extended into the overlying neocutanic B horizon during wet spells. The result of extended $s > 0.7$ events in the C1 horizon is evidenced by the occurrence of many Fe oxide mottles.

5.5 P204 (Longlands 2000)

5.5.1 Morphology

The profile is situated in a footslope position, with a slope of 8 % (Figure 3.3). The orthic A horizon has a loamy medium sand texture, and the rest of the profile a fine sandy loam texture, except for the G horizon which is a coarse sandy loam. The clay content increases (8 – 10 – 14 – 30 %) down the profile. The profile description and analytical data for this profile are given in Appendix A, Tables 7 and 8. The profile can be classified as Stagnic Hyperdistric Gleysol (ferric) (FAO, 1998b) or Aeric Albaqualfs (Soil Survey Staff, 1999). A greyish brown (7.5YR6/2) orthic A horizon (0–140 mm) overlies an orange (7.5YR7/5) E (140–300 mm) on a light grey

(10YR8/2) soft plinthic B (300–470 mm) on a light grey (10YR8/2) G horizon (470–1 000 mm).

5.5.2 Chemical properties

pH_{Water} is almost one unit higher in this profile than in the previous three profiles. It increases from 4.96 in the topsoil to 6.06 in the upper E horizon and then decreases to 5.45 in the subsoil (Figure 5.16). A somewhat constant pH_{KCl} , varying between 4.36 and 4.44, characterizes this profile.

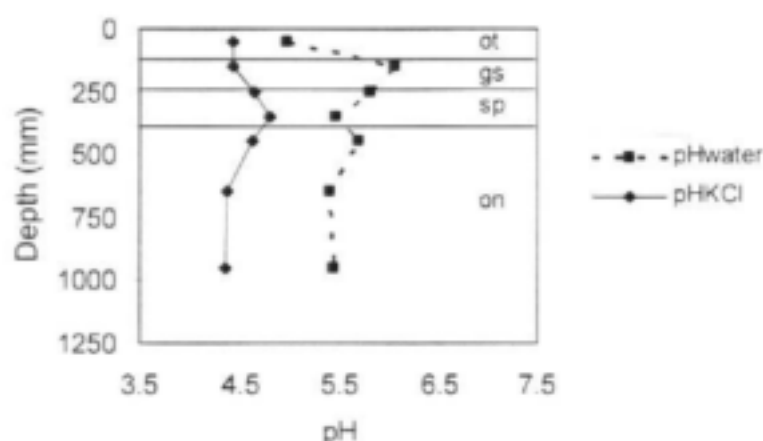


Figure 5.16 pH_{Water} and pH_{KCl} for P204 (Longlands 2000).

Base saturation increases with the CEC, but is lower in the E and soft plinthic B horizons than in the A (Figure 5.17). This supports the classification of the E horizon.

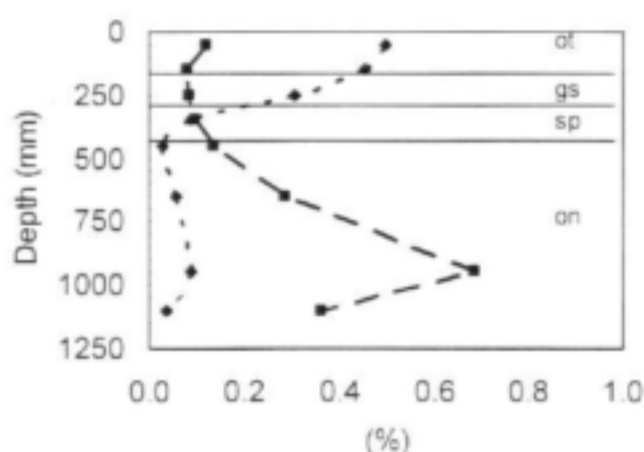


Figure 5.17 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P204 (Longlands 2000).

Total Fe content increases from 3 360 mg kg⁻¹ in the A horizon to 7 145 mg kg⁻¹ in the E, 12 600 mg kg⁻¹ in the soft plinthic B and then decreases to 3 363 mg kg⁻¹ in the underlying non-diagnostic unspecified material with signs of wetness (Figure 5.18). The high total Fe content and Fe : clay ratio in the soft plinthic B is a clear indication of Fe accumulation in this horizon.

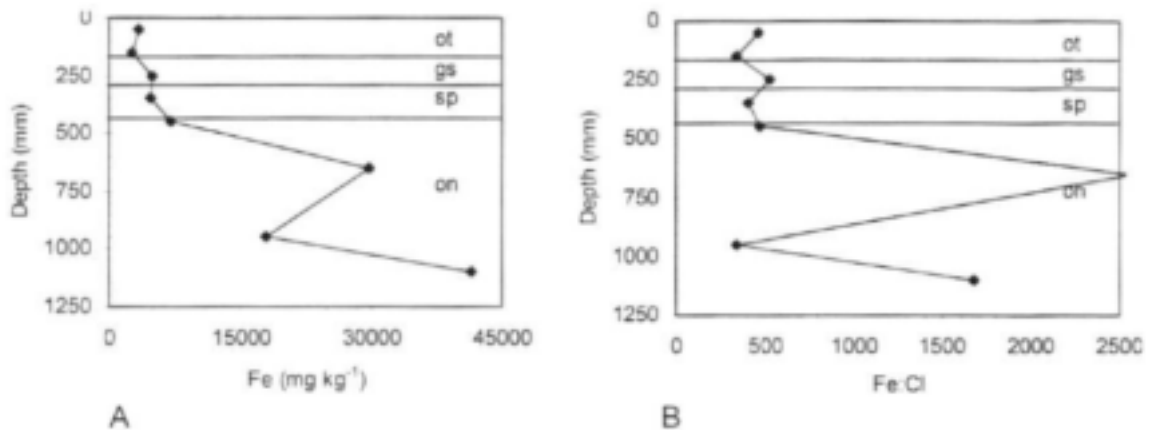


Figure 5.18 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P204 (Longlands 2000).

5.5.3 Physical properties

The clay content increases steadily from the A (8 %), through the E (10 %) to the soft plinthic B (14 %) horizon (Figure 5.19). This indicates eluviation of clay from the A and E horizons to the soft plinthic B horizon, and therefore supports the classification of an E horizon. The sharp decrease in clay from the soft plinthic B to the upper part of the C horizon is probably due to ferrollysis, which leads to clay degradation. This is supported by the observed silans in the upper C horizon. From there, the clay content rises sharply to 52 % at a depth of 500 to 1 100 mm, and then decreases to 25 % below 1 100 mm. The sharp increase in clay content could be due to eluviation from the upper horizons and upslope profiles, while the decrease is probably due to lack of weathering.

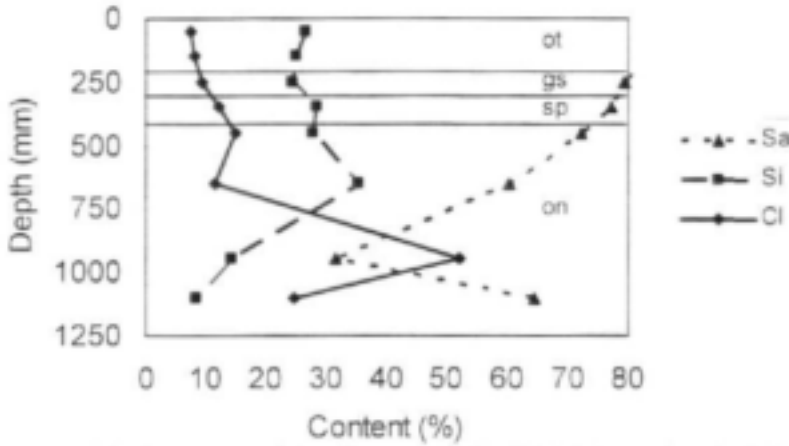


Figure 5.19 Texture of the fine earth in P204 (Longlands 2000).

5.5.4 Hydrology

Mean $AD_{s>0.7}$ values increase with depth (Figure 5.20), similar but higher than that observed in P201 (Longlands). At the orthic A/E horizon transition (220 mm) the mean $AD_{s>0.7}$ value is 94 days year⁻¹, with 3 $s>0.7$ events per year, each lasting 29 days. It seemed that this is the minimum duration of an $s>0.7$ event that would result in rusty root channels in orthic A horizons. At the soft plinthic B/G horizon transition (520 mm) the mean $AD_{s>0.7}$ value is 124 days year⁻¹, with 3 $s>0.7$ events per year, each lasting 37 days. For the unspecified material with signs of wetness (820 mm) the mean $AD_{s>0.7}$ value was 251 days year⁻¹, with 2 $s>0.7$ events per year, each lasting 143 days. In the lower unspecified material with signs of wetness (1120 mm) mean $AD_{s>0.7}$ was almost continuous (365 days year⁻¹).

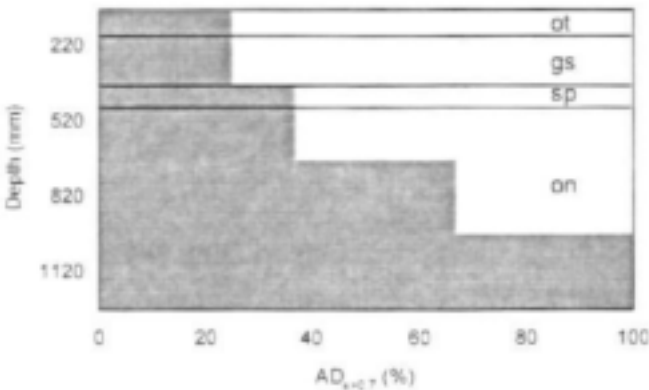


Figure 5.20 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P204 (Longlands 2000).

The high $AD_{s>0.7}$ values in this profile resulted in the formation of Fe oxide mottles and a bleached colour. In the orthic A, where $s>0.7$ events are shortest, there are only a few, fine Fe oxide mottles. This increased to many in the E and common in the soft plinthic B. The E, and soft plinthic B horizons also have a pale (10YR8/2) colour, providing evidence that colourants such as Fe and organic matter have been depleted.

This profile is located at the lower end of the upper shelf (Figure 3.3). Here the hard Elliott sandstone (Figure 3.4) prevents downward movement of water. This results in water moving laterally, slowly through the profile, before it cascades over the sandstone shelf.

5.6 P205 (Kroonstad 2000)

5.6.1 Morphology

The profile is situated in a lower midslope position, with a slope of 8 % (Figure 3.3). It has a coarse sandy loam texture throughout the profile. The clay content decreases from the A to the E horizon and then increases to the G (13 – 11 – 11 – 28 %). The profile description and analytical data for this profile are given in Appendix A, Tables 9 and 10. The profile can be classified as Gleyic Albic Planosol (hyperdistric) (FAO, 1998b) or Aeric Albaqualfs (Soil Survey Staff, 1999). A dark greyish yellow (2.5Y5/2) orthic A horizon (0–220 mm) overlies a yellowish grey (2.5Y6/1) E1 (220–460 mm), on a greyish yellow brown (10YR6/2) E2 (460–660 mm) on a light grey (2.5Y7/1) G horizon (660–1 400 mm).

5.6.2 Chemical properties

pH_{Water} increases from 5.38 in the topsoil to 5.97 in the subsoil (Figure 5.21). pH_{KCl} stays somewhat constant at 4.20 to 4.57 throughout the profile. The pH_{KCl} – value of 5.82 at a depth of 875 mm is most probably due to experimental error. The large difference between pH_{Water} and pH_{KCl} indicates a large residual acidity in this profile. As in the case of profile 204.

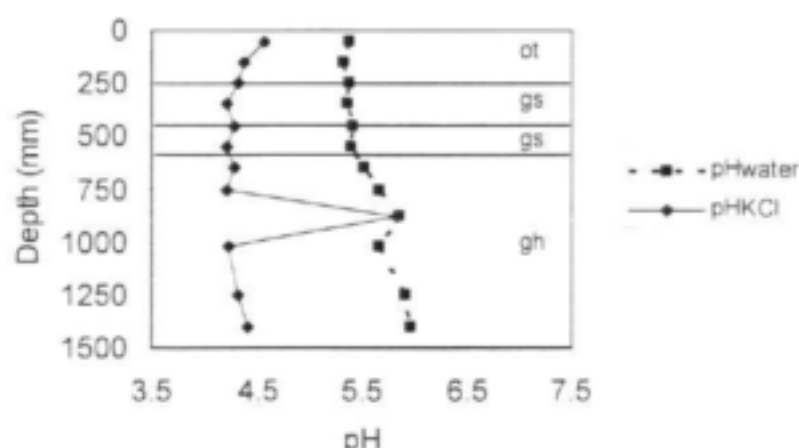


Figure 5.21 pH_{Water} and pH_{KCl} for P205 (Kroonstad 2000).

Base saturation decreases from 21 % in the A to 9 % in the E1 and E2, increasing to 34 % in the G horizon (Figure 5.22). The decrease in base saturation from the A to the E supports the classification of the E, while the increase in base saturation to the G supports its classification.

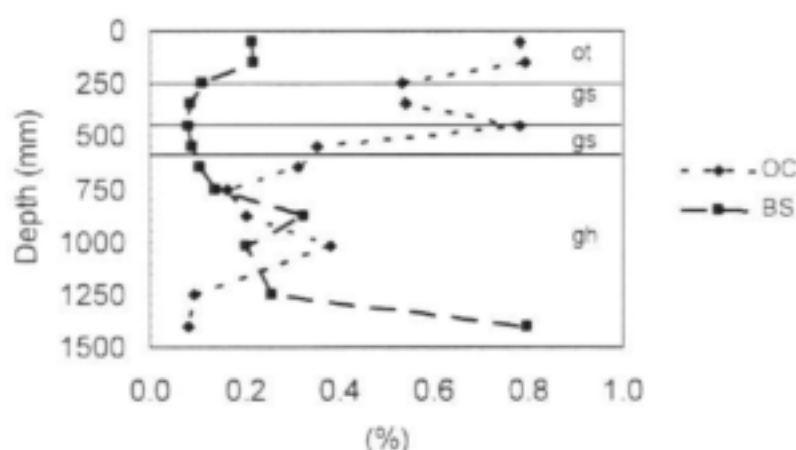


Figure 5.22 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P205 (Kroonstad 2000).

Total Fe content is fairly constant at 4 500 to 5 000 mg kg^{-1} throughout the profile (Figure 5.23). It is higher in the E1 horizon, with a maximum of 5 625 mg kg^{-1} and lower in the E2 horizon, with a minimum of 3 865 mg kg^{-1} . The Fe content is variable in the G horizon, with a mean of 4 793 mg kg^{-1} . It therefore seems that some Fe accumulation has taken place in the E1 horizon, while it has been depleted from the E2 and from zones in the G horizon (Figure 5.23).

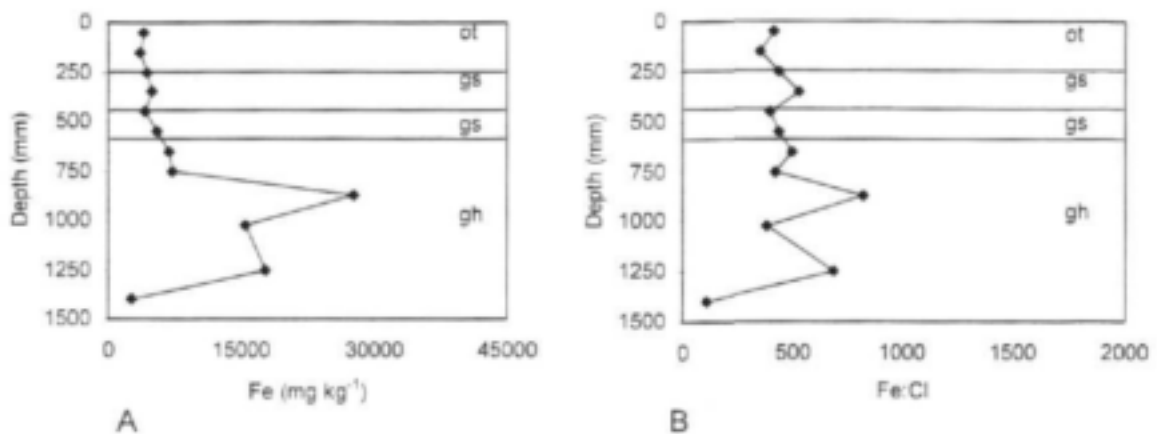


Figure 5.23 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P205 (Kroonstad 2000).

5.6.3 Physical properties

The texture pattern in this profile is remarkably similar to the previous profile. Clay content (Figure 5.24) is fairly stable throughout the A (10 %), E1 (10 %) and E2 (13 %) horizons, but then sharply increases in the G horizon (28 %). The texture pattern supports the classification of the E and G horizons, given the removal of clay in the E and the accumulation thereof in the G.

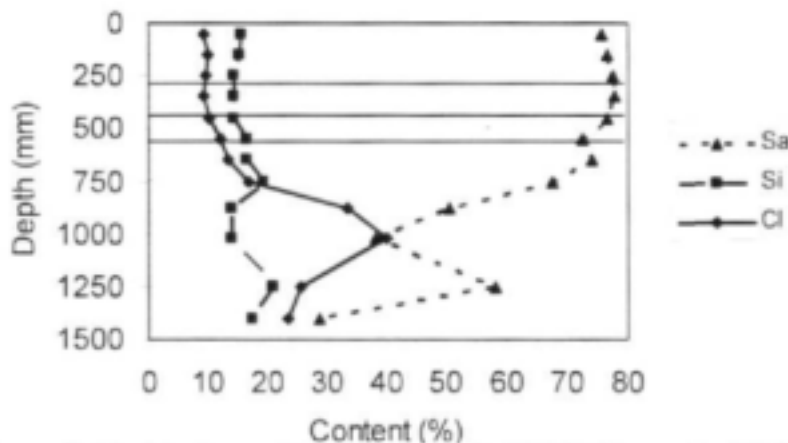


Figure 5.24 Texture of the fine earth in P205 (Kroonstad 2000).

5.6.4 Hydrology

Mean $AD_{s>0.7}$ values increased down the profile (Figure 5.25), similar to the pattern observed for P202 (Pinedene). In the orthic A horizon the mean $AD_{s>0.7}$ value was 31 days year⁻¹, with a mean of 6 $s>0.7$ events per year, each lasting 5 days. In the E1 and E2 horizons the mean $AD_{s>0.7}$ value was 47 days year⁻¹, with a mean of 5 $s>0.7$

events per year, each lasting 10 days. In the upper G horizon $s > 0.7$ was 244 days year^{-1} and continuous at the 1 130 and 1 430 mm measuring depths.

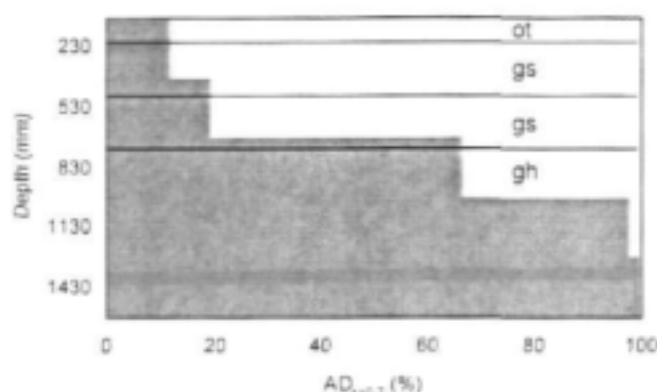


Figure 5.25 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P205 (Kroonstad 2000).

The high clay content and high bulk density in the G horizon probably prevented water from draining from the horizon. It might also be responsible for the accumulation of water in the overlying A and E horizons. The location of the profile (Figure 3.3), on a little ridge also causes the A and E horizons to drain faster. The presence of rusty pore coatings in the A, and common and many Fe oxide mottles in the E provide supporting evidence for the relatively high mean $AD_{s>0.7}$ value here, compared to the surface horizons of profiles 201, 202 and 203. The bleached colour as well as common Fe oxide mottles in the G horizon is an indication of the high $AD_{s>0.7}$ value in this horizon.

5.7 P206 (Kroonstad 1000)

5.7.1 Morphology

The profile is situated in a lower footslope position, with a slope of 7 % (Figure 3.3). The orthic A and E horizons have a loamy texture, while the G horizon has a clay loam texture. The clay content decreases from the A to the E and then increases to the G horizon (21 – 17 – 38 %). The profile description and analytical data for this profile are given in Appendix A (Tables 11 and 12). The profile can be classified as Mollic Gleyic Planosol (albic, endo-eutric) (FAO, 1998b) or Typic Argialbolls (Soil Survey Staff, 1999). A brownish grey (10YR5/1) orthic A horizon (0–550 mm) overlies a brownish grey (10YR5/1) E (550–800 mm) on a brownish grey (10YR6/1) G horizon (800–1100 mm).

5.7.2 Chemical properties

pH_{Water} is constant at 5.70 to 6.23 throughout the profile (Figure 5.26). pH_{KCl} decreases from 5.66 in the topsoil to 4.28 in the subsoil. The high pH_{Water} in relation to the previous profiles can be an indication of a cumulative pedological environment. This is supported by the base saturation which is in excess of 50 %. The widening difference between pH_{Water} and pH_{KCl} indicates increasing residual acidity with depth.

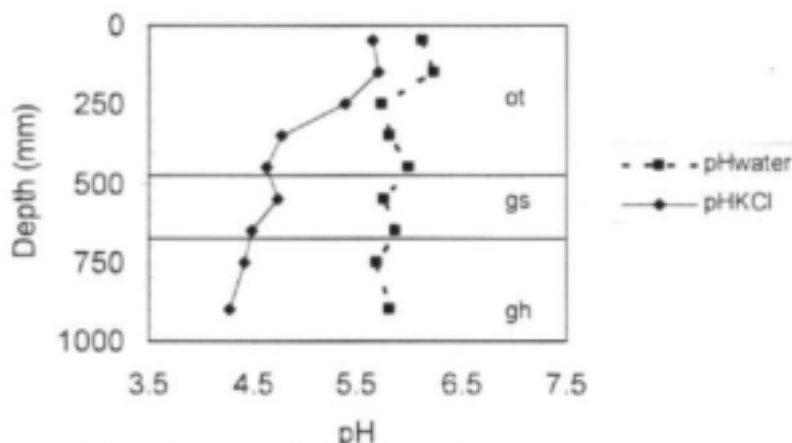


Figure 5.26 pH_{Water} and pH_{KCl} for P206 (Kroonstad 1000).

Base saturation is practically constant throughout the profile, ranging between 50 % in the A and 64 % in the E and G horizons (Figure 5.27). This profile does not have the clear decrease in base saturation associated with the E horizon, which can be observed in P201 (Longlands), P204 (Longlands) and P205 (Kroonstad).

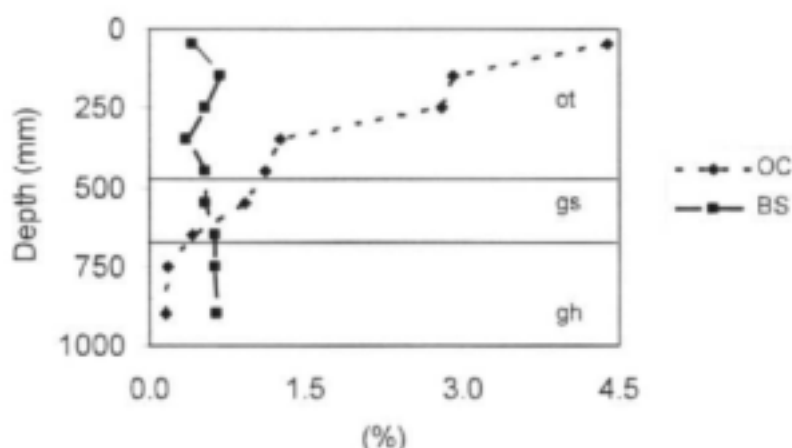


Figure 5.27 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P206 (Kroonstad 1000).

Total Fe content decreases down the profile, from 7 975 mg kg⁻¹ in the topsoil to 1 240 mg kg⁻¹ in the lower G horizon (Figure 5.28). The total Fe content decreases markedly from a depth of 300 to 700 mm, pointing to an absolute removal of Fe from the profile (Figure 5.28). This might point to erroneous demarcation of the E horizon. As was stated previously, the high organic matter content in A and E horizon partially masked the presence of the E horizon.

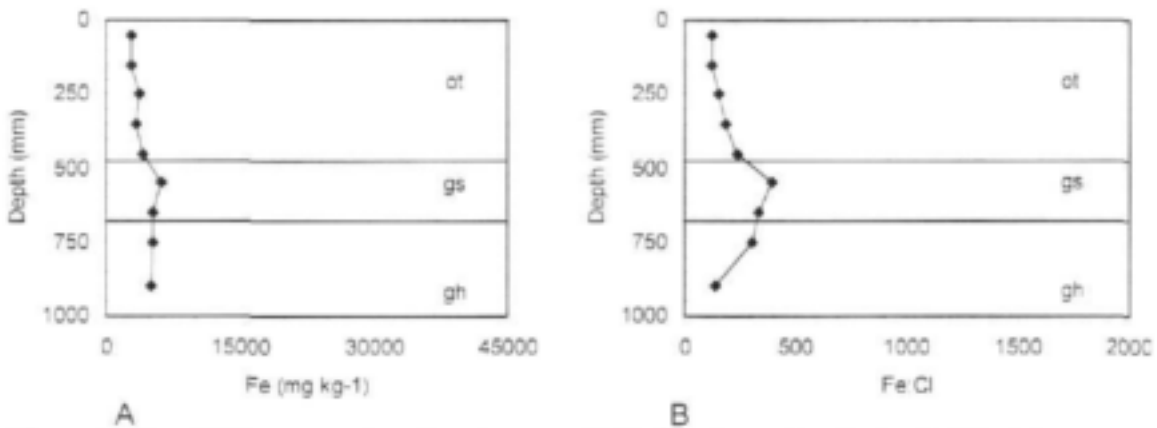


Figure 5.28 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P206 (Kroonstad 1000).

5.7.3 Physical properties

The clay content decreases from 22 % in the A horizon to 17 % in the E, and increases to 38 % in the G horizon (Figure 5.29). The sharp decrease in clay content at 300 mm might indicate that the lower boundary of the A horizon should be at this depth, or at least that the 300 – 500 mm horizon is a transition between the orthic A and the E horizon (the grey colour could be masked by the presence of large amounts of organic matter). The increase in clay content from the E to the G is consistent with the classification.

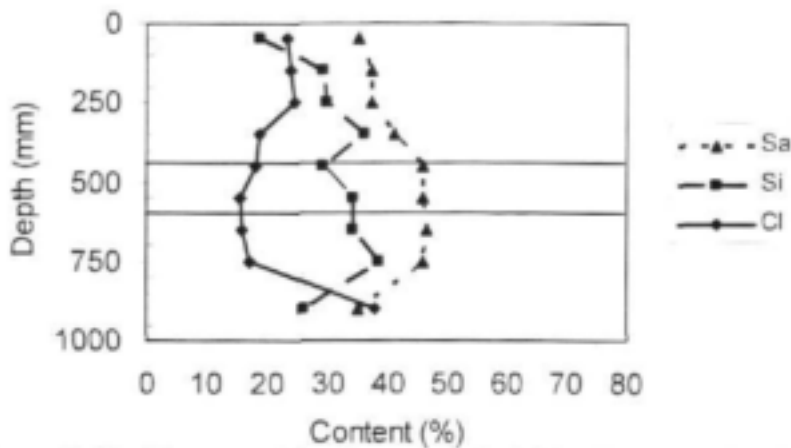


Figure 5.29 Texture of the fine earth in P206 (Kroonstad 1000).

5.7.4 Hydrology

The water content of almost the whole profile is above 0.7 of porosity for the entire year (Figure 5.30). The frequency of $s > 0.7$ events is therefore once per year, and the mean $AD_{s>0.7}$ value is 365 days year⁻¹.

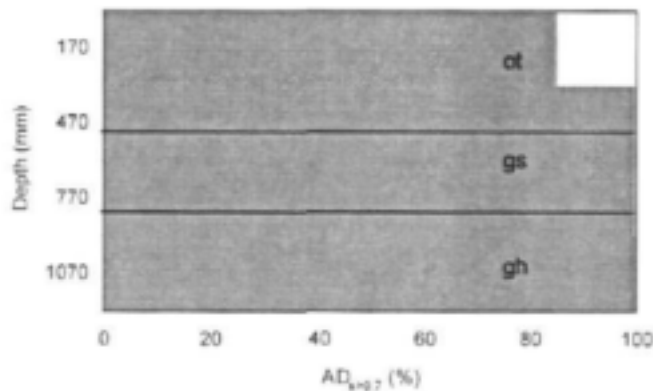


Figure 5.30 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the four measuring depths at P206 (Kroonstad 1000).

The high $AD_{s>0.7}$ value in this profile is attributable to the fact that it is situated in a small seep (Figure 3.3). Water from the higher lying soils therefore flows through this profile. Extended wetness has resulted in the accumulation of organic matter in the profile, especially at the soil's surface where 4.4 % organic carbon was measured.

5.8 P207 (Westleigh 1000)

5.8.1 Morphology

The profile is situated in a valley bottom position, with a slope of 5 % (Figure 3.3). The orthic A as well as the B1 and B2 soft plinthic B horizons have a silty loam texture, while the underlying unspecified material with signs of wetness has a clay texture. The clay content increases from the A to the B1, decreases to the B2 and then sharply increases to the unspecified material with signs of wetness (23 – 24 – 19 – 46 %). The profile description and analytical data for this profile are given in Appendix A, Tables 13 and 14. The profile can be classified as Gleyic-stagnic Albeluvisol (ferric, hyperdistric) (FAO, 1998b) or Aeris Albaqualfs (Soil Survey Staff, 1999). A greyish yellow brown (10YR6/2) orthic A horizon (0–300 mm) overlies a dull yellow orange (10YR6/3) soft plinthic B1 (300–560 mm) on a light grey (10YR8/1) soft plinthic B2 (560–670 mm) on a light grey (10YR8/2) unspecified material with signs of wetness (670–1 300 mm).

5.8.2 Chemical properties

pH_{Water} increases with depth, from 5.35 in the topsoil to 6.36 in the subsoil (Figure 5.31). pH_{KCl} varies slightly from 4.07 to 4.46 throughout the profile. The pH pattern is similar to that of profile 205 (Kroonstad 2000).

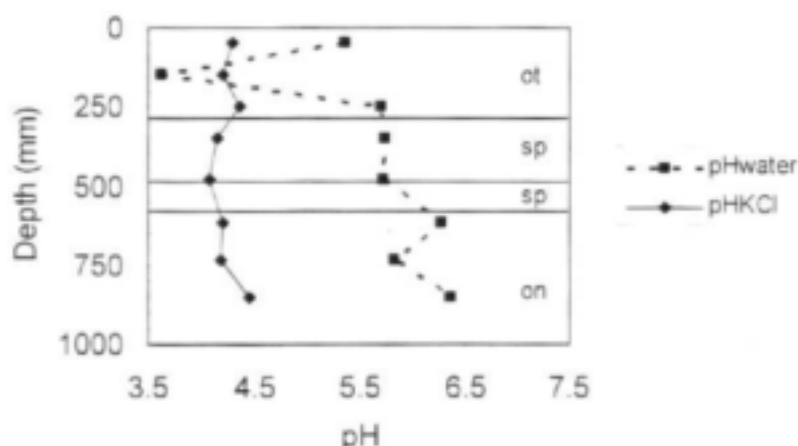


Figure 5.31 pH_{Water} and pH_{KCl} for P207 (Westleigh 1000).

Base saturation decreases slightly from 38 % in the topsoil to 26 % in the soft plinthic B and then increases to 57 % in the unspecified material with signs of wetness (Figure 5.32). The decrease in base saturation is linked with an absolute decrease in

basic cations, in the same order as CEC_{soil} . The decrease in basic cations indicates significant leaching from the soft plinthic B and accumulation in the unspecified material with signs of wetness.

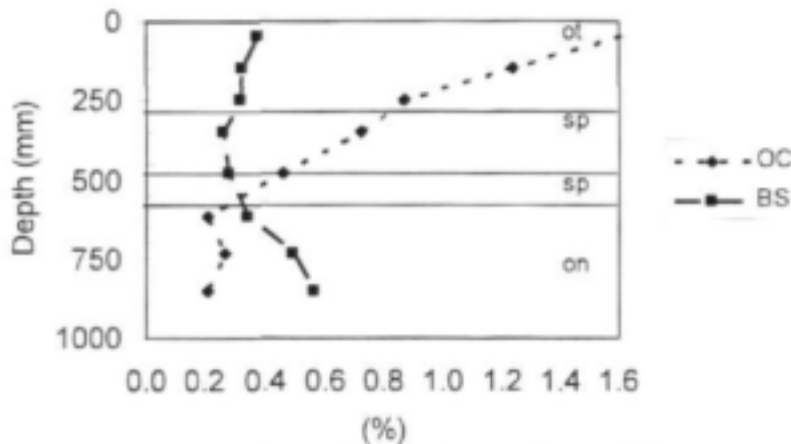


Figure 5.32 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P207 (Westleigh 1000).

Total Fe content is fairly constant in the first three horizons, decreasing from a maximum of $8\,200\text{ mg kg}^{-1}$ in the topsoil to a minimum of $6\,825\text{ mg kg}^{-1}$ in the B1 before increasing to $7\,980\text{ mg kg}^{-1}$ in the B2 (Figure 5.33). The B1 was described as having many Fe oxide mottles. It would appear from the analyses as if removal of Fe has taken place from this horizon. This would be a motivation for the classification of this horizon as an E horizon. The slight increased Fe content in the B2 horizon was expected, as it has common Fe oxide mottles.

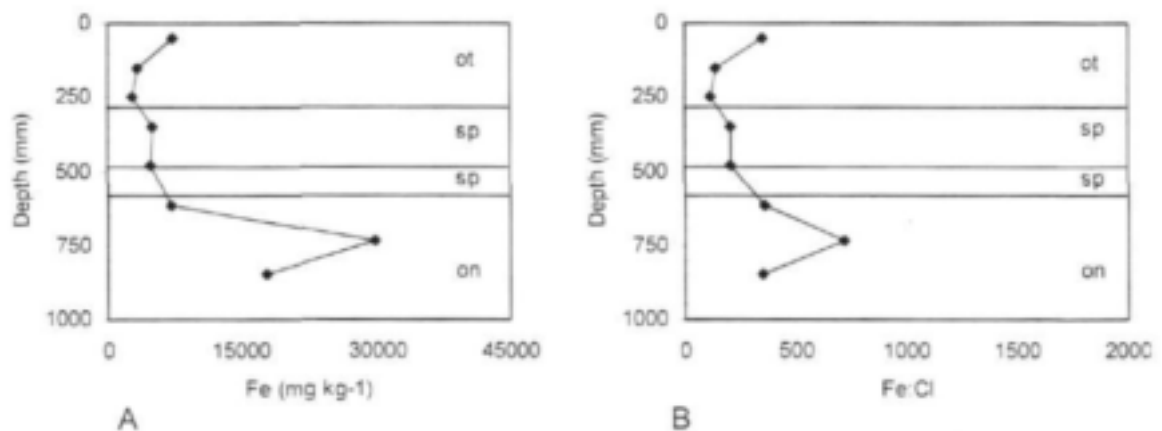


Figure 5.33 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P207 (Westleigh 1000).

5.8.3 Physical properties

Clay content is fairly stable from the A to the B1, but then drops sharply to the B2 (Figure 5.34). The clay content then sharply increases in the C horizon. The low clay content in the B2 might indicate that it should somewhat be classified as an E horizon.

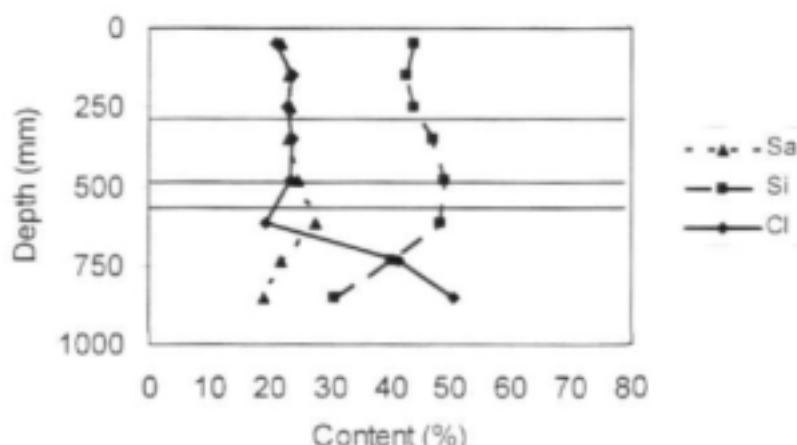


Figure 5.34 Texture of the fine earth in P207 (Westleigh 1000).

5.8.4 Hydrology

Although only two depths are measured in P207 (Westleigh), the $AD_{s>0.7}$ was somewhat similar to that in P208 (Kroonstad) and P209 (Katspruit). The mean $AD_{s>0.7}$ value for the A horizon was 197 days year⁻¹ (Figure 5.35). The $AD_{s>0.7}$ ranged from 89 days in 1997/98 to 273 days in 2000/01. The $s>0.7$ events took place 9 times per year and each lasted 43 days. In the soft plinthic B1 (at 480 mm) the mean $AD_{s>0.7}$ value is 285 days year⁻¹. The $AD_{s>0.7}$ varied from 76 days in 1999/2000 to 302 days in 2000/01. The mean frequency of $s>0.7$ was 2 times per year, each event lasting 97 days. Unfortunately no deeper NWM measurements are available, due to a short pipe installed at this site.

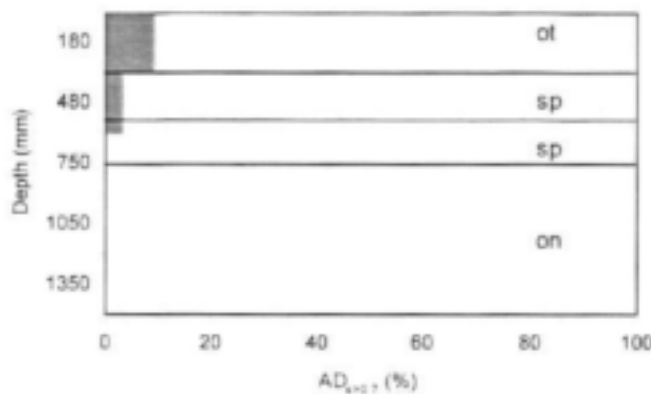


Figure 5.35 Mean ADs > 0.7 values based on estimated daily soil water contents, for the two measuring depths at P207 (Westleigh 1000).

Fairly high $AD_{s>0.7}$ values in this profile are associated with the occurrence of Fe oxide mottles in the A and B1 horizons. The lack of deeper NWM measurements prevents interpretation of the morphology of the B2 and G horizons.

5.9 P208 (Kroonstad 1000)

5.9.1 Morphology

The profile is situated in a lower footslope position, with a slope of 7 % (Figure 3.3). The orthic A horizon has a silty loam texture, while the rest of the profile has a loam texture. The clay content increases down the profile (13 – 17 – 25 – 25 %). The profile description and analytical data for this profile is given in Appendix A, Tables 15 and 16. The profile can be classified as Albic Planosol (epidistric) (FAO, 1998b) or Aeris Albaqualfs (Soil Survey Staff, 1999). A brownish grey (10YR6/1) orthic A horizon (0–350 mm) overlies a greyish yellow brown (10YR6/2) E (350–530 mm) on a light grey (10YR7/1) G1 (530–800 mm) on a greyish yellow brown (10YR6/2) G2 horizon (800–1 400 mm).

5.9.2 Chemical properties

pH_{Water} and pH_{KCl} increases with depth throughout the profile (Figure 5.36). pH_{Water} increases from 5.17 in the A horizon to 7.13 in the lower G horizon, while pH_{KCl} increases from 4.05 to 5.43. The increasing pH, as well as the difference between pH_{Water} and pH_{KCl} is similar to that observed in profiles 204, 205 and 207.

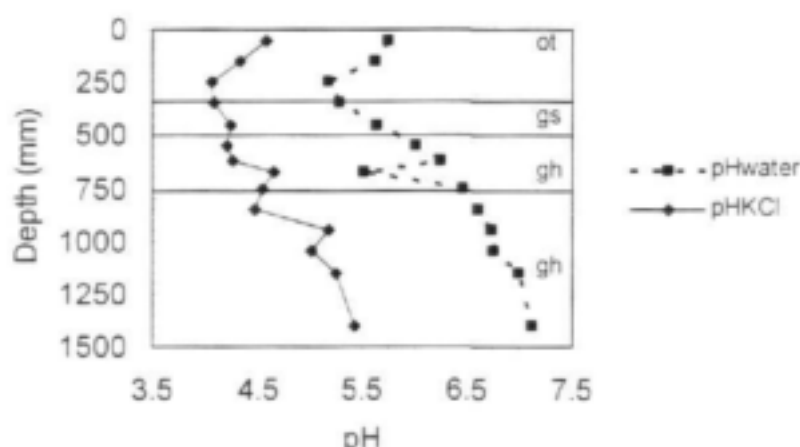


Figure 5.36 pH_{Water} and pH_{KCl} for P208 (Kroonstad 1000).

Base saturation increases from 27 % in the topsoil to 98 % in the G horizon (Figure 5.37). The increase is associated with sum of bases that follows the same pattern as the CEC_{soil} and is probably due to basic cation accumulation as a result of lateral water movement.

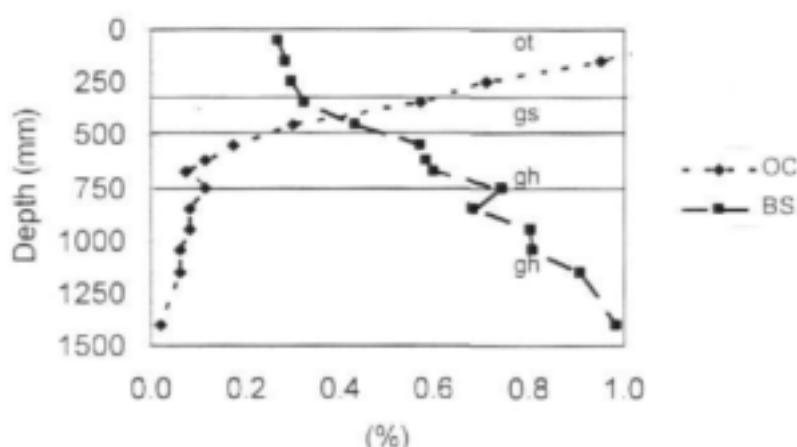


Figure 5.37 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P208 (Kroonstad 1000).

Total Fe content decreases from $2\,955\text{ mg kg}^{-1}$ in the topsoil to $1\,820\text{ mg kg}^{-1}$ in the E, and then increases to $7\,555\text{ mg kg}^{-1}$ in the G1 and $7\,840\text{ mg kg}^{-1}$ in the G2 (Figure 5.38). It has a minimum of $1\,335\text{ mg kg}^{-1}$ in the upper part of the G2. The low Fe content in the E horizon indicates reduction and leaching of Fe from this horizon, while the relatively higher Fe content in the G horizon might be due to Fe accumulation in this horizon. The lower Fe content in the upper G horizon indicates selective removal of Fe here, as evidenced by the silans. The G horizon of profile 205 has a similar reduction in Fe content within the G horizon.

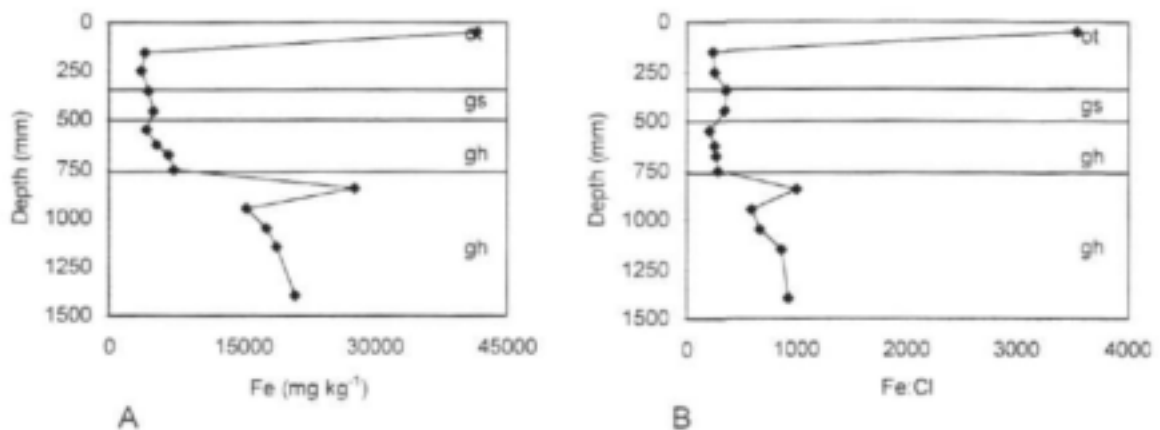


Figure 5.38 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P208 (Kroonstad 1000).

5.9.3 Physical properties

Clay content increases throughout the profile, but decreases slightly at 350 mm, supporting the classification of an E horizon (Figure 5.39). The increase in clay content from the E to the G horizon also supports the classification of the latter. The silt content in this profile is somewhat different from that in the other profiles, indicating a possible difference in parent material, and possibly due to the dolerite dyke upslope from the profile (Figure 3.4).

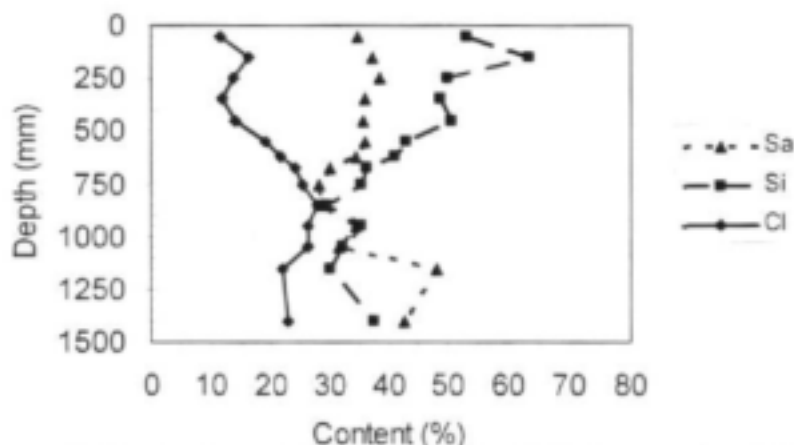


Figure 5.39 Texture of the fine earth in P208 (Kroonstad 1000).

5.9.4 Hydrology

The mean $AD_{s>0.7}$ value for the orthic A horizon is 180 days year⁻¹. The $AD_{s>0.7}$ values ranged from 102 days in 1997/98 to 256 days in 2000/01. The mean frequency of $s>0.7$ events was 2 per year, each lasting 86 days. The mean $AD_{s>0.7}$

value for the E horizon was 133 days year⁻¹, with $AD_{s>0.7}$ ranging from 33 days in 1999/2000 to 265 days in 2001/02. The mean frequency of $s>0.7$ events was 6 times per year with each event lasting 21 days. Mean $AD_{s>0.7}$ values for the G horizon were 166 days year⁻¹ at 805 mm and 365 days year⁻¹ at 1 105, and 1 405 mm (Figure 5.40).

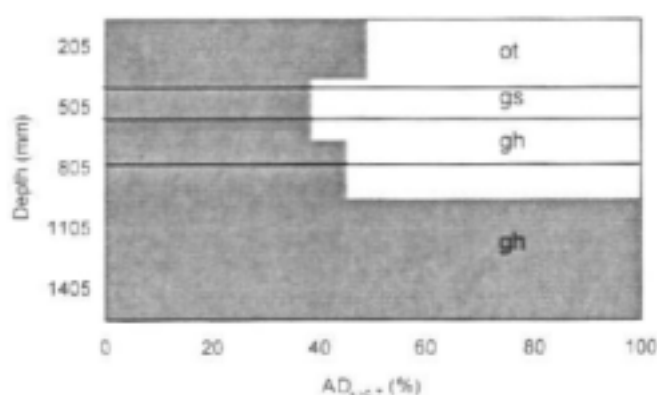


Figure 5.40 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P208 (Kroonstad 1000).

This profile was located in a small seep, receiving water from three directions in the landscape. This, linked with high clay content in the G, results in the long periods of wetness. Wetness in the overlying A and E horizons is probably due to the lack of internal drainage. The lower $AD_{s>0.7}$ value in the G1 horizon can be linked to its position in the profile, and / or the slightly lower sand and higher silt content.

5.10 P209 (Katspruit 1000)

5.10.1 Morphology

The profile is situated in an upper midslope position, with a slope of 13 % (Figure 3.3). The orthic A horizon has a loam texture, while the rest of the profile has a clay loam texture. The clay content increases down the profile (16 – 36 – 36 %). The profile description and analytical data for this profile is given in Appendix A, Tables 17 and 18. The profile can be classified as Stagnic Orthi-eutric Gleysol (FAO, 1998b) or Typic Albaqualfs (Soil Survey Staff, 1999). A greyish yellow brown (10YR5/2) orthic A horizon (0–450 mm) overlies a brownish grey (10YR6/1) G horizon (450–1 100 mm) on brownish grey (10YR6/1) saprolite (1 100–1 400 mm).

5.10.2 Chemical properties

pH_{Water} and pH_{KCl} increase with depth (Figure 5.41). pH_{Water} increases from 5.60 in the topsoil to 6.64 in the subsoil, while pH_{KCl} increases from 4.71 to 5.35. The distribution is similar, although with slightly larger values than that observed in profiles 204, 205, 207 and 208.

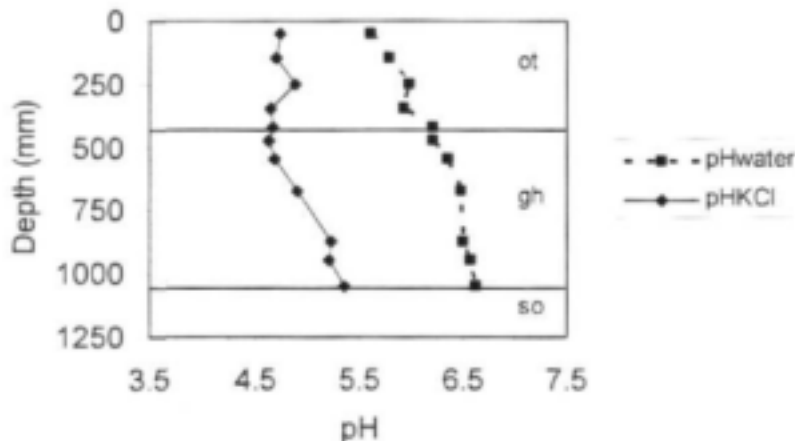


Figure 5.41 pH_{Water} and pH_{KCl} for P209 (Katspruit 1000).

Base saturation increases from 57 % in the topsoil to over 100 % in the G horizon (Figure 5.42). This is associated with a similar increase in sum of bases that more or less follows the CEC_{soil} distribution.

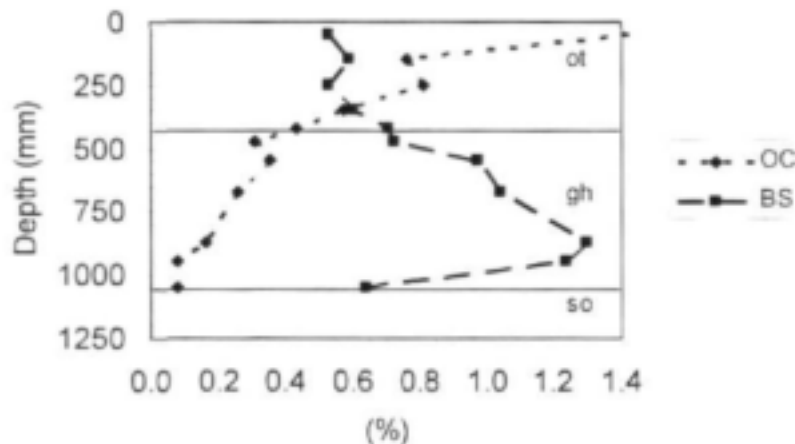


Figure 5.42 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P209 (Katspruit 1000).

Total Fe content increases from $5\,255\text{ mg kg}^{-1}$ at the surface to $7\,180\text{ mg kg}^{-1}$ in the lower A horizon, and then decreases to 390 mg kg^{-1} in the lower G horizon (Figure 5.43). The peak at 500 mm is most probably due to accumulation of Fe in

the upper part of the G horizon. The accumulation of Fe is also evidenced by the occurrence of many fine prominent Fe oxide mottles in the G horizon (Figure 5.43). The distribution of Fe in the profile points to some Fe accumulation in the lower part of the A horizon, a large accumulation in the upper G horizon and almost a depletion of Fe in the lower G horizon. This is supported by the Fe : clay ratio (Figure 5.43).

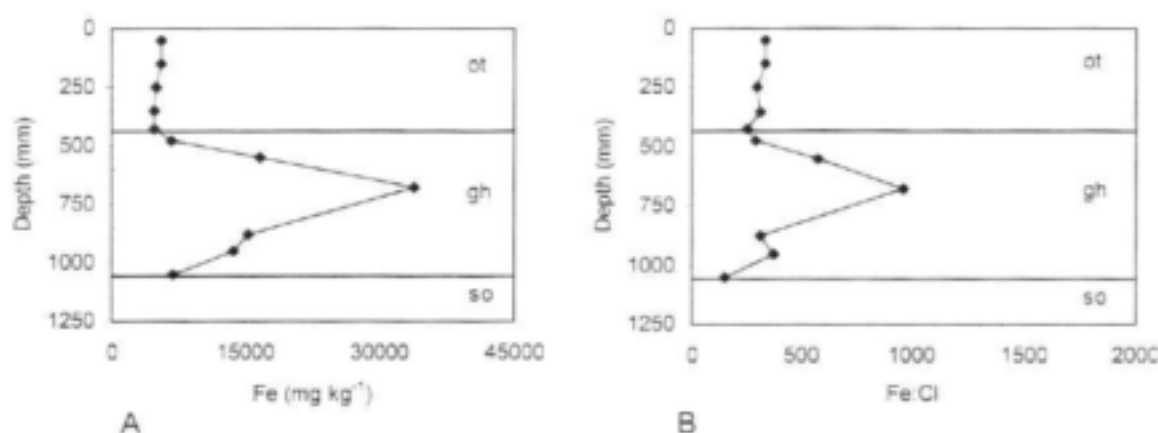


Figure 5.43 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P209 (Katspruit 1000).

5.10.3 Physical properties

The clay content steadily increases from 16 % in the A to 48 % at 900 mm in the G horizon (Figure 5.44). There is a slight decrease (1 %) in clay content at 300 – 400 mm, possibly indicating the presence of an E horizon. The high silt content, similar to that of P208 (Kroonstad), also possibly indicates a different parent material. It should be remembered that P208 (Kroonstad) and P209 (Katspruit) are located just below a dolerite dyke (Figure 3.4).

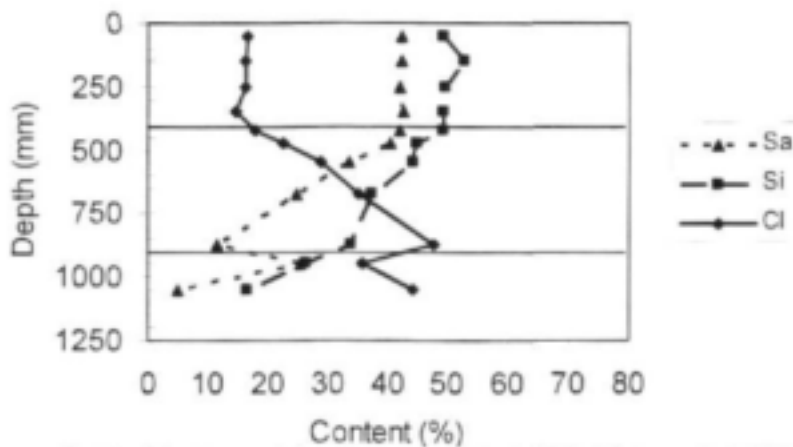


Figure 5.44 Texture of the fine earth in P209 (Katspruit 1000).

5.10.4 Hydrology

The mean $AD_{s>0.7}$ value for the orthic A horizon was 213 days year⁻¹. The $AD_{s>0.7}$ values range from 103 days in 1997/98 to 324 days in 2000/01. The mean frequency of $s>0.7$ events was 5 per year, with each event lasting 43 days. The mean $AD_{s>0.7}$ value at the boundary between the A and the G horizon is 285 days year⁻¹, with $AD_{s>0.7}$ values ranging from 195 days in 1999/2000 to 365 days in 1998/99 and 2001/02. The mean frequency of $s>0.7$ events is 2 per year, with each event lasting 178 days (Figure 5.45).

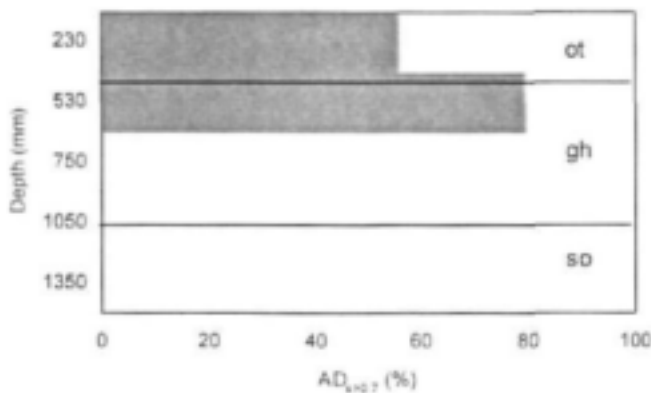


Figure 5.45 Mean $AD_{s>0.7}$ value based on estimated daily soil water contents, for the two measuring depths at P209 (Katspruit 1000).

This profile is subjected to long periods of wetness, probably due to its location (Figure 3.3) in a little seep, just upslope from P208 (Kroonstad). Evidence of long periods of $s>0.7$ is the occurrence of many distinct Fe oxide mottles as well as many

bleached and rusty pores in the A horizon. Many prominent Fe oxide mottles, Mn concretions as well as bleached and rusty pores occur in the G horizon.

5.11 P210 (Bloemdal 1100)

5.11.1 Morphology

The profile is situated in an upper midslope position, with a slope of 8 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated above the dolerite dyke. The A1 horizon has a clay loam texture, the A2, B1 and B2 horizons have a loam texture and the C1 horizon a coarse sandy loam texture. The clay content is fairly stable throughout the profile (19 – 17 – 24 – 18 – 17 – 20 %), but increases sharply at 780 mm. The profile description and analytical data for this profile are given in Appendix A, Tables 19 and 20. The profile can be classified as Hyper-district Regosol (FAO, 1998b) or Aquic Ustorthents (Soil Survey Staff, 1999). A greyish yellow brown (10YR4/2) orthic A1 horizon (0–260 mm) overlies a dull yellowish brown (10YR4/3) A2 (260–530 mm) on a brown (7.5YR4/6) red apedal B1 (530–800 mm) on an orange (7.5YR6/6) red apedal B2 (810–1 200 mm) on dull orange (7.5YR6/4) unspecified material with signs of wetness (1 200–1580 mm).

5.11.2 Chemical properties

The pH_{Water} is somewhat constant throughout the profile, ranging from 5.09 to 5.60 (Figure 5.46). The pH_{KCl} decreases sharply from 5.10 in the topsoil to 3.85 at the top of the red apedal B horizon (590 mm). It then stays constant with increasing depth. Although the distribution pattern differs the magnitude is remarkably similar to that in profiles 204 to 209, excluding 206.

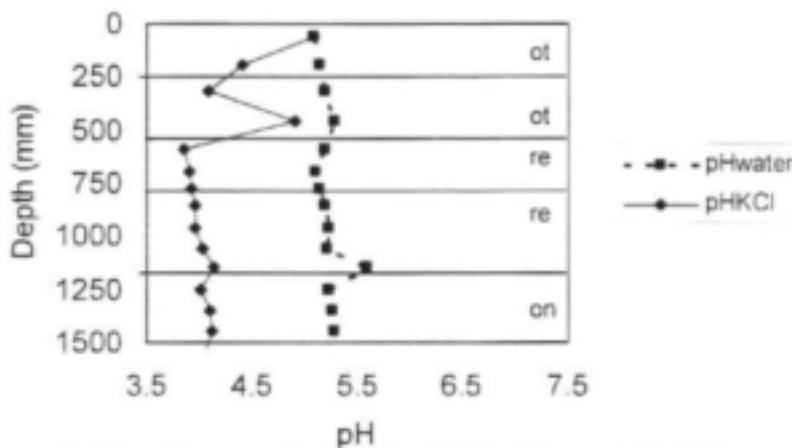


Figure 5.46 pH_{Water} and pH_{KCl} for P210 (Bloemdal 1100).

Base saturation is somewhat constant at 15 to 25 % throughout the profile and is associated with a narrow range in basic cation content of 1.0 to 1.5 $\text{cmol}_c \text{ kg}^{-1}$ throughout the profile, and a decreasing CEC_{soil} (Figure 5.47).

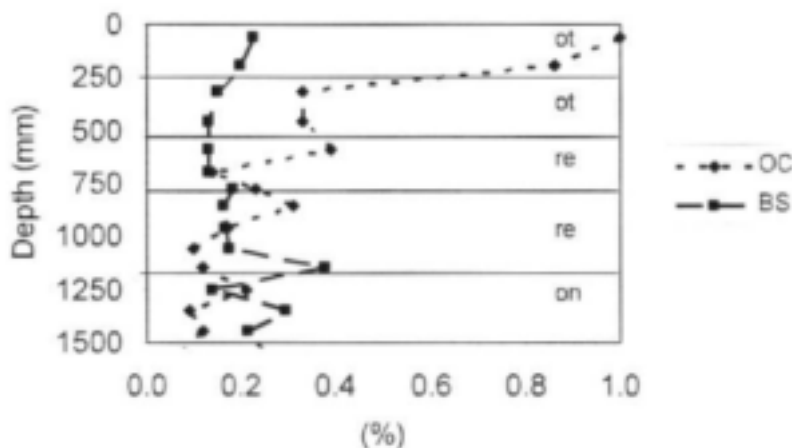


Figure 5.47 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P210 (Bloemdal 1100).

Total Fe contents in this profile do not show clear horization, ranging between 3 860 mg kg^{-1} and 13 950 mg kg^{-1} (Figure 5.48). The peak occurs in the lower part of the B2 horizon, while the lowest point occurs at a depth of 200 – 300 mm in the A1 horizon. The lack of Fe horization can be expected from these soils, because no removal and / or accumulation of Fe are evident from the morphology. The lack of Fe horization might also be due to even removal or accumulation of Fe in the profile. The decreasing organic carbon content and increasing water saturation probably resulted in this profile not being exposed to sufficiently reduced conditions that could have led to the formation of a soft plinthic or E horizon. The peak at

1 010 – 1 100 mm might be the first indications of Fe localisation and accumulation (plinthite formation) due to a fluctuating water table on the unspecified material with signs of wetness (Figure 5.48).

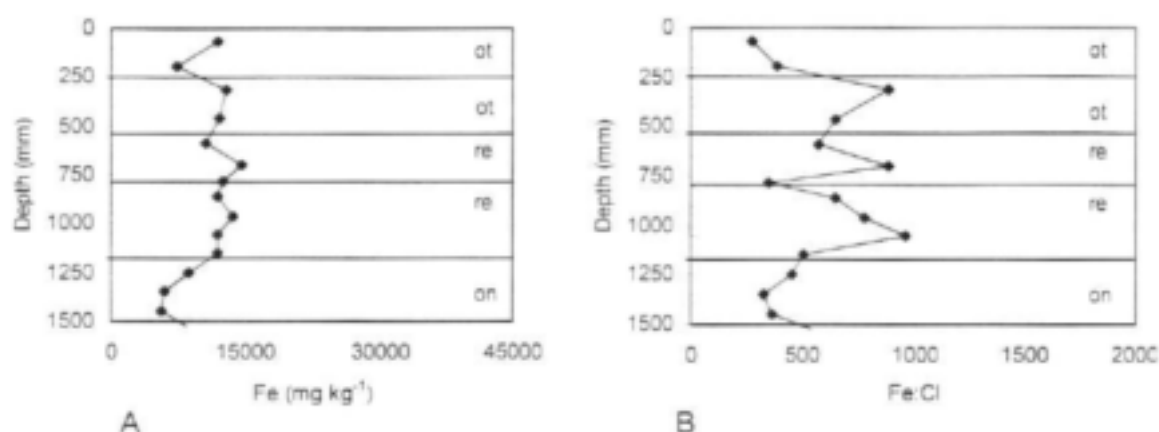


Figure 5.48 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P210 (Bloemdal 1100).

5.11.3 Physical properties

Clay content is somewhat uniform throughout the profile, ranging from 19 % in the A to 24 % in the B and 17 % in the C1 (Figure 5.49). The increase in clay content at 750 mm might be due to clay illuviation at this depth. The decreasing clay content in the C1 and C2 horizons are due to the slower rate of weathering at this depth. Silt and sand patterns indicate a different parent material to that in the other profiles.

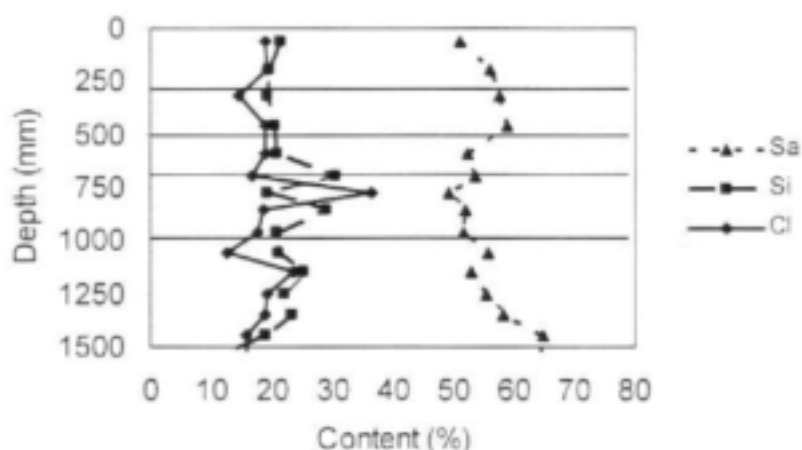


Figure 5.49 Texture of the fine earth in P210 (Bloemdal 1100).

5.11.4 Hydrology

Mean $AD_{s>0.7}$ in the A1 horizon was 1 day per year (Figure 5.50). At 490 mm, the A horizon had a mean $AD_{s>0.7}$ value of 46 days year⁻¹. The mean $AD_{s>0.7}$ value for the A2 horizon was 46 days year⁻¹, with $AD_{s>0.7}$ ranging from 4 days in 1997/98 to 161 days in 1999/2000. The mean frequency of $s>0.7$ events was 6 per year, with each event lasting 8 days. In the red apedal B1, the mean $AD_{s>0.7}$ was 109 days year⁻¹, with $AD_{s>0.7}$ values ranging from 39 days in 1997/98 to 228 days in 2000/01. The mean frequency of $s > 0.7$ events was 7 per year, with each event lasting 15 days. The mean $AD_{s>0.7}$ value for the red apedal B2 horizon was 357 days year⁻¹. At 1350 mm the unspecified material with signs of wetness had a mean $AD_{s>0.7}$ value of 170 days year⁻¹, with $AD_{s>0.7}$ values ranging from 91 days in 1998/99 to 358 days in 2001/02. The mean frequency of $s > 0.7$ was 3 events per year, lasting 57 days per event.

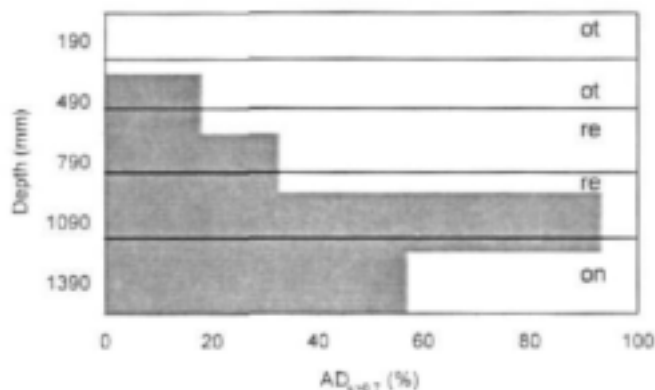


Figure 5.50 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P210 (Bloemdal 1100).

The low $AD_{s>0.7}$ values in the B1 were expected in view of the red colour. The high $AD_{s>0.7}$ value in the B2 was, however, not expected. This might be due to a degree of water accumulation above the unspecified material with signs of wetness that is insufficient to cause reduction and therefore redox morphology. A contributing factor may be wetness caused by oxygenated water that provides an electron acceptor for microorganisms and / or the absence of organic matter that inhibits the activity of microorganisms.

5.12 P211 (Katspruit 1000)

5.12.1 Morphology

The profile is situated in an upper footslope position, with a slope of 5 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated above the dolerite dyke. The A, G1 and G2 horizons have a clay loam texture. The clay content is fairly constant throughout the profile (32 – 38 – 38 %). The profile description and analytical data for this profile are given in Appendix A, Tables 21 and 22. The profile can be classified as Endo eutric Gleysol (FAO, 1998b) or Typic Endoaqualfs (Soil Survey Staff, 1999). A dark greyish brown (10YR4/2) orthic A horizon (0–150 mm) overlies a grey (10YR5/1) G1 horizon (150–450 mm) on a grey (10YR5/1) G2 horizon (450–1 200 mm).

5.12.2 Chemical properties

The pH_{Water} increases down the profile, from 5.07 to 6.19, and then decreases to 5.81 (Figure 5.51). The pH_{KCl} follows the same trend, from 3.99 in the topsoil to 4.50 in the lower G2 horizon (550 mm).

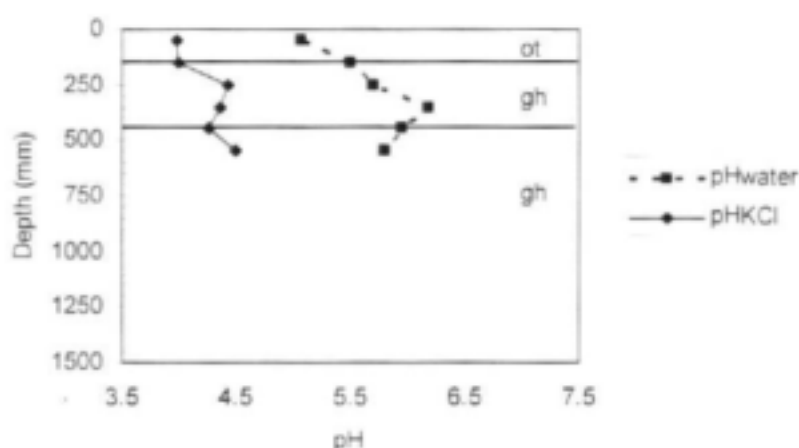


Figure 5.51 pH_{Water} and pH_{KCl} for P211 (Katspruit 1000).

Base saturation decreases sharply down the profile from 148 to 62 % (Figure 5.52) and is associated with relatively high basic cation content of 7.2 to 20.9 $cmol_c\ kg^{-1}$, and an increasing CEC_{soil} .

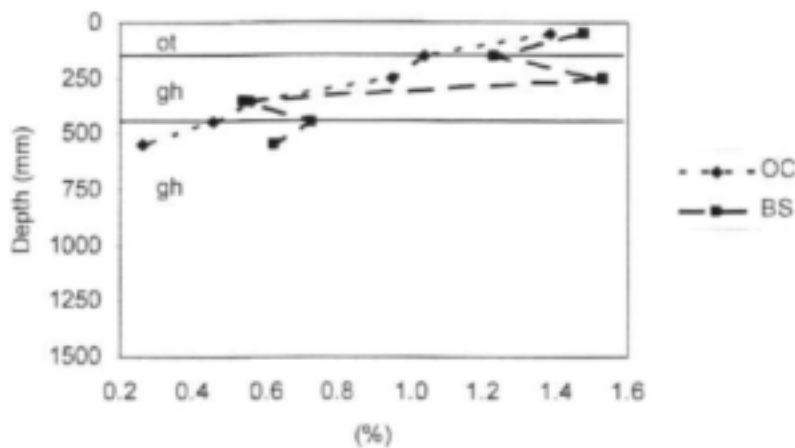


Figure 5.52 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P211 (Katspruit 1000).

Total Fe contents increases slightly from $9\,250\text{ mg kg}^{-1}$ in the orthic A horizon to $10\,900\text{ mg kg}^{-1}$ in the upper G2 horizon and then decreases to $4\,985\text{ mg kg}^{-1}$ lower down (Figure 5.53). The lower Fe content in the G2 horizon can be expected, given the presence of silans in the horizon.

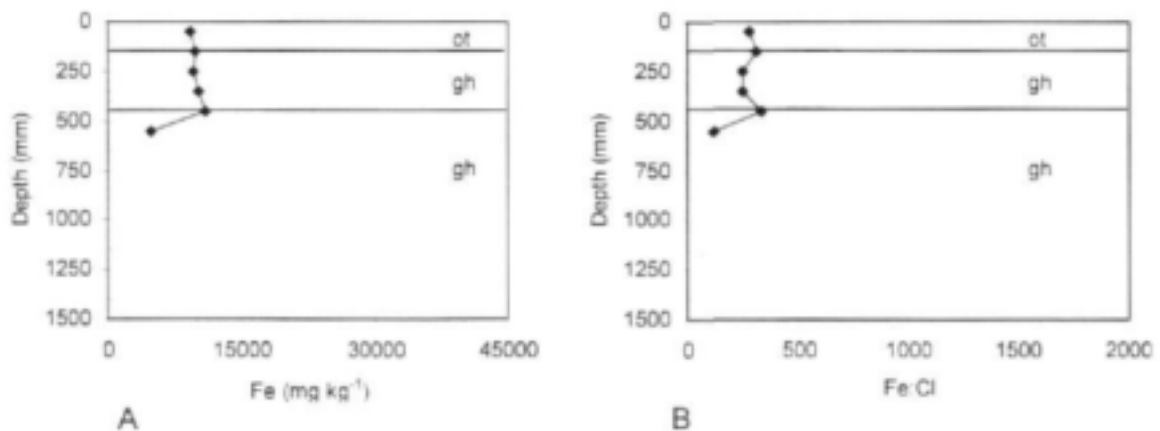


Figure 5.53 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P211 (Katspruit 1000).

5.12.3 Physical properties

Clay content increases from 33 % in the A to 41 % in the lower G1, decreases to 32 % in the upper G2 and then again increases to 42 % (Figure 5.54). The increase in clay content at 750 mm might be due to clay illuviation at this depth. The decreasing clay content in the upper G2 horizon is probably linked to the occurrence of silans.

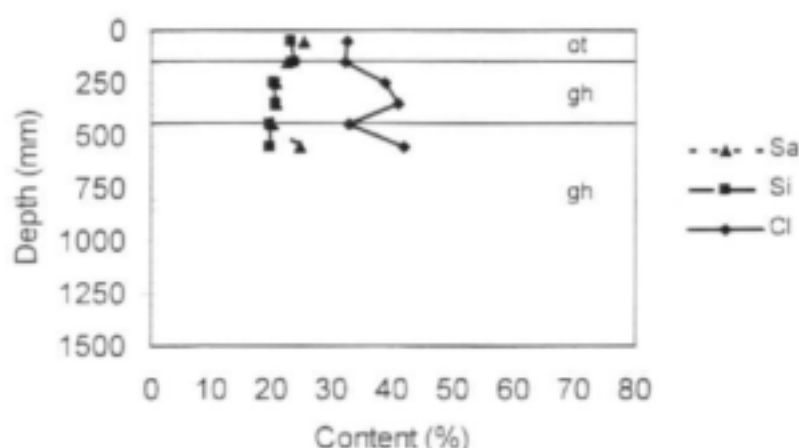


Figure 5.54 Texture of the fine earth in P211 (Katspruit 1000).

5.12.4 Hydrology

Annual duration of $s > 0.7$ ($AD_{s>0.7}$) in the A horizon was 215 days year⁻¹ (Figure 5.55). This increased to 363, 357 and 365 days year⁻¹ in the G1, G2 and G3 horizons. The high durations of $s > 0.7$ were expected, given the location of this profile in the bottom of the landscape (Figure 3.3). The high durations of $s > 0.7$ correlates with the reduced nature of the G horizons, the occurrence of common distinct Fe-oxide mottles and rusty pores.

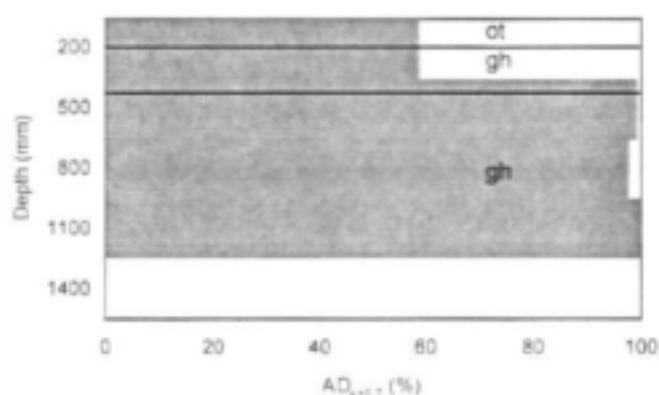


Figure 5.55 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P211 (Katspruit 1000).

5.13 P212 (Tukulu 1110)

5.13.1 Morphology

The profile is situated in an upper midslope position, with a slope of 13 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated above a dolerite dyke. The whole profile has a fine sandy loam texture. The clay increases

slightly throughout the profile (10 – 12 – 18 – 17 %). The profile description and analytical data for this profile are given in Appendix A, Tables 23 and 24. The profile can be classified as Orthi eutric Cambisol (FAO, 1998b) or Oxyaquic Udorthents (Soil Survey Staff, 1999). A dark brown (10YR3/2) orthic A horizon (0–300 mm) overlies a dark yellowish brown (10YR4/4) neocutanic B1 (300–570 mm) on a brown (7.5YR4/4) neocutanic B2 (570–1 300 mm) on brown (7.5YR4/4) unspecified material with signs of wetness (1300–1 500 mm).

5.13.2 Chemical properties

The pH_{Water} is fairly constant throughout the profile, ranging from 5.22 to 5.74 (Figure 5.56). The pH_{KCl} is also fairly constant, ranging from 4.05 to 4.44.

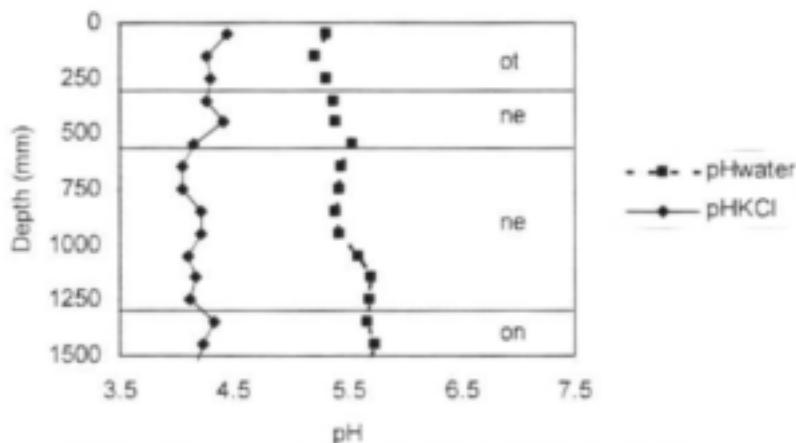


Figure 5.56 pH_{Water} and pH_{KCl} for P212 (Tukulu 1110).

Base saturation decreases slightly from 53 to 34 % down the profile (Figure 5.57), with an increase in the middle of the B1 and unspecified material with signs of wetness. It is associated with a low basic cation content of 1.3 to 1.9 $\text{cmol}_c \text{ kg}^{-1}$ and a low CEC_{soil} (2.4 to 4.0 $\text{cmol}_c \text{ kg}^{-1}$).

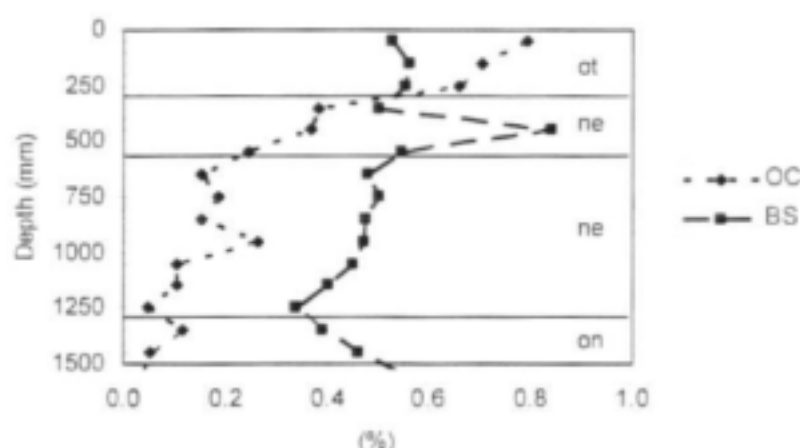


Figure 5.57 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P212 (Tukulu 1110).

Total Fe contents seem to increase down the profile, ranging between 3910 mg kg^{-1} and 12600 mg kg^{-1} (Figure 5.58). A peak occurs in the upper part of the B2 horizon, while the lowest value occurs at a depth of 100 – 200 mm in the A1 horizon. The lack of Fe horization can be expected from these soils, because no removal and / or accumulation of Fe are evident from the morphology. The lack of Fe horization might also be due to even removal or accumulation of Fe in the profile. The decreasing organic carbon content and increasing water saturation probably resulted in this profile not being exposed to sufficiently reduced conditions that could have led to the formation of a soft plinthic or E horizon.

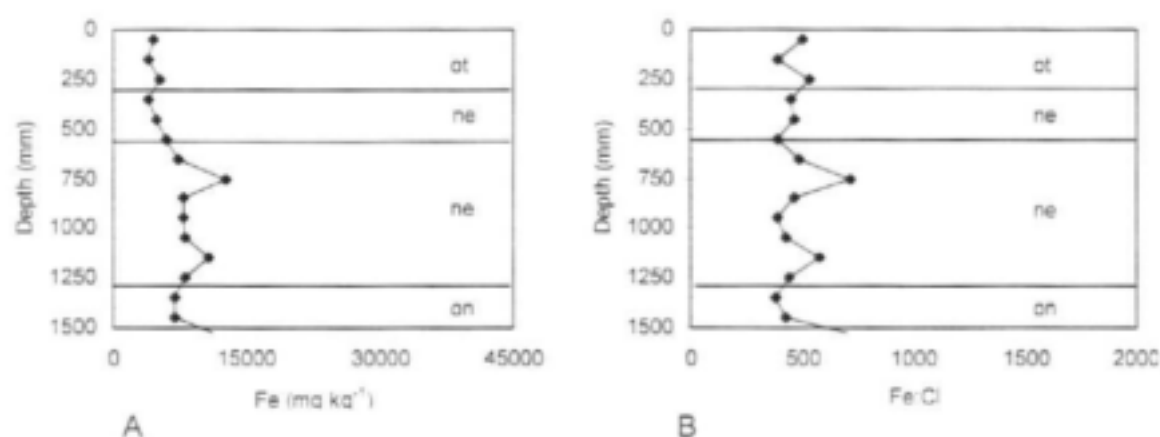


Figure 5.58 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P212 (Tukulu 1110).

5.13.3 Physical properties

Clay content increases down the profile, from 9 % in the A to 20 % in the B2 and then decreases to 16 % in the C (Figure 5.59). The increase in clay content at 1 000 mm might be due to clay illuviation at this depth, while the decreasing clay content in the C horizon is probably due to the slow rate of weathering at this depth.

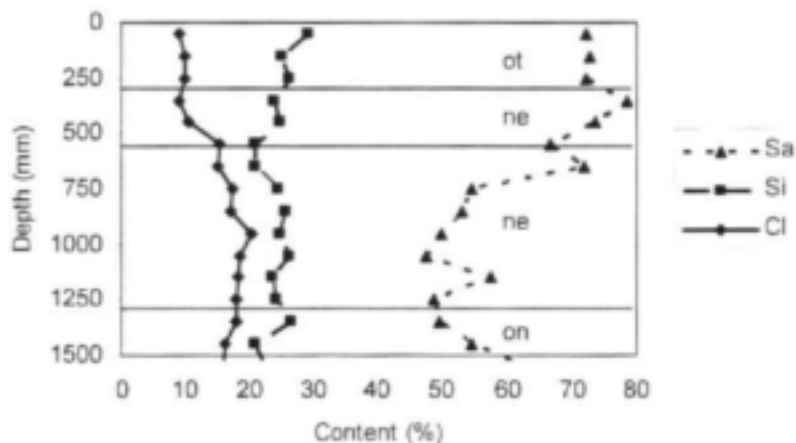


Figure 5.59 Texture of the fine earth in P212 (Tukulu 1110).

5.13.4 Hydrology

This profile was very dry, with an annual duration of $s > 0.7$ ($AD_{s>0.7}$) throughout the profile of less than 4 days year^{-1} (Figure 5.60). The low durations of $s > 0.7$ were expected, given the location of this profile in the upper midslope of the landscape (Figure 3.3). The low durations of $s > 0.7$ correlates with an absence of Fe-oxide mottles.

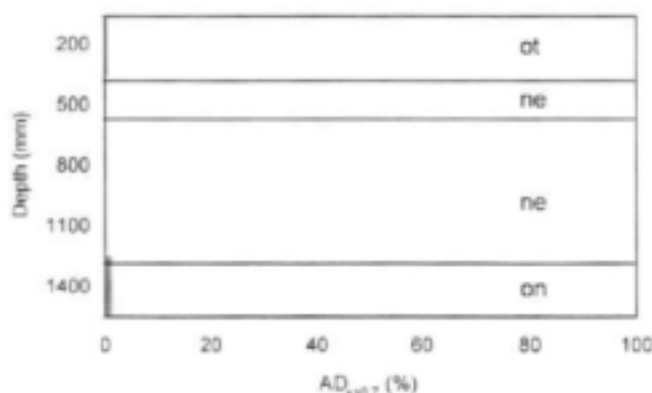


Figure 5.60 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P212 (Tukulu 1110).

5.14 P213 (Katspruit 1000)

5.14.1 Morphology

The profile is situated in an upper footslope position, with a slope of 6 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated above the dolerite dyke. The A horizon has a loam texture, the G1 a clay loam and B2 horizon a loam texture. The clay content is fairly stable throughout the profile (27 – 30 – 27 %), but increases slightly in the G1 horizon. The profile description and analytical data for this profile are given in Appendix A, Tables 25 and 26. The profile can be classified as Orthi eutric Gleysol (FAO, 1998b) or Typic Endoaqualfs (Soil Survey Staff, 1999). A dark brown (10YR3/2) orthic A horizon (0–500 mm) overlies a dark grey (10YR4/1) G1 (500–810 mm) on a dark grey (10YR4/1) G2 horizon (810–1 500 mm).

5.14.2 Chemical properties

The pH_{Water} increases slightly from 5.46 in the topsoil to 6.37 in the lower G2 horizon (Figure 5.61). The pH_{KCl} is somewhat constant throughout the profile ranging between 4.38 in the topsoil and 4.59 in the lower G2 horizon.

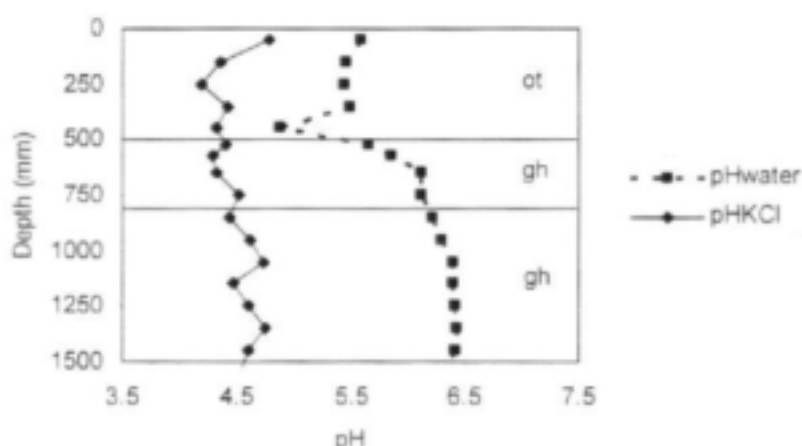


Figure 5.61 pH_{Water} and pH_{KCl} for P213 (Katspruit 1000).

Base saturation ranges between 65 and 100 % (Figure 5.62). It is associated with a basic cation content of 6.3 to 10.5 $cmol_c\ kg^{-1}$, and an increasing CEC_{soil} .

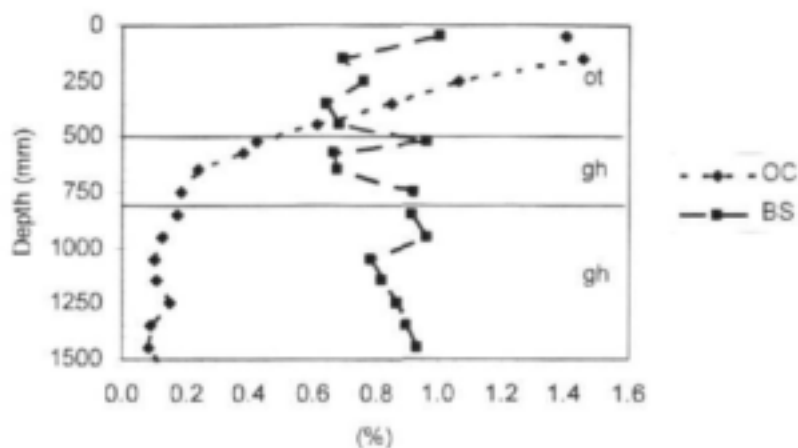


Figure 5.62 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P213 (Katspruit 1000).

Total Fe contents increases from $6\,015\text{ mg kg}^{-1}$ in the upper A horizon to $10\,150\text{ mg kg}^{-1}$ in the upper G1 and then decreases to $5\,000\text{ mg kg}^{-1}$ in the lower G2 horizon (Figure 5.63). There is a marked decrease in Fe just below the upper boundaries of the G1 and G2 horizons. These are probably due to the silans that are Fe depleted.

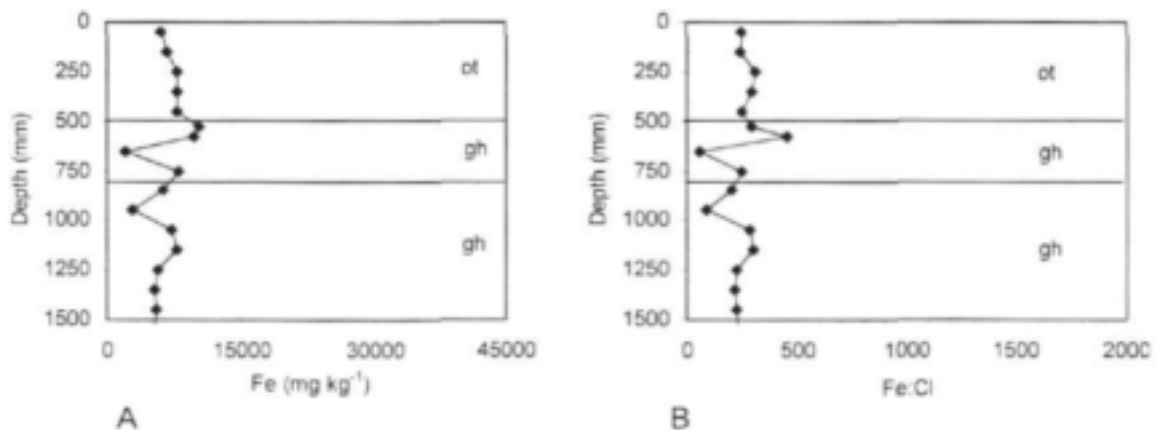


Figure 5.63 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P213 (Katspruit 1000).

5.14.3 Physical properties

Clay content increases in the A horizon to the upper G1, and then decreases slowly down the profile (Figure 5.64). The decrease in clay content at 550 mm might be due to experimental error.

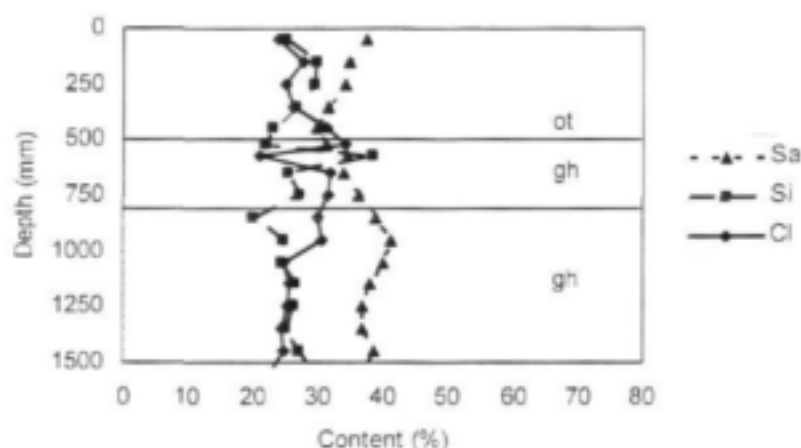


Figure 5.64 Texture of the fine earth in P213 (Katspruit 1000).

5.14.4 Hydrology

Annual duration of $s > 0.7$ ($AD_{s>0.7}$) increased down the profile, from 171 days year⁻¹ in the A horizon to 358 days year⁻¹ in the lower G horizon (Figure 5.65). This profile was located in the midslope of the landscape, close to a local seep (Figure 3.3). The high durations of $s > 0.7$ correlates with the reduced nature of the G horizons, and the occurrence of many distinct Fe-oxide mottles.

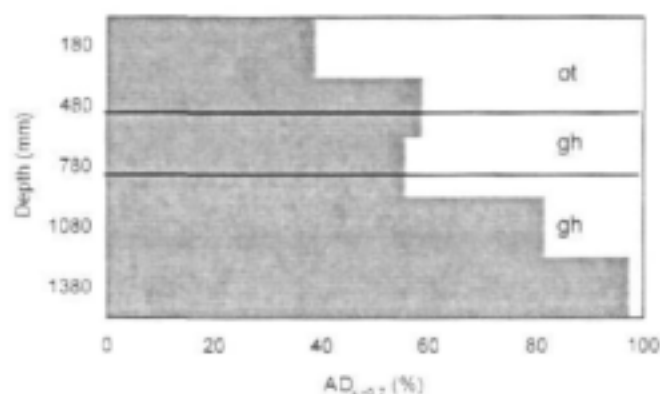


Figure 5.65 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P213 (Katspruit 1000).

5.15 P218 (Katspruit 1000)

5.15.1 Morphology

The profile is situated in a valley bottom position, with a slope of 2 % (Figure 3.3). It probably has mixed Molteno and Elliott sandstone and dolerite as parent material, due to its location in the valley bottom. The A1 and A2 horizons have a loam texture, and the G horizon has a clay loam texture. The clay content increases drastically in the G horizon (19 – 18 – 31 %). The profile description and analytical data for this

profile are given in Appendix A, Tables 27 and 28. The profile can be classified as Orthi eutric Gleysol (FAO, 1998b) or Typic Albaqualfs (Soil Survey Staff, 1999). A dark grey (7.5YR4/1) orthic A1 horizon (0–260 mm) overlies a dark greyish brown (10YR4/2) A2 (260–530 mm) on a strong brown (7.5YR5/6) G horizon (530–800 mm).

5.15.2 Chemical properties

The pH_{Water} and pH_{KCl} decreases from the A1 to the A2 and then increases in the G horizon (Figure 5.66). Average difference between pH_{Water} and pH_{KCl} is 1.20, indicating high reserve acidity. The decrease in pH is associated with a decrease in base saturation, and is a possible indication of the formation of an E horizon.

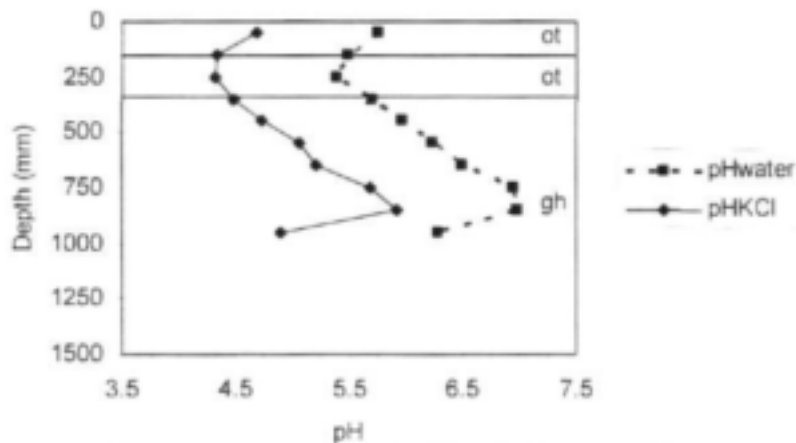


Figure 5.66 pH_{Water} and pH_{KCl} for P218 (Katspruit 1000).

Base saturation follows the same trend as pH, decreasing from 95 % in the A1 to 58 % in the A2 and then increasing to 122 % in the G horizon (Figure 5.67).

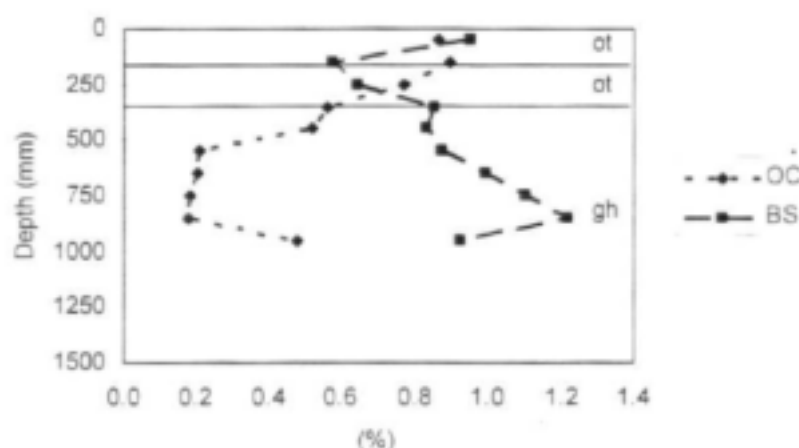


Figure 5.67 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P218 (Katspruit 1000).

Total Fe contents decreases from 5440 mg kg^{-1} in the A1 to 2200 mg kg^{-1} in the A2, increases to 19250 mg kg^{-1} in the upper G and then decreases to 6000 mg kg^{-1} lower in the profile (Figure 5.68). The peak occurs in the upper G horizon is associated with bright yellow colour in the profile (Figure 27 in Appendix A).

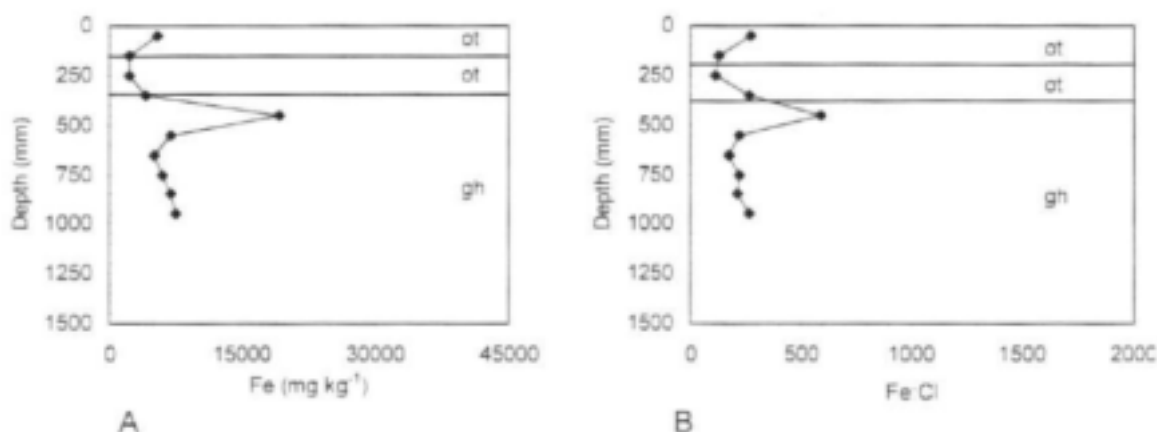


Figure 5.68 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P218 (Katspruit 1000).

5.15.3 Physical properties

Clay content increases from about 20 % in the A horizons to 30 % in the G horizon (Figure 5.69). The increase in clay content in the G horizon is expected, given the cumulative environment of the profile.

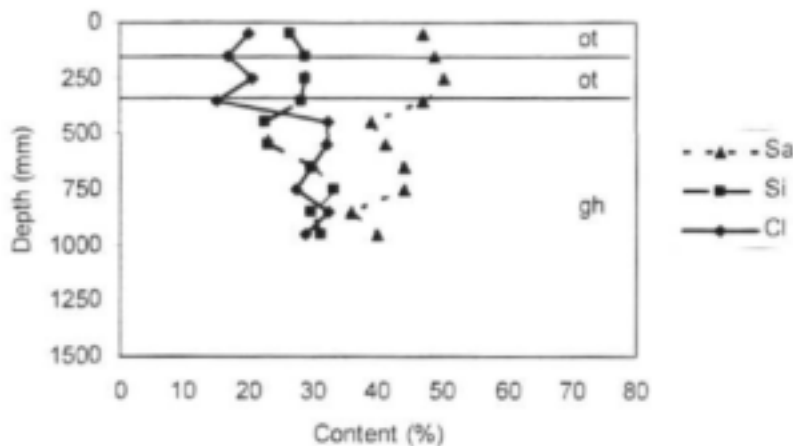


Figure 5.69 Texture of the fine earth in P218 (Katspruit 1000).

5.15.4 Hydrology

Annual duration of $s > 0.7$ ($AD_{s>0.7}$) increased down the profile, from 201 days year⁻¹ in the A horizon to 365 days year⁻¹ in the lower G horizon (Figure 5.70). This is similar, but wetter than P213 (Katspruit 1000). The profile was located in the valley bottom (Figure 3.3), giving rise to the accumulation of water in this locality. The high durations of $s > 0.7$ correlates with the reduced nature of the G horizons, and the occurrence of many prominent Fe-oxide mottles.

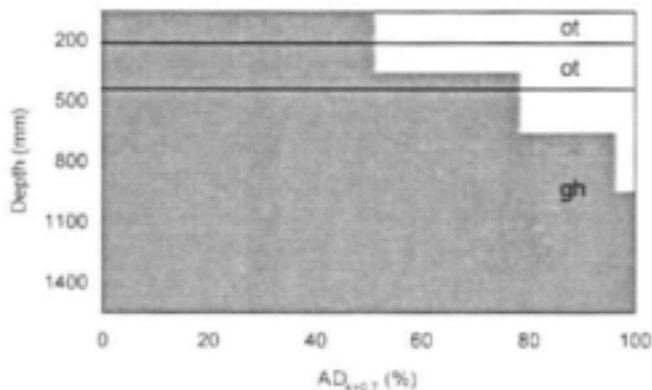


Figure 5.70 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P218 (Katspruit 1000).

5.16 P220 (Bloemdal 2100)

5.16.1 Morphology

The profile is situated in an upper midslope position, with a slope of 13 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated above the dolerite dyke. The whole profile has a sandy loam texture. The clay content is fairly

stable throughout the profile (14 – 15 – 20 – 11 %). The profile description and analytical data for this profile are given in Appendix A, Tables 29 and 30. The profile can be classified as Epidistric Cambisol (FAO, 1998b) or Aquic Ustipsamments (Soil Survey Staff, 1999). A dark brown (7.5YR3/2) orthic A horizon (0–540 mm) overlies a yellowish red (5YR4/6) red apedal B (540–880 mm) on dark reddish brown (5YR3/4) unspecified material with signs of wetness (880–1 080 mm) on reddish brown (5YR4/4) unspecified material with signs of wetness (1 080–1 580 mm).

5.16.2 Chemical properties

The pH_{KCl} decreases throughout the profile, from 4.77 in the upper A horizon to 4.14 in the lower C2 horizon (Figure 5.71). The pH_{Water} also decreases from 5.60 to 5.22 in the upper A horizon, but then slowly increases to 5.90 in the C1 horizon.

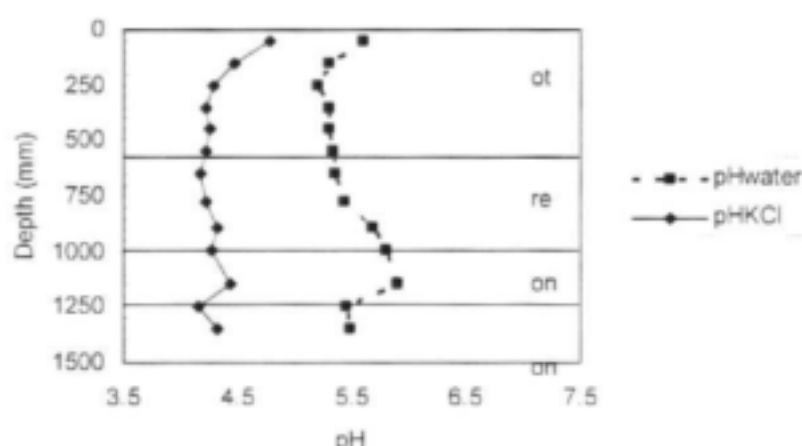


Figure 5.71 pH_{Water} and pH_{KCl} for P220 (Bloemdal 2100).

Base saturation is somewhat constant in the A horizon at 47 %, but then increases to 68 % in the upper C1 before decreasing to 52 % in the C2 horizon (Figure 5.72). This trend is associated with a decreasing basic cation content and CEC_{soil} . The base saturation trend is therefore the result of CEC_{soil} that decreases at a faster rate than the decrease in basic cation concentration.

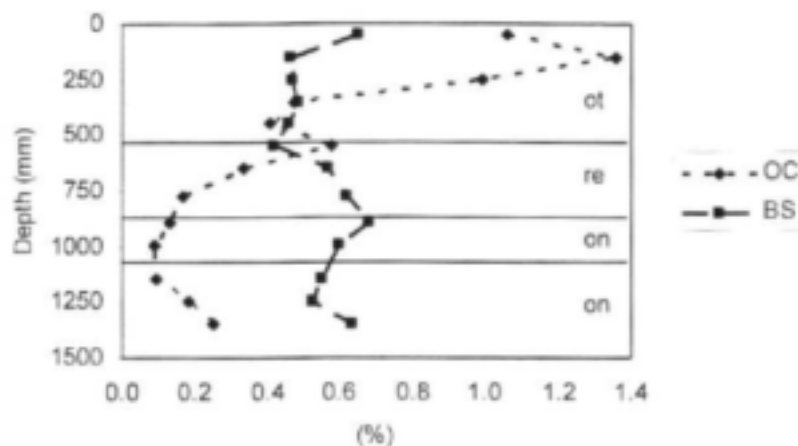


Figure 5.72 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P220 (Bloemdal 2100).

Total Fe contents in the profile increases slowly from 4 560 mg kg⁻¹ in the top of the A horizon to 7 910 mg kg⁻¹ in the lower C2 horizon (Figure 5.73). This pointed to the partial removal Fe from the red apedal B horizon, and accumulation of Fe in the C1 and C2 horizons.

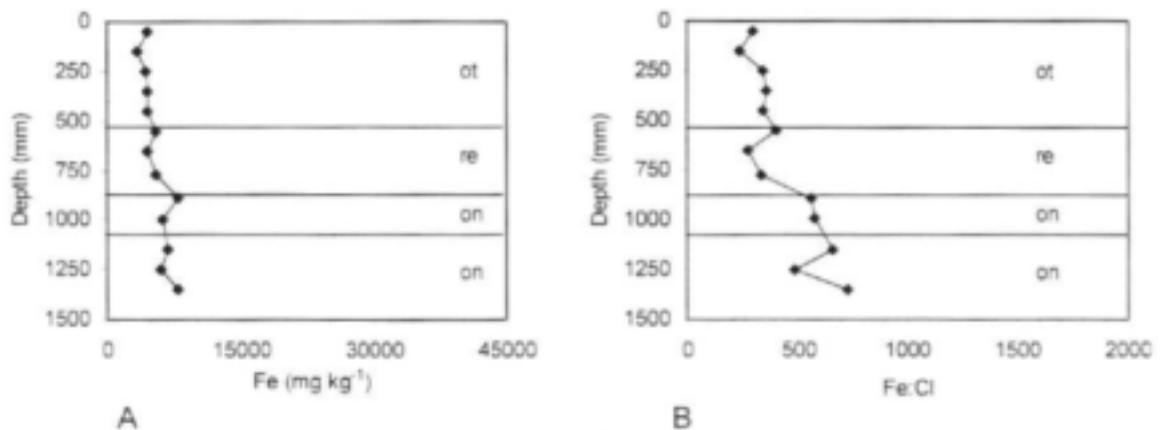


Figure 5.73 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P220 (Bloemdal 1100).

5.16.3 Physical properties

Clay content decreases from 14 % in the A horizon to 11 % in the lower C2 horizon (Figure 5.74). There is a slight increase in clay content in the red apedal B (750 mm), followed by a decrease in the C1 and increase in the C2. The decreasing clay content in C1 might partially be responsible for the grey mottles in this horizon.

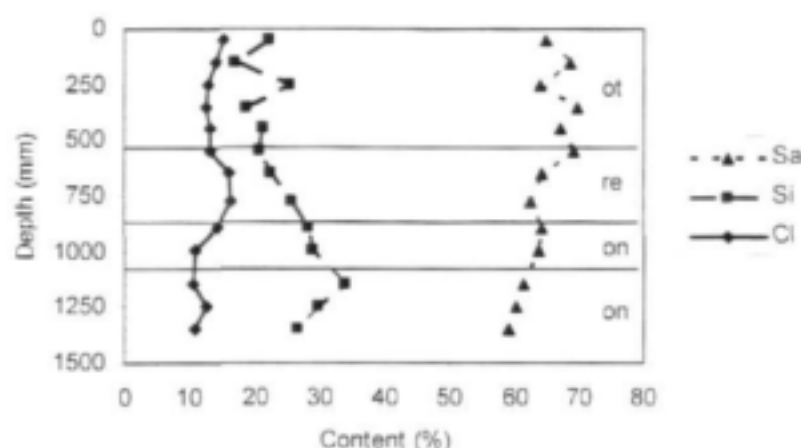


Figure 5.74 Texture of the fine earth in P220 (Bloemdal 2100).

5.16.4 Hydrology

Annual duration of $s > 0.7$ ($AD_{s > 0.7}$) was fairly high in the orthic A horizon (81 and 152 days year⁻¹), decreased to 0 days year⁻¹ in the red apedal B horizon and then increased to 300 days year⁻¹ in the lower unspecified material with signs of wetness (Figure 5.75). This profile was located in the upper midslope of the landscape, and probably gave rise to the dry nature thereof (Figure 3.3). The high duration of $s > 0.7$ in the orthic A horizon was unexpected, also given the absence of any mottling. The absence of saturation in the red apedal B was expected and also correlated with an absence in Fe-oxide mottling. The high duration of $s > 0.7$ in the unspecified material with signs of wetness was expected and correlated with the occurrence of many distinct Fe-oxide mottles. The high duration of $s > 0.7$ in the orthic A horizon can possibly be attributed to the high bulk density ($1.73 - 1.79 \text{ Mg m}^{-3}$) there, resulting in a low porosity and therefore little water needed to exceed $s > 0.7$. The bulk density in the B1 horizon is 1.63 Mg m^{-3} , resulting in a much higher porosity.

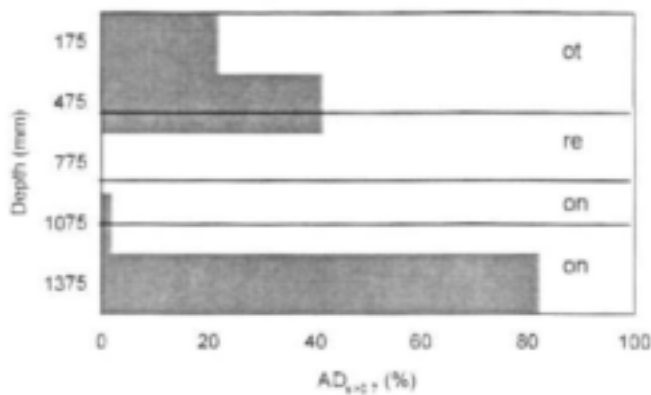


Figure 5.75 Mean $AD_{S>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P220 (Bloemdal 2100).

5.17 P221 (Hutton 2100)

5.17.1 Morphology

The profile is situated in an upper footslope position, with a slope of 10 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated below the dolerite dyke. The A and B1 horizons have a loam texture, while the B2 and C horizons have a sandy clay loam texture. The clay content is fairly stable in the A and B1 horizons, but increases markedly in the B2 and C horizons (17 – 19 – 31 – 33 %). The profile description and analytical data for this profile are given in Appendix A, Tables 31 and 32. The profile can be classified as Orthi-district Cambisol (FAO, 1998b) or Typic Ustorthents (Soil Survey Staff, 1999). A dark reddish brown (2.5YR3/4) orthic A horizon (0–250 mm) overlies a dark brown (7.5YR3/2) red apedal B1 (250–580 mm) on a dark reddish brown (2.5YR3/4) red apedal B2 (580–1 250 mm) on dark reddish brown (2.5YR3/4) unspecified material with signs of wetness (1 250–1 800 mm).

5.17.2 Chemical properties

The pH_{Water} is somewhat constant throughout the profile, ranging from 5.40 in the A horizon to 5.53 in the lower C horizon (Figure 5.76). The pH_{KCl} is also somewhat constant throughout the profile, ranging from 4.46 in the topsoil to 4.85 in the lower C horizon.

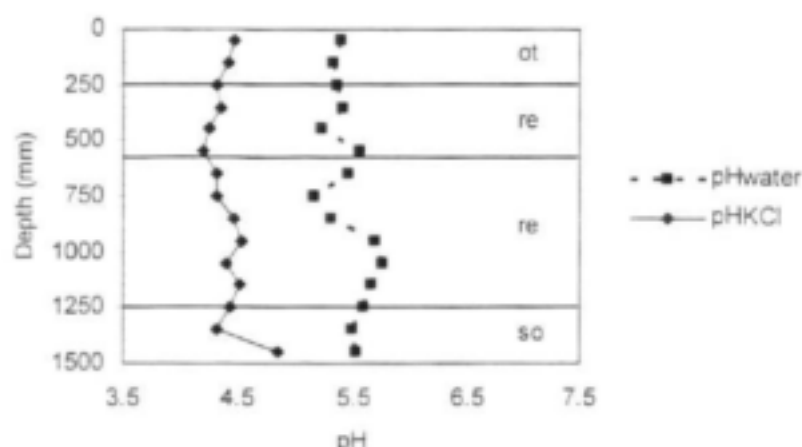


Figure 5.76 pH_{Water} and pH_{KCl} for P221 (Hutton 2100).

Base saturation increases slightly from 50 to 59 % throughout the profile (Figure 5.77). There is a slight decrease at 450 and 850 mm. The former is associated with a decrease in basic cation content, while the latter is associated with and increase in CEC_{soil} .

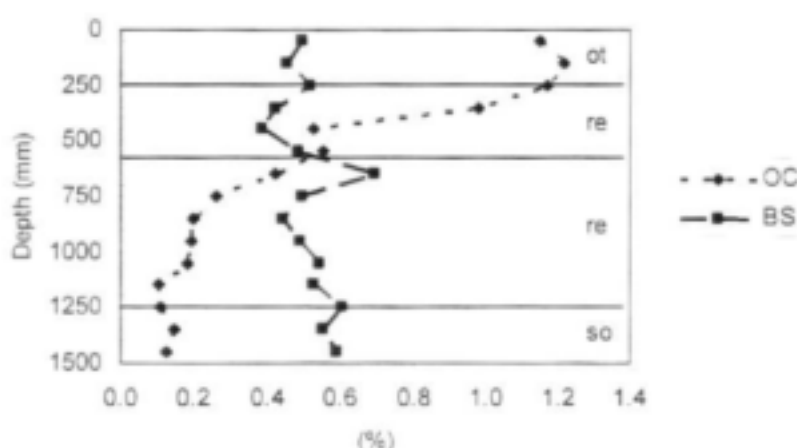


Figure 5.77 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P221 (Hutton 2100).

Total Fe contents increases from $5\,370\text{ mg kg}^{-1}$ in the A horizon to $10\,250\text{ mg kg}^{-1}$ in the lower C horizon (Figure 5.78). Peak accumulations occur in the B1 ($14\,250\text{ mg kg}^{-1}$) and B2 ($16\,150\text{ mg kg}^{-1}$) horizons.

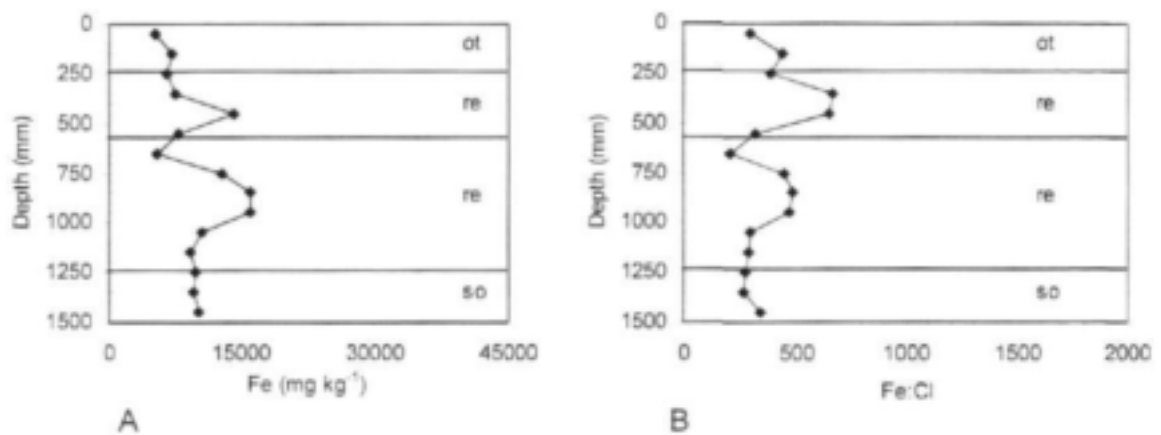


Figure 5.78 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P221 (Hutton 2100).

5.17.3 Physical properties

Clay content increases from 17 % in the A to 33 % in the C horizon (Figure 5.79). A slight decrease occurs in the upper B1 horizon, but is probably due to experimental error.

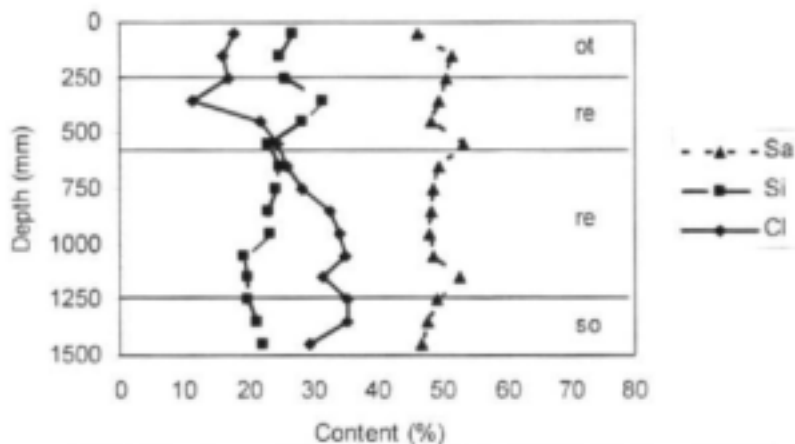


Figure 5.79 Texture of the fine earth in P221 (Hutton 2100).

5.17.4 Hydrology

Annual duration of $s > 0.7$ ($AD_{s>0.7}$) decreased from 99 days year⁻¹ in the A horizon to 0 and 1 day per year in the red apedal B1 and B2 horizons and then increased to 11 days year⁻¹ in the lower B2 horizon and 10 days year⁻¹ in the unspecified material with signs of wetness (Figure 5.80). The short durations of $s > 0.7$ correlates with the absence of Fe-oxide mottles.

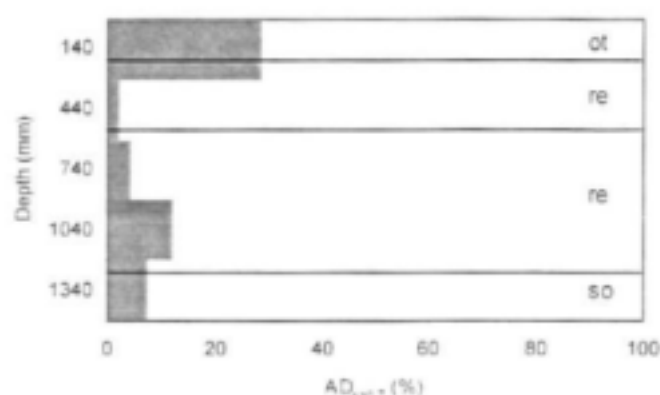


Figure 5.80 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P221 (Hutton 2100).

5.18 P222 (Oakleaf 1210)

5.18.1 Morphology

The profile is situated in a lower midslope position, with a slope of 10 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated below the dolerite dyke. The A1, B1 and C horizons have a loam texture, while the B2 horizon has a clay loam texture. The clay content increases slightly throughout the profile (20 – 23 – 28 – 20 %). The profile description and analytical data for this profile are given in Appendix A, Tables 33 and 34. The profile can be classified as Endo eutric Cambisol (FAO, 1998b) or Typic Ustorthents (Soil Survey Staff, 1999). A dark brown (7.5YR3/2) orthic A horizon (0–260 mm) overlies a dark reddish brown (5YR3/4) neocutanic B1 (260–530 mm) on a dark reddish brown (2.5YR3/4) neocutanic B2 (530–800 mm) on yellowish red (5YR5/8) unspecified material with signs of wetness (1 200–1580 mm).

5.18.2 Chemical properties

The pH_{Water} decreases from 5.46 in the A to 5.19 in the B1 horizon and then increases to 5.97 in the lower C horizon (Figure 5.81). The pH_{KCl} decreases from 4.62 in the A horizon to 5.94 at 1 500 mm. A peak of 4.87 occurs at 550 mm.

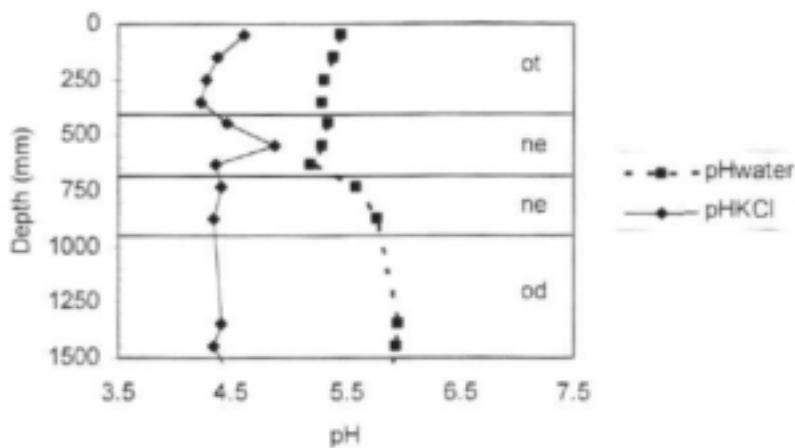


Figure 5.81 pH_{Water} and pH_{KCl} for P222 (Oakleaf 1210).

Base saturation decreases from 66 % in the topsoil to 42 % in the B1 horizon (450 mm) and then increases to 85 % in the C horizon (Figure 5.82). The base saturation is associated with first a decreasing and then increasing sum of basic cations and CEC_{soil} .

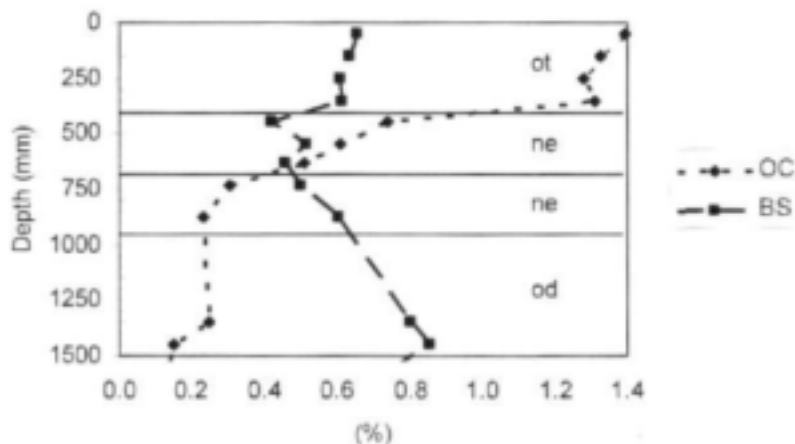


Figure 5.82 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P222 (Oakleaf 1210).

Total Fe contents is constant at $7\,900\text{ mg kg}^{-1}$ in the A horizon. It then increases to $15\,550\text{ mg kg}^{-1}$ in the B1, before decreasing to $12\,750\text{ mg kg}^{-1}$ in the B2 and $7\,790\text{ mg kg}^{-1}$ in the C horizon (Figure 5.83).

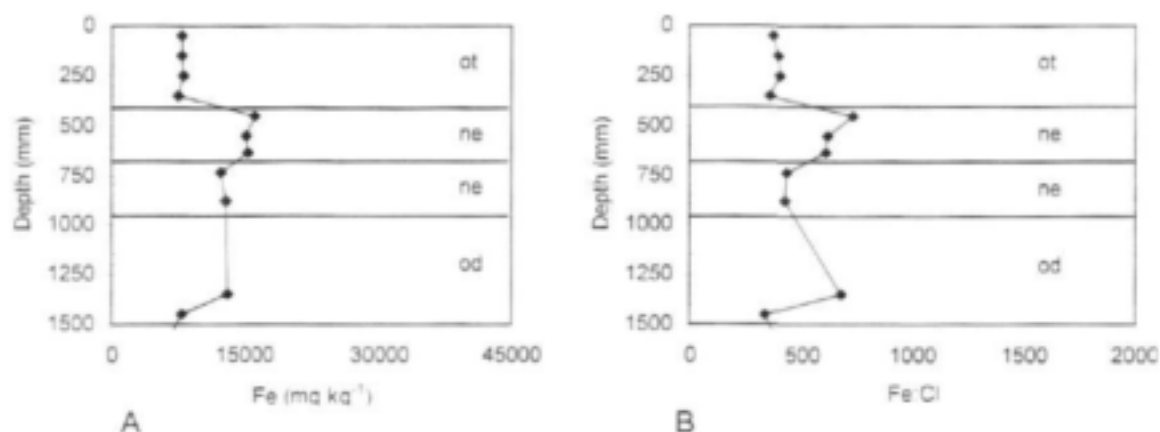


Figure 5.83 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P222 (Oakleaf 1210).

5.18.3 Physical properties

Clay content increases from 21 % in the top of the A horizon to 30 % in the lower B2 horizon. It then decreases to 20 % at 1 500 mm (Figure 5.84). The increase in clay content is probably due to clay illuviation.

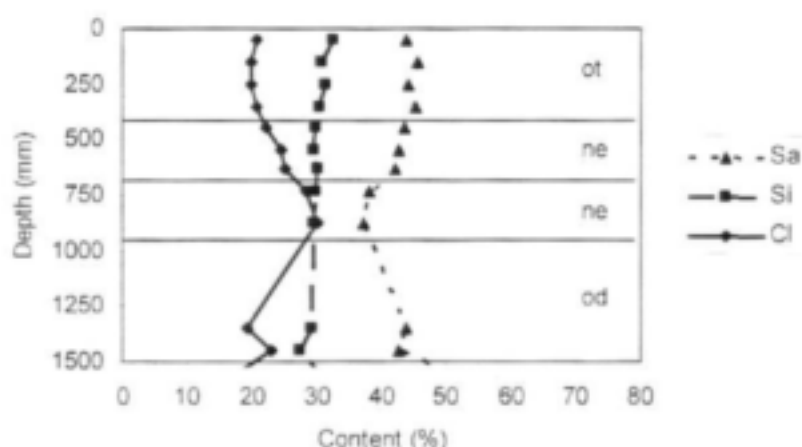


Figure 5.84 Texture of the fine earth in P222 (Oakleaf 1210).

5.18.4 Hydrology

Annual duration of $s > 0.7$ decreased from 171 days year⁻¹ in the orthic A horizon to 80 days year⁻¹ in the neocutanic B1 and then increased to 164 days year⁻¹ in the neocutanic B2 and 365 days year⁻¹ in the unspecified material with signs of wetness (Figure 5.85). The relatively high $AD_{s > 0.7}$ values in the B horizons were unexpected, but correlated with few distinct Fe-oxide mottles.

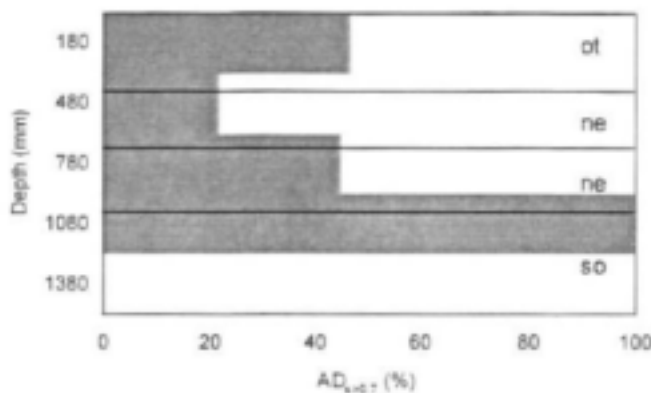


Figure 5.85 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P222 (Oakleaf 1210).

5.19 P225 (Longlands 1000)

5.19.1 Morphology

The profile is situated in a midslope position, with a slope of 5 % (Figure 3.3). It has Molteno sandstone as parent material. The A, E2 and B horizons have a sandy loam texture, while the E1 horizon have a loam and the C horizon a sandy clay loam texture. The clay content is fairly stable, with a slight increase down the profile (13 – 17 – 15 – 21 – 25 %). The profile description and analytical data for this profile are given in Appendix A, Tables 35 and 36. The profile can be classified as Ferric-Endo eutric Albeluvisol (FAO, 1998b) or Aeric Endoaquents (Soil Survey Staff, 1999). A very dark greyish brown (10YR3/2) orthic A horizon (0–340 mm) overlies a dark greyish brown (10YR4/2) E1 (340–560 mm) on a greyish brown (10YR5/2) E2 (560–840 mm) on an yellowish red (5YR4/6) soft plinthic B (840–1 220 mm) on yellowish red (5YR4/6) unspecified material with signs of wetness (1 220–1 640 mm).

5.19.2 Chemical properties

The pH_{Water} increases from 5.34 in the A horizon to 6.46 at 1 600 mm (Figure 5.86). The pH_{KCl} decreases slightly from 4.48 in the A horizon to 4.22 in the E2 horizon and then increases to 4.99 in the lower soft plinthic B and unspecified material with signs of wetness (1 400 mm).

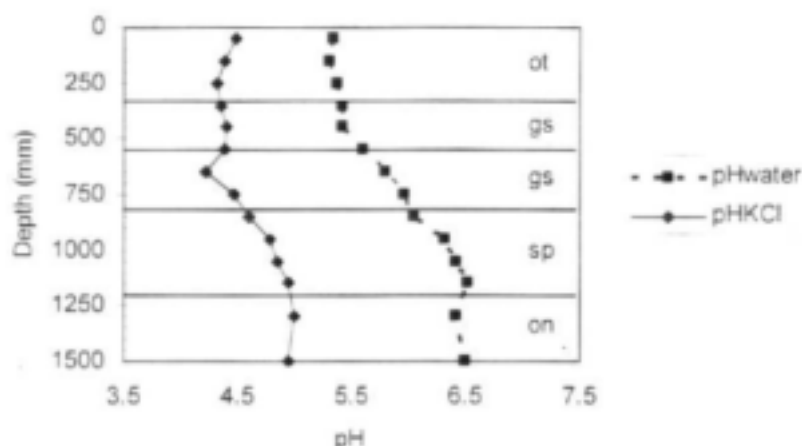


Figure 5.86 pH_{Water} and pH_{KCl} for P225 (Longlands 1000).

Base saturation decreases slightly in the A horizon (from 52 to 31 %) and then increase to 88 % in the bottom of the profile (Figure 5.87). This pattern is associated with decreasing basic cation content and a decreasing CEC_{soil} .

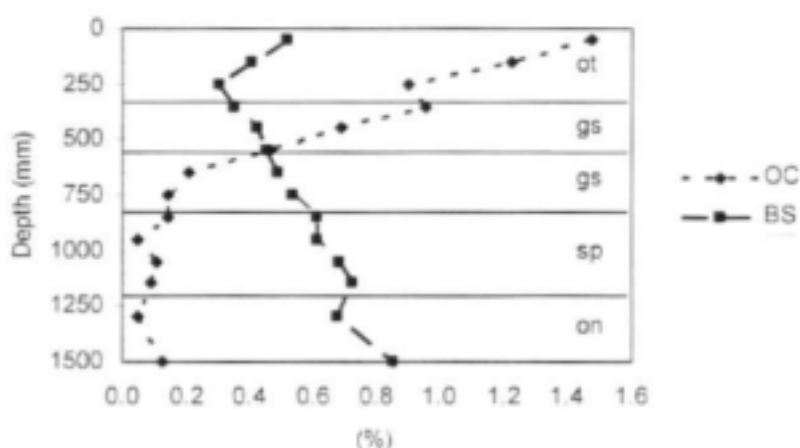


Figure 5.87 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P225 (Longlands 1000).

Total Fe contents is low in the A horizon ($3\,700\text{ mg kg}^{-1}$). It is higher in the E horizons ($6\,700$ to $10\,000\text{ mg kg}^{-1}$) and then increases to $12\,200\text{ mg kg}^{-1}$ lower in the profile (Figure 5.88).

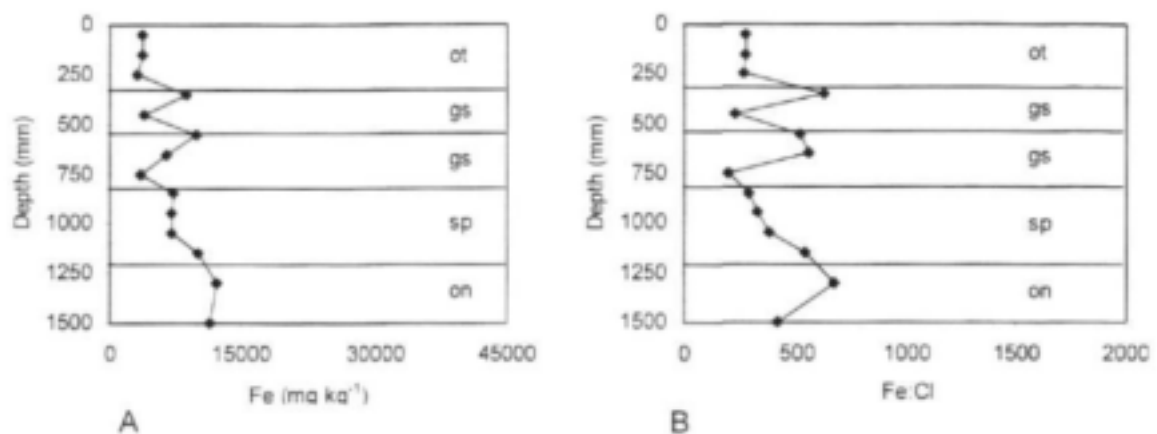


Figure 5.88 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P225 (Longlands 1000).

5.19.3 Physical properties

Clay content increases from 14 % in the A to 19 % in the E1, decreases to 12 % in the E2 and is then fairly constant further down at 19 % (Figure 5.89).

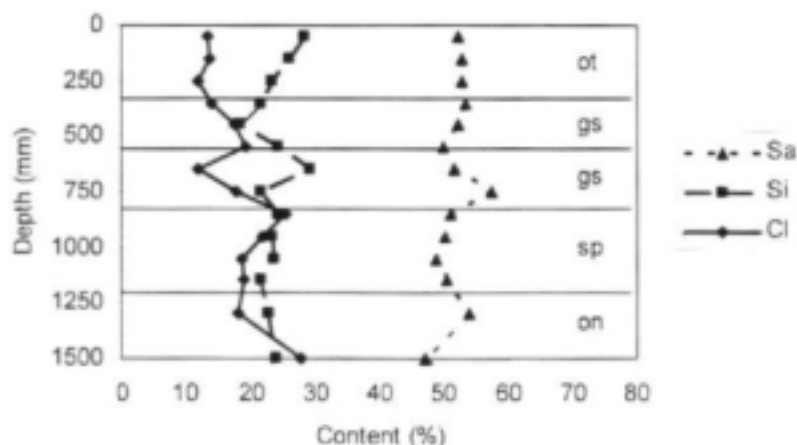


Figure 5.89 Texture of the fine earth in P225 (Longlands 1000).

5.19.4 Hydrology

Annual duration of $s > 0.7$ increased from 38 days year^{-1} in the orthic A horizon to 121 days year^{-1} in the E horizon, 220 days year^{-1} in the soft plinthic B and 255 days year^{-1} in the unspecified material with signs of wetness (Figure 5.90). The relatively high $\text{AD}_{s > 0.7}$ values in the E and B horizons correlated with few faint and many prominent Fe-oxide mottles.

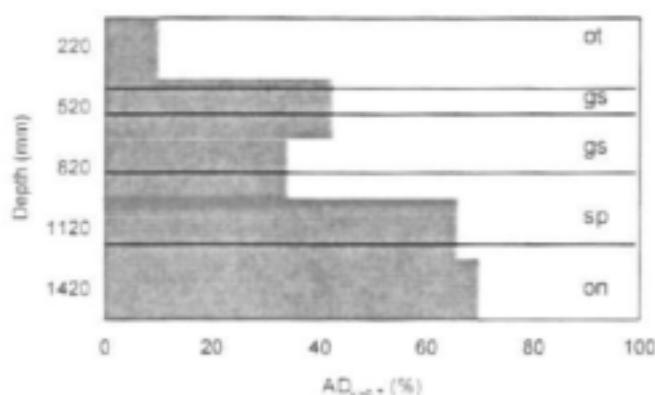


Figure 5.90 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P225 (Longlands 1000).

5.20 P226 (Kroonstad 1000)

5.20.1 Morphology

The profile is situated in an upper footslope position, with a slope of 4 % (Figure 3.3). It has Molteno sandstone as parent material. The A, E1 and E2 horizons have a sandy loam texture, while the G horizon has a sandy clay loam texture. The clay content increases slightly down the profile (10 – 10 – 13 – 21 %). The profile description and analytical data for this profile are given in Appendix A, Tables 37 and 38. The profile can be classified as Gleyic-Albic Planosol (FAO, 1998b) or Aeric Endoaquents (Soil Survey Staff, 1999). A very dark grey (10YR3/1) orthic A horizon (0–200 mm) overlies a very dark grey (10YR3/1) E1 (200–500 mm) on a very dark grey (10YR3/1) E2 (500–740 mm) on a dark greyish brown (10YR4/2) G horizon (740–1 000 mm).

5.20.2 Chemical properties

The pH_{Water} is between 5.22 and 5.66 in the A horizon, decreases to 4.87 in the E1 and then slowly increases to 5.93 in the G horizon (Figure 5.91). The pH_{KCl} decreases from 4.68 in the A horizon to 3.98 at the top of the E2 horizon. It then increases with depth to 4.43.

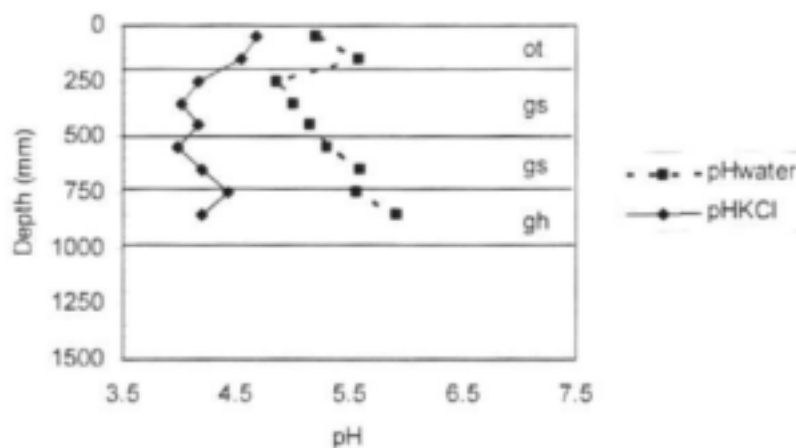


Figure 5.91 pH_{Water} and pH_{KCl} for P226 (Kroonstad 1000).

Base saturation decreases from 97 % in the A horizon to 30 % in the E1 and E2 horizons and then increases to 70 % in the G horizon (Figure 5.92). This trend is associated with a decreasing and then increasing basic cation content and CEC_{soil} .

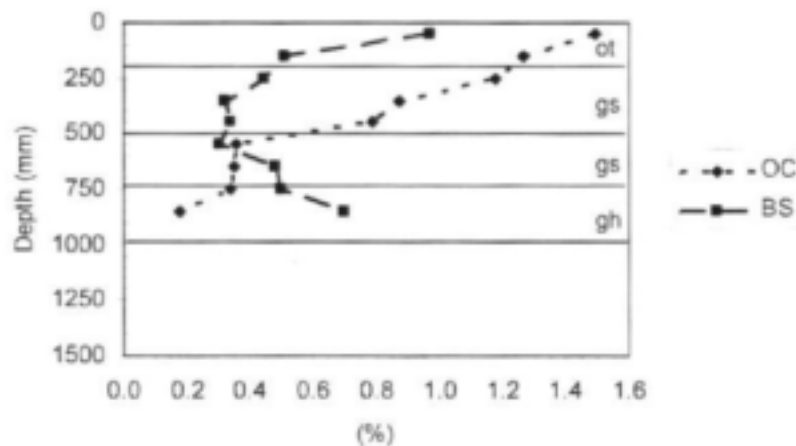


Figure 5.92 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P226 (Kroonstad 1000).

Total Fe contents decreases from a high of $25\,000\text{ mg kg}^{-1}$ in the A horizon to $3\,500\text{ mg kg}^{-1}$ in the G horizon (Figure 5.93).

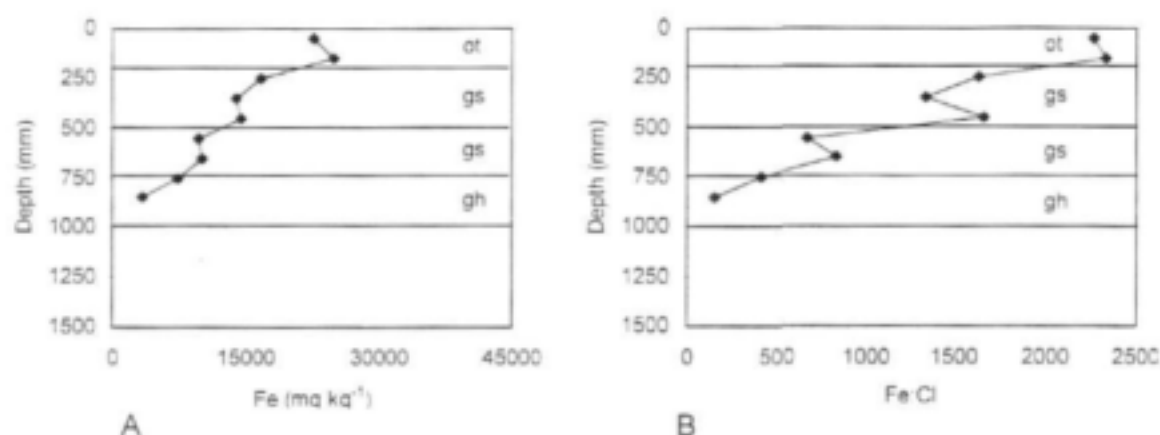


Figure 5.93 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P226 (Kroonstad 1000).

5.20.3 Physical properties

Clay content increases from 10 % in the A and E1 horizons to 13 % in the E2 and 21 % in the G horizons (Figure 5.94). Although the clay content is low in the E horizons, there is no nett removal of colloidal material as specified by the Soil Classification Working Group (1991).

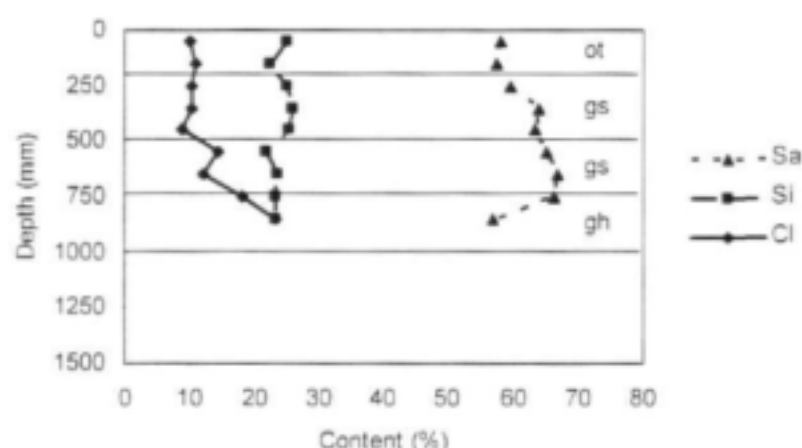


Figure 5.94 Texture of the fine earth in P226 (Kroonstad 1000).

5.20.4 Hydrology

Annual duration of $s > 0.7$ increased from 268 days year⁻¹ in the orthic A horizon to 360 days year⁻¹ in the E horizon and 365 days year⁻¹ in the G horizons (Figure 5.95). The high $AD_{s>0.7}$ values in the profile were unexpected, given the location of the profile in the footslope, the G horizon morphology and the occurrence of many distinct Fe-oxide mottles.

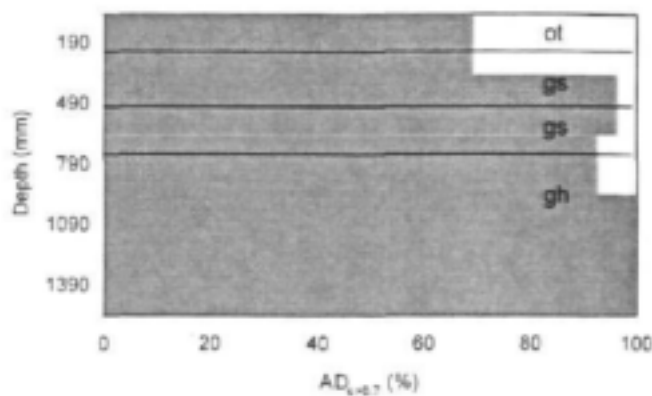


Figure 5.95 Mean $AD_{S>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P226 (Kroonstad 1000).

5.21 P229 (Kroonstad 1000)

5.21.1 Morphology

The profile is situated in an upper midslope position, with a slope of 13 % (Figure 3.3). It has Molteno sandstone as parent material. The A, E1 E2 and E3 horizons have a sandy loam texture, while the G horizon has a sandy clay loam texture. The clay content decreases from the A to the E1 and E2 and then increases to the E3 and G horizons (14 – 12 – 11 – 15 – 26 %). The profile description and analytical data for this profile are given in Appendix A, Tables 39 and 40. The profile can be classified as Gleyic-Albic Planosol (FAO, 1998b) or Aeris Endoaquents (Soil Survey Staff, 1999). A very dark grey (7.5YR3/0) orthic A horizon (0–190 mm) overlies a very dark grey (7.5YR3/0) E1 (190–450 mm) on a dark grey (7.5YR4/0) E2 (450–540 mm) on a dark grey (7.5YR4/0) E3 (540–1 000 mm) on a strong brown (7.5YR5/6) G horizon (1 000–1500 mm).

5.21.2 Chemical properties

The pH_{Water} decreases from 5.80 in the A horizon to 5.14 in the upper E1 and then increases to 5.81 in the lower E3 horizon (Figure 5.96). The pH_{KCl} also decreases from 4.91 in the A horizon to 4.14 in the E1 and then increases to 4.46 in the lower E3 horizon.

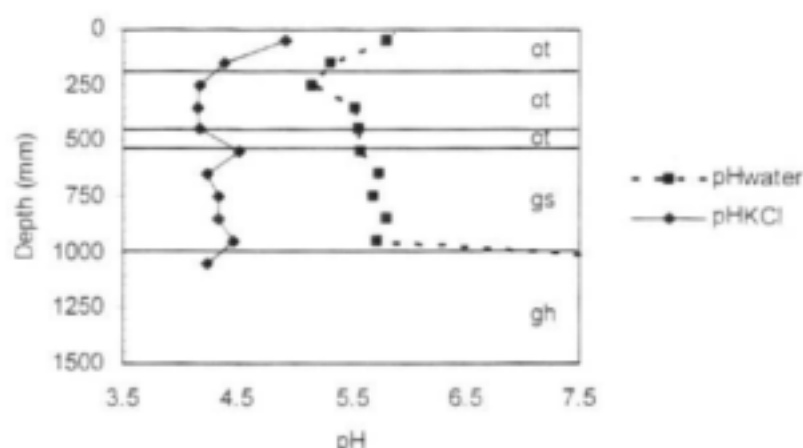


Figure 5.96 pH_{Water} and pH_{KCl} for P229 (Kroonstad 1000).

Base saturation decreases from 68 % in the A to 38 % in the E1 and then increases to 82 % in the G horizon (Figure 5.97). This is associated with a similar pattern in basic cation content and CEC_{soil} .

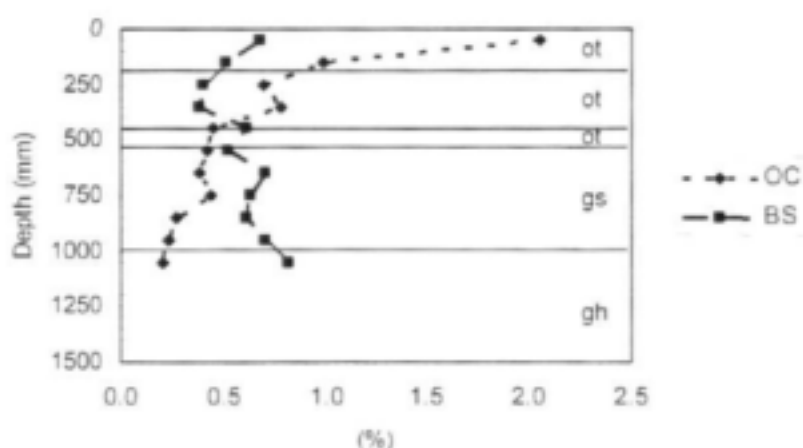


Figure 5.97 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P229 (Kroonstad 1000).

Total Fe contents decrease from $14\,000\text{ mg kg}^{-1}$ in the A horizon to $7\,375\text{ mg kg}^{-1}$ in the upper E1, but then increases to roughly $18\,000\text{ mg kg}^{-1}$ in the E2 and E3 horizons (Figure 5.98). It is therefore only in the upper E1 that removal of sesquioxides have taken place.

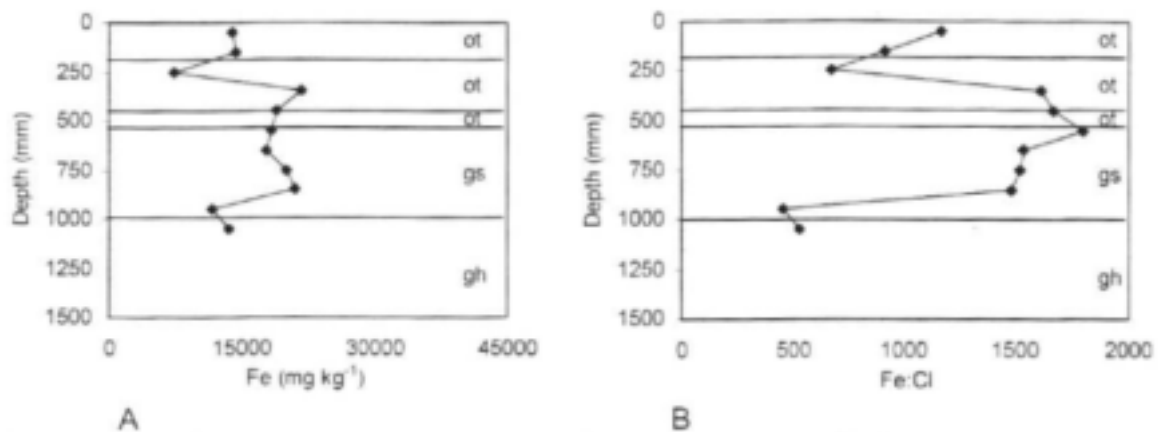


Figure 5.98 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P229 (Kroonstad 1000).

5.21.3 Physical properties

Clay content is somewhat uniform throughout the A, E1, E2 and E3 horizons, ranging between 11 % and 14 %, only increasing to 26 % in the G horizon (Figure 5.99).

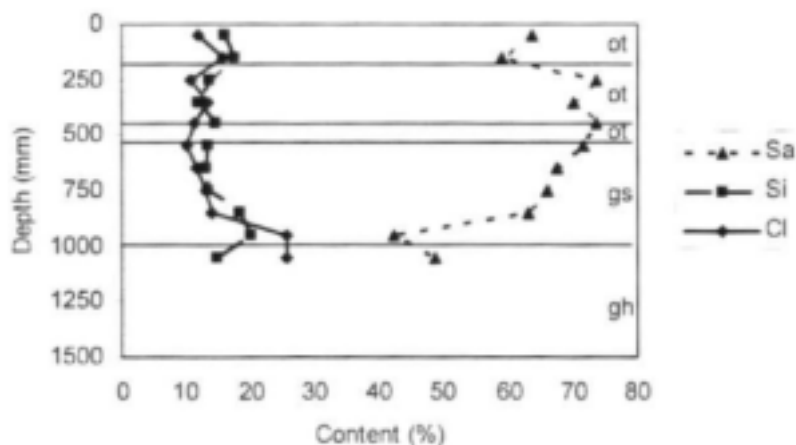


Figure 5.99 Texture of the fine earth in P229 (Kroonstad 1000).

5.21.4 Hydrology

Annual duration of $s > 0.7$ increased from 234 days year⁻¹ in the upper orthic A horizon to 359 days year⁻¹ in the lower orthic A and E horizons and 365 days year⁻¹ in the G horizons (Figure 5.100). The relatively high $AD_{s > 0.7}$ values in the profile were expected, given the location thereof in a local seep on the upper midslope, and correlated with the E and G horizon morphology and the occurrence of many prominent Fe-oxide mottles.

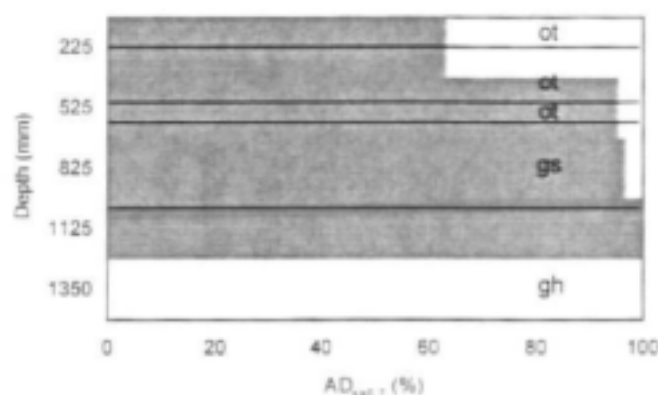


Figure 5.100 Mean $AD_{S>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P229 (Kroonstad 1000).

5.22 P230 (Westleigh 1000)

5.22.1 Morphology

The profile is situated in a lower footslope position, with a slope of 5 % (Figure 3.3). It has Molteno sandstone as parent material. The A and B horizons have a fine sandy loam texture, while the C1 and C2 horizons have a clay loam texture. The clay content increases down the profile (12 – 18 – 29 – 29 %). The profile description and analytical data for this profile are given in Appendix A, Tables 41 and 42. The profile can be classified as Ferric-Epidistric Gleysol (FAO, 1998b) or Aeric Endoaquents (Soil Survey Staff, 1999). A weak red (2.5YR4/2) orthic A horizon (0–400 mm) overlies a yellowish brown (10YR5/4) soft plinthic B (400–650 mm) on light yellowish brown (10YR6/4) (650–870 mm) unspecified material with signs of wetness on light brownish grey (10YR6/2) unspecified material with signs of wetness (870–1 680 mm)

5.22.2 Chemical properties

The pH_{Water} and pH_{KCl} increase down the profile, with a peak in the G1 horizon (Figure 5.101). pH_{Water} increases from 5.26 to 6.85 while pH_{KCl} increases from 4.40 to a high of 5.50.

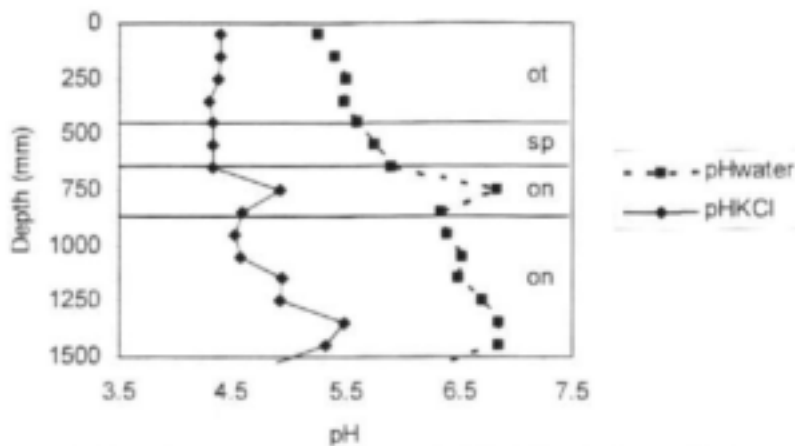


Figure 5.101 pH_{Water} and pH_{KCl} for P230 (Westleigh 1000).

Base saturation increases from 53 % in the A horizon to 74 % in the B and 118 % in the G horizon (Figure 5.102). This pattern is associated with a basic cation content and CEC_{soil} .

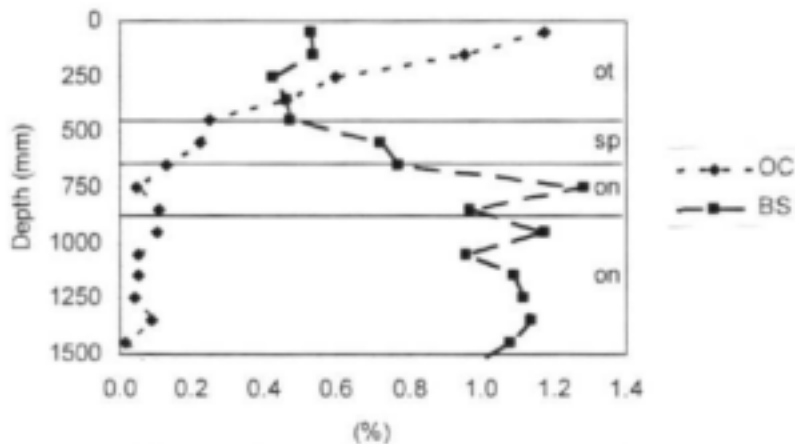


Figure 5.102 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P230 (Westleigh 1000).

Total Fe contents decreases from $17\,399\text{ mg kg}^{-1}$ in the A horizon to $5\,345\text{ mg kg}^{-1}$ in the soft plinthic B and then increases to $9\,333\text{ mg kg}^{-1}$ and $9\,425\text{ mg kg}^{-1}$ in the G1 and G2 (Figure 5.103). This analysis does not support the classification of the soft plinthic B horizon, but rather suggests the presence of an E horizon, where nett removal of Fe has taken place.

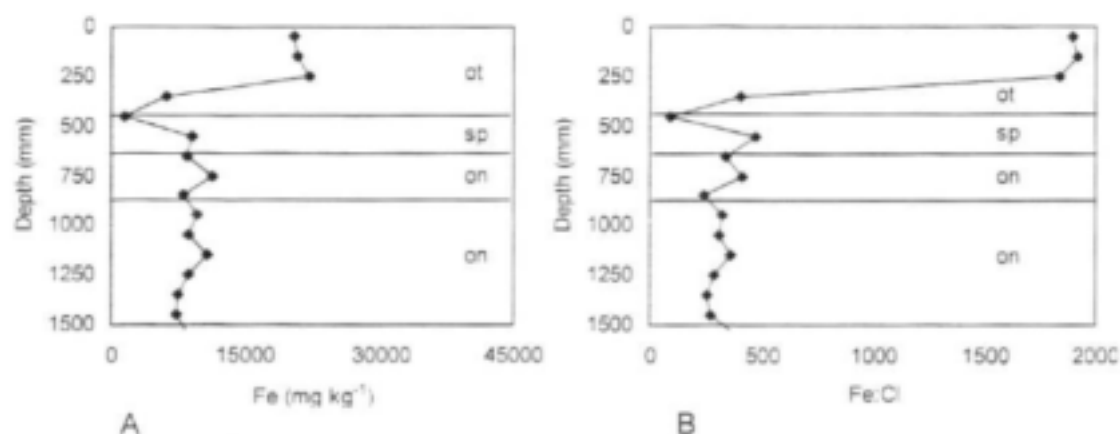


Figure 5.103 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P230 (Westleigh 1000).

5.22.3 Physical properties

Clay content almost increases linearly from 12 % in the A horizon to 29 % in the G1 and G2 horizons (Figure 5.104). The high clay content in the G horizons is expected, but not in the soft plinthic B, where clay normally degrades due to ferrollysis. The higher clay content in the B horizon does not support the argument for the classification of an E horizon, indicated by Fe analyses.

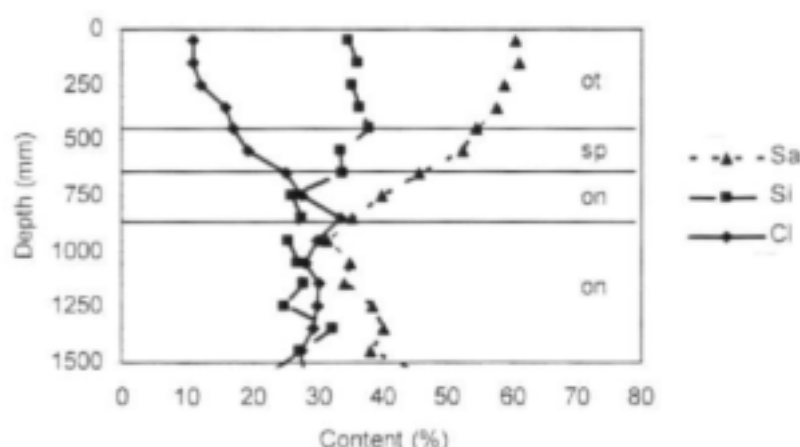


Figure 5.104 Texture of the fine earth in P230 (Westleigh 1000).

5.22.4 Hydrology

Annual duration of $s > 0.7$ decreased from 196 days year⁻¹ in the orthic A horizon to 82 days year⁻¹ in the soft plinthic B and then increased to 312 days year⁻¹ in the upper and 365 days year⁻¹ in the lower unspecified material with signs of wetness (Figure 5.105). The relatively high $AD_{s > 0.7}$ values in the B horizons were expected, given the correlation with few faint Fe-oxide mottles in the orthic A, common

prominent Fe-oxide mottles in the soft plinthic B and common prominent Fe-oxide mottles in the unspecified material with signs of wetness.

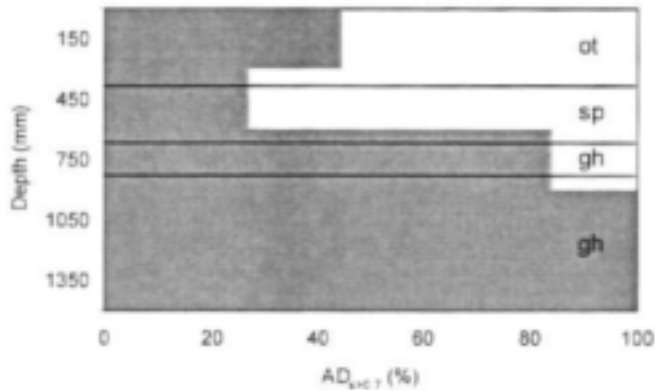


Figure 5.105 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P230 (Westleigh 1000).

5.23 P231 (Westleigh 2000)

5.23.1 Morphology

The profile is situated in a lower footslope position, with a slope of 10 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated below the dolerite dyke. The A, B1 and B2 horizons have a fine sandy loam texture, while the C1 horizon has a loam texture. The clay content increases from the surface of the profile downwards (12 – 18 – 17 – 21 %), but is fairly constant in the B1 and B2 horizons. The profile description and analytical data for this profile are given in Appendix A, Tables 43 and 44. The profile can be classified as Ferric-Orthi eutric Gleysol (FAO, 1998b) or Aeric Endoaquents (Soil Survey Staff, 1999). A very dark grey (10YR3/1) orthic A horizon (0–300 mm) overlies a dark greyish brown (10YR4/2) soft plinthic B1 (300–420 mm) on a light brownish grey (10YR6/2) soft plinthic B2 (420–550 mm) on a light reddish grey (2.5YR7/1) unspecified material with signs of wetness (550–1 440 mm).

5.23.2 Chemical properties

The pH_{Water} increases from 5.20 in the A horizon to 6.70 in the lower C horizon (Figure 5.106). The pH_{KCl} increases less steeply, from 4.37 in the A horizon to 5.30 in the lower C horizon.

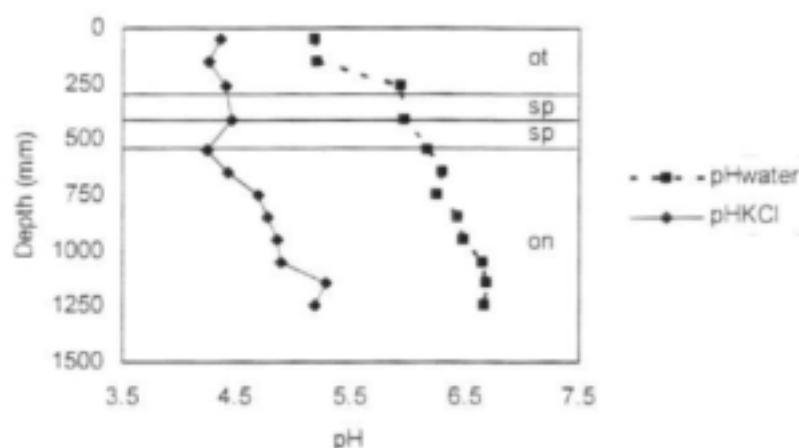


Figure 5.106 pH_{Water} and pH_{KCl} for P231 (Westleigh 2000).

Base saturation increases from 60 % in the A horizon to 145 % in the upper C and then drops to 95 % in the lower C horizon (Figure 5.107). This pattern is associated with an increasing and decreasing basic cation content and CEC_{soil} .

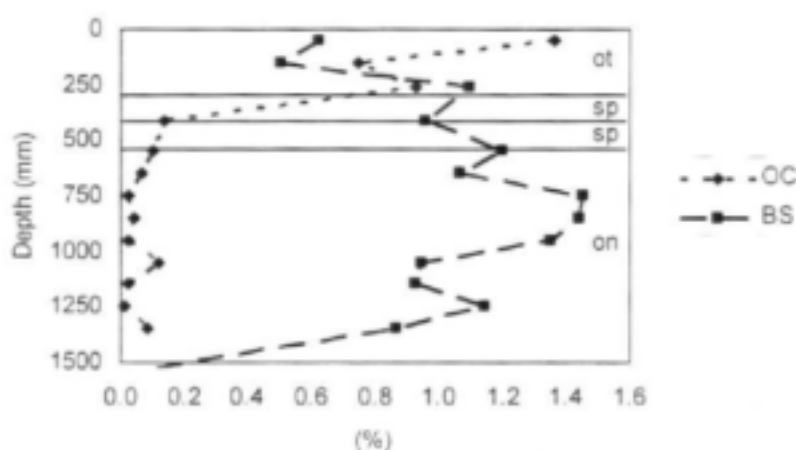


Figure 5.107 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P231 (Westleigh 2000).

Total Fe contents decreases from $13\,692\text{ mg kg}^{-1}$ in the A horizon to $8\,875\text{ mg kg}^{-1}$ in the B1, $9\,450\text{ mg kg}^{-1}$ in the B2 and $2\,666\text{ mg kg}^{-1}$ in the C horizon (Figure 5.108). The total Fe analyses do not support the classification of the soft plinthic B horizons, but rather the classification of E horizons.

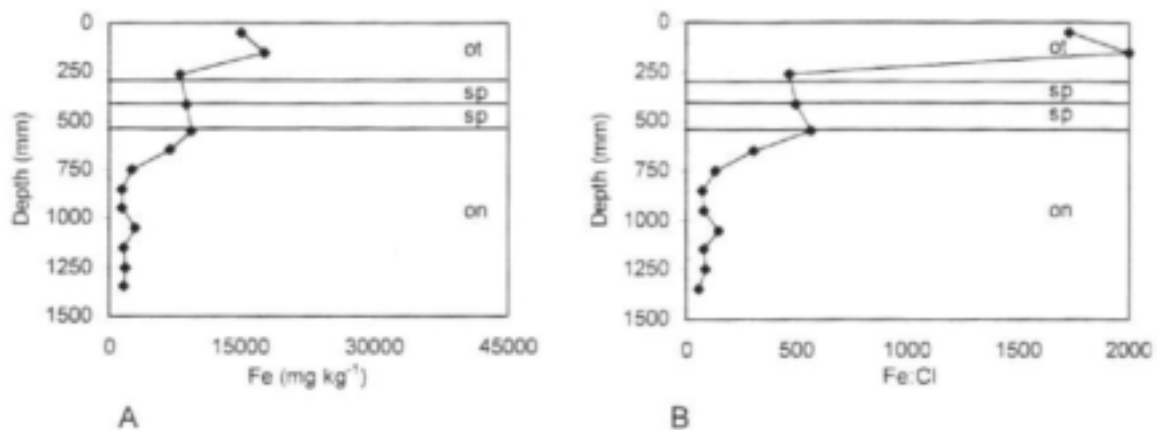


Figure 5.108 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P231 (Westleigh 2000).

5.23.3 Physical properties

Clay content increases from 12 % in the A to 18 % in the B1, 17 % in the B2 and 21 % in the C horizon (Figure 5.109). The increase in clay content in the B1 and B2 horizons does not support the classification of E horizons. The increased clay content in the C horizon is expected as this forms a restriction to water movement, leading to mottle formation in the horizons above it.

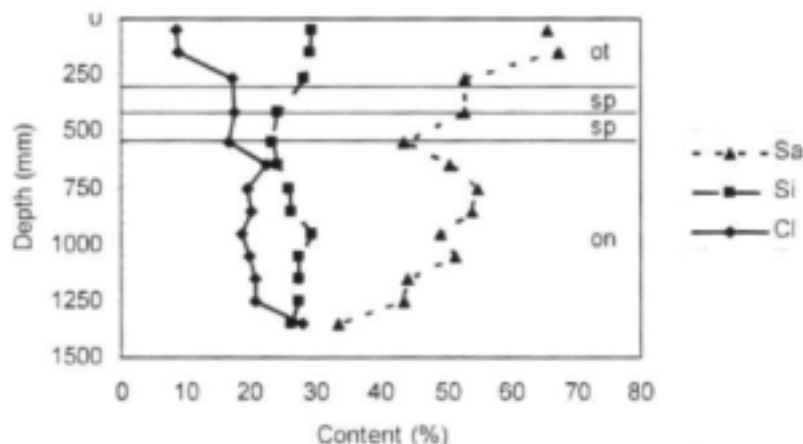


Figure 5.109 Texture of the fine earth in P231 (Westleigh 2000).

5.23.4 Hydrology

Annual duration of $s > 0.7$ increased from 191 days year⁻¹ in the orthic A horizon to 215 days year⁻¹ in the soft plinthic B and upper unspecified material with signs of wetness, and 365 days year⁻¹ in the lower unspecified material with signs of wetness (Figure 5.110). The relatively high $AD_{s > 0.7}$ values in the B horizons were expected,

given the correlation with few faint Fe-oxide mottles in the orthic A, many prominent Fe-oxide mottles in the soft plinthic B and unspecified material with signs of wetness.

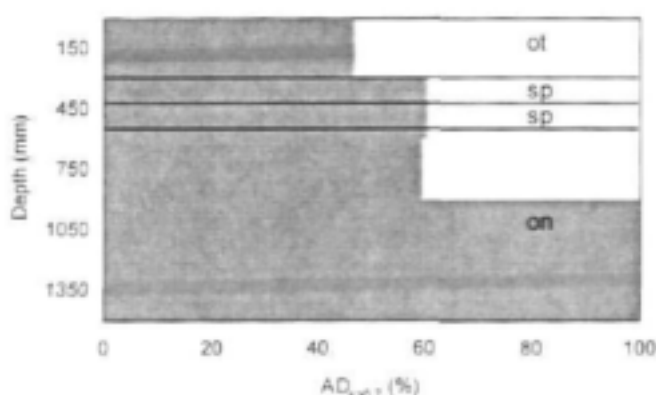


Figure 5.110 Mean $AD_{S>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P231 (Westleigh 2000).

5.24 P232 (Katspruit 1000)

5.24.1 Morphology

The profile is situated in a crest in the footslope position, with a slope of 6 % (Figure 3.3). It has Molteno sandstone as parent material, and is situated below the dolerite dyke. The A1 and A2 horizons have a fine sandy loam texture, the G1, G2 and G3 horizons have a clay loam texture and the G4 horizon a sandy loam texture. The clay content increases from the A to the G1, but is then stable throughout the profile (12 – 20 – 20 – 21 – 21 – 14 %). The profile description and analytical data for this profile are given in Appendix A, Tables 45 and 46. The profile can be classified as Hyperdistric Gleysol (FAO, 1998b) or Typic Endoaqualfs (Soil Survey Staff, 1999). A very dusky red (2.5YR2/2) orthic A1 (0–220 mm) overlies a dusky red (2.5YR3/2) orthic A2 (220–500 mm) on a weak red (2.5YR4/2) G1 (500–840 mm) on a pale red (2.5YR6/2) G2 (840–1 120 mm) on a reddish brown (2.5YR5/4) G3 (1 120–1 360 mm) on a weak red (10YR5/2) G4 horizon (1 360–1 500 mm).

5.24.2 Chemical properties

The pH_{Water} and pH_{KCl} is somewhat constant throughout the profile. The pH_{Water} ranges from 5.15 in the A horizon to 5.64 in the G4 horizon (Figure 5.111). The pH_{KCl} ranges from 4.29 in the A horizon to 3.95 in the G4 horizon.

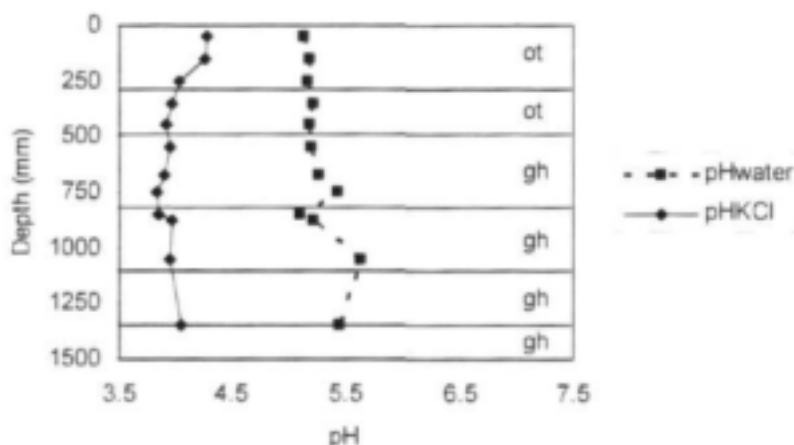


Figure 5.111 pH_{Water} and pH_{KCl} for P232 (Katspruit 1000).

Base saturation decreases from 30 % in the A to 22 % in the G1, and then increases to 53 % in the G2 and 53 % in the G3 horizon (Figure 5.112). This pattern is associated with a decreasing and then increasing basic cation content and CEC_{soil} .

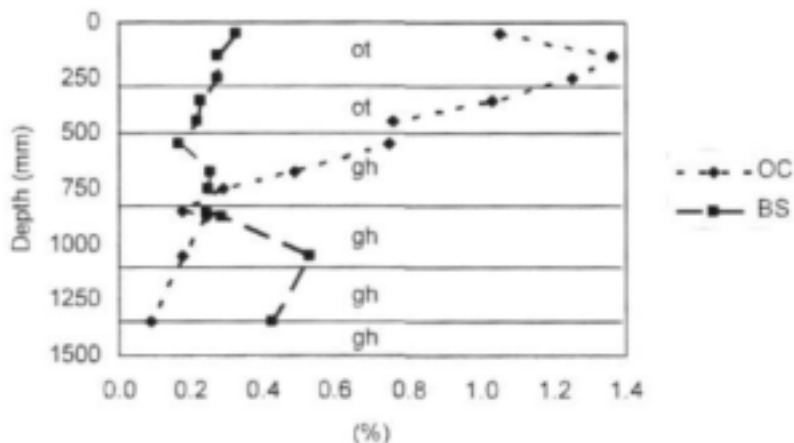


Figure 5.112 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P232 (Katspruit 1000).

Total Fe contents increases from $1\,130\text{ mg kg}^{-1}$ in the A1 horizon to $8\,145\text{ mg kg}^{-1}$ in the G3 horizon, and then decreases slightly to $8\,050\text{ mg kg}^{-1}$ in the G4 horizon (Figure 5.113). The total Fe analyses support the classification of the G horizons, since it is a cumulative environment.

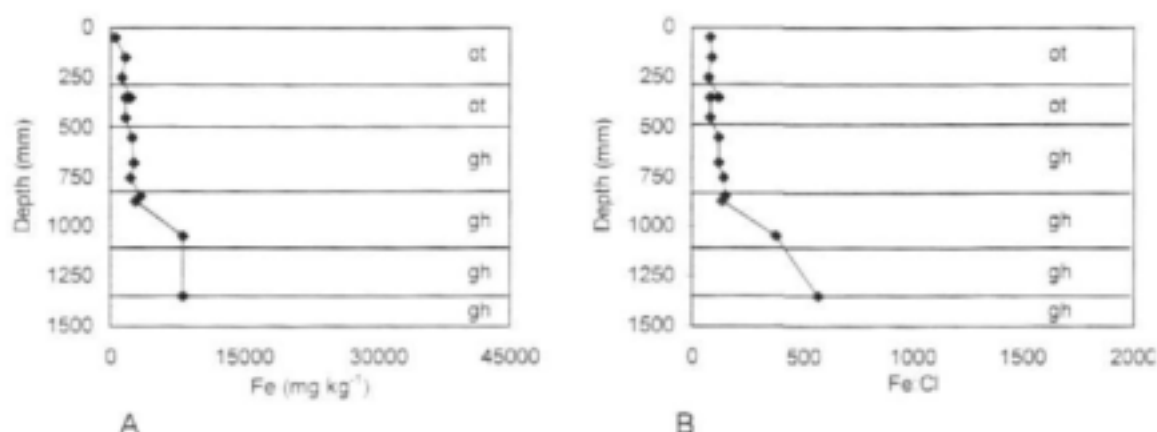


Figure 5.113 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P232 (Katspruit 1000).

5.24.3 Physical properties

Clay content increases from 12 % in the A1 horizon to 20 % in the A2, and is then somewhat uniform throughout the profile at 21 %, before decreasing to 14 % in the G4 horizon (Figure 5.114). The increase in clay content is typical of G horizons, and is probably due to clay illuviation.

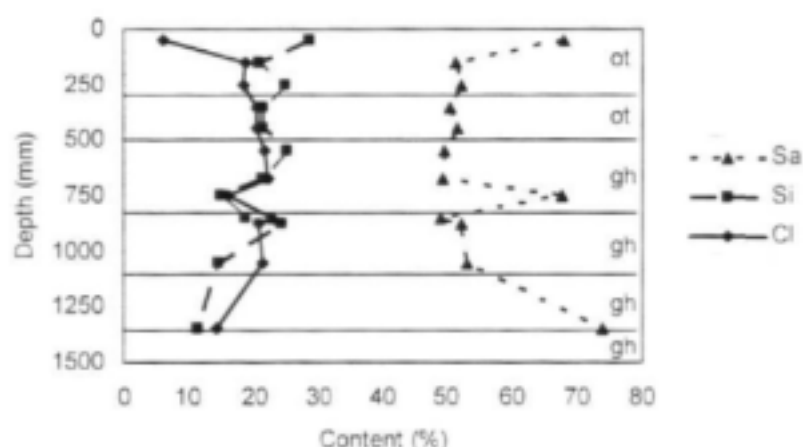


Figure 5.114 Texture of the fine earth in P232 (Katspruit 1000).

5.24.4 Hydrology

Annual duration of $s > 0.7$ increased down the profile, from 87 days year⁻¹ in the orthic A horizon to 165 days year⁻¹ in the soft plinthic B1, 203 days year⁻¹ in the soft plinthic B2, and 365 days year⁻¹ in the unspecified material with signs of wetness (Figure 5.115). The relatively high $AD_{s>0.7}$ values in the B horizons were expected, given the correlation with G horizon morphology and the occurrence of many distinct and prominent Fe-oxide mottles in the G horizons.

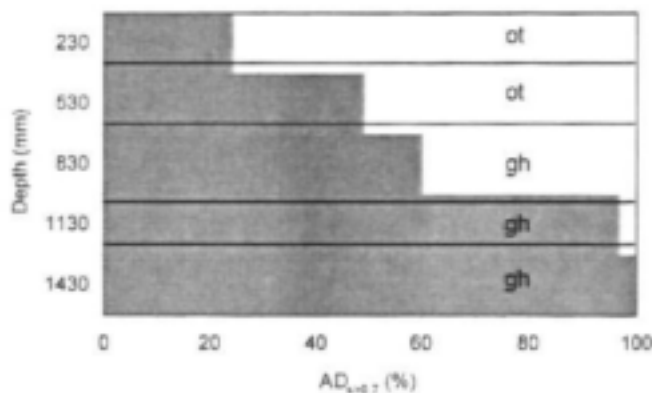


Figure 5.115 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P232 (Katspruit 1000).

5.25 P233 (Pinedene 2100)

5.25.1 Morphology

The profile is situated in a footslope position, with a slope of 10 % (Figure 3.3). It has Molteno sandstone as parent material. The A, B1 and B2 horizons have a sandy loam texture, while the C1 and C2 horizons have a clay loam texture. The clay content is fairly stable in the A and B horizons, but increases to the C horizons (10 – 11 – 10 – 34 – 28 %). The profile description and analytical data for this profile are given in Appendix A, Tables 47 and 48. The profile can be classified as Hyperdistric Cambisol (FAO, 1998b) or Aquic Ustipsamments (Soil Survey Staff, 1999). A very dark greyish brown (10YR3/2) orthic A horizon (0–300 mm) overlies a dark brown (10YR3/3) yellow-brown apedal B1 (300–500 mm) on a dark yellowish brown (10YR4/4) yellow-brown apedal B2 (500–600 mm) on dark greyish brown (10YR4/2) unspecified material with signs of wetness (600–1 040 mm) on dark yellowish brown (5YR4/6) unspecified material with signs of wetness (1 040–1 570 mm).

5.25.2 Chemical properties

The pH_{Water} is somewhat constant throughout the profile, ranging from 5.31 in the A horizon to 5.50 in the lower C2 horizon (Figure 5.116). The pH_{KCl} decreases slightly from 4.52 in the A horizon to 3.77 in the lower C2 horizon.

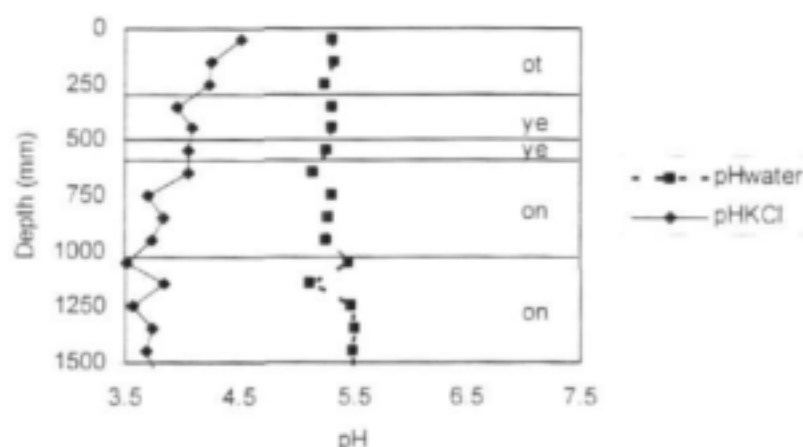


Figure 5.116 pH_{Water} and pH_{KCl} for P233 (Pinedene 2100).

Base saturation is low and decreases slightly in the profile, from 46 % in the upper A horizon to 25 % in the lower C horizon (Figure 5.117). The pattern is associated with decreasing basic cation content and CEC_{soil} in the A and B horizons, followed by an increase in the C horizons.

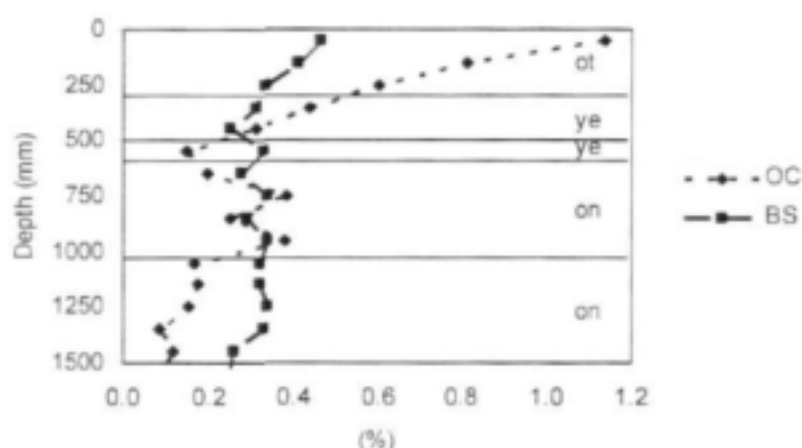


Figure 5.117 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P233 (Pinedene 2100).

Total Fe content is low and somewhat constant in this profile. It decreases from $4\,297\text{ mg kg}^{-1}$ in the A horizon to $3\,633\text{ mg kg}^{-1}$ and $3\,335\text{ mg kg}^{-1}$ in the B1 and B2 horizons and then increases to $4\,954\text{ mg kg}^{-1}$ and $4\,169\text{ mg kg}^{-1}$ in the C1 and C2 horizons (Figure 5.118).

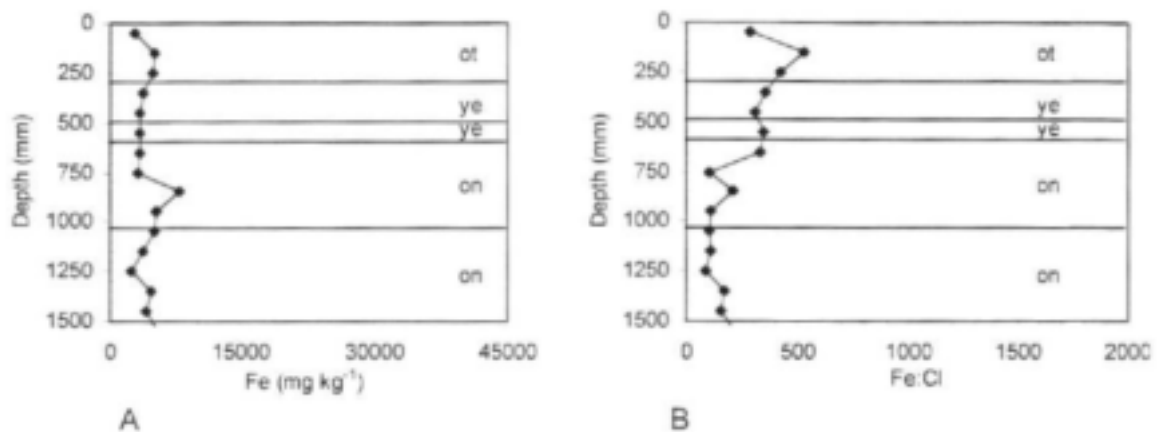


Figure 5.118 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P233 (Pinedene 2100).

5.25.3 Physical properties

Clay content is somewhat uniform throughout in the A (10 %), B1 (11 %) and B2 (10 %) horizons, but then increases in the C1 (34 %) and decreases again to 28 % in the C2 (Figure 5.119). The increase in clay content in the C1 might be due to clay illuviation.

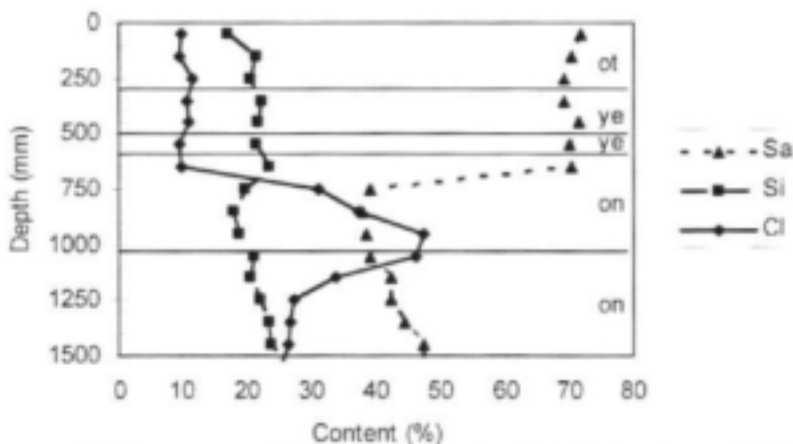


Figure 5.119 Texture of the fine earth in P233 (Pinedene 2100).

5.25.4 Hydrology

Annual duration of $s > 0.7$ increased down the profile, from 10 days year⁻¹ in the orthic A horizon to 20 days year⁻¹ in the yellow-brown apedal B1 and B2 horizons, and 365 days year⁻¹ in the unspecified material with signs of wetness (Figure 5.120). The low $AD_{s>0.7}$ values in the A and B horizons were expected, given their morphology, while the high $AD_{s>0.7}$ values in the unspecified material with signs of wetness correlated with its morphology.

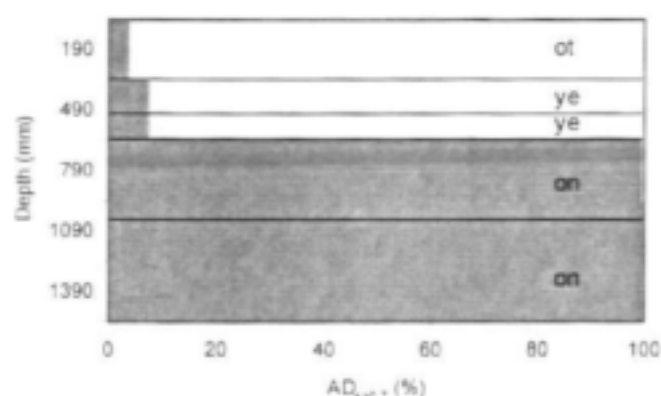


Figure 5.120 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P233 (Pinedene 2100).

5.26 P234 (Avalon 2100)

5.26.1 Morphology

The profile is situated in a midslope position, with a slope of 11 % (Figure 3.3). It has Elliot sandstone as parent material. The A, B1 and B2 horizons have a sandy loam texture, while the B3, C1 and C2 horizons have a loam texture. The clay content is fairly stable throughout the profile (10 – 14 – 17 – 19 – 15 – 15 %). The profile description and analytical data for this profile are given in Appendix A, Tables 49 and 50. The profile can be classified as Ferric-Hyperdistric Cambisol (FAO, 1998b) or Aquic Ustipsamments (Soil Survey Staff, 1999). A very dark greyish brown (10YR3/2) orthic A horizon (0–500 mm) overlies a dark yellowish brown (10YR4/4) yellow-brown apedal B1 (500–880 mm) on a yellowish brown (10YR5/4) yellow-brown apedal B2 (880– 1070 mm) on an yellowish brown (10YR5/6) soft plinthic B3 (1 070–1 300 mm) on light yellowish grey (10YR6/2) unspecified material with signs of wetness (1 300– 1 500 mm) on yellowish brown (10YR5/4) unspecified material with signs of wetness (1 500–1 600 mm).

5.26.2 Chemical properties

The pH_{Water} increases slightly from 5.25 in the top of the A horizon to 5.76 in the soft B3 horizon (Figure 5.121). The pH_{KCl} decreases slightly from 4.44 in the top of the A horizon to 3.93 in the B3 horizon.

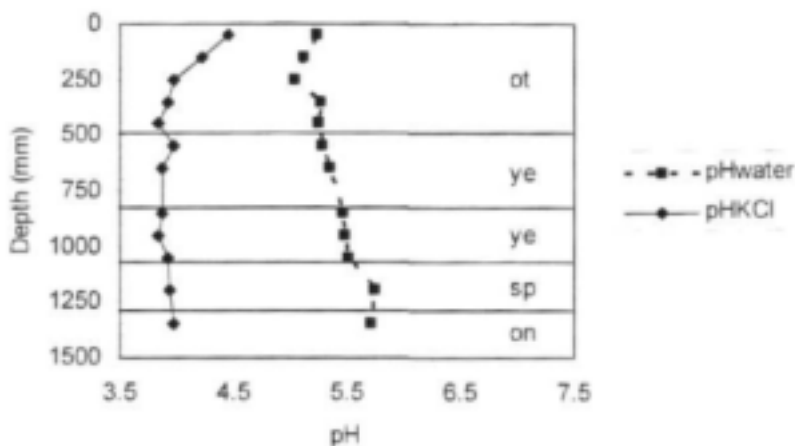


Figure 5.121 pH_{Water} and pH_{KCl} for P234 (Avalon 2100).

Base saturation decreases from 38 % in the upper A and to 11 % in the upper B1 horizon and then increases to 41 % in the C horizon (Figure 5.122). This pattern is associated with first a decreasing and then increasing basic cation content and a decreasing CEC_{soil} .

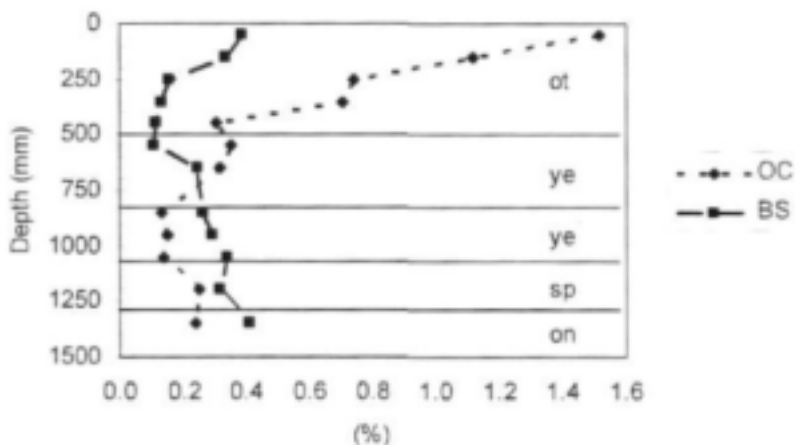


Figure 5.122 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P234 (Avalon 2100).

Total Fe contents is fairly low, decreasing from 6.093 mg kg^{-1} in the A to 4.887 mg kg^{-1} in the B1, 4.810 mg kg^{-1} in the B2 and then increasing to 5.375 mg kg^{-1} in the B3 and 6.260 mg kg^{-1} in the C (Figure 5.123).

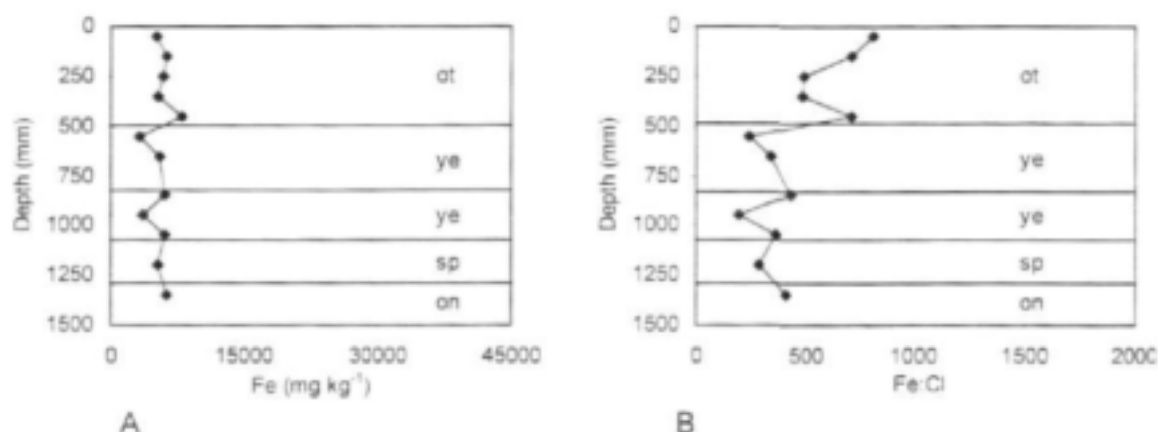


Figure 5.123 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P234 (Avalon 2100).

5.26.3 Physical properties

Clay content increases from 10 % in the A to 14 % in the B1, 17 % in the B2 and 19 % in the B3, before decreasing to 15 % in the C horizon (Figure 5.124).

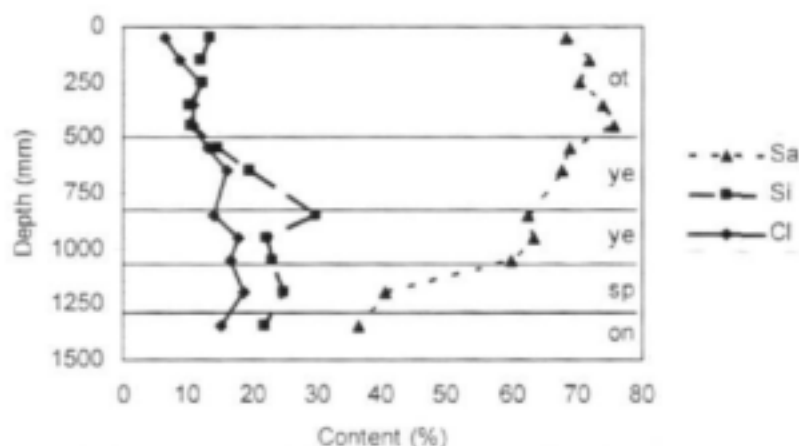


Figure 5.124 Texture of the fine earth in P234 (Avalon 2100).

5.26.4 Hydrology

Annual duration of $s > 0.7$ increased down the profile, from 24 days year⁻¹ in the orthic A horizon to 44 days year⁻¹ in the yellow-brown apedal B1 and B2 horizons, 287 days year⁻¹ in the soft plinthic B3 horizon, and 322 days year⁻¹ in the unspecified material with signs of wetness (Figure 5.125). The low $AD_{s>0.7}$ values in the A, B1 and B2 horizons were expected, given their morphology, while the high $AD_{s>0.7}$ values in the soft plinthic B3 horizons and unspecified material with signs of wetness correlated with its morphology.

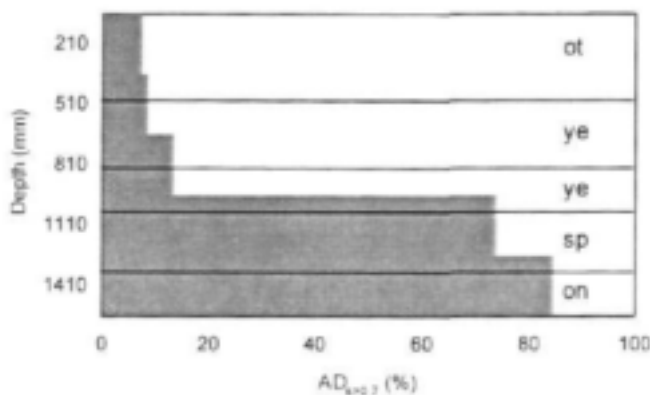


Figure 5.125 Mean $AD_{S>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P234 (Avalon 2100).

5.27 P235 (Katspruit 1000)

5.27.1 Morphology

The profile is situated in a lower footslope position, with a slope of 3 % (Figure 3.3). It has Molteno sandstone as parent material. The A1 and A2 horizons have a sandy loam texture, the G1 a sandy clay loam texture and the G2 a clay loam texture. The clay content increases from the A to the G horizons (10 – 11 – 30 – 36 %). The profile description and analytical data for this profile are given in Appendix A, Tables 51 and 52. The profile can be classified as Hyperdistric Gleysol (FAO, 1998b) or Typic Albaqualfs (Soil Survey Staff, 1999). A dark greyish brown (10YR4/2) orthic A1 horizon (0–250 mm) overlies a dark grey (10YR4/1) orthic A2 (250–490 mm) on a grey (10YR6/1) G1 (490–780 mm) on a grey (10YR6/1) G2 (780–1 200 mm).

5.27.2 Chemical properties

The pH_{Water} is constant at 5.50 in the A horizons, but increases to 6.10 and 6.76 in the G horizons (Figure 5.126). The pH_{KCl} decreases slightly from 4.25 in the A1 to 4.07 in the A2, but then increases to 4.14 in the G1 and 4.87 in the G2.

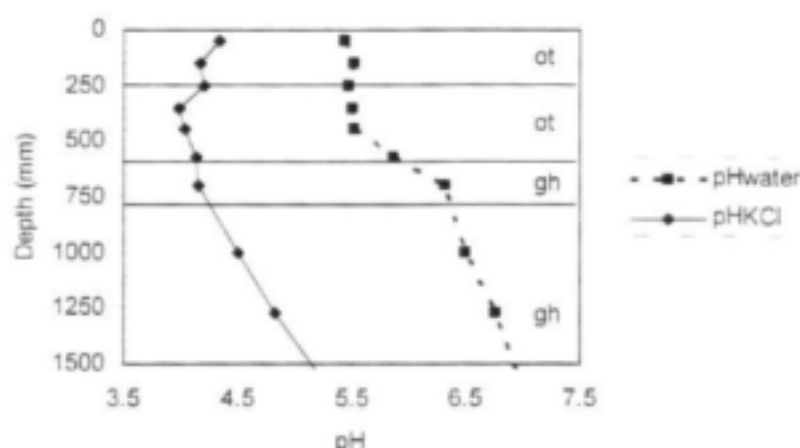


Figure 5.126 pH_{Water} and pH_{KCl} for P235 (Katspruit 1000).

Base saturation increases from 36 % in the A1 to 39 % in the A2; 70 % in the G1 and then decreases to 20 % in the G2 (Figure 5.127). This pattern is associated with a basic cation content that increases to the G1 and then decreases, and an increasing CEC_{soil} .

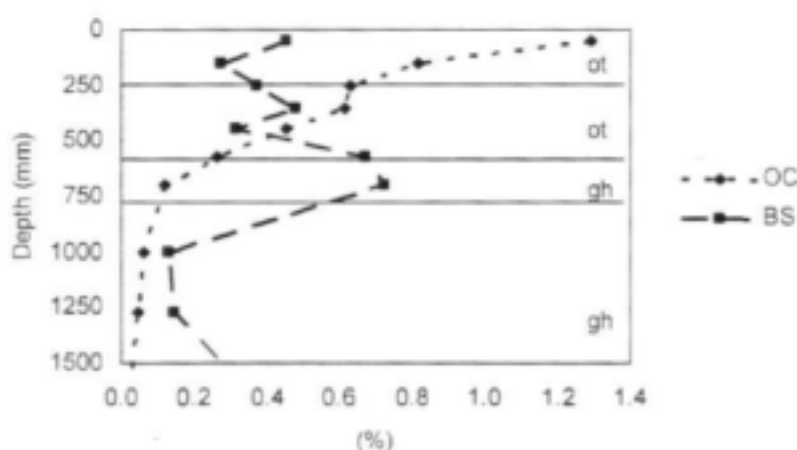


Figure 5.127 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P235 (Katspruit 1000).

Total Fe contents decreases from $6\,695\text{ mg kg}^{-1}$ in the A1 to $5\,185\text{ mg kg}^{-1}$ in the A2; increases to $5\,745\text{ mg kg}^{-1}$ in the G1 and then decreases to $4\,438\text{ mg kg}^{-1}$ in the G2 (Figure 5.128).

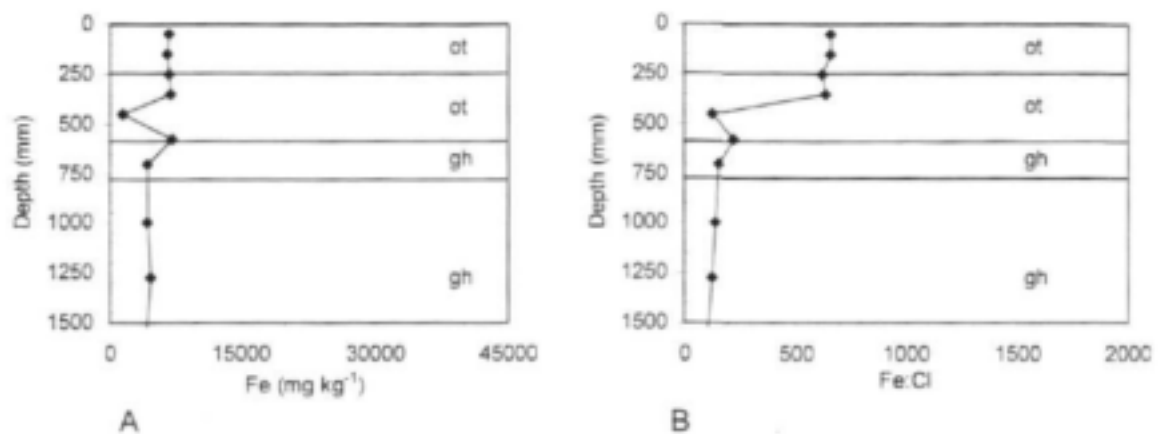


Figure 5.128 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P235 (Katspruit 1000).

5.27.3 Physical properties

Clay content increases from 10 % in the A1, and 11 % in the A2 to 30 % in the G1 and 36 % in the G2 (Figure 5.129).

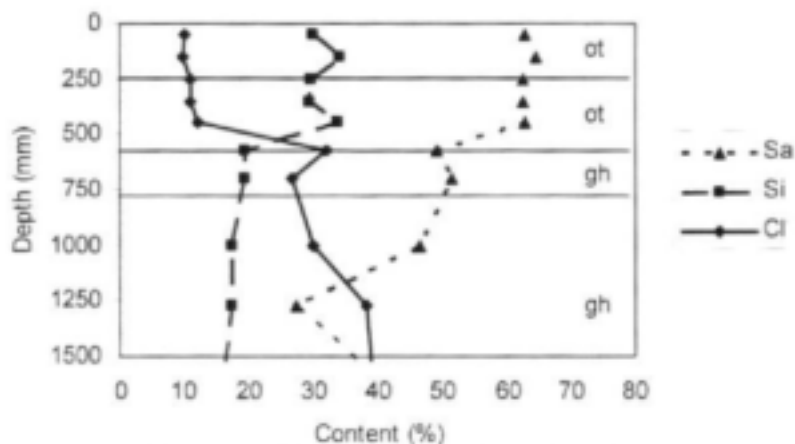


Figure 5.129 Texture of the fine earth in P235 (Katspruit 1000).

5.27.4 Hydrology

Annual duration of $s > 0.7$ increased down the profile, from 178 days year⁻¹ in the orthic A1 horizon to 365 days year⁻¹ in the orthic A2 and G horizons (Figure 5.130). The high $AD_{s>0.7}$ values in this profile were expected, given the G horizon morphology, and the occurrence of common distinct and prominent Fe-oxide mottles.

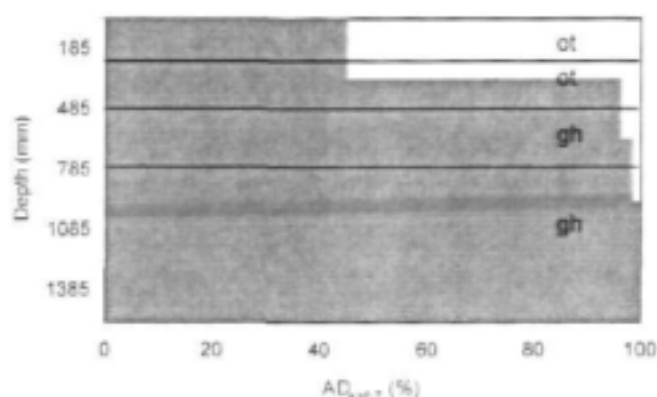


Figure 5.130 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P235 (Katspruit 1000).

5.28 P236 (Katspruit 1000)

5.28.1 Morphology

The profile is situated in a midslope position, with a slope of 6 % (Figure 3.3). It has Molteno sandstone as parent material. The A horizon has a sandy loam texture and the G1 and G2 horizons have a clay loam texture. The clay content is fairly stable throughout the profile (15 – 34 – 28 %). The profile description and analytical data for this profile are given in Appendix A, Tables 53 and 54. The profile can be classified as Epidistric Gleysol (FAO, 1998b) or Typic Albaqualfs (Soil Survey Staff, 1999). A very dark grey (10YR3/1) orthic A horizon (0–500 mm) overlies a grey (10YR6/1) G1 (500–970 mm) on a grey (10YR6/1) G2 horizon (970–1 650 mm).

5.28.2 Chemical properties

The pH_{Water} increases from 5.63 in the A horizon to 6.18 in the G1 and 6.57 in the G2 horizon (Figure 5.131). The pH_{KCl} increases from 4.09 in the A horizon to 4.20 in the G1 and 4.82 in the G2 horizon.

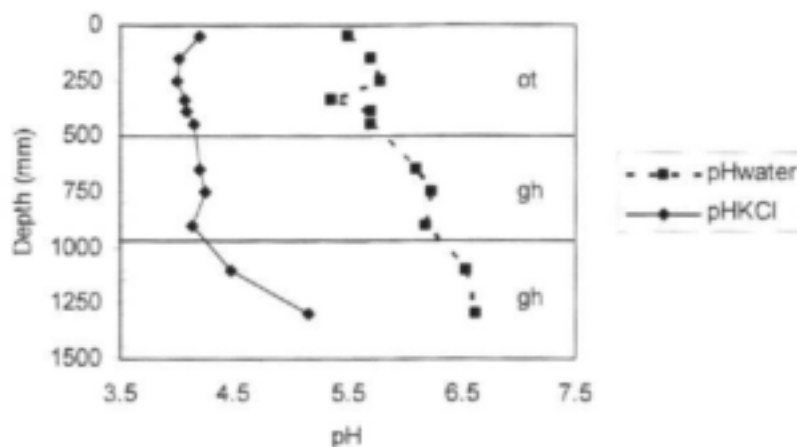


Figure 5.131 pH_{Water} and pH_{KCl} for P236 (Katspruit 1000).

Base saturation increases from 34 % in the A horizon to 65 % in the G1 horizon and 84 % in the G2 horizon (Figure 5.132). The pattern is indicative of the cumulative nature of G horizons and is associated with an increasing basic cation content and CEC_{soil} .

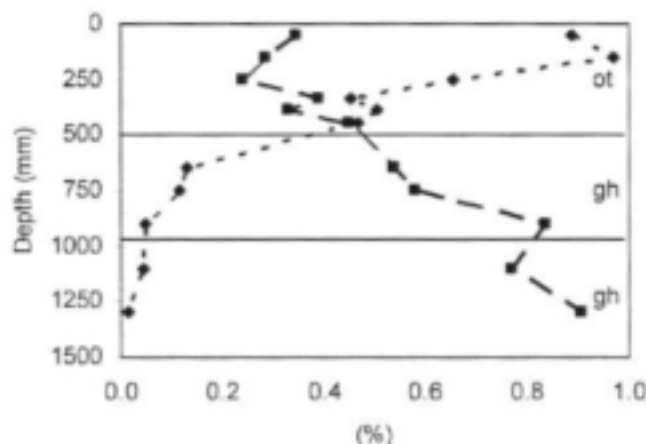


Figure 5.132 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P236 (Katspruit 1000).

Total Fe content increases from $3\,264\text{ mg kg}^{-1}$ in the A horizon to $7\,780\text{ mg kg}^{-1}$ in the G1 horizon and then decreases to $6\,113\text{ mg kg}^{-1}$ in the G2 horizon (Figure 5.133). This pattern is also indicative of the cumulative nature of G horizons.

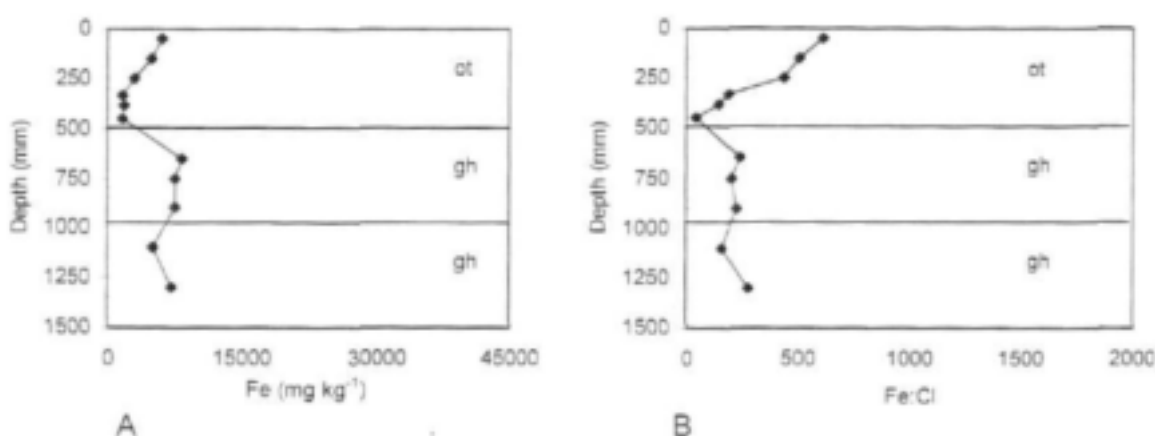


Figure 5.133 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P236 (Katspruit 1000).

5.28.3 Physical properties

Clay content increases sharply from 15 % in the A horizon to 34 % in the G1 and then decreases to 28 % in the G2 horizon (Figure 5.134). This pattern is also indicative of the cumulative nature of G horizons.

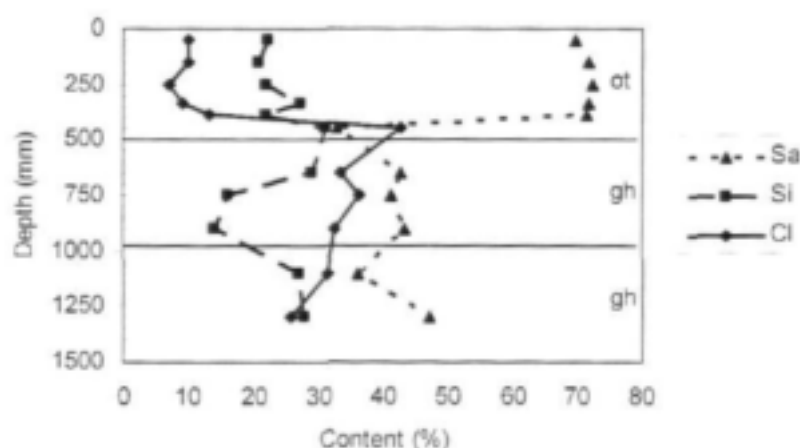


Figure 5.134 Texture of the fine earth in P236 (Katspruit 1000).

5.28.4 Hydrology

Annual duration of $s > 0.7$ was relatively high and increased down the profile, from 156 days year⁻¹ in the orthic A horizon to 365 days year⁻¹ in the G horizons (Figure 5.135). The high $AD_{s > 0.7}$ values in this profile were expected, given the G horizon morphology, and the occurrence of common and many, distinct and prominent Fe-oxide mottles.

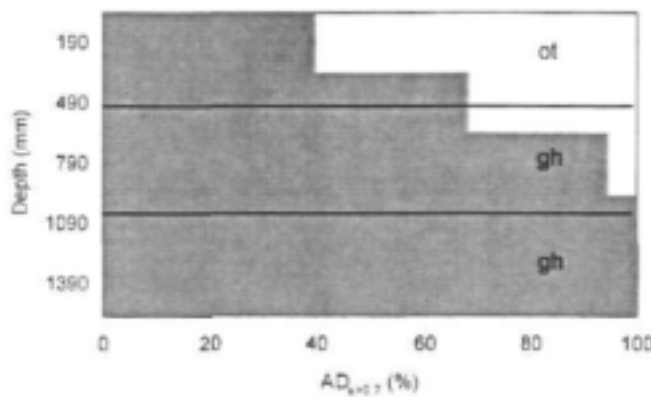


Figure 5.135 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P236 (Katspruit 1000).

5.29 P237 (Westleigh 1000)

5.29.1 Morphology

The profile is situated in an upper midslope position, with a slope of 10 % (Figure 3.3). It has Molteno sandstone and mudstone as parent material. The A1 and A2 horizons have a sandy loam texture; the B1 horizon has a loamy coarse sand texture; the B2 a clay texture; the B3 a sandy loam texture and the C horizon a sandy clay loam texture. The clay content is low in the B horizons, except the B3 (8 – 10 – 4 – 40 – 5 – 23 %), and increases in the C horizon. The profile description and analytical data for this profile are given in Appendix A, Tables 55 and 56. The profile can be classified as Hyperdistric Gleysol (FAO, 1998b) or Aerice Endoaquents (Soil Survey Staff, 1999). A very dark grey (7.5YR3/0) orthic A1 horizon (0–200 mm) overlies a very dark grey (7.5YR3/0) orthic A2 (200–500 mm) on a grey (7.5YR5/0) soft plinthic B1 (500–760 mm) on a light brown (7.5YR6/4) soft plinthic B2 (760–1 100 mm) on a pinkish grey (7.5YR6/2) soft plinthic B3 (500–1 100 mm) on reddish yellow (7.5YR6/8) unspecified material with signs of wetness (1 100–1 500 mm).

5.29.2 Chemical properties

The pH_{Water} decreases from 5.52 in the A1 horizon to 5.43 in the A2; it then increases to 5.96 in the B1, decreases to 5.73 in the B2 and increases again to 5.95 in the B3 and 5.91 in the C horizon (Figure 5.136). The pH_{KCl} decreases from 4.35 in the A1 to 4.11 in the A2; increases to 4.34 in the B1 and 4.33 in the B2 and decreases to 4.15 in the B3 and 4.14 in the C horizon.

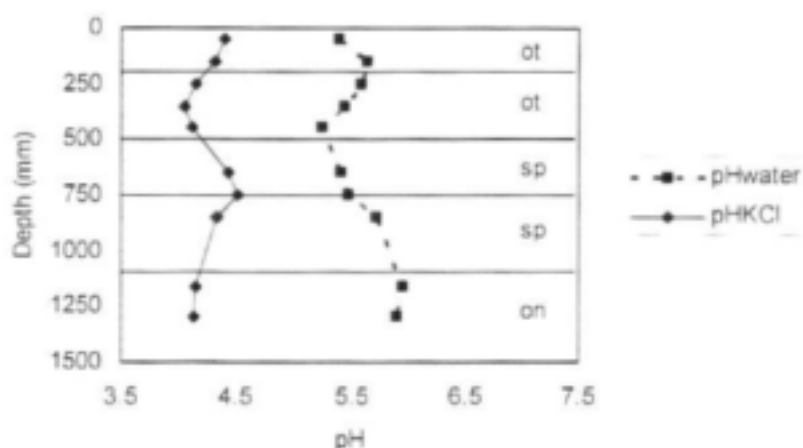


Figure 5.136 pH_{Water} and pH_{KCl} for P237 (Westleigh 1000).

Base saturation decreases from 38 % in the A1 to 26 % in the A2; it then increases to 70 % in the B1; decreases to 34 % in the B2 and increases to 59 % in the B3 and C (Figure 5.137). This pattern is associated with a similar distribution in basic cation content and CEC_{soil} .

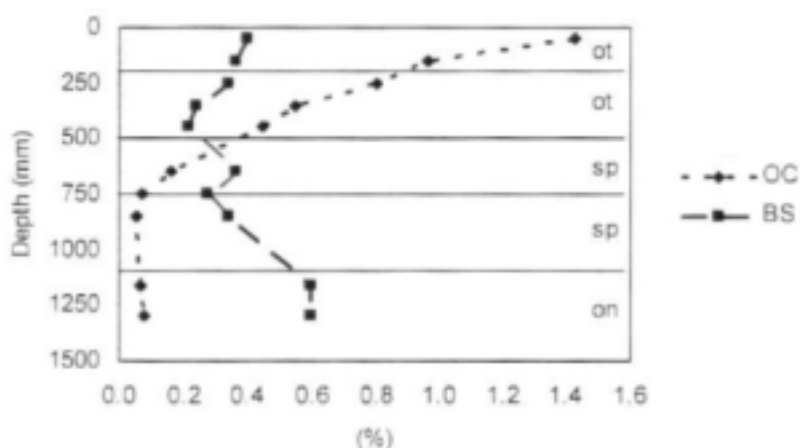


Figure 5.137 Distribution of organic carbon (OC, as a percentage) and base saturation (BS, as a fraction) in P237 (Westleigh 1000).

Total Fe contents increases from $4\,610\text{ mg kg}^{-1}$ in the A to $5\,898\text{ mg kg}^{-1}$ in the B1 and $6\,495\text{ mg kg}^{-1}$ in the B2; decreases slightly to $6\,145\text{ mg kg}^{-1}$ in the B3; increases to $8\,240\text{ mg kg}^{-1}$ in the upper C and decreases to $1\,740\text{ mg kg}^{-1}$ in the lower C horizon (Figure 5.138).

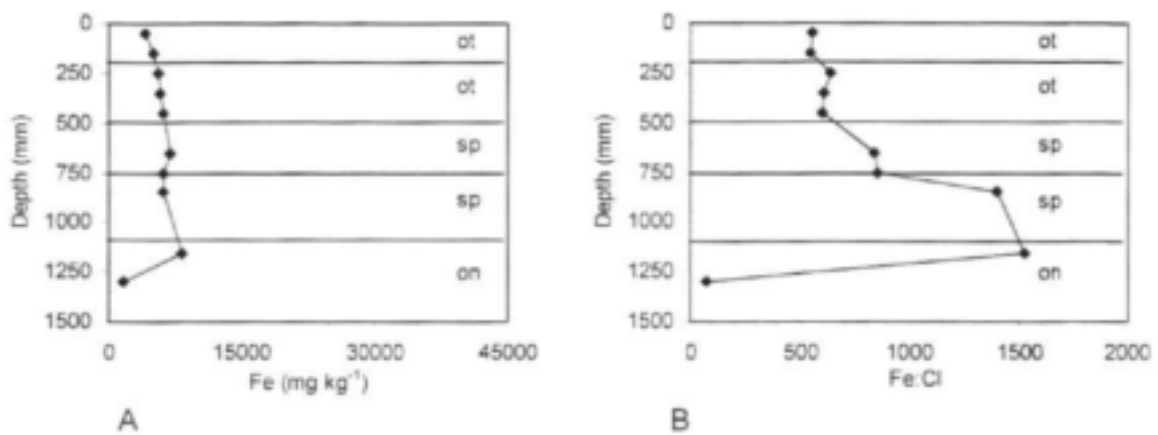


Figure 5.138 CBD extractable Fe (A) and CBD Fe:clay ratio (B) for P237 (Westleigh 1000).

5.29.3 Physical properties

Clay content increases from 8 % in the A1 to 10 % in the A2 and 40 % in the B1; decreases to 4 % in the B2 and 5 % in the B3 and then increases to 23 % in the C horizon (Figure 5.139).

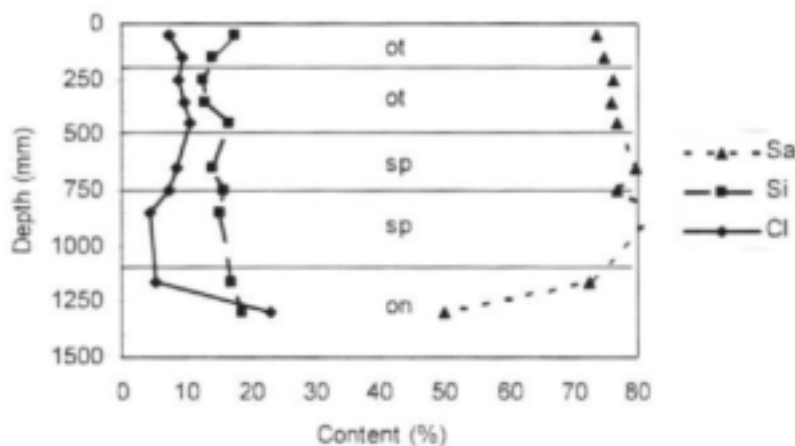


Figure 5.139 Texture of the fine earth in P237 (Westleigh 1000).

5.29.4 Hydrology

Annual duration of $s > 0.7$ increased down the profile, from 53 days year⁻¹ in the orthic A horizon to 196 days year⁻¹ in the soft plinthic B1, and 365 in the days year⁻¹ in the soft plinthic B2 horizon and unspecified material with signs of wetness (Figure 5.140). The high $AD_{s > 0.7}$ values in the soft plinthic B horizons and unspecified material with signs of wetness were expected, given their morphology, and the occurrence of common and many prominent Fe-oxide mottles.

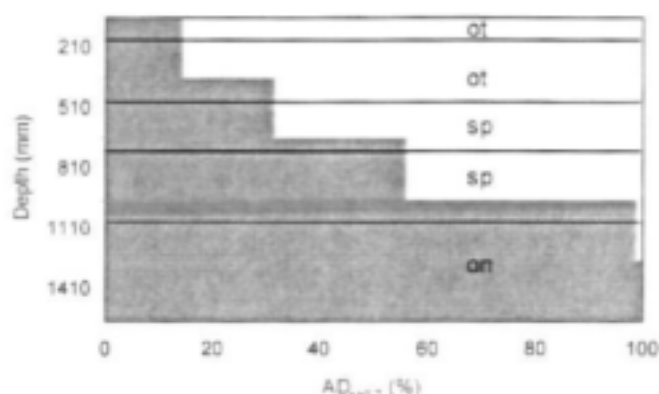


Figure 5.140 Mean $AD_{s>0.7}$ values based on estimated daily soil water contents, for the five measuring depths at P237 (Westleigh 1000).

5.30 Summary

Soil pH values in the Weatherley catchment were low, ranging between 3.7 and 5.4 for pH_{KCl} . This is common for the region, given the high rainfall and the acid nature of the sandstone parent material. pH_{water} and pH_{KCl} were generally constant with depth, except in cumulative environments (G horizons and unspecified materials with signs of wetness) where it increased. The same higher pH values were observed for profiles in cumulative environments like depressions in the landscape. This was the case with, for example, P206 (Kroonstad). pH_{KCl} was generally 1.26 units lower than pH_{water} . This indicated significant acidity on the exchange complex.

The organic carbon content ranged from 2.50 % to 0.03 % in the soils of Weatherley. Organic carbon content in the orthic A horizons was generally around 1 %, and decreased to 0.2 % in the subsoil. It is postulated that 0.2 % carbon in the subsoil was sufficient to provide sustenance for reducing bacteria. It could therefore be ruled out as a limiting factor in the reducing process.

Base saturation generally increased down the profile, from 20 % in the topsoil to 60 % and sometimes 100 % in the subsoil. Base saturation reflects the cumulative nature of horizons (G horizons and unspecified material with signs of wetness) and profiles that occur in lower lying positions (P206, P213, P218 and P231).

The observed Fe contents ranged between 75 and 2 296 $mg\ kg^{-1}$. No real difference was found in the distribution of Fe and Fe:clay. The Fe content was fairly stable with depth in most profiles, but did accumulate in some G horizons and unspecified

material with signs of wetness. No clear evidence of accumulation in soft plinthic B horizons or depletion of Fe in E horizons was observed.

Topsoils were generally sandy in nature with 10 % clay. This increased to 40 % in the G horizons and unspecified material with signs of wetness, or stayed constant in the absence of these horizons. The sandy nature of the soils was attributed to the Elliott and Molteno sandstone, while the increase in clay content with depth was probably due to geological clay layers and luviation.

$AD_{s>0.7}$ was almost constant ($365 \text{ days year}^{-1}$) in the poorly drained profiles (Kroonstad and Katspruit). Only P212 (Tukulu 1110) and P221 (Hutton 2100) had negligible $AD_{s>0.7}$. $AD_{s>0.7}$ in the other profiles generally increased with depth, from zero in the topsoil to constant in the subsoil. These relationships confirmed current understanding, but with the main advantage of providing measured values.

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6 QUANTIFICATION OF SOIL COLOUR FROM DIGITAL IMAGES

6.1 Introduction

This chapter discusses results obtained from digital photograph colour quantification, using the methods discussed in section 2.6.5. This chapter does not directly address the project aims, but were researched to ascertain the feasibility of the methodology. Due to the degree of further research needed, it was only applied to the ten profiles P201 to P210.

The results of digital photographs classification can be summarised to calculate the occurrence of each diagnostic colour, using the amount of cells classified into each colour (Table 6.1). Erroneous colour classification (sections 4.7 and 4.8) may influence the results. All colours refer to the dry state, because only photographs taken in the dry state were used in the calculations. Yellow and grey E horizons can therefore not be differentiated.

6.2 Incidence of diagnostic colours

The digital colour classification of most of the orthic A horizons as diagnostic grey is in line with the Munsell notations determined during the field descriptions (Table 6.2). The grey colour in A horizons may form during varying periods of wetness (section 7.2). Diagnostic grey dominates in E, G and unspecified materials with signs of wetness. The grey count can increase, decrease or remain constant down the profile. Yellow-brown colours dominate in some orthic A horizons, the yellow-brown apedal B horizons, the upper soft plinthic B of P207 (Westleigh), neocutanic B horizons and unspecified materials with signs of wetness under neocutanic B horizons, while red colours only dominate in the red apedal B horizons and the G horizon of P204 (Longlands) (Table 6.1).

Table 6.1 The occurrence of diagnostic red, yellow and grey colours (Soil Classification Working Group, 1991) as well as black determined from digital photographs taken per diagnostic horizon

Profile	Form	Depth (mm)	Horizon	Grey	Yellow	Red	Black
				%			
P201	Lo	430	ot	3.0	96.9	0.0	0.1
		730	gs	0.0	98.6	1.3	0.1
		1000	sp	78.5	19.4	0.5	1.6
		1210	on	90.9	8.1	0.1	0.9
P202	Pn	400	ot	91.0	3.5	0.0	5.4
		820	ye	28.6	67.4	0.1	3.9
		990	on	64.2	27.2	0.1	8.5
		1500	on	74.7	17.3	1.0	7.0
P203	Tu	380	ot	88.6	4.5	0.0	6.9
		960	ne	8.2	83.1	6.0	2.7
		1300	on	9.2	81.9	4.2	4.7
P204	Lo	140	ot	92.4	6.5	0.0	1.1
		300	gs	63.5	35.7	0.2	0.6
		470	sp	9.6	62.6	27.0	0.8
		1000	on	9.9	44.3	45.1	0.6
P205	Kd	220	ot	10.6	87.0	0.1	2.3
		460	gs	98.9	0.4	0.0	0.7
		660	gs	91.7	8.1	0.1	0.1
		1400	gh	5.1	52.5	41.8	0.6
P206	Kd	550	ot	90.3	0.1	0.0	9.6
		800	gs	99.2	0.2	0.0	0.6
		1100	gh	98.0	1.7	0.0	0.3
P207	We	300	ot	94.6	3.6	0.0	1.8
		560	sp	27.1	71.8	0.0	1.1
		670	sp	70.4	26.9	0.1	2.6
		1300	on	66.0	31.1	0.1	2.8
P208	Kd	350	ot	92.9	0.6	0.0	6.5
		530	gs	98.7	0.1	0.0	1.2
		800	gh	89.4	10.3	0.0	0.2
		1700	gh	96.3	2.9	0.0	0.8
P209	Ka	450	ot	55.4	40.3	0.0	4.3
		1100	gh	54.6	38.0	5.5	2.0
		1400	so	98.4	1.1	0.0	0.5
P210	Bd	260	ot	65.3	32.3	0.0	2.3
		530	ot	68.7	28.8	0.0	2.5
		810	re	0.2	67.6	31.6	0.6
		1200	re	0.0	36.4	62.2	1.4
		1580	on	0.0	44.3	54.8	0.9

Table 6.2 Results of Munsell colour calculation from RGB values determined from digital photographs

Profile	Form	Depth (mm)	Horizon	Calculated from photo			Dry Munsell colour (field)	Calculated from RGB		
				R	G	B		hue	value	chroma
P201	Lo	430	ot	133	118	97	10YR4/4	0.68Y	7.26	1.33
		730	gs	153	126	84	7.5YR6/4	1.45Y	7.49	2.6
		1000	sp	133	125	121	7.5YR6/4	3.05YR	7.43	0.49
		1210	on	138	136	141	7.5YR7/2	3.63P	7.68	0.61
P202	Pn	400	ot	120	121	120	10YR4/3	1.29G	7.29	0.05
		820	ye	62	62	48	7.5YR5/6	0.52GY	5.43	1.13
		960	on	134	127	119	10YR8/2	9.17YR	7.47	0.51
		1500	on	132	127	114	2.5Y8/2	3.75Y	7.45	0.64
P203	Tu	380	ot	123	119	117	10YR5/3	2.76YR	7.26	0.25
		960	ne	40	42	27	7.5YR7/4	2.07GY	4.54	1.77
		1300	on	140	120	93	7.5YR7/4	0.44Y	7.33	1.74
P204	Lo	140	ot	127	122	111	7.5YR6/2	2.99Y	7.33	0.57
		300	gs	136	126	107	7.5YR7/5	2.21Y	7.44	1.02
		470	sp	154	126	97	10YR8/2	8.76YR	7.52	2.06
		1000	on	159	126	112	10YR8/2	2.31YR	7.57	1.99
P205	Kd	220	ot	134	119	99	2.5Y5/2	0.38Y	7.29	1.28
		460	gs	122	120	112	2.5Y6/1	5.77Y	7.26	0.38
		660	gs	136	129	112	10YR6/2	3.46Y	7.5	0.84
		1400	gh	163	129	99	2.5Y7/1	7.75YR	7.62	2.29
P206	Kd	550	ot	110	115	120	10YR5/1	2.36PB	7.12	0.71
		800	gs	142	141	139	10YR5/1	1.23Y	7.78	0.09
		1100	gh	157	153	132	10YR6/1	6.64Y	8.04	0.83
P207	We	300	ot	128	124	119	10YR6/2	9.75YR	7.38	0.31
		560	sp	138	126	103	10YR6/3	2.25Y	7.44	1.25
		670	sp	142	132	116	10YR8/1	1.21Y	7.59	0.88
		1300	on	137	128	106	10YR8/2	3.54Y	7.48	1.11
P208	Kd	350	ot	111	114	116	10YR6/1	0.52PB	7.1	0.33
		530	gs	133	133	136	10YR6/2	9.53PB	7.6	0.36
		800	gh	136	131	124	10YR7/1	0.27Y	7.56	0.4
		1700	gh	131	131	128	10YR6/2	0.37GY	7.54	0.12
P209	Kd	450	ot	119	111	100	10YR5/2	0.67Y	7.06	0.71
		1100	gh	139	127	110	10YR6/1	0.56Y	7.48	1.01
		1400	so	157	158	146	10YR6/1	2.28GY	8.14	0.42
P210	Bd	260	ot	120	114	111	10YR4/2	3.10YR	7.14	0.38
		530	ot	120	113	106	10YR4/3	8.56YR	7.11	0.52
		810	re	151	121	98	7.5YR4/6	6.74YR	7.41	1.99
		1200	re	153	117	84	7.5YR6/6	8.29YR	7.33	2.64
		1580	on	165	128	87	10YR6/4	9.43YR	7.59	2.85

The digital classified colour of the diagnostic horizons in P201 (Longlands 2000) is totally dominated by a single diagnostic colour, contrary to other profiles. The orthic A and E horizons are dominantly yellow (96.9 % and 98.6 % respectively) and change abruptly to dominantly grey in the soft plinthic B (78.5 %) and saprolite (90.9 %) horizons. This correlates with Munsell determined brown (10YR4/4) colour

in the orthic A, a red dull orange (7.5YR6/4) colour in the E and a red dull orange (7.5YR6/4) colour in the soft plinthic B horizons (Table 6.2). There are very few red colours (1.3 %) in the E, some yellow (19.4 %) and very few black (1.6 %) in the soft plinthic B horizon and some yellow in the saprolite (8.1 %). Yellow, red and black colours due to mottling are expected in the E, soft plinthic B and underlying saprolite horizons.

The E horizon, classified as diagnostic grey in the dry state during field investigations, may have classified as yellow during calculation due to two reasons. First the observed dry Munsell colour (7.5YR6/4), is a colour definition boundary value. Secondly, the mathematical description of diagnostic grey, yellow-brown and red can be improved to allow for more accurate colour classification. The combination of colours in the saprolite is expected, given the typical pale Elliott sandstone and the redistribution of Fe and Mn in the weathered localities.

In profile P202 (Pinedene 1100), the orthic A horizon and both layers of the unspecified material with signs of wetness are dominated by a digitally determined diagnostic grey colour (91.0 %, 64.2 % and 74.7 % respectively) and the yellow-brown apedal B horizon by a yellow colour (67.4 %) and some grey (28.6 %). This correlates with dull yellowish brown (10YR4/3), bright brown (7.5YR5/6), light grey (10YR8/2) and pinkish white (2.5YR8/2) colours in the orthic A, yellow-brown apedal B and unspecified material with signs of wetness respectively. The digital calculation identified 3.9 % to 8.5 % black colour in all the horizons of the profile and negligible red colouring. The dominance of grey in the orthic horizon is probably due to short periods of saturation and reduction, followed by vertical leaching of Fe and Mn. This is supported by the Fe and Mn:clay ratios that are fairly low in the A horizon. However the yellow and grey colour domination in the yellow-brown apedal B horizon and the unspecified material with signs of wetness are according to expectation. The nearly 30 % of grey in the yellow-brown apedal B horizon may indicate a significant duration of water saturation. The occurrence of black colours is probably due to shadows occurring in the photograph. The occurrence of 1 % diagnostic red in the C2 horizon is due to the presence of very small red mottles.

The A horizon of P203 (Tukulu 2100), is also predominantly grey (88.6 %), as observed in P202 (Pinedene). The colour distribution of the neocutanic B horizon and the unspecified material with signs of wetness are very similar, mainly diagnostic yellow (83.1 % and 81.9 % respectively) with some grey, red and black colouring. This correlates with dull yellowish brown (10YR5/3) in the orthic A, dull orange (7.5YR7/4) in the neocutanic B horizon and pinkish white (7.5YR8/2) the unspecified material with signs of wetness (C1). The yellow-brown colour count in both horizons is higher than in the yellow-brown apedal B horizon of P202 (Pinedene). The digitally determined colour of the subsoil horizons of the Tukulu is more normally distributed, supporting the variegated colour found in neocutanic horizons. The black colouring may again be shadow.

The colour pattern in P204 (Longlands) is remarkably similar to that in P203 (Tukulu). The digitally calculated colour values change from predominantly grey in the upper two horizons to predominantly yellow-brown and red in the deeper subsoil. The orthic A is also predominantly grey but the E horizon has more diagnostic grey and less diagnostic yellow. This correlates with a greyish brown (7.5YR6/2) orthic A horizon, an orange (7.5YR7/5) E, a light grey (10YR8/2) soft plinthic B (300–470 mm), and a light grey (10YR8/2) G horizon, as determined in the field. The soft plinthic B horizon has 27.0 % diagnostic red colouring, an indication of the Fe oxide mottles present. It therefore supports the classification as a soft plinthic B horizon. The unspecified material with signs of wetness, underlying the soft plinthic B horizon, has a broad normal distribution pattern with 45.1 % diagnostic red, 44.3 % diagnostic yellow and 9.9 % diagnostic grey colouring calculated. The morphology of the deep subsoil is typical of some underlying horizons with very small prominent red spots, where preparation of the profile face resulted in red streaking. This effect can account for up to 95 % of the red colour in these photographs.

The A (dark greyish yellow; 2.5Y5/2) and G horizons (light grey; 2.5Y7/1) of P205 (Kroonstad 2000) is predominantly diagnostic yellow (87.0 % and 52.5 %), while the E1 (yellowish grey; 2.5Y6/1) and E2 (greyish yellow brown; 10YR6/2) horizons are predominantly diagnostic grey (98.9 % and 91.7 %). The quantified colours therefore support the classification of these horizons. The G horizon has 41.8 % diagnostic red, the reason being the same as discussed for P204 (Longlands).

P206 (Kroonstad 2000) is diagnostic grey throughout the profile (90.3 % – 99.2 % – 98.0 %). This correlates with a brownish grey (10YR5/1) orthic A horizon, a brownish grey (10YR5/1) E and a brownish grey (10YR6/1) G horizon. The A horizon has 9.6 % black, which is largely due to the high level of organic material (4.4 % OC in the 0 – 100 mm layer), and shadows in the horizon.

The dominant colours in P207 (Westleigh 1000) are 94.6 % diagnostic grey in the A horizon (greyish yellow brown; 10YR6/2), 71.8 % diagnostic yellow in the soft plinthic B1 horizon (dull yellow orange; 10YR6/3), 70.4 % diagnostic grey in the soft plinthic B2 horizon (light grey; 10YR8/1), and 66.0 % diagnostic grey in the C horizon (light grey; 10YR8/2). The subdominant colour in the B1 horizon is diagnostic grey (27.1 %), while it is diagnostic yellow (26.9 % and 31.1 %) in the B2 and C horizons. The B1 horizon was classified as a soft plinthic B horizon, although it has grey colour, as defined for an E horizon, due to the presence of prominent vesicular mottles. The varied nature of this horizon's colour is clear from the colour classification. The presence of 26.9 % diagnostic yellow in the B2 horizon is due to Fe oxide mottles. It therefore supports the classification as a soft plinthic B horizon. The occurrence of black in these horizons is mainly due to shadows.

The horizon colours of P208 (Kroonstad 1000) are classified as diagnostic grey throughout the profile (92.9 % – 98.7 % – 89.4 % – 96.3 %). This correlates with a brownish grey (10YR6/1) colour in the orthic A, a greyish yellow-brown (10YR6/2) colour in the E, a light grey (10YR7/1) colour in the G1, and a greyish yellow brown (10YR6/2) colour in the G2 horizon. There is 10.3 % diagnostic yellow in the G1 horizon and 2.9 % diagnostic yellow in the G2 horizon. The colours indicate a very wet profile. It also supports the classification of the diagnostic horizons and the profile as a whole. The presence of yellow colours in the G1 is as a result of Fe oxide mottles. The black colours in the G1 and G2 horizons are mainly due to shadows caused by cracks.

Diagnostic grey increases (55.4 % – 54.6 % – 98.4 %) throughout P209 (Katspruit 1000). This correlates with a greyish yellow-brown (10YR5/2) colour in the orthic A horizon, a brownish grey (10YR6/1) colour in the G horizon and a brownish grey

(10YR6/1) colour in the saprolite. It has 40.3 % diagnostic yellow in the A and 38.0 % diagnostic yellow as well as 5.5 % diagnostic red in the G horizon. The yellow and red colours in the A and G horizons are due to Fe oxide mottling. The black colours in the A horizon are due to shadows. The increasing area of diagnostic grey as well as yellow mottling might indicate increased durations of water saturation.

P210 (Bloemdal 1100) is the only profile with significant areas of diagnostic red colours. The A1 and A2 horizons are predominantly diagnostic grey (65.3 % and 68.7 %). The B1 horizon has 67.6 % diagnostic yellow and 31.6 % diagnostic red while the B2 horizon has 36.4 % diagnostic yellow and 62.2 % diagnostic red. The underlying unspecified material with signs of wetness has 44.3 % diagnostic yellow and 54.8 % diagnostic red. This correlates with a greyish yellow brown (10YR4/2) orthic A1, a dull yellowish brown (10YR4/3) A2, a brown (7.5YR4/6) red apedal B1, an orange (7.5YR6/6) red apedal B2 and a dull orange (7.5YR6/4) unspecified material with signs of wetness. The colour classification of the B1 and B2 horizons supports the diagnostic horizon classification. The over-estimation of diagnostic yellow in the B1 horizon might be due to unrefined colour definitions for the colour classification.

6.3 Mean horizon colour

The mean colour of each horizon, excluding diagnostic colour classification can be calculated in ArcView as a zone summary, or it can be calculated as the product of the percentage diagnostic colour occurrence and the respective R, G or B values. An evaluation of the results provided by the two methods is given in Figure 6.1. It is clear that these two methods are fairly similar ($R^2 = 0.98$), although the weighed mean values are typically 12 units higher for Red, 11 units higher for Blue and one unit lower for Green, than the zone summary. The weighted mean values can therefore be used to save time during the calculation process – provided they are corrected, using the proposed equations.

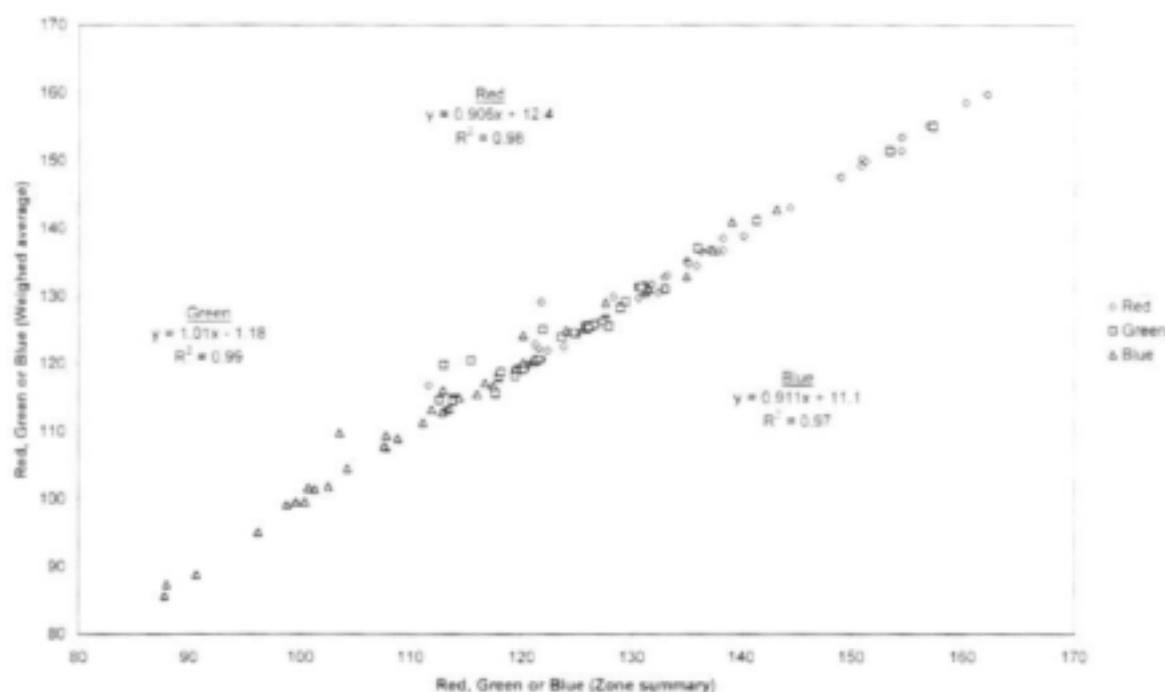


Figure 6.1 The relationship between two methods for determining soil colour.

An attempt was made to calculate the Munsell colour from the mean RGB horizon colour. This yielded results that were difficult to interpret, due to the continuous nature of the hue values and the fact that hue values fell outside that normally expected in soil (Table 6.2). This might be due to the colour classification procedure and the colour correlation programme used (Anon, 2003b). A further disadvantage is that the programme cannot be forced to select a colour within the expected soil colour limits, or within a specific hue. It is proposed that these issues be researched further, due to the possibilities that they offer for the objective determination of soil colour.

6.4 Colour correlations

Although colour correlations were not a specific aim of this research, it would be interesting to evaluate results obtained against published colour indices. The colour indices developed by Torrent *et al.* (1980 and 1983), Mokma & Cremeens (1991) as well as Van Huyssteen (1995), are discussed in section 2.3. These colour indices were evaluated against colour and soil water data obtained for this study. The colour index developed by Van Huyssteen (1995) gave the best correlation with duration of water saturation with $R^2 = 0.33$. The redness rating developed by Torrent *et al.*

(1980 and 1983), had a $R^2 = 0.16$, while the colour index developed by Mokma & Cremeens (1991) had a $R^2 = 0.13$. The colour index of Van Huyssteen (1995) also correlated reasonably well with mean $AD_{s>0.7}$ ($R^2 = 0.35$).

Determination of new coefficients for the colour index developed by Van Huyssteen (1995), increases the correlation coefficient to $R^2 = 0.38$. The equation is given by:

$$AD_{s>0.7} (\text{days year}^{-1}) = -38.6 \times H_d + 35.2 \times V_d + 1.94 \times C_d - 51.3 \quad (6.1)$$

Where:

$AD_{s>0.7}$	Mean annual duration of water saturation above 0.7 of porosity
H_d	= numeric dry colour hue
V_d	= dry colour value
C_d	= dry colour chroma

Mean Red, Green and Blue values, or combinations thereof, did not correlate with $AD_{s>0.7}$ (Table 6.3). The colour quantification methodology was not studied in further detail, because it would not have had a marked impact on the outcome of this study. It should, however, be studied further to exploit its possibilities for colour quantification and therefore soil classification as well as to aid in correlations with $AD_{s>0.7}$.

Table 6.3 The correlation (R^2) of mean photo Red, Green and Blue with mean $AD_{s>0.7}$, mean duration and mean frequency of water saturation

	Red	Green	Blue
Mean $AD_{s>0.7}$	0.10	0.17	0.19
Mean duration	0.08	0.16	0.20
Mean frequency	0.06	0.01	0.01

6.5 Summary

The colour variation in digital photographs of soils can be quantified and classified meaningfully, using ArcView SpatialAnalyst. This methodology is, however, not yet sufficiently refined, but holds great promise for the unbiased and quantitative determination of soil and mottle colour properties as well as statistical correlation with related soil conditions.

The black classification was used mainly for the elimination of shaded areas from the photographs. Unfortunately this class includes Mn mottles. This cannot be prevented at this stage. The occurrence of significant amounts of diagnostic red is restricted to P210 (Bloemdal). Where diagnostic red occurs in other profiles, it is associated with Fe oxide mottles. This is the case in P201 (Longlands), P203 (Tukulu), P204 (Longlands), P205 (Kroonstad) and P209 (Katspruit).

Grey and yellow are the dominant colours in the profiles described for this study. For example in P201 (Longlands) and P209 (Katspruit) the amount of grey increase with depth, at the expense of yellow. The amount of diagnostic grey is, however, much more in the Katspruit than in the Longlands. In P202 (Pinedene) diagnostic grey decreases and then increases with depth. In P203 (Tukulu), P204 (Longlands), P205 (Kroonstad) and P207 (Westleigh) the amount of diagnostic grey decreases with depth. This might indicate a drier subsoil water regime. Artificial increases in the amount of red caused by smearing of Fe oxide mottles during profile preparation explain this feature in P204 (Longlands) and P205 (Kroonstad). Profiles P206 (Kroonstad) and P208 (Kroonstad) are diagnostic grey throughout the profile.

Mean horizon colour can be calculated directly in ArcView, or from the results of diagnostic colour classification. The two methods do not give significantly different results. Results of colour classification do not show great promise regarding correlations with $AD_{5-0.7}$, but can successfully be used in colour determination for diagnostic horizon classification, or for the determination of other soil morphological features.

7 DIAGNOSTIC HORIZON CHARACTERIZATION

7.1 Introduction

Duration of $s > 0.7$ can be described in relation to soil profiles, or it can be described for each individual diagnostic horizon group. The South African soil classification system (Soil Classification Working Group, 1991) gives high priority to horizon identification in profiles. This makes it possible to characterize the diagnostic horizons in terms of diagnostic and non-diagnostic soil qualities. The aim of this chapter is to characterize diagnostic horizon hydrology and to propose subdivisions, when appropriate.

The mean values of a number of different parameters, and standard errors of the means per diagnostic horizon group are presented as follows: $AD_{s>0.7}$ in Figure 7.1; clay content in Figure 7.2; texture in Figure 7.3; organic carbon content in Figure 7.4; nitrogen content in Figure 7.5; CEC_{soil} and CEC_{clay} in Figure 7.6; sum of basic cations in Figure 7.7; base saturation in Figure 7.8; pH_{Water} in Figure 7.9; pH_{KCl} in Figure 7.10; Fe content in Figure 7.11; and Mn content in Figure 7.12.

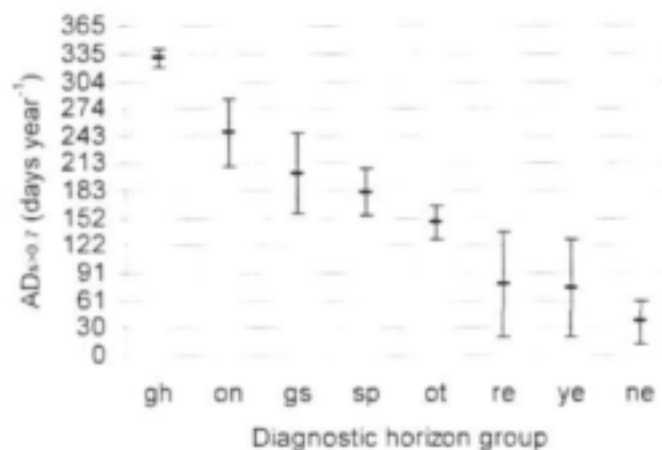


Figure 7.1 Mean and standard error of mean the $AD_{s>0.7}$ values per diagnostic horizon group.

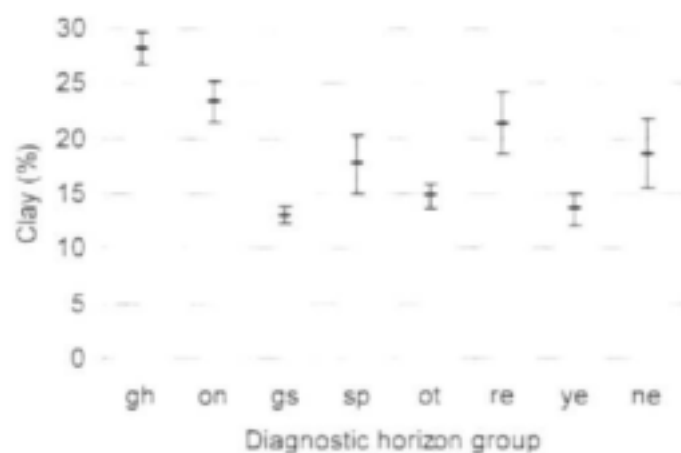


Figure 7.2 Clay content mean and standard error, per diagnostic horizon group.

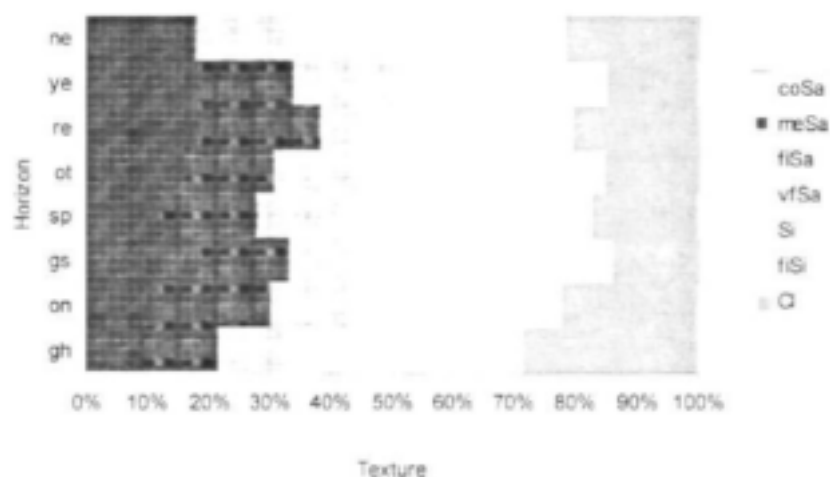


Figure 7.3 Mean texture per diagnostic horizon group.

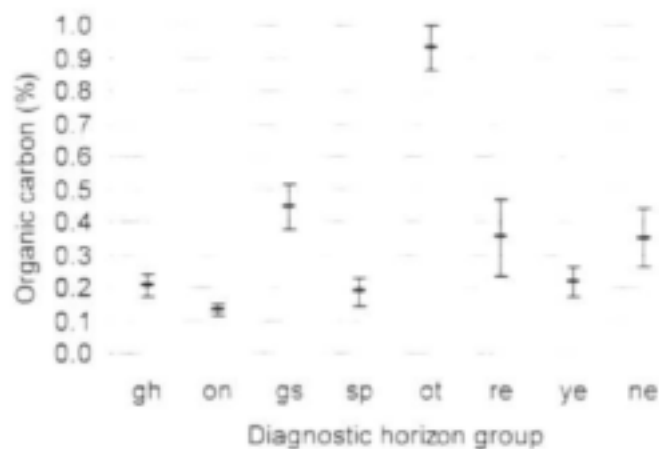


Figure 7.4 Organic carbon mean and standard error, per diagnostic horizon group.

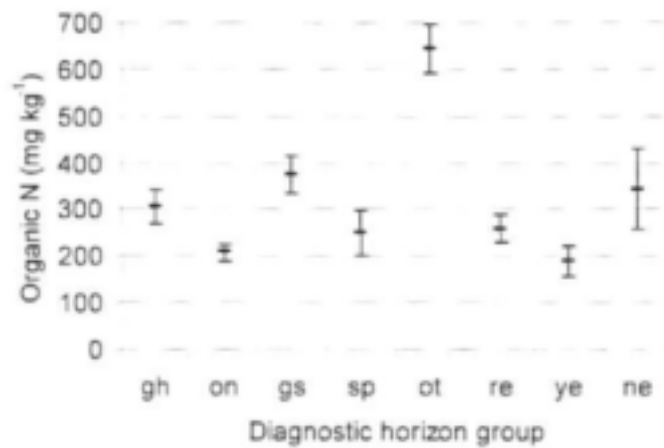


Figure 7.5 Organic nitrogen (N) mean and standard error, per diagnostic horizon group.

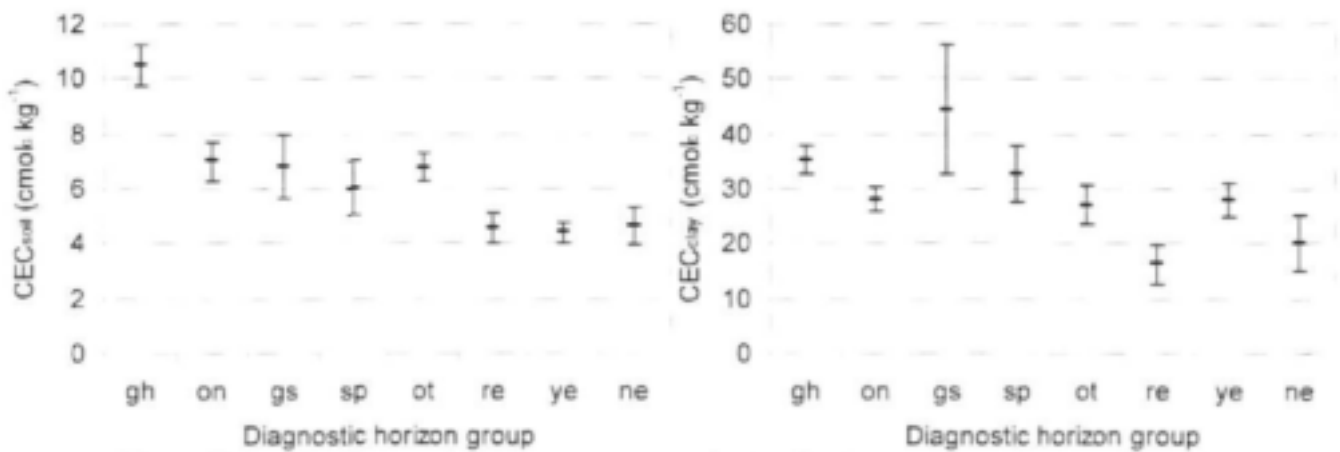


Figure 7.6 CEC_{sol} and CEC_{clay} mean and standard error, per diagnostic horizon group.

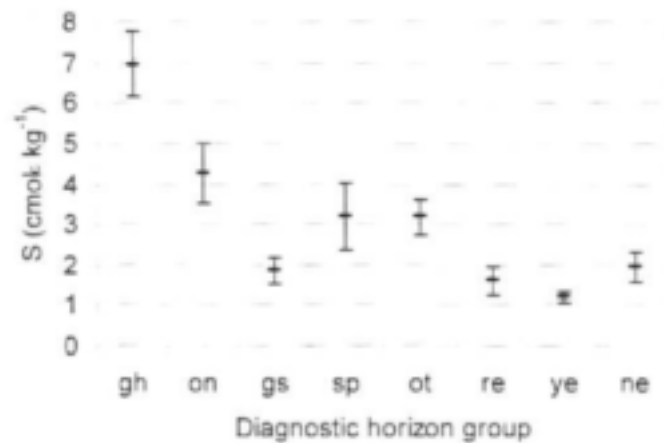


Figure 7.7 Sum of basic cations (S) mean and standard error, per diagnostic horizon group.

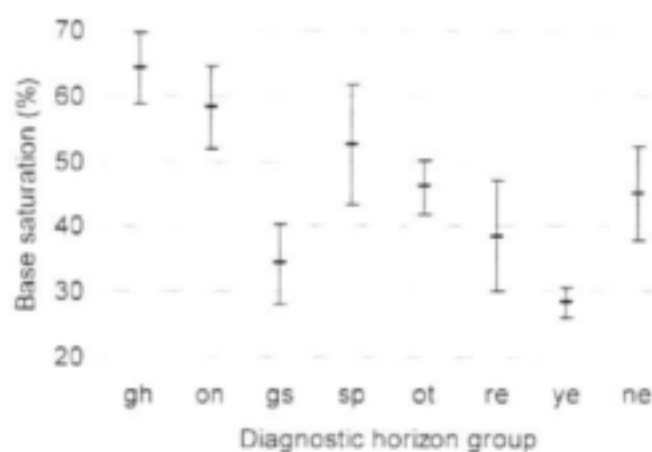


Figure 7.8 Base saturation mean and standard error, per diagnostic horizon group.

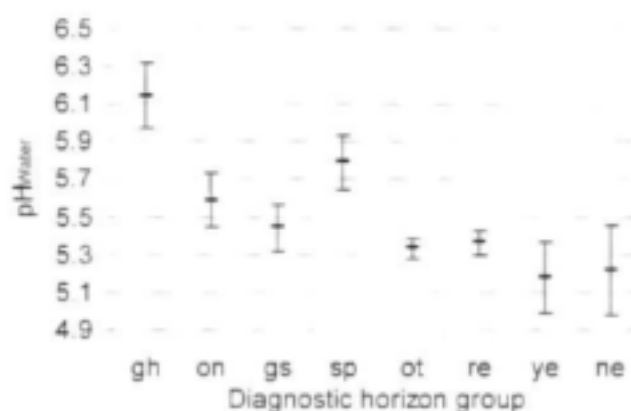


Figure 7.9 pH_{Water} mean and standard error, per diagnostic horizon group.

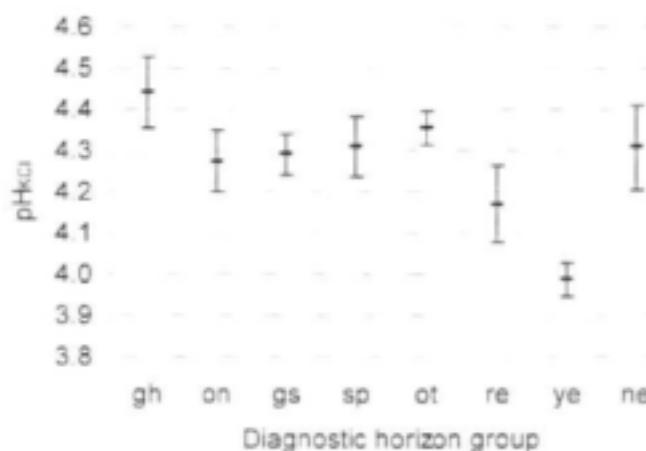


Figure 7.10 pH_{KCl} mean and standard error, per diagnostic horizon group.

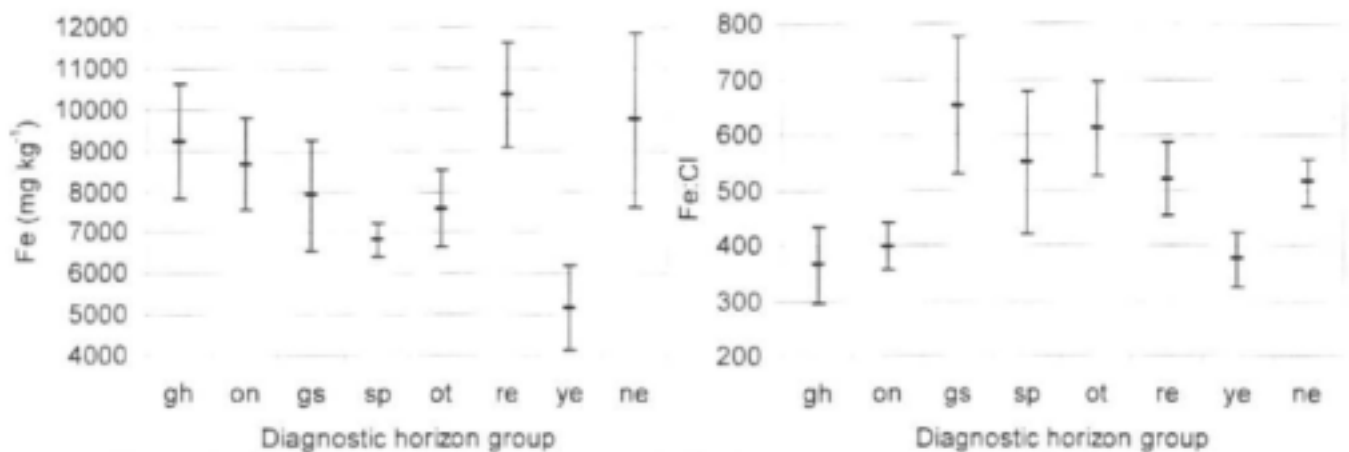


Figure 7.11 CBD extractable Fe and Fe:clay mean and standard error, per diagnostic horizon group.

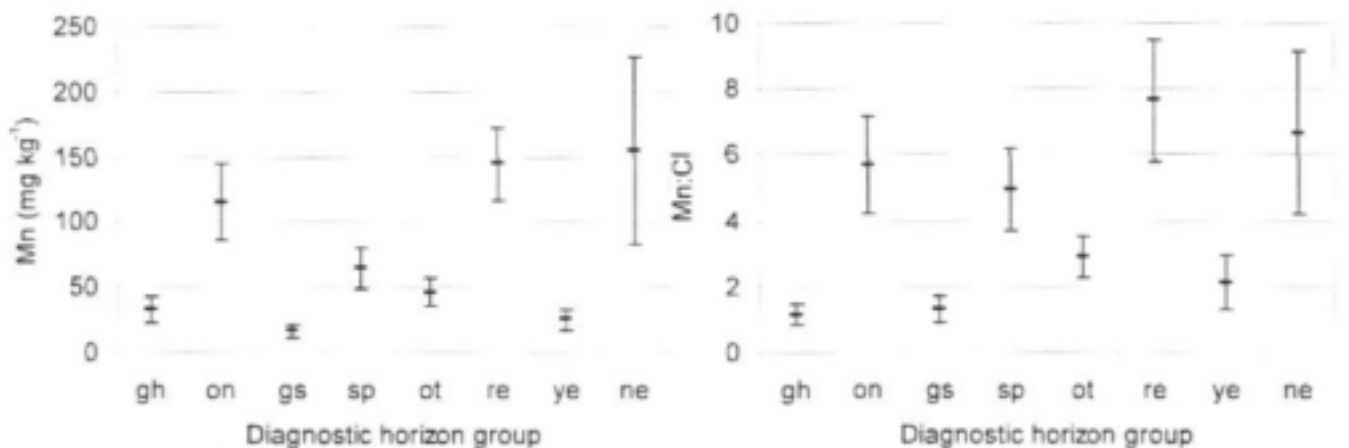


Figure 7.12 CBD extractable Mn and Mn:clay mean and standard error of, per diagnostic horizon group.

7.2 Orthic A horizons

Orthic A horizons (ot) have varying properties, including degrees of wetness. This is mainly due to the definition by which all non organic, vertic, humic or melanic A horizons are classified as orthic A horizons (Soil Classification Working Group, 1991). The properties of orthic A horizons can, however, largely be determined by inference from the underlying horizons (Le Roux *et al.*, 1999; Van Huyssteen *et al.*, 2005).

Thirty seven orthic A horizons are included in this study. All profiles have at least one orthic A horizon, while for some two orthic A horizons were described. The varied nature of orthic A horizons is clear from the soils used in this study. Mean $AD_{5>0.7}$ values range from 1 to 360 days year⁻¹ (Figure 7.1), clay content from 8 to

32 % (Figure 7.2 and Figure 7.3) and organic carbon content from 0.3 to 2.5 % (Figure 7.4).

The mean value of the sum of basic cations ($3.17 \text{ cmol}_c \text{ kg}^{-1}$ with standard error of $0.43 \text{ cmol}_c \text{ kg}^{-1}$), is significantly higher in the orthic A horizons, than in the E, or chromatic horizons and significantly lower than in G horizons (Figure 7.7). This is probably due to biocycling, resulting in the accumulation of organic matter and basic cations in the topsoil. The higher organic matter content could also result in a higher CEC. Basic cation concentration in the orthic A horizon is, however, lower than in the G horizons or unspecified material with signs of wetness. This is largely due to cation accumulation in these horizons, due to lateral leaching from up-slope profiles and vertical leaching from the overlying horizons.

Organic carbon and nitrogen are higher in the orthic A horizons than in E, chromatic, soft plinthic B, G horizons or unspecified material with signs of wetness (Figure 7.4 and Figure 7.5). The higher organic carbon and nitrogen contents are most probably due to the proliferation of plant roots in the topsoil, followed by the accumulation of organic matter by humification and slow mineralization.

pH_{Water} in orthic A horizons is significantly lower than in soft plinthic B, G and unspecified material with signs of wetness. It does not differ significantly from the other horizons (Figure 7.9). pH_{KCl} significantly higher than in yellow-brown apedal B and red apedal B horizons (Figure 7.10). Residual acidity is therefore much less in orthic A horizons, probably due to the accumulated organic matter. The lower pH points to increased leaching of basic cations from the orthic A horizons as well as the increased acidity of organic matter, which is higher in these horizons. Other variables did not differ significantly between orthic A and the other horizons.

Wetness classes (in terms of duration of saturation) as defined by the USDA's Soil Survey Division Staff (1993) are presented in Table 7.1. They do not, however, specify the degree of saturation (volumetric water as a fraction of porosity). As a useful first approximation it has been assumed here that $s > 0.7$ will qualify as being "saturated" in their terminology. The orthic A horizons of this study are ranked according to these classes in Table 7.2. There is a reasonably good agreement

between the defined Soil Survey Division Staff (1993) wetness classes and the measured mean $AD_{8>0.7}$ values for orthic A horizons in this study.

There is also a good relationship between defined wetness classes of the orthic A horizons and nature of the underlying horizon. Wetness class A has yellow-brown apedal B, red apedal B and neocutanic B horizons as the underlying horizon. The fact that the second horizon in profile 201 was an E horizon with wetness class A, can be explained by the fact that it was a border-line case as far as colour is concerned and at least one researcher classified it as yellow-brown apedal B (Roberts *et al.*, 1996). Wetness class A generally had no mottles, except for profile 201 where there were few.

Wetness classes B, C and D seem generally to apply to orthic A horizons overlying E, soft plinthic B and G horizons. There does not seem to be a meaningful differentiation in terms of underlying horizon between these wetness classes. The occurrence of mottles and matrix colour can, however, be used for further differentiation.

Orthic A horizons in the B wetness class are those in profiles 210 and 204. The mean $AD_{8>0.7}$ data for profile 210 at 150 mm is highly suspect, as it increases yearly. It seems that the pale colour (chroma = 2) of these orthic A horizons might be indicative of the longer duration of water saturation. The orthic A horizon in the C wetness class had common mottles, with matrix chroma equal to 2.

Table 7.1 Classes of duration of the wet state (Soil Survey Division Staff, 1993)

Wetness class	Description	Saturation	
		(months year ⁻¹)	(days year ⁻¹)
A	Well drained	< 1	< 30
B	Moderately well drained	1 – 4	30 – 122
C	Moderately to poorly drained	4 – 6	122 – 183
D	Poorly drained	> 6	> 183

Wetness class D had either common, many, or no mottles described. No mottles were described in the A horizon of profile 205. This horizon does, however, have a very pale colour with a chroma of 1.

The theory in soil science that Fe mottles is associated with significant periods of subsoil saturation was confirmed by the absence of these mottles in orthic A horizons with $AD_{s>0.7}$ less than 50 days year⁻¹ and a general presence in horizons with $AD_{s>0.7}$ more than 178 days year⁻¹. However an exemption to this rule is confirmed by the absence of Fe mottles in P229 (Kroonstad 1000) at 0 to 375 mm depth (measurement at 225 mm). The horizon had an $AD_{s>0.7}$ value of 234 days year⁻¹ and overlaid an E horizon. More exemptions are P222 (Tukulu 1210) and P213 (Katspruit 1000). The orthic A horizons of these profiles have no Fe mottles but had $AD_{s>0.7}$ 171 days year⁻¹.

Table 7.2 Classification of mean $AD_{s>0.7}$ values in orthic A horizons according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{s>0.7}$ (days year ⁻¹)	Wetness class	Underlying horizon	Occurrence of mottles
202	190	ot	1	A	ye	—
203	190	ot	1	A	ne	—
210	190	ot	1	A	ot	—
212	200	ot	3	A	ne	—
201	160	ot	4	A	gs	few geo
233	190	ot	10	A	ye	common humus
234	210	ot	24	A	ot	few humus
234	510	ot	26	A	ye	few humus
205	230	ot	31	B	gs	—
225	220	ot	38	B	gs	few humus
210	490	ot	46	B	re	—
237	210	ot	53	B	sp	common Fe
220	175	ot	81	B	ot	—
232	230	ot	87	B	gh	common Fe
204	220	ot	94	B	gs	few Fe
221	140	ot	99	B	re	—
220	475	ot	152	C	re	—
236	190	ot	156	C	ot	common Fe
213	180	ot	171	C	ot	few humus
222	180	ot	171	C	ne	—
235	185	ot	178	C	ot	common Fe
208	205	ot	180	C	gs	common Fe
231	150	ot	191	D	sp	few Fe
230	150	ot	196	D	sp	few Fe
207	180	ot	197	D	sp	common Fe
218	200	ot	201	D	gh	few Fe
209	230	ot	213	D	ot	many Fe
211	200	ot/gh	215	D	gh	many Fe
213	480	ot	218	D	gh	few humus
229	225	ot	234	D	gs	—
236	490	ot	266	D	gh	common Fe
226	190	ot	268	D	gs	few Fe
209	530	ot/gh	285	D	gh	many Fe
206	170	ot	313	D	gs	few Fe
235	485	ot	365	D	ot	common Fe
235	785	ot	365	D	gh	common Fe
Mean			148			

7.3 E horizons

E horizons (gs) are *inter alia* defined as a grey horizon, having undergone marked *in situ* net removal of colloidal material, defined as Fe oxides, silicate clays and organic matter (Soil Classification Working Group, 1991).

The mean $AD_{s>0.7}$ values in E horizons vary from 24 days year⁻¹ in profile 201 to 365 days year⁻¹ in profile 206. The group mean $AD_{s>0.7}$ values for E horizons are 202 days year⁻¹ with standard error of 45 days year⁻¹ (Figure 7.1). The colour of the E horizon in profile 201 is close to that of a yellow-brown apedal B horizon. It can therefore be expected to have a relatively dry water regime. The mottles in this horizon are bleached, indicating somewhat more Fe oxide removal relative to Fe oxide accumulation than in the other E horizons (Table 7.3).

The relatively dry E horizon of profile 205 (mean $AD_{s>0.7} = 34$ days year⁻¹) can only be attributed to the location of the profile on a local ridge. It is possible that the water regime in this profile has changed over time, as the local drainage lines shifted. This horizon is characterized by many Fe oxide mottles and a very pale 2.5Y6/1 colour.

Table 7.3 Classification of mean $AD_{s>0.7}$ values in E horizons (gs) using the wetness classes of the Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{s>0.7}$ (days year ⁻¹)	Wetness class	Underlying horizon	Mottle occurrence
201	460	gs	24	A	sp	many Fe
205	530	gs	47	B	gh	many Fe
204	300	gs	94	B	sp	many Fe
225	820	gs	121	B	gs	common Fe
208	505	gs	133	C	gh	many Fe
225	520	gs	155	C	sp	common Fe
226	490	gs	360	D	gh	common Fe
229	825	gs	362	D	gh	common Fe
206	470	gs	365	D	gs	common Fe
206	770	gs	365	D	gh	common Fe
Mean			202			

The E horizons in profiles 206 and 208 have mean $AD_{s>0.7}$ values larger than 232 days year⁻¹. They therefore fall into the "poorly drained" wetness class (Soil Survey Division Staff (1993). These horizons also occur exclusively on G horizons, or unspecified material with signs of wetness, and have common or many Fe oxide mottles. The colour is mainly pale (10YR5/1, 10YR6/3 and 10YR6/2). It is therefore

proposed that E horizons with these characteristics, and occurring on G horizons or unspecified material with signs of wetness, should be classified as poorly drained, while those occurring on soft plinthic B horizons should be classified as well or moderately well drained.

E horizons with shorter $AD_{s>0.7}$ values had more Fe mottles, indicating that Fe mottles were associated with varied redox conditions. E horizons with $AD_{s>0.7}$ less than about 100 days year⁻¹ had many mottles (< 20 %) and those with $AD_{s>0.7}$ more than about 140 days year⁻¹ had common mottles (2 – 20 %). The role of varying redox conditions on the nature of Fe mottles should be investigated further.

$AD_{s>0.7}$ values of 24 to 94 days year⁻¹ were recorded in the yellow E horizons and values of 121 to 365 days year⁻¹ in grey E horizons. This is in line with the perception that yellow E horizons are drier than grey E horizons, but wetter than yellow-brown apedal B horizons.

The sum of basic cations (1.85 cmol_c kg⁻¹ with standard error of 0.31 cmol_c kg⁻¹) is significantly lower in E horizons than in orthic A, soft plinthic B, G horizons or unspecified material with signs of wetness (Figure 7.7). The sum of basic cations (S) is significantly higher in E than in yellow-brown apedal B horizons. The sum of basic cations is similar in E, red apedal B and neocutanic B horizons. These relationships are indicative of accumulation of basic cations in orthic A, soft plinthic B and G horizons and unspecified material with signs of wetness, with associated removal from E and chromatic B horizons.

The clay content in E horizons, with a mean of 13.0 % and standard error of 0.8 %, (Figure 7.2) is significantly lower than in soft plinthic B, red apedal B, neocutanic B, G and unspecified material with signs of wetness. It has a similar clay content to yellow-brown apedal B and orthic A horizons. The mean CBD extractable Fe (7 924 mg kg⁻¹, with standard error of 1 354 mg kg⁻¹) is significantly higher than in yellow-brown apedal B horizons and similar to the other horizons (Figure 7.11). Mn (16.8 mg kg⁻¹, with standard error of 5.4 mg kg⁻¹), is significantly lower in E than in orthic A, soft plinthic B, red apedal B, neocutanic B and G horizons and unspecified material with signs of wetness (Figure 7.12). Clay content and Mn

analyses support their classification which stipulates net removal of colloidal material relative to the over and underlying horizons (Soil Classification Working Group, 1991). Clay and total Fe content are not significantly lower in E than in the orthic A horizons.

7.4 G horizons

G horizons (gh) are saturated for long periods and have grey colours on the macro pore and ped surfaces. They have not undergone marked removal of colloidal material, as in the case of E horizons, but are rather characterized by the accumulation of colloidal material (Soil Classification Working Group, 1991).

With a mean $AD_{s>0.7}$ of 331 days year⁻¹, with standard error of 10 days year⁻¹, the G horizons are significantly wetter than all other diagnostic horizons (Figure 7.1). The main causes are presumably the location of these horizons at the bottom of the profile, as well as the position of the profiles in which they occur in the landscape, normally as the end member of a catena. The relatively high clay content and high bulk density in these horizons are also contributing factors. All G horizons fall into the "poorly drained" wetness class (Table 7.4), with the exception of the upper G horizons in P208 (Kroonstad) and P232 (Katspruit), which falls in the moderately to poorly drained class.

The theory that G horizons are saturated with water for prolonged periods was confirmed by the results. The duration of $AD_{s>0.7}$ of 200 to 365 days year⁻¹ is a significant norm for this region. An inconsistency in the data is the duration of $AD_{s>0.7}$ of 166 days year⁻¹ at 805 mm for P208 (Kroonstad 1000). This could imply that the upper G horizon of the profile is part of the E horizon. The texture and Fe content of the horizon supports this theory.

The sum of basic cations ($6.94 \text{ cmol}_c \text{ kg}^{-1}$, with standard error of $0.81 \text{ cmol}_c \text{ kg}^{-1}$), clay content (28.2 %, with standard error of 1.4 %), CEC_{soil} ($10.8 \text{ cmol}_c \text{ kg}^{-1}$, with standard error of $0.8 \text{ cmol}_c \text{ kg}^{-1}$) and pH_{Water} (6.15, with standard error of 0.17) is significantly higher than in the other horizons (Figure 7.7; Figure 7.2; Figure 7.6 and Figure 7.9). Base saturation (64.2 %, with standard error of 5.4 %) in the G horizons is also significantly higher than in orthic A, E or chromatic horizons (Figure 7.8). The

CBD extractable Fe is significantly higher than in the soft plinthic B and yellow-brown apedal B horizons, while the CBD extractable Mn is significantly lower than in soft plinthic B, red apedal B, neocutanic B and unspecified material with signs of wetness (Figure 7.11 and Figure 7.12). The data is characteristic of horizons that form in cumulative environments.

Table 7.4 Classification of mean $AD_{5-0.7}$ values in G horizons (gh) according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{5-0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
232	530	gh	165	C	many	Fe
208	805	gh	166	C	common	Fe
232	830	gh	203	D	common	Fe
213	780	gh	205	D	many	Fe
205	830	gh	244	D	common	Fe
218	500	gh	292	D	many	Fe
213	1080	gh	323	D	many	Fe
226	790	gh	352	D	few	grey
211	800	gh	357	D	common	Fe
213	1380	gh	358	D	many	Fe
218	800	gh	360	D	many	Fe
211	500	gh	363	D	common	Fe
205	1130	gh	365	D	common	Fe
205	1430	gh	365	D	common	Fe
206	1070	gh	365	D	many	Fe
208	1105	gh	365	D	many	Fe
208	1405	gh	365	D	many	Fe
211	1100	gh	365	D	common	Fe
218	1100	gh	365	D	many	Fe
218	1400	gh	365	D	many	Fe
226	1090	gh	365	D	few	grey
226	1390	gh	365	D	few	grey
229	1125	gh	365	D	many	grey
232	1130	gh	365	D	many	Fe
232	1430	gh	365	D	many	Fe
235	1085	gh	365	D	common	Fe
235	1385	gh	365	D	common	Fe
236	790	gh	365	D	many	Fe
236	1090	gh	365	D	common	Fe
236	1390	gh	365	D	common	Fe
Mean			331	D		

7.5 Red apedal B horizons

The red apedal B (re) horizons are defined by virtue of their red, high chroma colour (typically a chroma of 3 or 5 or more), lack of structure and lack of lime. Red apedal B horizons occurred only in three profiles.

The mean $AD_{>0.7}$ value for red apedal B horizons is 80 days year⁻¹, with a standard error of 58 days year⁻¹. It is the driest diagnostic horizon group, although it is not significantly different from the E, soft plinthic B and orthic A horizons. Chromatic horizons fall into the A, B, C and D wetness classes (Table 7.5). The wetter chromatic horizons are typically deeper than 600 mm, and occur on unspecified material with signs of wetness. The $AD_{>0.7}$ values for the two red apedal B horizons in P210 are probably erroneous. In profiles P220 (Bloemdal 1100) and P221 (Hutton 2100) they had $AD_{>0.7}$ values as expected, with a few days of $AD_{>0.7}$ per year. However in P210 (Bloemdal 1100) the red apedal B horizon exceed this for 109 days year⁻¹ at a depth of 790 mm and for nearly the full year a depth of 1 090 mm. The colour of this red apedal B horizon is similar to that of the other two profiles and mottling is restricted to humus. This anomaly requires more investigation. The mean $AD_{>0.7}$ value for red apedal B horizons, excluding the two anomalies is 4 days year⁻¹.

Table 7.5 Classification of mean $AD_{>0.7}$ values in red apedal B horizons (re), according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{>0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
220	775	re	0	A	few	humus
221	740	re	0	A	—	—
221	440	re	1	A	—	—
221	1040	re	11	A	—	—
210	790	re	109	B	many	humus
210	1090	re	357	D	many	humus
Mean			80			

Clay content in red apedal B horizons (21.4 %, with a standard error of 2.9 %) is significantly higher than in E, orthic A and yellow-brown apedal B horizons and significantly lower than in G horizons (Figure 7.2).

Sum of basic cations in red apedal B horizons (1.61 cmol_c kg⁻¹, with a standard error of 0.35 cmol_c kg⁻¹) is significantly lower than in G, orthic A, soft plinthic B and unspecified material with signs of wetness (Figure 7.7). It does not differ significantly from the other horizons.

Organic carbon in red apedal B horizons (0.35 %, with a standard error of 0.12 %) is significantly higher than in G, unspecified material with signs of wetness, yellow-

brown apedal B and soft plinthic B horizons, and significantly lower than in orthic A horizons (Figure 7.4). It does not differ significantly from the other horizons.

Total Fe in red apedal B horizons ($10\,338\text{ mg kg}^{-1}$, with a standard error of $1\,285\text{ mg kg}^{-1}$) is significantly higher than in orthic A, soft plinthic B and yellow-brown apedal B horizons (Figure 7.11). It does not differ significantly from the other horizons.

Total Mn in red apedal B horizons (145 mg kg^{-1} , with a standard error of 28 mg kg^{-1}) is significantly higher than in G, E orthic A, soft plinthic B and yellow-brown apedal horizons (Figure 7.12). It does not differ significantly from neocutanic B horizons and unspecified material with signs of wetness.

7.6 Yellow-brown apedal B horizons

The yellow-brown apedal (ye) B horizons are defined by virtue of their yellow-brown, high chroma colour (typically a chroma of 3 or 5 or more), lack of structure and lack of lime.

The mean $AD_{s>0.7}$ value for yellow-brown apedal horizons is 75 days year^{-1} , with a standard error of 53 days year^{-1} . It is the driest diagnostic horizon group, although it is not significantly different from the E, soft plinthic B and orthic A horizons. Chromatic horizons fall into the A, B, C and D wetness classes (Table 7.6). The wetter chromatic horizons are typically deeper than 600 mm, and occur on unspecified material with signs of wetness. These results confirmed that yellow-brown apedal B horizons do saturate for a significant time. The short duration of $AD_{s>0.7}$ in P202 (Pinedene 1100) at 490 mm would, however, rather fit the red apedal or neocutanic B horizons. In contrast the $AD_{s>0.7}$ at 790 mm is $234\text{ days year}^{-1}$, much longer than expected. This may be explained by the point of measurement and the presence of mottles. The measurement incorporates about 25 % of the underlying unspecified material with signs of wetness. Although only a few mottles ($< 2\%$) were described it may be significant. The Fe content was also higher than the other horizons, indicating soft plinthic horizon characteristics. The mean $AD_{s>0.7}$ value for yellow-brown apedal horizons, excluding the measurement at 790 mm in P202, was 22 days year^{-1} .

Table 7.6 Classification of mean $AD_{5>0.7}$ values in yellow-brown apedal B horizons (ye), according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{5>0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
202	490	ye	2	A	few	Fe
233	490	ye	20	A	many	humus
234	810	ye	44	B	many	humus
202	790	ye	234	D	few	Fe
Mean			75			

Clay content in yellow-brown apedal horizons (13.6 %, with a standard error of 1.4 %) is significantly lower than in G, neocutanic B, and red apedal B horizons and unspecified material with signs of wetness (Figure 7.2).

Sum of basic cations in yellow-brown apedal horizons (1.20 cmol_c kg⁻¹, with a standard error of 0.12 cmol_c kg⁻¹) is significantly lower than in G, E, neocutanic B, orthic A and soft plinthic B horizons and unspecified material with signs of wetness (Figure 7.7). It does not differ significantly from red apedal B horizons.

Organic carbon in yellow-brown apedal horizons (0.22 %, with a standard error of 0.04 %) is significantly lower than in E, neocutanic B, orthic A and red apedal B horizons and significantly higher than in unspecified material with signs of wetness (Figure 7.4). It does not differ significantly from G and soft plinthic B horizons.

Total Fe content in yellow-brown apedal horizons (5 152 mg kg⁻¹, with a standard error of 1 033 mg kg⁻¹) is significantly lower than in the other horizons (Figure 7.11)

Total Mn content in yellow-brown apedal horizons (25 mg kg⁻¹, with a standard error of 8 mg kg⁻¹) is significantly lower than orthic A, neocutanic B, red apedal B and soft plinthic B horizons and unspecified material with signs of wetness (Figure 7.12). It does not differ significantly from G and E horizons.

7.7 Neocutanic B horizons

Neocutanic B horizons (ne) are defined as being non-calcareous and having undergone limited pedogenesis (Soil Classification Working Group, 1991).

The mean $AD_{s>0.7}$ value for neocutanic B horizons is 37 days year⁻¹, with a standard error of 24 days year⁻¹. It is the driest diagnostic horizon group, although it is not significantly different from the E, soft plinthic B and orthic A horizons. Chromatic horizons fall into the A, B, C and D wetness classes (Table 7.7). The wetter chromatic horizons are typically deeper than 600 mm, and occur on unspecified material with signs of wetness. The presence of common Fe mottles in most of the neocutanic horizons contradict the low $AD_{s>0.7}$ values. In profiles P212 (Tukulu 1110) and P203 (Tukulu 2110) the colour of the B horizon disqualified it as red or yellow-brown apedal B horizons. The colour of the neocutanic horizon of P222 (Oakleaf 1210) was, however, diagnostic red and very similar to that of the other red apedal horizons. The varied colour and mottles disqualified it as a red apedal B horizon. It is therefore surprising to find $AD_{s>0.7}$ values of 80 and 164 days in P222 (Oakleaf 1210). Without these two values, the mean $AD_{s>0.7}$ value for neocutanic B horizons would have been 3 days year⁻¹.

Table 7.7 Classification of mean $AD_{s>0.7}$ values neocutanic B horizons (ne), according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{s>0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
212	500	ne	0	A	many	humus
212	800	ne	1	A	common	Fe
212	1100	ne	1	A	common	Fe
203	490	ne	5	A	common	Fe
203	790	ne	6	A	common	Fe
222	480	ne	80	B	few	Fe
222	780	ne	164	C	common	Fe
Mean			37			

Clay content in neocutanic B horizons (18.6 %, with a standard error of 3.2 %) is significantly higher than E and yellow-brown apedal B horizons; and significantly lower than G horizons (Figure 7.2). It does not differ significantly from orthic A, red apedal B and soft plinthic B horizons and unspecified material with signs of wetness.

Sum of basic cations in neocutanic B horizons (1.95 cmol_c kg⁻¹, with a standard error of 0.36 cmol_c kg⁻¹) is significantly higher than yellow-brown apedal B horizons and significantly lower than orthic A, G and soft plinthic B horizons and unspecified material with signs of wetness (Figure 7.7). It does not differ significantly from E and red apedal B horizons.

Organic carbon in neocutanic B horizons (0.35 %, with a standard error of 0.09 %) is significantly higher than in G, soft plinthic B and yellow-brown apedal B horizons and unspecified material with signs of wetness and significantly lower than in orthic A horizons (Figure 7.4). It does not differ significantly from E and red apedal B horizons.

Total Fe content in neocutanic B horizons ($9\,741\text{ mg kg}^{-1}$, with a standard error of $2\,115\text{ mg kg}^{-1}$) is significantly higher than in soft plinthic and yellow-brown apedal B horizons (Figure 7.11). It does not differ significantly from G, E, orthic A and red apedal B horizons and unspecified material with signs of wetness.

Total Mn content in neocutanic B horizons (155 mg kg^{-1} , with a standard error of 73 mg kg^{-1}) is significantly higher than in G, E, soft plinthic B, yellow-brown apedal B and orthic A horizons (Figure 7.12). It does not differ significantly from red apedal B horizons and unspecified material with signs of wetness.

7.8 Soft plinthic B horizons

Soft plinthic B horizons (sp) form due to the localisation and accumulation of Fe and Mn oxides under a fluctuating water table to produce more than 10 % mottles (Soil Classification Working Group, 1991).

Soft plinthic B horizons have a mean $AD_{s>0.7}$ value of $171\text{ days year}^{-1}$, with a standard error of 25 days year^{-1} . This is significantly lower than in G horizons and unspecified material with signs of wetness (Figure 7.1). It does, however, not differ significantly from the mean $AD_{s>0.7}$ value in orthic A, E and chromatic horizons. Soft plinthic B horizons fall into the B, C and D wetness classes (Table 7.8). $AD_{s>0.7}$ values in soft plinthic B horizons were varied. This seemed to be the nature of these horizons. Future research, focussing on the impact of fluctuating periods of saturation, coupled with variations in duration and bulk density might shed more light on this issue.

Table 7.8 Classification of mean $AD_{s>0.7}$ value in soft plinthic B horizons (sp), according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{s>0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
230	450	sp	82	B	few	Fe/Mn
201	750	sp	83	B	many	Fe/Mn
237	510	sp	100	B	many	Fe
204	520	sp	124	C	common	Fe
237	810	sp	198	D	common	Fe
231	450	sp	215	D	many	Fe
225	1120	sp	220	D	many	Fe
207	480	sp	230	D	many	Fe
234	1110	sp	287	D	common	Fe
Mean			171			

The clay content in soft plinthic B horizons (17.6 % with a standard error of 2.7 %) is significantly higher than in E horizons and significantly lower than in G horizons and unspecified material with signs of wetness (Figure 7.2). It does not differ significantly from neocutanic B, red apedal B, yellow-brown apedal B and orthic A horizons.

Sum of basic cations in soft plinthic B horizons ($3.20 \text{ cmol}_c \text{ kg}^{-1}$ with a standard error of $0.83 \text{ cmol}_c \text{ kg}^{-1}$) is significantly higher than in E, neocutanic B, red apedal B and yellow-brown apedal B horizons and significantly lower than in G horizons (Figure 7.7). It does not differ significantly from orthic A horizons and unspecified material with signs of wetness.

Organic carbon in soft plinthic B horizons (0.19 %, with a standard error of 0.04 %) is significantly lower than in E, neocutanic B, red apedal B and orthic A horizons (Figure 7.4). It does not differ significantly from G and yellow-brown apedal B horizons and unspecified material with signs of wetness.

Total Fe content in soft plinthic B horizons ($6\,835 \text{ mg kg}^{-1}$, with a standard error 428 mg kg^{-1}) is significantly higher than in yellow-brown apedal B horizons and significantly lower than in G, neocutanic B and red apedal B horizons and unspecified material with signs of wetness (Figure 7.11). It does not differ significantly from E and orthic A horizons.

Total Mn content in soft plinthic B horizons (64 mg kg^{-1} , with a standard error 16 mg kg^{-1}) is significantly higher than in G, E and yellow-brown apedal B horizons

and significantly lower than in neocutanic B and red apedal B horizons and unspecified material with signs of wetness (Figure 7.12). It does not differ significantly from orthic A horizons.

7.9 Unspecified material with signs of wetness

The properties of unspecified material with signs of wetness (on) vary considerably. The main diagnostic criterion is the presence of grey, low chroma matrix colours due to the reduction and loss of Fe oxides (Soil Classification Working Group, 1991). It is therefore analogous to the G horizons and unconsolidated material with signs of wetness (Soil Classification Working Group, 1991), the main difference being its occurrence under a red apedal, neocutanic or neocarbonate B horizon. In this study, the material underlying a soft plinthic B was also included into this group.

The mean $AD_{s>0.7}$ in unspecified material with signs of wetness is 248 days year⁻¹ with a standard error of 37 days year⁻¹ (Figure 7.1). The measurements in P212, P220 and P221 are clearly erroneous. This might be due to erroneous classification or errors in the water content measurements and calculations. Without these three values $AD_{s>0.7}$ in unspecified material with signs of wetness would be 304 days year⁻¹ with a standard error of 28 days year⁻¹. This is significantly higher than the value for the soft plinthic B, orthic A and chromatic horizons, and significantly lower than the value in G horizons. Although the mean $AD_{s>0.7}$ is higher than in E horizons, the difference is not significant. Unspecified material with signs of wetness fall into the C and D wetness classes (Table 7.9). The low $AD_{s>0.7}$ values in the unspecified horizons with signs of wetness of P212 (Tukulu 1110), P220 (Bloemdal 2110) and P203 (Tukulu 1110) is in harmony with the theory that these horizons underlie better drained horizons. The $AD_{s>0.7}$ value of 170 days year⁻¹ for P210 contradicts this theory.

Table 7.9 Classification of mean $AD_{5>0.7}$ values in unspecified material with signs of wetness (on) according to the wetness classes of Soil Survey Division Staff (1993)

Profile No	Depth (mm)	Diagnostic horizon	Mean $AD_{5>0.7}$ (days year ⁻¹)	Wetness class	Occurrence of mottles	Type of mottles
212	1400	on	4	A	common	grey
220	1075	on	7	A	many	grey
221	1340	on	10	A	few	Fe
203	1390	on	100	B	many	Fe
203	1090	on	135	C	many	Fe
210	1390	on	170	C	—	
231	750	on	215	D	many	Fe
204	820	on	251	D	many	Fe
220	1375	on	300	D	many	Fe
230	750	on	312	D	few	Fe
234	1410	on	322	D	common	Fe
202	1090	on	365	D	many	Fe
202	1390	on	365	D	many	Fe
204	1120	on	365	D	many	Fe
222	1080	on	365	D	—	
230	1050	on	365	D	few	Mn
230	1350	on	365	D	few	Mn
231	1050	on	365	D	many	Fe
231	1350	on	365	D	many	Fe
233	790	on	365	D	many	Fe
233	1090	on	365	D	many	Fe
233	1390	on	365	D	many	Fe
237	1110	on	365	D	many	grey
237	1410	on	365	D	many	grey
Mean			248			

The clay content in unspecified material with signs of wetness (23.4 % with a standard error of 1.9 %) is significantly higher than in E, soft plinthic B, yellow-brown apedal B and orthic A horizons and significantly lower than in G horizons (Figure 7.2). It does not differ significantly from neocutanic B and red apedal B horizons.

Sum of basic cations in unspecified material with signs of wetness (4.25 cmol_c kg⁻¹ with standard error of 0.74 cmol_c kg⁻¹) is significantly higher than in E, neocutanic B, red apedal B and yellow-brown apedal B horizons and is significantly lower than in G horizons (Figure 7.7). It does not differ significantly from soft plinthic B and orthic A horizons.

Organic carbon content in unspecified material with signs of wetness (0.13 % with standard error of 0.02 %) is significantly lower than in G, E, neocutanic B, red apedal

B, soft plinthic B and orthic A horizons (Figure 7.4). It does not differ significantly from the soft plinthic B horizons.

Total Fe content in unspecified material with signs of wetness ($8\,669\text{ mg kg}^{-1}$ with standard error of $1\,122\text{ mg kg}^{-1}$) is significantly higher than in soft plinthic B and yellow-brown apedal B horizons (Figure 7.11). It does not differ significantly from G, E, neocutanic B, red apedal B and orthic A horizons.

Total Mn content in unspecified material with signs of wetness (115 mg kg^{-1} with standard error of 30 mg kg^{-1}) is significantly higher than in G, E, soft plinthic B, yellow-brown apedal B and orthic A horizons (Figure 7.12). It does not differ significantly from neocutanic B and red apedal B horizons.

7.10 Summary

This information exposed by this research lays down quantities norms of the wetness of soils and diagnostic soil horizons that was inferred from field observations in the past.

The diagnostic horizons and soil forms of the SA Soil Taxonomy are not unique functional units as far as $AD_{s>0.7}$ are concerned. Although the average values for $AD_{s>0.7}$ is roughly following the trend observed and interpreted from field observations there are several exceptions. In general, neocutanic B horizons had $AD_{s>0.7}$ 3 days year⁻¹, red apedal B horizons had $AD_{s>0.7}$ 4 days year⁻¹, yellow-brown apedal B horizons had $AD_{s>0.7}$ 22 days year⁻¹, soft plinthic B horizons had $AD_{s>0.7}$ 182 days year⁻¹, E horizons had $AD_{s>0.7}$ 202 days year⁻¹, unspecified material with signs of wetness had $AD_{s>0.7}$ 248 days year⁻¹, and G horizons had $AD_{s>0.7}$ 331 days year⁻¹.

Orthic A horizons can be meaningfully subdivided, to differentiate between wetness classes. Subdivision is mainly on the nature of the underlying horizon, with orthic A horizons on red apedal B, yellow-brown apedal B and neocutanic horizons classified in the A wetness class. Orthic A horizons in the B wetness class occur on E horizons and have either no mottles or few mottles. Orthic A horizons in the C wetness class occur on E and G horizons and have few to many mottles. The orthic A horizons in

the D wetness class occur on soft plinthic B and E horizons and have common mottles.

As expected, the orthic A horizons have the highest organic carbon and nitrogen content. The organic carbon content is lowest in G horizons and unspecified material with signs of wetness. There is no significant difference in the organic carbon content of E, neocutanic B and red apedal B horizons. The nitrogen content follows a similar pattern.

Sum of bases is significantly higher in orthic A horizons than in E, neocutanic B, red apedal B and yellow-brown apedal B horizons and is significantly lower than in G horizons. There is no significant difference in sum of basic cations between orthic A and soft plinthic B horizons and unspecified material with signs of wetness.

The clay content does not differ significantly between neocutanic B, red apedal B, yellow-brown apedal B and soft plinthic B horizons and unspecified material with signs of wetness. It is, however, significantly higher in G horizons and is lowest in E, yellow-brown apedal B and orthic A horizons.

Total Fe content is highest in red apedal B horizons and lowest in soft plinthic B and yellow-brown apedal B horizons. It does not vary significantly between G, E, neocutanic B and orthic A horizons and unspecified material with signs of wetness.

Total Mn content is lowest in G, E, soft plinthic B, yellow-brown apedal B and orthic A horizons. Highest total Mn content was found in neocutanic B and red apedal B horizons and unspecified material with signs of wetness.

The chemical and physical analyses as well as mean $AD_{8>0.7}$ values generally supported the classification of diagnostic horizons (Soil Classification Working Group, 1991). This implies that diagnostic horizons can be used to infer these properties, given the current research environment.

8 CORRELATION OF SOIL CHARACTERISTICS WITH HYDROLOGICAL RESPONSE CHARACTERISTICS

8.1 Introduction

The large amount of hydrological and pedological data that has been collected for the Weatherley catchment provides a favourable environment for initial contributions on this subject. The cooperation of Prof. S. Lorentz is greatly valued. His experience is clearly reflected in the careful way in which the Weatherley project has been planned and executed since 1995. All the hydrograph data in this section and much of the soil water content data come from his records. The 12 minute tensiometer records, during critical periods, at carefully selected sites, have provided invaluable information for estimating interflow rates.

The total runoff (R) from a small catchment, as expressed by the hydrograph, can be subdivided into three categories viz. (a) the runoff which occurs from the soil surface immediately after a rainfall event during which rainfall intensity (P_i) exceeds the infiltration rate of the soil and which provides the peaks in the hydrograph; (b) baseflow; (c) the flow recorded on the hydrograph between (a) and (b), caused by relatively rapid lateral flow (interflow) in the vadose zone. The vadose zone is defined by Lin (2003) and Lin *et al.* (2004) as the region between the water table and the soil surface (Figure 8.1). For our purpose it will be subdivided into two portions, the upper vadose zone consisting of the soil profile to a maximum depth of around 1.5 m, and the lower vadose zone consisting of the remaining portion down to the water table. Although there are specific portions of the hydrograph which represent each of the subdivisions of the hydrograph, there will not be clear boundaries between them. The fraction of runoff contributed by each of these categories, and the shapes of the respective portions of the hydrograph, are determined by a number of catchment characteristics. Significant rainfall events cause peaks in the hydrograph. These reflect conditions in the catchment regarding topography, infiltration rate, land use, and rainfall intensity and duration during the event. The peaks do not give definitive information about the pedology of the catchment. The contribution of category (b) is frequently extremely important for socio-economic reasons in spite of its relatively low volume. It is hypothesized that the portion of the hydrograph which is most closely correlated with the soils of the catchment, their

distribution pattern, and their extent and characteristics, is presented by category (c). This portion of the hydrograph, and to a lesser extent category (b), will therefore receive the most attention in this study.

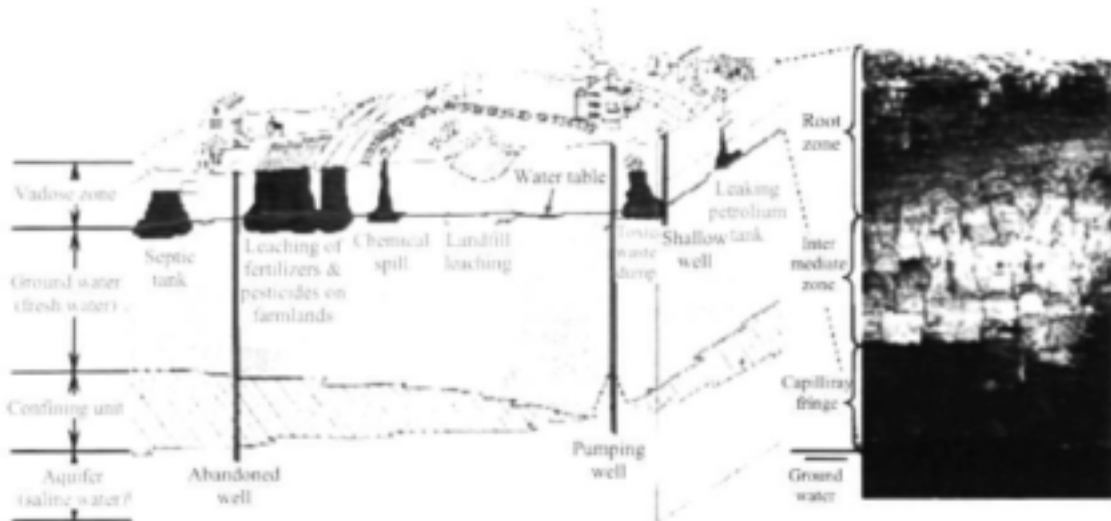


Figure 8.1 The extent of the vadose zone in relation to the ground water (Lin, 2003).

During autumn each year the rain at Weatherley generally stops fairly abruptly around the end of March. This sharp decrease in rainfall is well described by comparing the long term average rainfalls for March and April at Maclear; they are 108 and 43 mm respectively (Roberts *et al.*, 1996). At the end of the normal wet summer the water content of the whole vadose zone in the Weatherley catchment is generally far above the drained upper limit. This water then drains in autumn providing what is considered to be a characteristic category (c) portion of the hydrograph. It is suggested that the closer a measuring site, with soil from which interflow comes, is located to the hydrograph, the easier it is to correlate soil characteristics with hydrological response characteristics. This is presumably an important reason why hydrological process studies are considered on small 'primary' catchments like Weatherley. Hence the wisdom of Prof. Lorentz in focussing attention (Lorentz, 2001) on the sub-catchment, designated here as the 'upper eastern catchment' or UEC (Figure 8.2), where interflow seepage discharges over the sandstone shelf at P204.



Figure 8.2 The Weatherley catchment showing contours (2 mm interval), some convenient sub-catchments, hydrographical weirs, and NWM measuring sites.

It is possible to estimate the amount of this outflow because of the intensive soil water content and other measurements made since 1995 at P204. Although this is an advantage for studying the UEC it is postulated in the following section that the relevant physiographic feature, i.e. the sandstone shelf, is one of the factors in the Weatherley catchment that tends to camouflage the correlation between soil characteristics and hydrological response characteristics for the catchment as a whole.

8.2 Catchment features camouflaging the correlation between soil and hydrological response characteristics

The first prominent landscape feature is the sandstone top of the Molteno formation which forms a clearly visible shelf around the rim of the catchment along the eastern and southern sides at an altitude of approximately 1 316-1 318 m (Figure 8.2). The

shelf is present, but less visible, along the western side where the slope is less steep. Sandstone and mudstone of the Elliot formation occur above the Molteno shelf. The latter appears to be relatively impermeable, causing lateral drainage water from the soils above it (Figure 8.2), to flow slowly over the shelf at specific sites during the rain season. Over centuries these flows have eroded the shelf into defined indentations. Below these indentations small rivulets have formed, channelling the runoff (surface and interflow) into the marsh below, and eventually into the stream bed. They are most clearly defined where the land above the shelf is fairly steep, *i.e.* on the eastern and southern sides of the catchment. They are clearly shown in Figure 3.3. These rivulets appear to play an important role in the hydrological response characteristics of the catchment. They promote a very rapid hydrograph response after rainfall events, and consequently are probably one of the causes of the low baseflow from the catchment. On the upper side of the shelf edge, particularly opposite the indentations, hydromorphic soils have developed. They exhibit the diagnostic horizons E (gs), soft plinthic (sp), G (gh) and unspecified material with signs of wetness (on). Interflow from the higher lying soils is conducted through these horizons to the marsh below. These patches, with map symbol Ca or Cb can be identified by comparing Figure 3.3 and Figure 3.5, for example at P204, P232, above P212.

The second prominent landscape feature is the large marsh area which occupies approximately 25% of the catchment. Below the indentations / flow points in the sandstone shelf the marsh has frequently crept right up to the shelf, even on relatively steep slopes (Figure 3.5). This is due to the hydromorphic conditions which prevail over long periods at these sites. The dominant soils in the marsh belong to Katspruit (Ka) and Kroonstad (Kd) forms. They remain close to saturation for most of the year (Figure 5.40 and Figure 5.45). Because of this the runoff response from the marsh is very rapid after the start of a storm, and also ends relatively abruptly. An example is presented in Figure 8.3, where the flow rate at the upper weir is plotted against rainfall intensity values during two rainfall events in February 1999. The marsh serves as a buffer by absorbing the lateral drainage water from the upslope parts of the catchment, and retaining it for a considerable time. Due to the relatively higher ET rate of the marsh compared to that of the hillsides, a large fraction of the water in the marsh is lost to ET.

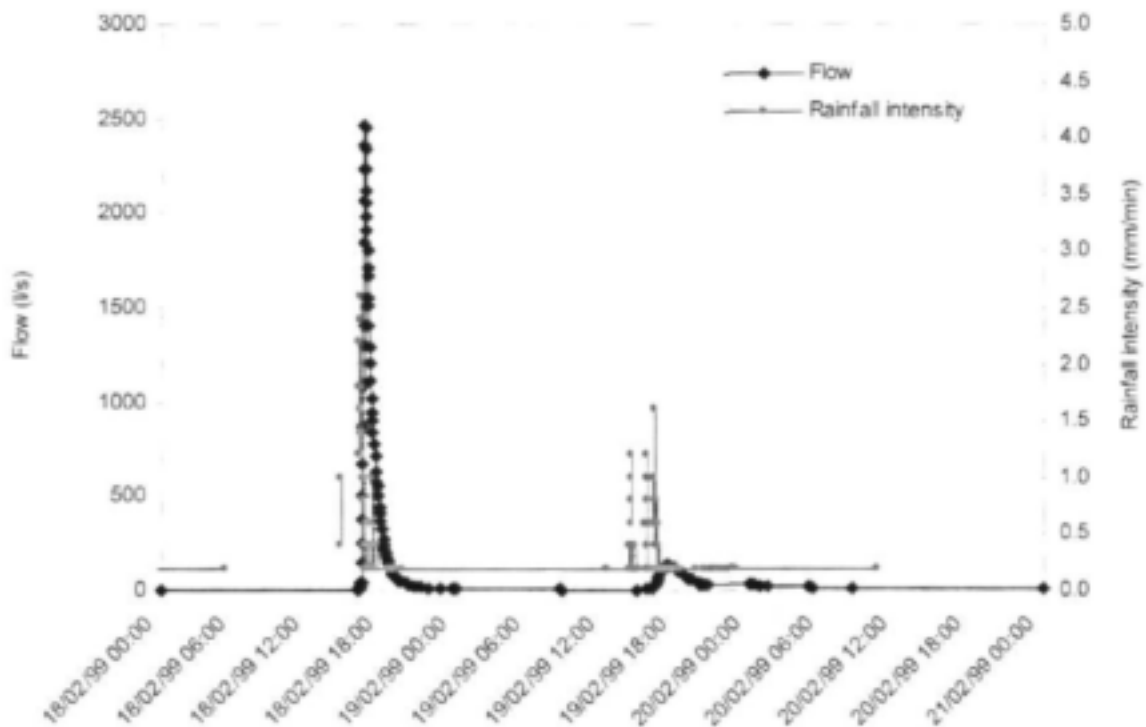


Figure 8.3 Examples of quick runoff response to varying rainfall intensities as reported at the upper weir in February 1999 (BEEH, 2003).

The third prominent landscape feature is the marked difference between the topography west of the stream and that to the east. An associated feature is the location of most of the marsh on the eastern side of the catchment, that also being the side on which the sandstone shelf is most prominent. The geological characteristics and geomorphological forces responsible for this topographical difference cannot be explained at present. It is possible that the dolerite dyke which occurs along the western side (Figure 3.4), at least as far northwards as P210 (Figure 3.3) and probably beyond, could have been a contributing cause. It may have provided relatively easily weatherable material for the formation of the deep red soils in the large Af map unit to the northern end where the marsh is at its narrowest. Although its influence cannot be measured, this soil-related topographical feature will certainly cause the hydrological response characteristics of the western portion to be significantly different from that of the eastern portion.

The influence of the named catchment features and related soil characteristics on the hydrological response characteristics of the Weatherley catchment become

highlighted when they are compared with another catchment with very different characteristics, viz. Cathedral Peak (VI) in the Drakensberg region of KwaZulu-Natal. Detailed information about the water balance in this catchment is presented in a report to the Water Research Commission by Everson *et al.* (1998). A topographic map is presented in Figure 8.4. The area is 67.7 ha, with 92% having slopes greater than 11%. Other important features are: two relatively small saturated zones, the upper one "on a topographic convergence midway in the catchment and the other where the stream flattens before the catchment outlet" - the total area is approximately 5.5 ha or about 8% of the catchment; soils classified as "lateritic red and yellow earths", grading into black soils (Katspruit and Champagne) in the saturated zones and along the stream banks." Although Everson *et al.* (1998) do not present a soil map of the catchment, other information about the soils shows that they are generally deep, high in organic matter (6–10 %); have low bulk densities and high infiltration rates. Typical autumn drainage curve hydrographs of the two catchments are presented in Figure 8.5. They are clearly very different. Total outflow during rain-free periods from the two catchments was 4 362 m³ (2.7 mm) for Weatherley and 52 093 m³ (76.9 mm) for Cathedral Peak (VI). Outflow was presumed to come mainly from interflow (*i.e.* excluding base flow). Surface flow (or runoff) could be excluded, because a rain-free period was chosen.

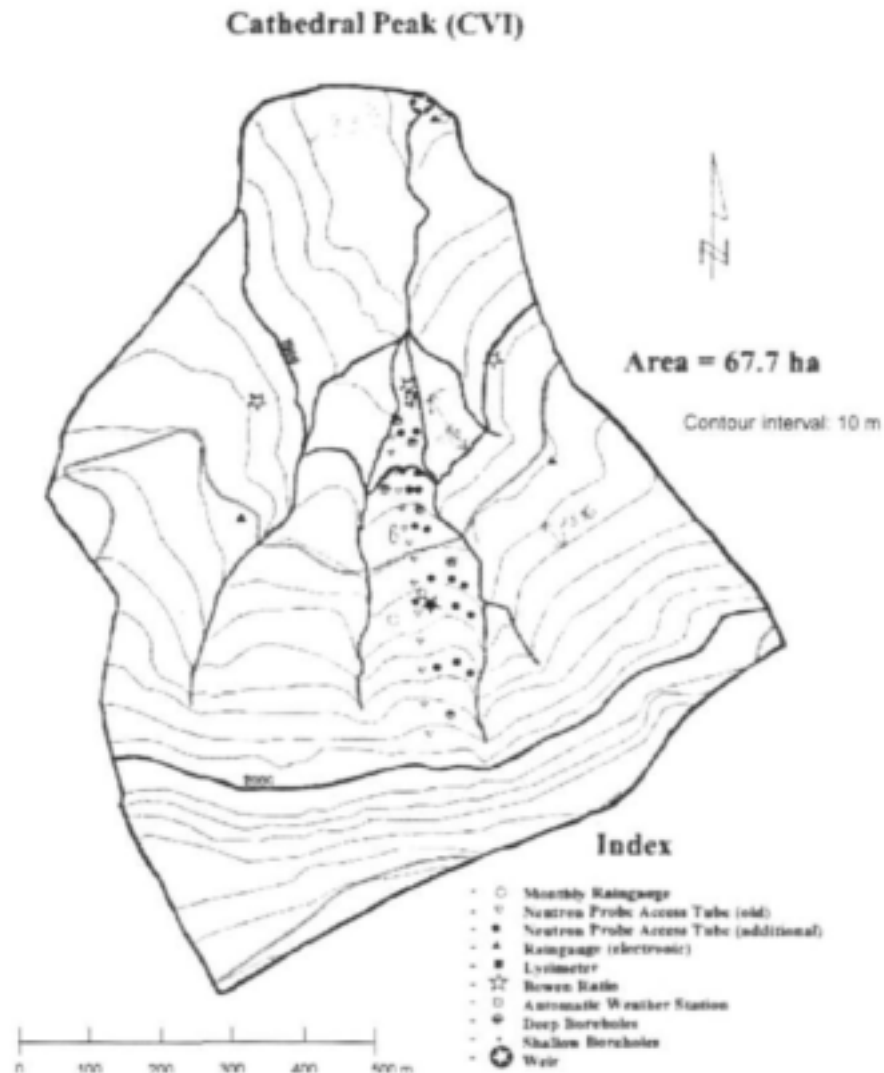


Figure 8.4 Topographic map of Catchment VI showing the location of the various monitoring sites (Everson *et al.*, 1998).

It is suggested that the reason for the large difference is mainly the large difference between the water storage capacities of both the upper and lower vadose zones in the two catchments. For the upper vadose zone of the Cathedral Peak catchment a detailed soil survey will be needed before this calculation can be made, whereas for Weatherley the necessary information is available. It is quite clear, however, that the deep, high porosity soils of the Cathedral Peak catchment, and relatively small saturated zone, compared to the shallow low storage capacity soils and large marsh area of Weatherley, have made a major contribution to the differences recorded above.

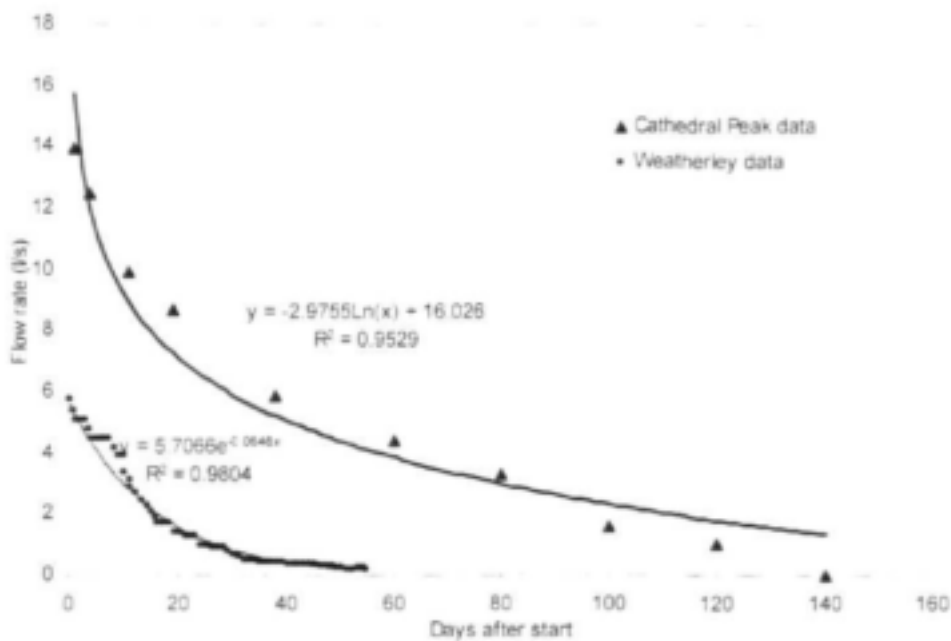


Figure 8.5 Typical hydrographs for the Weatherley and Cathedral Peak (VI) catchments during a rain-free period at the end of the rain season, approximately up to the stage when base flow starts.

What has been presented in this section provides the motivation for three important initial steps in a procedure for correlating soil characteristics and hydrological response characteristics in the landscape. The first one is the construction of detailed, large scale, topographical, geological, and soil survey maps of the catchment. The second one is the collection of data that will make it possible to estimate the total catchment storage capacity of the upper vadose zone, and if possible also the lower vadose zone. The third one is obtaining reliable ET data for the vegetation in the catchment. Even small errors in this value have a large influence on the water balance, especially for the "interflow" portion of the hydrograph.

8.3 Upper eastern catchment

8.3.1 Topographical and hydropedological characteristics

An enlarged map of the upper eastern catchment (UEC) is presented in Figure 8.6. This sub-catchment consists of an approximate area of 36 530 m² or about 3.7 ha. It is located above the Molteno shelf, on a western aspect with 10% slope, 255 m in length. A large variety of soils occur in this relatively small catchment. They include

soils with apedal and neocutanic B horizons, generally overlying horizons with hydromorphic characteristics (mainly Bd, Pn, Av, Tu forms); hydromorphic soils (mainly Ka, Kd, Lo, forms); and shallow soils. The areas for each soil type, in the form of map units, and the depths above a slowly permeable horizon were obtained from the detailed soil survey results of Roberts *et al.* (1996). This information, together with bulk density data collected in this research project, was used to compute the total pore space in the fairly rapidly water conducting zone of the UEC, *i.e.* the zone above a slowly permeable horizon.

Assuming an average degree of saturation under field conditions of 0.8f (f = the total pore space of the soil above the slowly permeable horizon), and an average drained upper limit (DUL) of 0.6f, about 0.2f would be available to drain out of the very wet hillslope after good rains. For these assumptions to be meaningful attention needs to be drawn to section 7.1 regarding focusing on the portion of the hydrograph which best describes the contribution of fairly rapid interflow (*i.e.* lateral flow). It is considered that this portion of the hydrograph provides the most information regarding the correlation between soil characteristics and hydrological response characteristics in the landscape. For the sake of this study the fraction of the pore space that potentially provides fairly rapid interflow water is termed drainable water capacity (DWC). The areas and DWC values for each map unit are presented in Table 8.1.

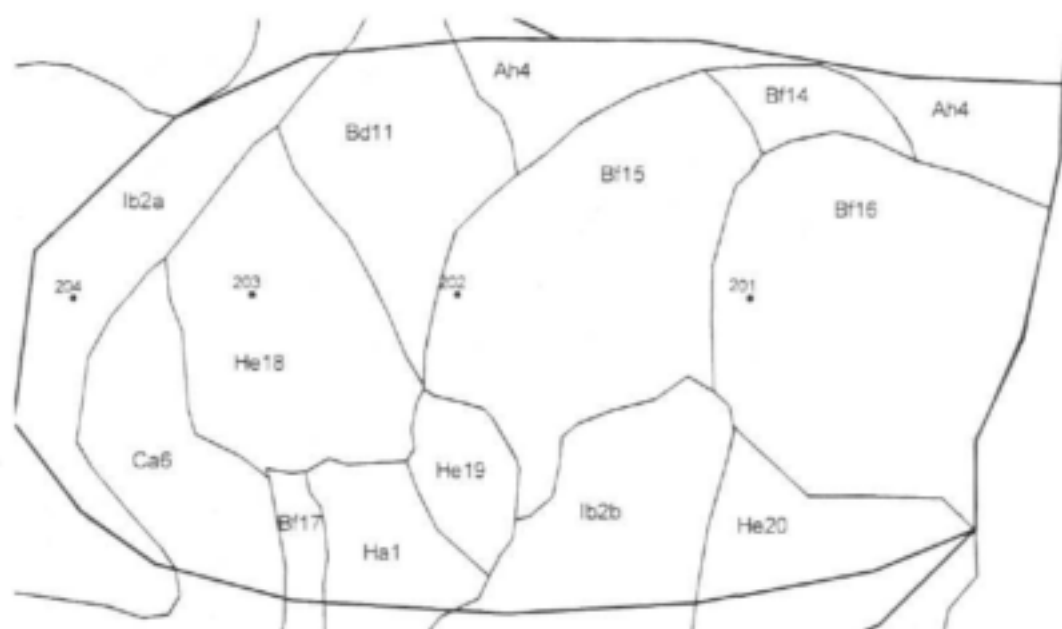


Figure 8.6 Map of the upper eastern catchment with its map units and 2 m interval contour lines. 201 to 204 (204 is at location B in Figure 8.8) are the sites of soil profiles, tensiometer nests and NWM access tubes. Soil map information obtained from Roberts *et al.* (1996).

Table 8.1 Soils in the UEC, areas they occupied, and their drainable water capacities

Map unit	Soil family	Depth (m)	Area (m ²)	DWC [†] (m ³)	DWC/ha (m ³ /ha)
Ah4	Cv2100	1.51	2 640	289	1 096
Bd11	Bd2100	0.75	3 060	170	555
Bf14	Pn2100	0.45	810	28	341
Bf15	Pn2100	0.80	6 070	359	592
Bf16	Av2100	0.75	7 070	427	604
Bf17	Pn2100	0.45	400	14	341
<i>Sub-total</i>			20 050	1 286	
Ha1	Fw1210	1.51	1 340	163	1 216
He18	Tu2210	0.35	4 140	109	264
He19	Oa2120	1.51	1 010	109	1 076
He20	Tu2110	0.45	1 700	55	324
<i>Sub-total</i>			8 190	436	
Ca6a	Ka1000	0.40	2 490	71	284
Ca6b	Ka1000	0.40	937	27	284
<i>Sub-total</i>			3 427	97	
Ib2a	Gs1121	0.20	2 990	42	142
Ib2b	Gs1121	0.20	1 873	27	142
<i>Sub-total</i>			4 863	69	
Total			36 530	1 889	

[†] DWC (drainable water capacity) = $0.8f - 0.6f$; f = total pore space of the soil above a slowly permeable horizon

The DWC and DWC/ha values in Table 8.1 indicate the potential contribution of each map unit to the total catchment water yield via fairly rapid interflow. Nearly 70% of the total DWC value of the UEC comes from the apedal soils which occupy about

55% of the whole area. Considering the DWC/ha values, the deepest soils have the highest values.

8.3.2 Hydrological response characteristics

The hydrological response characteristics of the UEC will be described in two ways. First, by describing the response of representative soils after isolated rainfall events; and secondly, by quantifying the total fairly rapid outflow of water from the catchment at the end of a wet season. The procedures are briefly described in the following two sub-sections.

8.3.2.1 *Hydrological response characteristics of selected soils in the UEC*

Tensiometer data (BEEH, 2003), describing the soil water regime before, during and following isolated rainfall events, were used to describe the hydrological response characteristics of certain diagnostic horizons at soil profiles P201, P202, P203 and P204. The rainfall events include a low intensity event on 23 March (17 mm in 6.2 hr), and a high intensity event on 10 April 2001 (32 mm in 30 min). During the 17-day interval there was little rain with only two events which would have exceeded the day's ET, i.e. 7 mm on 3 April and 9 mm on 8 April. The data are presented in Figure 8.7. At P201 both the ot and gs responded rapidly to both rainfall events, becoming saturated immediately. The ot dried out quicker and further compared to the gs because of its greater loss by ET.

As shown in Figure 8.7, at P202 the ot became saturated for a short period following both events and dried immediately thereafter. The ye also became saturated but then dried out to a lesser degree compared to the ot. The third measurement at the top of the on horizon remained close to saturation throughout showing no clear response to any of the rainfall events.

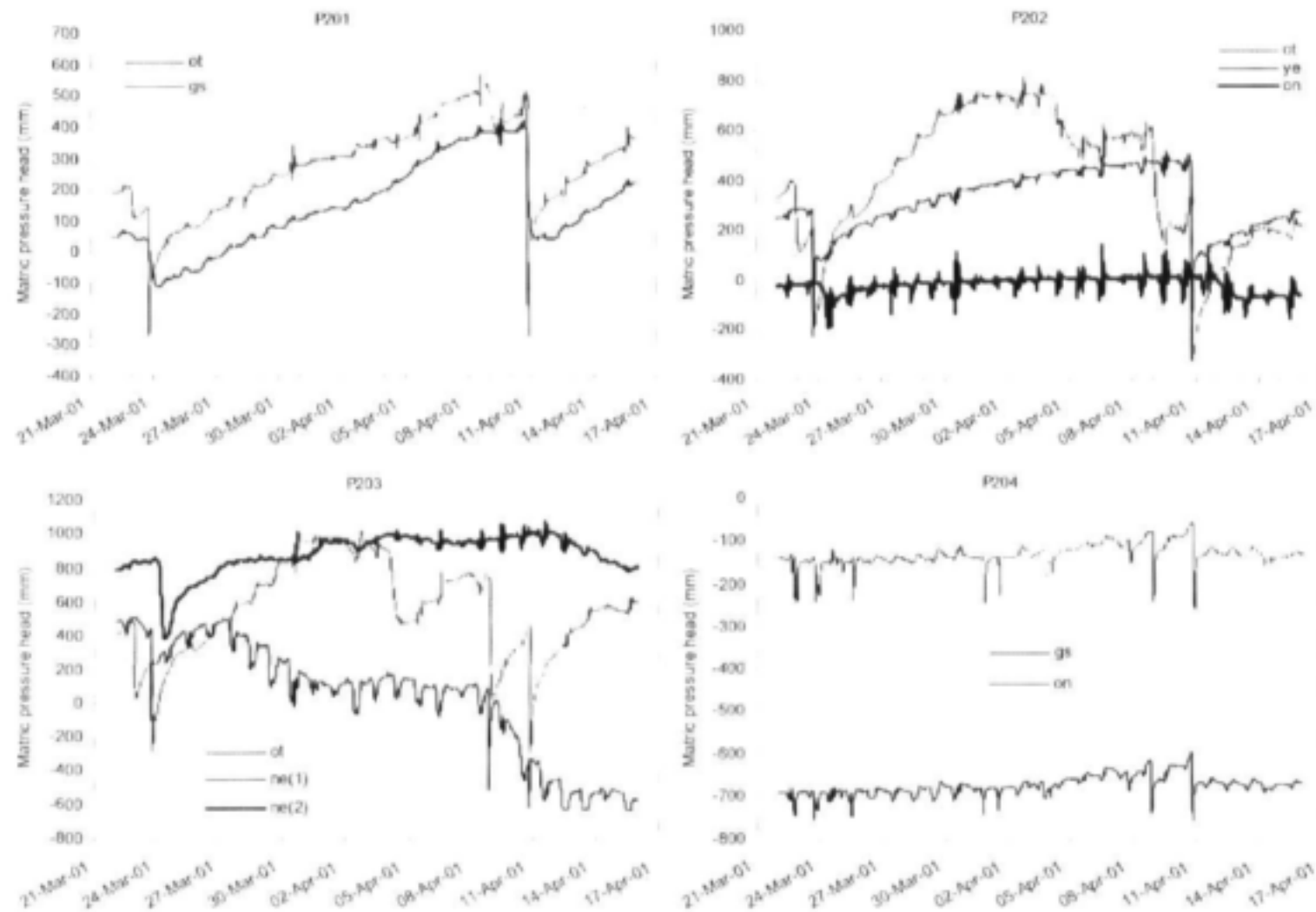


Figure 8.7 Hydrological responses of different diagnostic horizons following isolated rainfall events.

At P203 the ot responded rapidly to both events in a similar manner to the ot horizons at P201 and P202. The upper part of the ne (ne1) became wet to near saturation for a brief period following the first event, and thereafter dried fairly rapidly for the next few days. After that it slowly became wet to near saturation during the period before the second rainfall event, presumably due to lateral water movement from higher lying soils. This wetting rate was accelerated by the second event. The lower part of the ne (ne2) also responded only slightly to both events, but never reached saturation during or between the events. This probably indicates that the slowly permeable ne1 did not allow water to redistribute to ne2.

At P204 the two readings taken in the gs and the on horizons clearly show that both horizons remained saturated during the whole period and did not respond significantly to the rainfall events. These horizons were clearly maintained in a saturated state by lateral water movement from above.

8.3.2.2 Hydrological response of the UEC

Lorentz (2001) described the major flow mechanisms prevailing in the UEC using Figure 8.8. His description of the flow mechanisms are presented in the first three columns of Table 8.2. In the last column we provide a brief description of the dominant diagnostic horizons associated with each type of flow. The hydrological conditions prevailing in different parts of the landscape, as described in Table 8.2, have resulted in the formation of specific soils in specific places.

Water outflow out of the UEC was estimated during the period 23 March 2001 to 12 May 2001. This period was selected because the landscape was fairly full on the starting date, causing continuous flow over the sandstone shelf at location B in Figure 8.8. Since the water flowing over the shelf was not measured, flow was estimated using tensiometer data together with estimated ET values.

NWM measured soil water contents reported on 23 March 2001 at P201, P202, P203 and P204, and matric suction data (section 7.4.2.1), indicate that the soils were fairly full on this date. There were no other NWM measurements available until later in the season. Matric pressure head data obtained from tensiometers programmed to read at 12 minute intervals at P204 (BEEH, 2003) were therefore used to estimate the

saturated rate of flow out of the catchment during the period 23 March to 1 May 2001, and thereafter the decreasing flow rate until 12 May. The matric pressure head data were converted to soil water contents using soil water characteristic curve parameters reported by Lorentz *et al.* (2001). Results for readings taken at 250 mm and 700 mm depths at P204 are presented in Figure 8.9.

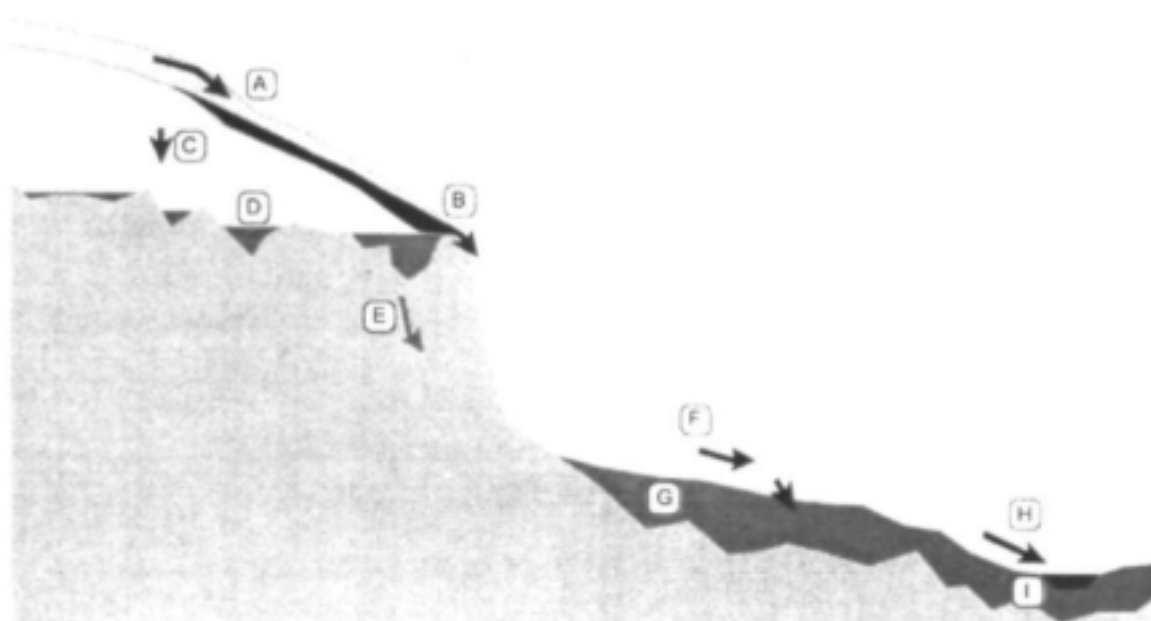


Figure 8.8 Conceptual model of flow mechanisms in the Weatherley research catchment (Lorentz, 2001).

The readings at both depths showed that the profile was saturated until 1 May 2001, *i.e.* there were negligible changes in water content, indicating that the net inflow rate into this soil from upslope was equal to the outflow rate over the shelf plus the water loss due to ET. The water content started decreasing on 1 May in the 0–470 mm layer (ot + gs + sp), and on 11 May in the 470–770 mm layer (upper part of the on). The outflow rate during the period 23 March to 01 May can therefore be considered to have been fairly constant.

Table 8.2 Summary of flow mechanisms and their occurrence in the Weatherley catchment (first three columns, Lorentz, 2001) and correlation of flow mechanisms and pedology (fourth column)

Code	Description	Occurrence	Hydrology of the dominant diagnostic soil horizons
A	Rapid lateral flow near the surface due to macropore conductance. Local perched water table of short duration. Matric pressure head discontinuity with deeper water table, D.	In upper slope segments in downstream catchment during high intensity events and some low intensity events with large volumes (>30 mm).	Vertically draining ot, re, ye, and ne; laterally draining gs and sp; slowly vertically and laterally draining on and gs.
B	Accumulation at the toe of the slope segment with emergence and flow over bedrock.	In upper slope segments in downstream catchment.	Laterally draining ot, gs and sp; slow lateral drainage from the on.
C	Slow percolation to water tables perched on bedrock.	In all slope segments for most events except low intensity and volume.	N/A
D	Water tables perched on bedrock and in bedrock hollows.	All slope segments. Disconnected from soil water in upper slopes of downstream catchment, but connected in lower slopes and in upstream catchment during moderate to intense events.	N/A
E	Seepage of old water through fractured bedrock hollows.	Assumed to occur in all slope segments.	N/A
F	Rapid 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.	Suspect that lateral flow occurs through gs and sp from slightly raised areas in the marsh into shallow rivulets. The fact that most of the marsh is Ka indicates minimal lateral flow within the marsh soil itself.
G	Marsh ground water level fluctuation.	Rapid for most events in lower downstream catchment. Slower, but connected in upper catchment.	N/A
H	Exfiltration and macro-pore discharge to stream	In downstream catchment. Not observed in upstream catchment.	Laterally draining gs and sp.
I	Marsh ground water discharge into stream.	Assumed to occur in upstream and downstream catchments.	Slowly lateral draining gh or on.

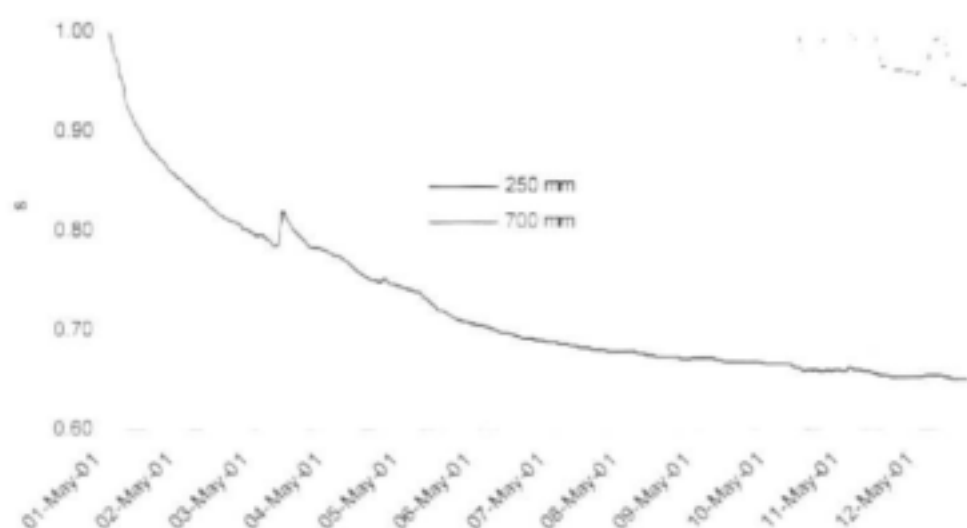


Figure 8.9 Changes in the degree of saturation (s) between 1 May and 12 May 2001 at P204, at 250 mm and 700 mm depths.

The shape of the hydraulic conductivity vs. water content curve indicates that the hydraulic conductivity characteristically remains fairly constant for a short period just below saturation, and then decreases rapidly. The constant flow rate was therefore estimated from the flow rate that occurred immediately after the water content had started decreasing below saturation. An estimated value of lateral K_s of 3.16 mm hr^{-1} was obtained. This agrees well with the vertical K_s value of between 5 and 7 mm hr^{-1} for these layers reported by Lorentz *et al.* (2001).

The outflow rate in Figure 8.9 indicates that the change in water content after 12 May is only due to water loss by ET. The measurement at 700 mm depth indicates that the water content of this layer started decreasing only around 11 May, just one day before the top layer stopped draining at all. However, the water loss from the on is so small that it could be attributed to ET loss. Calculating the water balance for the whole sub catchment for the period between 23 March and 12 May provides an estimate of lateral drainage out of the UEC for this period. Results are presented in Table 8.3. Note that surface runoff, and vertical drainage below the on, have been considered to be negligible.

Table 8.3 Soil water balance for the UEC during the period 23 March 2001 to 12 May 2001

Parameter	Value	
Estimated area of UEC (m ²)		36 530
Width of water conducting zone at P204 (m)		100
	mm	m ³
Total P	104	3 792
Total ET	102	3 741
P-ET		51
Water loss out of 0-470 mm depth:		
During constant rate period (38 days)	2 884	288
During decreasing rate period (12 days)	66	7
Total		295
Water loss out of 470-770 mm depth:		
During constant rate period (48 days)	2 088	209
During decreasing rate period (2 days)	5	0.5
Total		209
Estimated total water loss		504
Estimated total outflow (corrected for P and ET)		453

In Table 8.1 data is presented showing the estimated drainable water capacity (DWC) of the UEC. The total value is 1 889 m³. There is a reasonable similarity of order of magnitude between this value and the estimated outflow from the sub-catchment in autumn after being fairly full of water in the late summer, *i.e.* 453 m³. The results obtained are considered to provide support for the procedure adopted to obtain an estimate of the amount of interflow water in a catchment based on the distribution and characteristics of its soils. There are a number of possibilities to explain the discrepancies between the estimated DWC and outflow values. Among these are the following: inaccuracies in estimating the water content of each of the polygons at the start of the measuring period (23 March); inaccuracies in the estimation of the lower limit of DWC for each polygon; possible underestimation in the estimates of ET and runoff from the saturated zone around 204; lack of reliable information about the width of the water conducting zone on each side of 204; inaccuracies in the determination of the saturated lateral hydraulic conductivity in the upper vadose zone; and inability to estimate the amount of water lost by seepage at E in Figure 8.8. The results obtained and the procedures followed do, however, provide some guidance as to how the relationship between hydrology and pedology can be studied in a very small catchment.

8.4 Summary

This chapter suggested a procedure to correlate soil characteristics with hydrological response characteristics in the landscape. The procedure consisted of three initial

steps: (i) construction of detailed, large scale, topographical, geological, and soil survey maps of the catchment; (ii) collection of data enabling the estimation of the total catchment storage capacity of the upper (and if possible the lower) vadose zone; and (iii) obtaining reliable evapotranspiration (ET) data for the vegetation in the catchment. These initial steps were carried out for the whole Weatherley. This and other information was used to correlate soil characteristics with hydrological response characteristics in the upper eastern (UEC) part of Weatherley.

Three prominent catchment features tended to camouflage this correlation in Weatherley, namely the sandstone shelf, the large marsh area, and the marked difference between the topography west of the stream and that to the east. The influence of these catchment features and related soil characteristics on the hydrological response characteristics in Weatherley was clearly visible when the catchment water yield was compared to that of Cathedral Peak (VI), KwaZulu-Natal. The latter has >11 % slope on 92 % of its area and a marsh of about 8% of its total area; and generally has deep soils with low bulk density, high organic matter (6–10 %) and high infiltration rates. Typical autumn interflow rates were 27 m³ ha⁻¹ for Weatherley and 769 m³ ha⁻¹ for Cathedral Peak.

The topographical and hydropedological characteristics of the UEC were described in detail. The interflow portion of the total stream flow was considered to be closely correlated with the soils of the catchment, their distribution pattern, their extent and characteristics. The fraction of the total pore space that potentially provided fairly rapid interflow water, termed drainable water capacity (DWC), for 50 days in winter 2001 was 1 889 m³. Apedal soils (55 % of total area) contributed nearly 70 % of the total DWC of the UEC. The highest DWC ha⁻¹ values were observed in the deepest soils. The DWC values compared fairly well with the estimated outflow of the UEC.

Hydrological response characteristics of selected soils in the UEC described by matric suction data indicated that ot, gs and ye horizons of the hillslope soils generally responded fairly rapidly to rainfall events, whereas gs horizons of footslope soils remained saturated throughout the observation period due to lateral water movement from above. The on horizons also generally remained saturated, with no clear response to the rainfall events.

9 SUMMARY AND RECOMMENDATIONS

9.1 Summary

Orthic A horizons can be subdivided, to differentiate between wetness classes, using the nature of the underlying horizon. Orthic A horizons in the well drained wetness class occurred on red apedal B, yellow-brown apedal B and neocutanic horizons. Orthic A horizons in the moderately well drained wetness class occurred on E horizons and had no to few mottles. Orthic A horizons in the moderately to poorly drained wetness class occurred on E and G horizons and had few to many mottles. The orthic A horizons in the poorly drained wetness class occurred on soft plinthic B and E horizons and had common mottles.

Table 9.1 lists the means of selected soil properties, grouped per diagnostic horizon. Orthic A horizons had the highest organic carbon ($0.93 \pm 0.07\%$) and nitrogen content. Organic carbon content was lower in E, red apedal B and neocutanic B horizons ($0.45 \pm 0.09\%$, $0.36 \pm 0.12\%$ and $0.35 \pm 0.09\%$ respectively). The organic carbon content was lowest in yellow-brown apedal B ($0.21 \pm 0.04\%$), G ($0.20 \pm 0.03\%$), soft plinthic B horizons ($0.19 \pm 0.04\%$) and unspecified material with signs of wetness ($0.13 \pm 0.02\%$). The last three of these horizons had clear signs of hydromorphy, caused by microbial induced reduction in redox potential. It therefore seemed that sufficient organic material was available throughout the profile to supply substrate needed by micro organisms to fulfil their role in reduction whenever the soil was wet enough. It should be borne in mind, however, that the threshold carbon and water contents for reduction to occur are interdependent. The higher the water saturation, the less carbon is required for redox conditions to occur and *vice versa*.

The sum of basic cations was highest in G horizons ($6.94 \pm 0.81 \text{ cmol}_c \text{ kg}^{-1}$). It then decreased in the following order: unspecified material with signs of wetness ($4.25 \pm 0.74 \text{ cmol}_c \text{ kg}^{-1}$); orthic A ($3.17 \pm 0.43 \text{ cmol}_c \text{ kg}^{-1}$); E ($1.85 \pm 0.31 \text{ cmol}_c \text{ kg}^{-1}$); soft plinthic B ($3.20 \pm 0.83 \text{ cmol}_c \text{ kg}^{-1}$); neocutanic B ($1.95 \pm 0.36 \text{ cmol}_c \text{ kg}^{-1}$), red apedal B ($1.61 \pm 0.35 \text{ cmol}_c \text{ kg}^{-1}$) and yellow-brown apedal B horizons ($1.20 \pm 0.12 \text{ cmol}_c \text{ kg}^{-1}$). The difference in sum of basic cations was, however, not significant between these horizons. The high sum of bases in the G horizon indicated a cumulative environment, and therefore minimal leaching. Consequently, from a

hydrological point of view, it either releases water very slowly to the stream or a very small amount, or both. In contrast, the low sum of bases in the E, soft plinthic B and chromatic horizons indicated leaching and removal of basic cations. These horizons therefore supplied water more rapidly to the stream, compared to the G horizons. The relative volume of these horizons in a catchment can therefore be expected to have a significant influence on the shape of the outflow hydrograph. It was especially Ca^{2+} and Mg^{2+} that differed between the diagnostic horizons, whereas K^+ and Na^+ remained almost constant throughout the profiles.

The clay content was significantly higher in G horizons ($28.2 \pm 1.4\%$) and unspecified material with signs of wetness ($23.4 \pm 1.9\%$), than in red apedal B ($21.4 \pm 2.9\%$) neocutanic B ($18.6 \pm 3.2\%$), soft plinthic B ($17.6 \pm 2.7\%$), orthic A horizons ($14.8 \pm 1.1\%$) and yellow-brown apedal B ($13.6 \pm 1.4\%$). It was lowest in E horizons ($13.0 \pm 0.8\%$). The pattern in clay content substantiated the process of accumulation in the G horizon and luviation from the E and soft plinthic B horizons.

Total Fe content (CBD extractable) was highest in red apedal B horizons ($10\,338 \pm 1\,284 \text{ mg kg}^{-1}$), followed by neocutanic B ($9\,741 \pm 2\,115 \text{ mg kg}^{-1}$), G ($9\,227 \pm 1\,398 \text{ mg kg}^{-1}$), unspecified material with signs of wetness ($8\,669 \pm 1\,122 \text{ mg kg}^{-1}$), soft plinthic B ($6\,835 \pm 428 \text{ mg kg}^{-1}$), orthic A ($7\,586 \pm 920 \text{ mg kg}^{-1}$), and horizons E ($7\,924 \pm 1\,353 \text{ mg kg}^{-1}$). It was lowest in yellow-brown apedal B ($5\,152 \pm 1\,033 \text{ mg kg}^{-1}$).

Table 9.1 Means of selected soil properties in the Weatherley catchment, grouped per diagnostic horizon

Hor	Clay	S	CEC _{low}	CEC _{high}	BS	OC	N	pH _{water}	pH _{KCl}	Fe	Mn	Mean AD ₅₋₁₀₇ (days year ⁻¹)
	(%)		(cmol _c kg ⁻¹)		(%)		(mg kg ⁻¹)			(mg kg ⁻¹)		
ne	18.6	2.0	4.6	20.1	45.1	0.35	343	5.22	4.31	9741	155.3	37
ye	13.6	1.2	4.4	28.0	28.3	0.22	187	5.18	3.99	5152	25.2	75
re	21.4	1.6	4.5	16.3	38.5	0.35	259	5.36	4.17	10338	144.6	80
ot	14.8	3.2	6.8	27.0	46.0	0.93	645	5.33	4.36	7586	46.6	148
sp	17.6	3.2	6.0	32.7	52.5	0.19	249	5.79	4.31	6835	64.5	182
gs	13.0	1.9	6.8	44.5	34.3	0.45	374	5.44	4.29	7924	16.8	202
on	23.4	4.3	7.0	28.1	58.2	0.13	208	5.59	4.27	8669	115.4	248
gh	28.2	6.9	10.5	35.3	64.2	0.20	306	6.15	4.44	9227	33.0	331

Total Mn content (CBD extractable) showed the same trend as the total Fe content, except that two clear groups could be distinguished. Total Mn was significantly

higher in neocutanic B ($155.4 \pm 72.5 \text{ mg kg}^{-1}$), red apedal B ($144.6 \pm 27.8 \text{ mg kg}^{-1}$), unspecified material with signs of wetness ($115.4 \pm 29.8 \text{ mg kg}^{-1}$) than in soft plinthic B ($64.5 \pm 15.8 \text{ mg kg}^{-1}$), orthic A ($46.6 \pm 11.4 \text{ mg kg}^{-1}$), G ($33.0 \pm 10.0 \text{ mg kg}^{-1}$), yellow-brown apedal B ($25.2 \pm 8.3 \text{ mg kg}^{-1}$) or E ($16.8 \pm 5.4 \text{ mg kg}^{-1}$) horizons.

G horizons ($331 \pm 10 \text{ days year}^{-1}$) and unspecified material with signs of wetness ($248 \pm 37 \text{ days year}^{-1}$) had the highest mean $AD_{s>0.7}$. Mean $AD_{s>0.7}$ was slightly lower in E ($202 \pm 45 \text{ days year}^{-1}$), soft plinthic B ($182 \pm 25 \text{ days year}^{-1}$) and orthic A horizons ($148 \pm 19 \text{ days year}^{-1}$), although there was no significant difference within the latter group. Red apedal B ($80 \pm 58 \text{ days year}^{-1}$), yellow-brown apedal B ($75 \pm 25 \text{ days year}^{-1}$) and neocutanic B horizons ($37 \pm 24 \text{ days year}^{-1}$) had the lowest mean $AD_{s>0.7}$.

Colour indices, used to predict duration of $s>0.7$ from morphological data did not yield meaningful correlations in this study. The following equation yielded the best correlation ($R^2 = 0.38$):

$$AD_{s>0.7} (\text{days year}^{-1}) = -38.6 \times H_d + 35.2 \times V_d + 1.94 \times C_d - 51.3 \quad (9.1)$$

Where:

$AD_{s>0.7}$	=	mean annual duration of water saturation above 0.7 of porosity
H_d	=	dry colour (numeric) hue
V_d	=	dry colour value
C_d	=	dry colour chroma

9.2 Conclusions

It is considered that the three objectives of the project have been achieved in a satisfactory way and that the necessary results have been appropriately presented.

It seemed likely that one of the best ways that pedologists, working in collaboration with soil physicists, will be able to make a useful contribution to hydrologists was to provide quantitative and qualitative information on the hydrological and related properties of diagnostic horizons and soil profiles. It should be useful for hydrological process modelling, for technology transfer between catchments, and for making a contribution towards the shape of the interflow and low flow portions of the

hydrograph. An added bonus is the contribution made to soil classification and interpretation in South Africa and possibly internationally.

Digital classification of digital photographs of soil horizons for colour classification could be done with reasonable accuracy. Results have shown that digital photographs could be quantified and classified meaningfully using ArcView SpatialAnalyst. This methodology holds great promise for the unbiased quantitative determination of soil colour and mottles, but will need further refinement before it can be implemented.

The results of a comparison between the Weatherley catchment and Cathedral Peak catchment VI showed that the curved portion of the hydrograph during a rain-free period, and following a high rainfall period which filled the catchment, was correlated with the soil distribution pattern and soil characteristics of the catchment. Three important initial steps in the procedure to correlate soil characteristics with hydrological characteristics in a catchment were identified. They were: (a) construction of detailed, large scale topographical, geological and soil maps; (b) collection of the data needed to estimate the drainable water capacity of the soils; (c) obtaining reliable estimates of ET for the vegetation in the catchment.

Chemical and physical analyses as well as mean $AD_{s>0.7}$ values generally supported the classification of diagnostic horizons in Soil Classification – A Taxonomic System for South Africa. Diagnostic horizons could therefore be used to infer these properties within the current research environment. These relationships could be extrapolated, with caution, to other catchments having similar climate and geology.

9.3 Recommendations for future research

Since this study was concerned mainly with soils that have developed in siliceous parent material, the effect of different parent materials on Fe supply, and hence soil colour should be researched. The same is true for climate – especially rainfall and temperature. Similar studies should therefore be carried out under different climatic conditions. The predictive value of diagnostic horizon and soil form characterization in relation to hydrology should also be evaluated by verification against other profiles

in other catchments. The hypothesis regarding these relationships and the effect of lithology, topography and time on it should therefore receive further scrutiny.

Research should be done to quantitatively determine the degree of saturation where reduction would set in and the impact of bulk density on this value. This should refine the limit of 0.7 of porosity used in this study.

The possibilities of digital photograph interpretation should be investigated further. It is especially the effect of different cameras and lighting conditions that should receive attention. The relationship between Munsell hue, value and chroma on the one hand and RGB colour notation on the other should also be investigated, for example the difference between look-up tables and computer algorithms. Meaningful differentiation between diagnostic red, yellow and grey colours, as well as the interpretation of dry and wet photographs should also be investigated.

Further research at Weatherley is needed on the following:

- a) Continuation of measuring and processing neutron water meter measurements and improving the relationship between these and other continuous water monitoring procedures.
- b) Changes in the water regime of specific soils caused by specific tree species.
- c) Changes in ET caused by afforestation.
- d) In depth redox studies. For example the role of frequency and duration of saturation events.
- e) The formulation of appropriate wetness classes for South African soils.
- f) Determination of pre-planted soil organic carbon contents. This should be repeated in five to ten year cycles. The aim should be to determine the impact of forestry on the organic carbon sequestration in soil.
- g) Study the interconnectivity of the surface water, soil water and ground water.

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Appendix A

Results for 28 profiles (P201 to P237). Data is grouped per profile and is given in the following sequence:

- a) Profile description.
- b) Chemical and physical analyses.
- c) Photograph of the profile, including horizon demarcations, location of piezometer pipes, tensiometers and NWM measurements.
- d) Degree of water saturation and daily rainfall is given from 1 January 1997 until 31 December 2004.

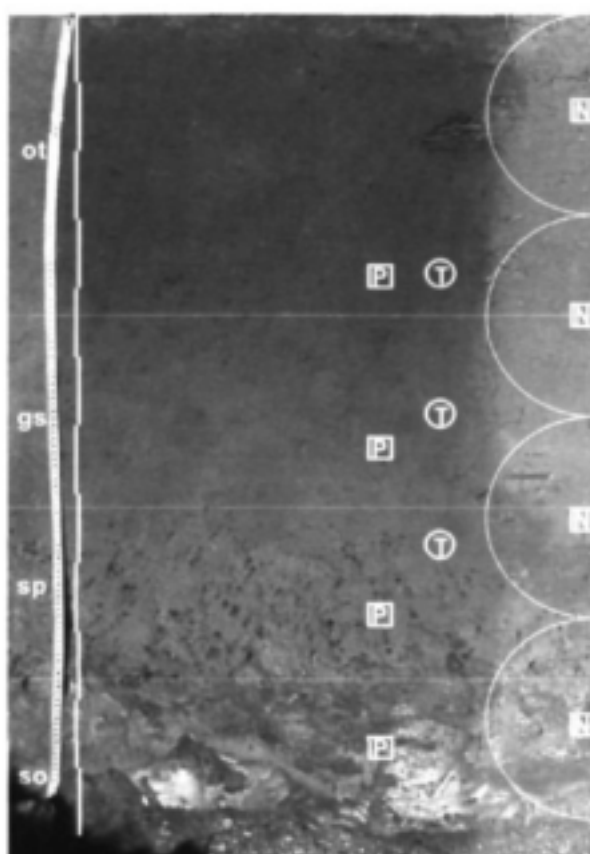


Figure 1 Profile 201 (Longlands 2000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

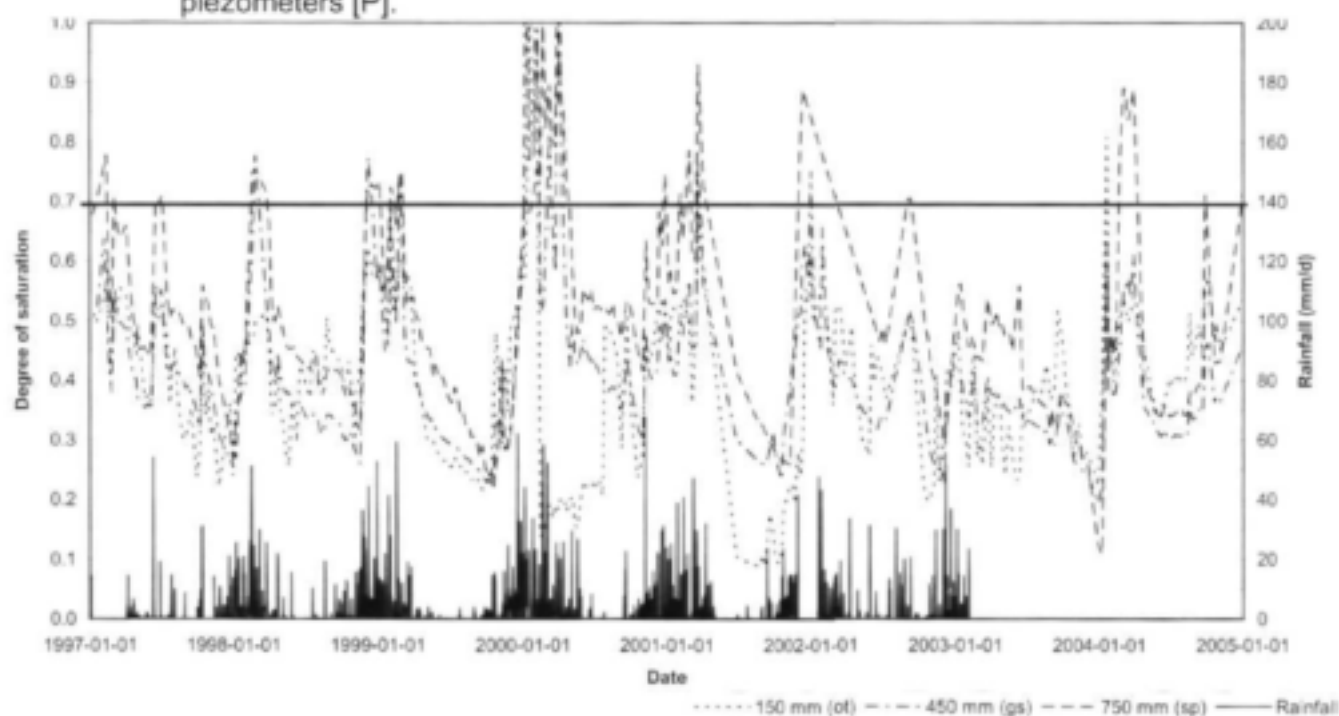


Figure 2 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 201.

Table 2 Profile description for profile 201 (Longlands 2000)

Profile No: 201 Mapphoto: 3125AB Latitude & Longitude: 31° 06' 06.0" / 28° 20' 18.0" Surface stoniness: None Altitude: 1 337 m Terrain unit: Upper midslope Slope: 10 % Slope shape: Convex Aspect: West Microrelief: None Parent material/solus: Origin single, solid rock Underlying material: Feldspathic sandstone Geological Group: Elliot	Soil form: Longlands Soil family: 2000 Surface rockiness: None Occurrence of flooding: None Wind erosion: None Water erosion: None Vegetation / Land use: Grassveld, closed Water table: None Described by: C. W. van Huyssteen & W. Boschhoff Date described: 19/06/2001 Weathering of underlying material: Weak physical, weak chemical Alteration of underlying material: Ferruginised
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Horizon	Depth(mm)	Description	Diagnostic horizons
A	0 - 430	Moisture status: dry; dry colour: 10YR4/4 (80 %), 10YR4/2 (20 %); moist colour: 10YR3/3 (80 %), 10YR3/2 (20 %); 8.9 % clay; coarse sandy loam; few fine lent 10YR4/2 dry, 10YR3/2 moist; geogenic Fe and humus mottles; apical massive, soft, friable, non-sticky, non-plastic; no fine and very fine pores; common normal medium and coarse pores; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; gradual smooth transition	orthic A horizon
E	430 - 730	Moisture status: moist; dry colour: 7.5YR5/4 (95 %), 10YR4/4 (5 %); moist colour: 10YR4/4 (95 %), 10YR4/4 (5 %); 11.9 % clay; coarse sandy loam; common medium, distinct 10YR4/4 dry, 10YR3/3 moist; bluish humus mottles; common fine distinct 2.5YR4/6 dry, 10YR4/6 moist; iron oxide mottles; apical massive, soft, friable, non-sticky, non-plastic; no fine and very fine pores; few normal medium and coarse pores; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; gradual smooth transition	E horizon
B	730 - 980	Moisture status: moist; dry colour: 7.5YR5/4 (100 %); moist colour: 10YR4/4 (100 %); 12.6 % clay; coarse sandy loam; many fine prominent 2.5YR4/6 dry, 10YR4/6 moist; iron oxide mottles; few fine distinct 2.5YR3/3 dry, 2.5YR2/5 moist; manganese mottles; apical massive, soft, friable, non-sticky, non-plastic; few normal fine and very fine pores; no medium and coarse pores; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; gradual tonguing transition. Remark: B2 horizon has tongues of sandstone saprolite with manganese concretions and red surfaces, surrounded by grey silts	soft plastic B horizon
C	980 - 1210	Moisture status: moist; dry colour: 10YR5/4 (50 %), 7.5YR2/2 (40 %), 10YR4/6 (10 %); moist colour: 7.5YR5/6 (50 %), 7.5YR4/4 (40 %), 10YR4/6 (10 %); 11.4 % clay; coarse sandy loam; no mottles; apical massive, soft, friable, non-sticky, non-plastic; no fine and very fine pores; no medium and coarse pores; many sickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); no normal roots; transition not reached. Remark: 870 to 1000 mm is a wavy transition between the soft plastic B horizon and rock horizons. Cores are gray and yellow with red mottles	saprolite / rock

Table 3 Soil analyses for profile 201 (Longlands 2000)

Soil analysis for profile 207 (continued 2006)																		
Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
				coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
				%	%	%	%	%	%	%	cmol/kg	cmol/kg	cmol/kg	cmol/kg	cmol/kg			
A	0-100	ot	3.4	20.4	30.6	14.3	8.5	7.9	8.8	9.2	1.38	0.48	0.16	0.11	2.14	4.84	52.6	44.2
	100-200		5.8	26.9	30.8	12.4	7.4	6.7	7.3	7.7	1.21	0.47	0.09	0.12	1.89	4.47	58.1	42.3
	200-300		1.7	25.4	30.3	12.9	7.4	6.6	7.8	8.4	0.83	0.35	0.10	0.11	1.38	4.11	48.9	33.6
	300-400		2.2	21.9	30.4	13.9	8.7	6.9	7.5	10.2	0.45	0.22	0.10	0.10	0.87	3.75	36.8	23.2
E	400-500	gs	1.6	26.2	31.0	12.5	7.3	2.6	9.8	10.0	0.31	0.15	0.13	0.09	0.67	3.04	30.4	22.0
	500-600		3.7	17.7	30.0	15.1	10.4	7.1	6.6	12.8	0.24	0.10	0.11	0.11	0.55	2.83	22.1	19.4
	600-700		6.8	17.7	30.0	15.1	10.4	7.1	6.6	12.8	0.25	0.11	0.07	0.09	0.51	3.43	26.8	14.9
B	700-800	sp	13.6	20.6	28.8	12.6	10.3	5.5	7.0	13.7	0.26	0.13	0.05	0.12	0.56	2.66	19.4	21.1
	800-900		17.1	19.0	28.6	12.7	11.0	7.7	7.0	12.8	0.26	0.16	0.04	0.06	0.55	3.10	24.2	17.7
	900-1000		44.1	16.4	30.8	13.2	11.8	8.4	8.4	11.4	0.28	0.17	0.03	0.11	0.59	2.34	20.5	25.2

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C/N	Fe			Mn		
			H ₂ O	KCl				CBD	Ox	Pyro	CBD	Ox	Pyro
			mg kg ⁻¹										
A	0-100	1.53	4.73	4.54	0.99	625	15.9	4510	474	1362	31.5	33.5	20.4
	100-200		4.65	4.51	0.96	554	17.2	4750	477	1456	21.5	18.0	12.0
	200-300		4.43	4.28	0.61	516	11.8	5030	517	1643	14.0	7.5	8.7
	300-400		4.55	4.20	0.43	423	10.0	5180	400	1476	9.0	2.5	7.0
E	400-500	1.57	4.49	4.17	0.68	360	18.9	5425	431	1944	8.5	1.5	7.0
	500-600		4.44	4.19	0.29	260	11.2	5470	528	1526	8.0	1.5	6.7
	600-700		4.36	4.14	0.21	234	9.1	6875	322	1205	18.5	1.5	6.5
B	700-800	1.65	4.30	4.13	0.14	196	7.3	5385	325	834	15.5	2.0	18.1
	800-900		4.35	4.15	0.33	156	20.9	3900	374	509	26.0	7.0	11.0
	900-1000		4.52	4.14	0.11	116	9.6	4295	362	487	19.5	19.0	12.0

Table 4 Profile description for profile 202 (Pinedene 1100)

Profile No: 202	Soil form: Pinedene
Map/photo: 3125A3	Soil fertility: 1100
Latitude & Longitude: 31° 06' 06" S; 28° 20' 15" E	Surface rockiness: None
Surface stoniness: None	Occurrence of Rooting: None
Altitude: 1 325 m	Wind erosion: None
Terrain unit: Upper mid-slope	Water erosion: Slight, partially stabilised
Slope: 17 %	Vegetation / Land use: Grassland, open
Slope shape: Convex	Water table: None
Aspect: West	Described by: M. Hensley & M. Smit
Moisture: None	Date described: 15/06/2001
Parent material: siltstone, origin binary, local colluvium, solid rock	Weathering of underlying material: Moderate physical, strong chemical
Underlying material: Mudstone	Alteration of underlying material: Fungus/growth
Geological Group: E301	

Horizon	Depth(mm)	Description	Diagnostic horizons
A	0-400	Moisture status: dry; dry colour: 10YR4/3 (100 %); moist colour: 10YR3/3 (100 %); 10.1 % clay; medium sandy loam; no mottles; weak fine subangular blocky; soft, friable; non-sticky; non-plastic; many normal fine and very fine pores; many normal medium and coarse pores; no stickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; clear smooth transition.	orthic A horizon
B	400-820	Moisture status: dry; dry colour: 7.5YR5/6 (85 %); 7.5YR5/6 (5 %); moist colour: 7.5YR4/6 (85 %); 7.5YR4/4 (5 %); 18.1 % clay; medium sandy loam; few medium large 7.5YR4/4 dry; 7.5YR5/6 moist; iron oxide mottles; few fine large 7.5YR5/6 dry; 7.5YR4/4 moist; iron oxide mottles; weak fine subangular blocky; soft, friable; non-sticky; non-plastic; many normal fine and very fine pores; many normal medium and coarse pores; no stickensides; no cracks; no cutans; common 2-6 mm round stones; water absorption 3 second(s); many normal roots; clear smooth transition.	yellow-brown apedal B horizon
C1	820-990	Moisture status: moist; dry colour: 10YR5/2 (90 %); 7.5YR5/6 (5 %); 7.5YR5/6 (5 %); moist colour: 7.5YR5/6 (85 %); 7.5YR4/4 (10 %); 7.5YR5/6 (5 %); 19.9 % clay; fine sandy loam; common medium large 5YR4/6 dry; 5YR4/6 moist; iron oxide mottles; common medium large 7.5YR5/6 dry; 7.5YR5/6 moist; iron oxide mottles; apedal massive; hard, friable; non-sticky; non-plastic; many normal fine and very fine pores; no medium and coarse pores; no stickensides; no cracks; no cutans; common 25-75 mm round stones; water absorption 1 second(s); many normal roots; abrupt smooth transition.	unsorted material with signs of wetness
C2	990-1500	Moisture status: moist; dry colour: 2.5Y5/2 (70 %); 7.5YR5/6 (20 %); 10YR4/6 (10 %); moist colour: 2.5Y5/2 (70 %); 10YR5/6 (20 %); 10YR4/6 (10 %); 24.7 % clay; fine sandy clay loam; few fine prominent 2.5YR4/6 dry; 2.5YR4/4 moist; iron oxide mottles; many fine prominent 10YR5/6 dry; 10YR5/6 moist; iron oxide mottles; moderate coarse prismatic; very hard; friable; very sticky; slightly plastic; few normal fine and very fine pores; few bleached medium and coarse pores; no stickensides; fine cracks; very many slick cutans; no coarse fragments; water absorption 2 second(s); few bleached roots; transition not reached.	unsorted material with signs of wetness

Table 5 Soil analyses for profile 202 (Pinedene 1100)

Horizon		Depth	Diagnostic horizon	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat	
				coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
				%	%	%	%	%	%	%	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil			%	
A		mm	ot	2.7	11.2	30.6	22.8	13.7	4.4	6.5	6.9	0.74	0.22	0.10	0.11	1.17	3.32	33.5	35.2
		0-100		2.9	13.9	31.6	21.5	12.1	10.6	1.1	8.5	0.59	0.20	0.13	0.12	1.04	3.31	38.9	31.4
		100-200		11.3	12.1	30.2	22.2	15.7	4.0	3.9	11.1	0.51	0.20	0.16	0.10	0.97	3.64	32.8	26.6
		200-300		4.9	10.9	29.9	22.8	14.0	5.0	5.5	11.0	0.47	0.17	0.16	0.11	0.91	2.83	25.7	32.2
		300-400		13.7	11.7	27.9	21.3	16.1	2.8	1.3	16.4	0.44	0.18	0.16	0.11	0.89	2.56	15.6	34.8
B		mm	ye	14.3	10.5	24.6	20.7	14.5	7.2	5.3	17.2	0.44	0.20	0.16	0.12	0.93	3.86	22.4	24.1
		400-500		23.1	15.7	23.3	18.2	14.2	5.5	6.7	16.3	0.43	0.22	0.16	0.10	0.91	3.52	21.6	25.9
		500-550		31.7	13.0	21.9	19.5	15.4	6.6	5.9	15.8	0.44	0.23	0.16	0.11	0.94	3.97	25.1	23.7
		550-600		34.3	13.2	20.8	20.2	15.2	6.4	8.3	14.8	0.41	0.24	0.13	0.11	0.88	2.72	18.4	32.4
		600-700		11.2	13.3	14.9	23.0	19.8	1.5	9.7	17.0	0.65	0.48	0.09	0.13	1.37	4.02	23.6	34.1
C1		mm	on	2.2	4.1	9.6	22.0	23.3	6.9	10.6	21.2	0.87	0.68	0.11	0.13	1.79	4.41	20.8	40.6
		700-800		2.3	6.2	9.4	21.9	18.0	10.6	10.6	21.5	1.44	0.94	0.12	0.13	2.63	5.65	26.3	46.5
C2		mm	on	1.6	11.1	7.5	21.4	17.3	7.6	10.8	26.1	1.61	1.41	0.16	0.15	3.34	8.10	31.0	41.2
		800-850		1.7	9.0	4.9	26.0	18.1	6.5	7.2	26.0	1.78	1.79	0.24	0.16	3.95	9.68	37.2	40.8
		850-900		2.1	8.7	4.8	26.0	21.5	7.5	6.4	23.8	2.78	2.68	0.25	0.16	5.86	8.04	33.8	72.9
		900-1000		0.2	8.5	4.6	30.0	18.7	7.8	7.9	22.9	2.92	2.72	0.27	0.16	6.07	8.21	35.9	73.9
Horizon	Depth	Bulk density	pH	Org C	N	C:N	Fe			Mn									
							CBD	Ox	Pyro	CBD	Ox	Pyro							
				H ₂ O	KCl	%	mg kg ⁻¹	mg kg ⁻¹			mg kg ⁻¹								
A		mm	1.68	4.54	4.19	0.76	410	18.6	5165	268	663	13.5	7.5	13.1					
		0-100		4.65	4.25	0.75	373	20.2	4960	296	689	11.0	4.5	11.0					
		100-200		4.67	4.21	0.83	358	23.1	3945	283	723	12.0	3.5	11.0					
		200-300		4.65	4.20	0.42	261	16.0	3420	262	718	9.5	4.0	11.0					
		300-400		4.49	4.12	0.13	228	5.5	6010	383	796	15.0	4.0	11.0					
B		mm	1.61	4.46	4.10	0.21	218	9.6	7305	479	695	16.0	4.5	11.0					
		400-500		4.44	4.06	0.22	229	9.6	6610	519	730	16.5	7.0	12.0					
		500-550		4.44	4.09	0.10	206	4.8	7455	528	530	40.0	24.5	17.1					
		550-600		4.42	4.12	0.16	192	8.3	7845	552	420	61.0	46.0	21.1					
		600-700		4.50	4.14	0.10	163	6.4	12200	1085	326	98.0	60.0	21.1					
C1		mm	1.72	4.50	4.09	0.19	209	9.2	17850	1145	277	57.5	32.0	20.1					
		700-800		4.52	4.08	0.14	230	6.2	16750	1345	264	69.5	50.5	17.1					
		800-850		4.53	4.03	0.13	212	4.8	15250	1032	239	44.0	18.0	14.1					
C2		mm	1.71	4.59	4.02	0.11	281	4.1	7800	558	223	57.0	62.0	16.1					
		850-900		4.52	4.11	0.14	238	5.8	3055	592	217	8.0	13.0	12.0					
		900-1000		4.67	4.15	0.04	209	1.9	8185	2065	215	7.0	3.5	11.0					

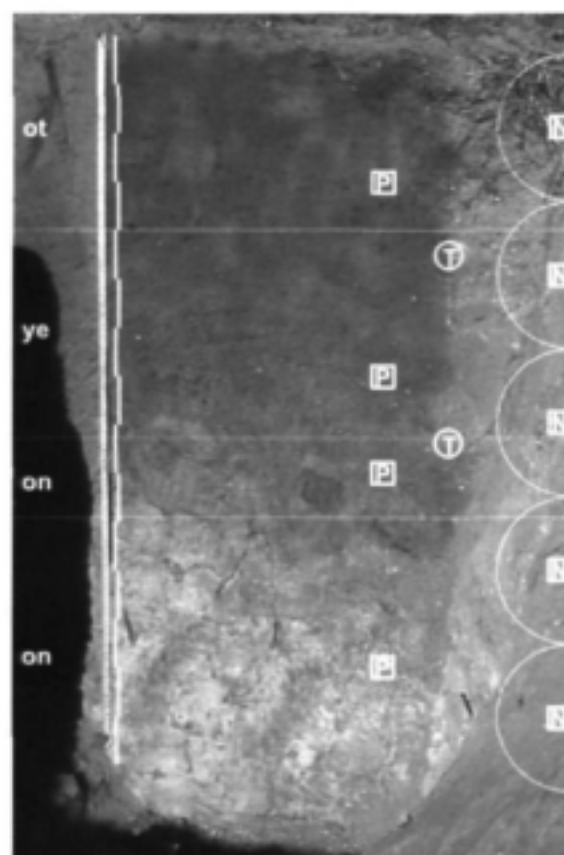


Figure 3 Profile 202 (Pinedene 1100), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

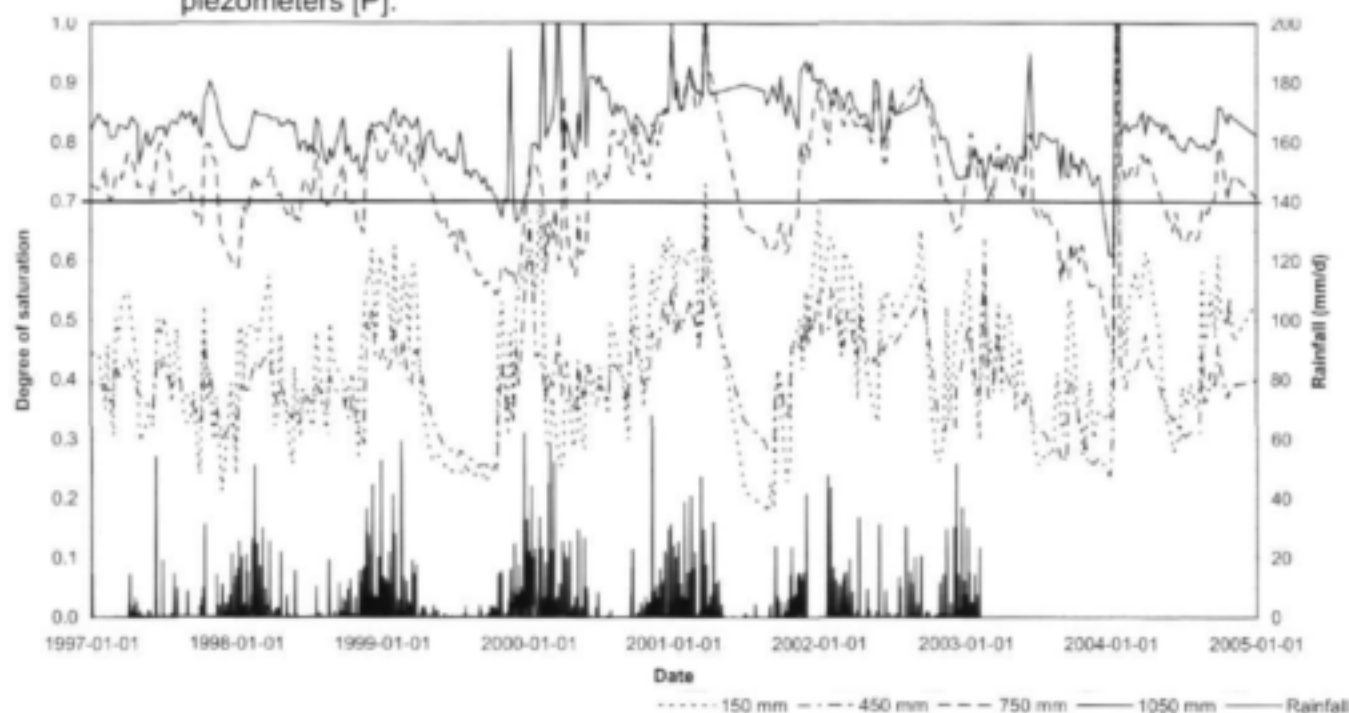


Figure 4 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 202.

Table 6 Profile description for profile 203 (Tukulu 2110)

Profile No: 203
Mapref: 1125A8
Latitude & Longitude: 31° 06' 05" S / 28° 20' 13" E
Surface stoniness: None
Altitude: 1 322 m
Terrain unit: Upper mid-slope
Slope: 14 %
Slope shape: Convex
Aspect: West
Microrelief: None
Parent material source: Single, solid rock
Underlying material: Felspathic sandstone
Geological Group: Eboi

Soil form: Tukulu
Soil family: 2110
Surface rockiness: None
Occurrence of Roadings: None
Wind erosion: None
Water erosion: None
Vegetation / Land use: Grassveld, open
Water table: None
Described by: P. A. L. le Roux & D. Scholtz
Date described: 19/06/2001
Weathering of underlying material: Strong physical, strong chemical
Alteration of underlying material: Ferruginised

Horizon	Depth (mm)	Description	Diagnostic horizons
A	0 - 380	Moisture status: dry; dry colour: 10YR5/3 (100 %); moist colour: 7.5YR3/2 (100 %); 9.8 % clay; coarse sandy loam; no mottles; weak fine subangular blocky, slightly hard, friable, non-sticky, non-plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; many 2-6 mm round stones; water absorption 2 second(s); many normal roots; gradual smooth transition.	orthic A horizon
B	380 - 960	Moisture status: dry; dry colour: 7.5YR7/4 (90 %); 7.5YR5/6 (10 %); moist colour: 7.5YR5/6 (90 %); 2.5YR5/8 (10 %); 12.8 % clay; medium sandy loam; common coarse prominent 2.5YR5/8 dry; 2.5YR4/8 moist; iron oxide mottles; common coarse prominent 5YR7/4 dry; 5YR6/4 moist; iron oxide mottles; weak fine subangular blocky, very hard, friable, non-sticky, non-plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); common normal roots; gradual smooth transition.	neocutanic B horizon
C1	960 - 1300	Moisture status: moist; dry colour: 7.5YR7/4 (90 %); 7.5YR5/6 (10 %); moist colour: 5YR5/6 (90 %); 2.5YR4/8 (10 %); 13.8 % clay; coarse sandy clay loam; many medium distinct 5YR5/8 dry; 5YR4/8 moist; iron oxide mottles; few medium distinct 5YR5/8 dry; 5YR5/8 moist; iron oxide mottles; apedal massive; very hard, friable, non-sticky, non-plastic; common normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 3 second(s); few normal roots; gradual smooth transition.	unspecified material with signs of wetness
C2	1300 - 1500	Moisture status: moist; dry colour: 7.5YR6/2 (40 %); 7.5YR5/6 (40 %); 7.5YR5/8 (20 %); moist colour: 5YR7/2 (40 %); 5YR5/6 (40 %); 2.5YR4/8 (20 %); 27.8 % clay; coarse sandy clay loam; many fine prominent 2.5YR5/8 dry; 2.5YR4/8 moist; iron oxide mottles; many fine prominent 10YR5/8 dry; 7.5YR5/8 moist; iron oxide mottles; apedal massive; very hard, friable, non-sticky, non-plastic; few normal fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 6 second(s); few normal roots; transition not reached.	unspecified material with signs of wetness

Table 7 Soil analyses for profile 203 (Tukulu 2110)

Horizon	Depth mm	Diagnostic horizon	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat	
			coSa	meSa	fsa	vtSa	Si	fsi	Cl	Ca	Mg	K	Na	S				
			%							cmol/kg					%			
A	0-100	ot	5.5	15.4	26.6	23.2	15.4	5.3	9.2	3.7	0.53	0.18	0.05	0.10	0.87	3.74	101.1	23.3
	100-200		9.1	16.3	25.4	20.9	14.7	5.5	5.1	10.9	0.68	0.31	0.06	0.12	1.17	2.77	25.4	42.2
	200-300		9.4	14.0	22.9	21.8	17.6	5.4	4.6	12.3	0.58	0.29	0.05	0.15	1.07	2.62	21.3	40.8
	300-400		7.0	21.3	27.1	20.5	13.7	0.9	1.9	12.2	0.56	0.29	0.06	0.15	1.06	2.61	21.4	40.6
B	400-500	ne	4.9	14.8	25.9	21.4	14.8	9.4	1.2	12.1	0.39	0.38	0.08	0.14	0.98	6.37	52.6	15.1
	500-600		8.4	18.0	26.0	20.5	14.1	9.7	5.2	10.7	0.51	0.40	0.09	0.13	1.13	4.51	42.1	25.1
	600-800		13.3	13.3	26.4	21.9	15.7	5.5	4.3	13.4	0.43	0.40	0.09	0.13	1.06	6.14	45.8	17.3
C1	900-1200	on	5.6	15.6	25.4	20.3	15.1	4.5	4.0	13.8	0.46	0.46	0.09	0.13	1.14	5.93	43.0	19.2
C2	1200+		20.8	18.4	18.0	11.5	10.0	5.1	8.7	27.8	1.63	2.05	0.23	0.19	4.06	5.93	21.3	68.5

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe			Mn			
			H ₂ O	KCl	%	mg kg ⁻¹		CBD	Ox	Pyro	CBD	Ox	Pyro	
	mm	Mg m ⁻³			%	mg kg ⁻¹								
A	0-100	1.65	4.25	4.06	0.31	231	13.3	4975	513	379	17.5	5.0	13.1	
	100-200		4.24	4.06	0.27	229	11.7	4630	515	334	19.5	11.0	17.1	
	200-300		4.28	4.02	0.21	130	16.4	4500	430	303	17.0	9.0	14.1	
	300-400				0.25	147	17.2	5250	440	287	19.0	8.0	14.1	
B	400-500	1.74	4.30	4.00	0.19	205	9.3	5715	424	388	15.0	5.5	13.1	
	500-600		4.35	4.15	0.27	206	13.1	5630	481	399	17.5	5.5	14.1	
	600-800		4.21	4.15	0.27	121	22.4	4975	432	373	11.5	3.5	11.0	
C1	900-1200	1.75	4.48	4.07	0.08	121	7.0	5110	376	271	17.0	5.0	11.0	
C2	1200+	1.77	4.82	4.17	0.04	149	2.4	8100	590	211	36.5	17.0	16.1	

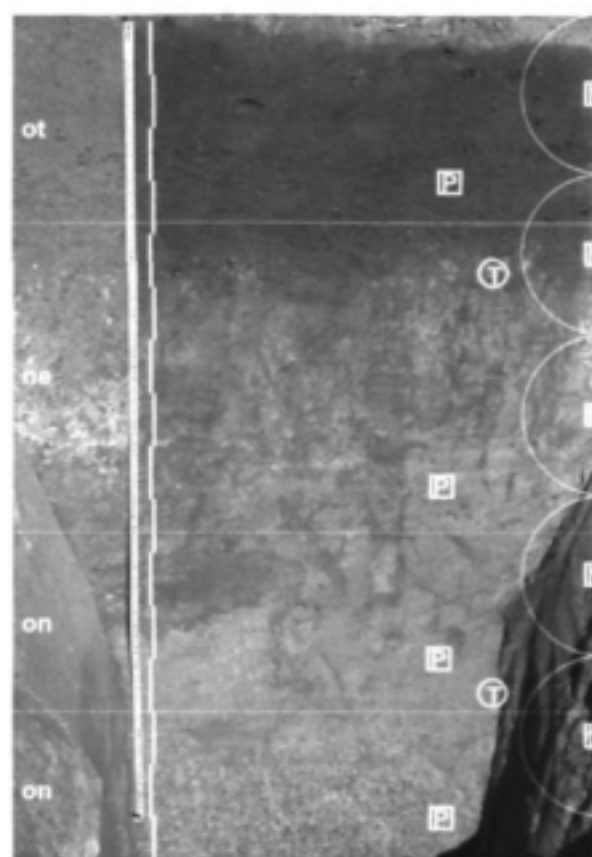


Figure 5 Profile 203 (Tukulu 2110), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

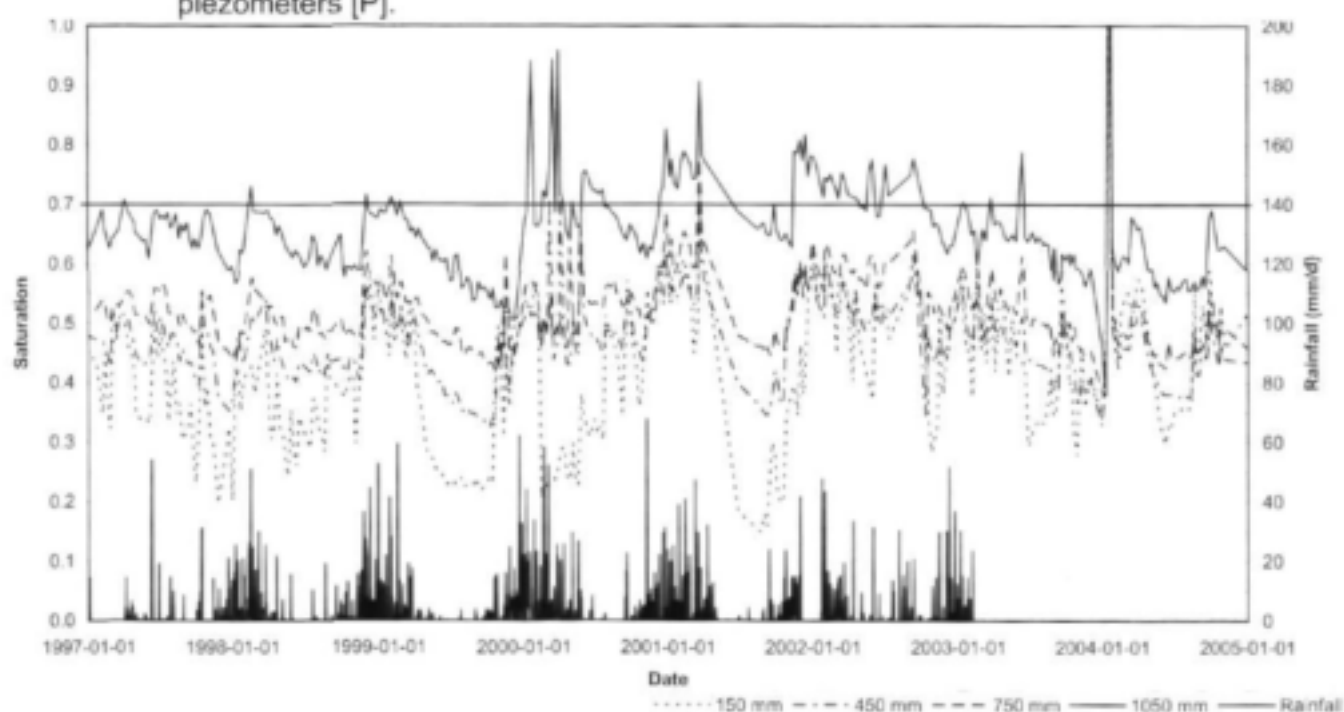


Figure 6 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 203.

Table 8 Profile description for profile 204 (Longlands 2000)

Profile No: 204	Soil form: Longlands
Map photo: 2128AB	Soil family: 2000
Latitude & Longitude: 31° 06' 06" S / 28° 20' 11" E	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 317 m	Wind erosion: None
Terrain unit: Crest / homologue	Water erosion: None
Slope: 5 %	Vegetation / Land use: Grassveld, open
Slope shape: Straight	Water table: None
Aspect: West	Described by: P.A.L. le Roux & D. Scholtz
Microrelief: Terraces: 2 %	Date described: 19/06/2001
Parent material column: Origin single: solid rock	Weathering of underlying material: Advanced physical: strong chemical
Underlying material: Mudstone	Alteration of underlying material: Ferruginised
Geological Group: Eilat	

Horizon	Depth (mm)	Description	Diagnostic horizons
A	0-140	Moisture status: moist, dry colour: 7.5YR5/2 (50 %), 7.5YR7/2 (50 %), moist colour: 10YR3/3 (50 %), 10YR5/5 (50 %), 7.5 % clay, loam, medium sand, few fine prominent 5YR5/5 dry, 2.5YR4/5 moist, iron oxide mottles, apedal massive, loose, loose, non-sticky, non-plastic, many rufy fine and very fine pores, no medium and coarse pores, no slickensides, no cracks, few sesquioxide cutans, no coarse fragments, water absorption 1 second(s), many rufy mottles, clear smooth transition.	orthic A horizon
E	140-300	Moisture status: moist, dry colour: 7.5YR7/5 (50 %), 7.5YR7/2 (40 %), moist colour: 10YR5/5 (50 %), 2.5YR2/4 (40 %), 9.5 % clay, fine sandy loam, many medium distinct 5YR5/5 dry, 2.5YR4/5 moist, iron oxide mottles, apedal massive, soft, friable, non-sticky, non-plastic, many rufy fine and very fine pores, no medium and coarse pores, no slickensides, no cracks, few sesquioxide cutans, no coarse fragments, water absorption 1 second(s), many rufy mottles, clear smooth transition.	E horizon
B	300-470	Moisture status: moist, dry colour: 10YR5/2 (40 %), 2.5YR5/5 (40 %), 2.5YR5/4 (20 %), moist colour: 10YR5/4 (40 %), 2.5YR4/5 (40 %), 2.5YR3/4 (20 %), 13.6 % clay, fine sandy loam, common coarse prominent 2.5YR4/5 dry, 2.5YR4/5 moist, iron oxide mottles, common coarse prominent 10YR4/5 dry, 7.5YR5/5 moist, mottles, apedal massive, very hard, very firm, non-sticky, non-plastic, no fine and very fine pores, few beached medium and coarse pores, no slickensides, coarse cracks, few silica cutans, very few 75-250 mm round & flat stones, water absorption 2 second(s), few beached roots, gradual smooth transition.	soil profile B horizon
G	470-1000	Moisture status: moist, dry colour: 10YR5/2 (50 %), 2.5YR5/5 (10 %), moist colour: 10YR7/2 (50 %), 2.5YR4/5 (10 %), 26.5 % clay, coarse sandy loam, many fine prominent 2.5YR4/5 dry, 2.5YR4/5 moist, argillaceous iron mottles, strong coarse angular blocky, very hard, very firm, very sticky, very plastic, no fine and very fine pores, few beached medium and coarse pores, no slickensides, coarse cracks, common silica cutans, no coarse fragments, water absorption 5 second(s), few beached roots, transition not reached. Remark: clear difference in consistency and structure between horizon B and G.	G horizon

Table 9 Soil analyses for profile 204 (Longlands 2000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat %
				coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
				%	%	%	%	%	%	%	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil	cmolc kg ⁻¹ soil			
A	0-100	af	5.5	11.9	21.3	28.5	21.6	5.1	4.3	7.5	0.48	0.24	0.06	0.13	0.91	7.72	102.9	11.8
E	100-200	gs	7.5	11.8	22.7	27.7	20.4	4.8	4.5	8.2	0.41	0.25	0.05	0.12	0.82	10.28	125.4	8.0
	200-300		9.6	9.4	20.4	27.4	22.3	2.2	5.4	9.5	0.36	0.26	0.06	0.12	0.79	9.62	101.3	8.2
B	300-400	sp	4.0	6.4	20.3	26.1	22.3	6.2	7.5	12.1	0.43	0.44	0.06	0.14	1.05	11.15	92.1	9.4
	400-500		3.4	5.0	12.3	31.6	23.1	4.9	5.6	15.1	0.58	0.71	0.07	0.13	1.5	11.04	73.1	13.6
G	500-600	gh	2.5	5.8	14.3	22.9	17.3	18.1	7.3	11.6	1.18	1.13	0.09	0.14	2.55	8.97	77.3	28.4
	800-1100		3.5	3.2	7.0	12.3	9.2	5.3	9.3	52.1	6.97	6.61	0.43	0.30	14.2	20.77	39.9	68.4
	1100+		68.9	28.0	20.5	10.0	5.6	2.7	5.4	24.8	1.93	2.13	0.09	0.13	4.27	11.91	48.0	35.9

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C:N	Fe			Mn		
			H ₂ O	KCl				CBD	Ox	Pyro	CBD	Ox	Pyro
			mg kg ⁻¹										
A	0-100	1.60	4.96	4.44	0.50	394	12.6	4130	1060	613	8.5	5.0	13.1
E	100-200		6.06	4.43	0.45	344	13.1	2590	472	605	5.0	2.5	12.0
	200-300		5.80	4.65	0.31	290	10.5	7145	720	534	54.5	4.5	12.0
B	300-400	1.74	5.47	4.80	0.09	125	6.9	12600	1170	312	3.5	41.5	16.1
	400-500		5.69	4.62	0.03	133	2.0	12600	1265	603	22.0	60.0	18.1
G	500-800	1.82	5.41	4.38	0.06	146	4.0	3560	462	261	28.5	13.5	14.1
	800-1100	1.82	5.45	4.36	0.09	265	3.4	2865	257	200	16.5	1.0	12.0
	1100+				0.04	125	2.9	3665	213	275	8.5	21.5	12.0

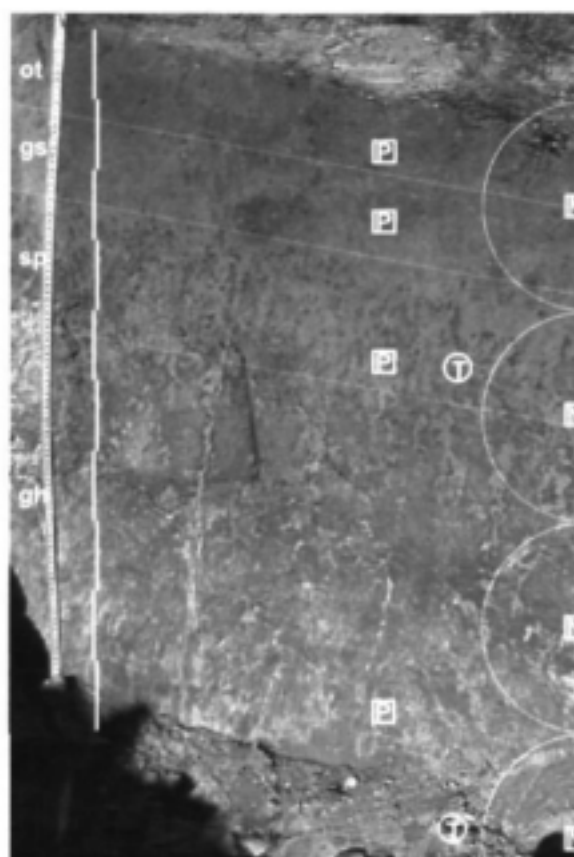


Figure 7 Profile 204 (Longlands 2000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

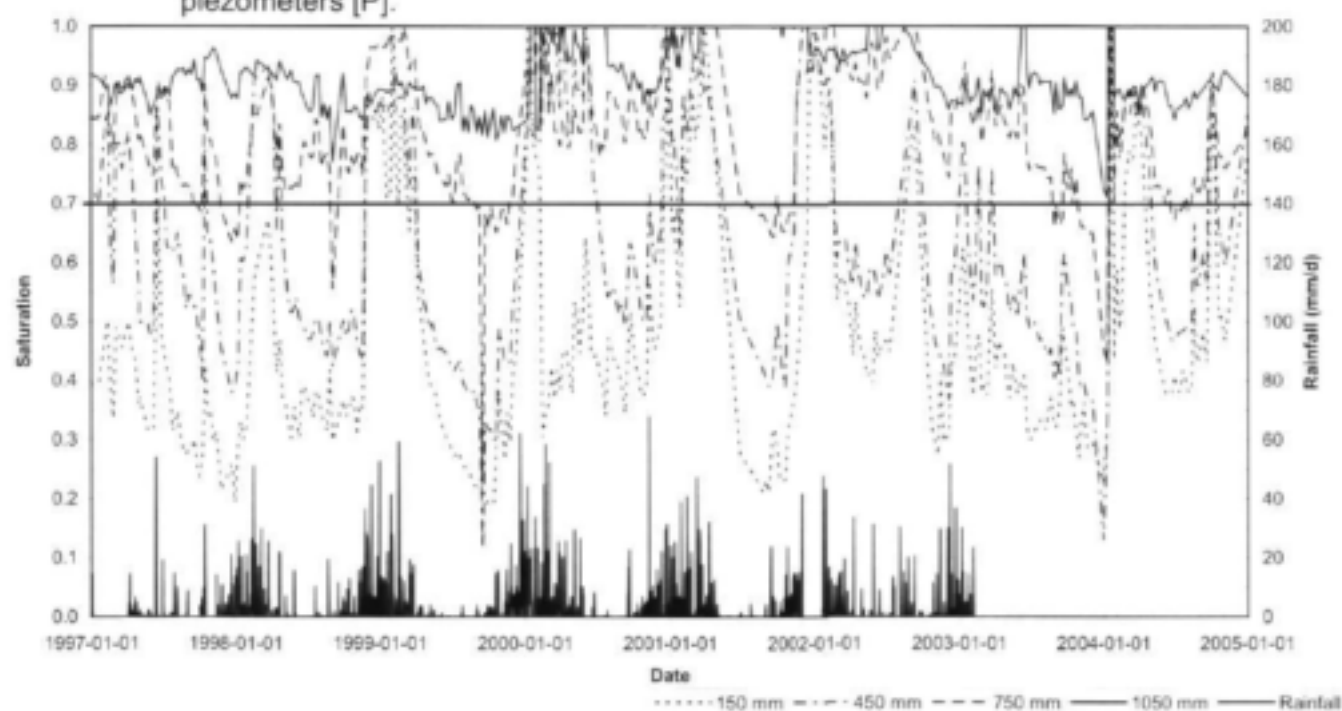


Figure 8 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 204.

Table 10 Profile description for profile 205 (Kroonstad 2000)

Profile No: 205 Map photo: 312848 Latitude & Longitude: 31° 06' 07" S / 28° 20' 03" E Surface stoniness: None Altitude: 1 286 m Terrain unit: Lower middle Slope: 8 % Slope shape: Concave Aspect: North-west Microclimate: None Parent material source: Origin single: solid rock Underlying material: Mudstone Geological Group: Moteng	Soil form: Kroonstad Soil family: 2000 Surface rockiness: None Occurrence of flooding: None Wind erosion: None Water erosion: None Vegetation / Land use: Grassland closed Water table: None Described by: D. Scholtz & T. B. Zere Date described: 19/06/2001 Weathering of underlying material: Moderate physical, strong chemical Alteration of underlying material: Ferruginised
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Horizon	Depth (mm)	Description	Diagnostic horizons
A	0-220	Moisture status: moist; dry colour 2.5Y5/2 (100 %); moist colour 2.5Y3/2 (100 %); 13.1 % clay; coarse sandy loam; no mottles; weak fine subangular blocky; hard; friable; non-sticky; non-plastic; many rusty fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; no bullfrogs; no coarse fragments; water absorption 1 second(s); many normal roots; diffuse smooth transition.	Other A horizon
E1	220-450	Moisture status: moist; dry colour 2.5Y5/1 (70 %); 10YR5/5 (30 %); moist colour 10YR3/3 (70 %); 10YR4/5 (30 %); 11.0 % clay; coarse sandy loam; rusty medium distinct 10YR5/5 dry; 10YR4/5 moist; iron oxide mottles; common medium distinct 2.5Y4/2 dry; 2.5Y3/2 moist; humus mottles; weak fine granular; hard; friable; non-sticky; non-plastic; many rusty fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no bullfrogs; no coarse fragments; water absorption 2 second(s); many normal roots; clear smooth transition.	E horizon
E2	450-960	Moisture status: moist; dry colour 10YR5/2 (80 %); 10YR5/5 (10 %); 10YR5/2 (10 %); moist colour 10YR3/2 (80 %); 7.5YR5/5 (10 %); 10YR4/3 (10 %); 11.0 % clay; coarse sandy loam; common medium distinct 10YR5/5 dry; 7.5YR5/5 moist; iron oxide mottles; common medium prominent 2.5Y4/2 dry; 2.5Y3/2 moist; humus mottles; weak fine granular; hard; friable; slightly sticky; slightly plastic; many rusty fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 4 second(s); common normal roots; abrupt smooth transition.	E horizon
G	960-1420	Moisture status: moist; dry colour 2.5Y7/1 (70 %); 10YR4/5 (30 %); moist colour 2.5Y5/2 (70 %); 10YR4/5 (30 %); 28.0 % clay; coarse sandy loam; common fine prominent 2.5YR4/5 dry; 10YR4/5 moist; iron oxide mottles; common medium prominent 10YR5/5 dry; 7.5YR4/5 moist; iron oxide mottles; strong coarse angular blocky; very hard; very firm; sticky; plastic; common normal fine and very fine pores; no medium and coarse pores; many slickensides; fine cracks; common silica cutans; few 2-6 mm round stones; water absorption 8 second(s); few normal roots; transition not reached.	G horizon

Table 11 Soil analyses for profile 205 (Kroonstad 2000)

Horizon		Depth	Diagnostic horizon	Gravel	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
		mm			coSa	meSa	fSa	vfSa	Si	tSi	Cl	Ca	Mg	K	Na	S			
				%	%							cmolc kg ⁻¹							%
A	E1	0-100	ot	7.1	28.1	23.6	12.7	11.0	4.7	8.8	9.5	1.40	0.55	0.16	0.10	2.21	10.49	110.4	21.1
		100-200		5.5	29.2	23.2	12.5	11.7	3.6	9.1	10.0	1.35	0.56	0.16	0.13	2.18	10.17	101.7	21.4
E1	E2	200-300	gs	3.5	32.8	22.0	11.9	10.8	3.5	8.4	9.8	0.68	0.42	0.08	0.11	1.3	11.85	120.9	11.0
		300-400		5.4	34.0	22.7	11.1	9.9	4.5	7.8	9.4	0.71	0.27	0.09	0.11	1.18	14.30	152.1	8.3
E2	G	400-500	gs	7.7	33.5	22.2	11.3	9.6	4.8	8.7	10.2	0.70	0.34	0.11	0.13	1.26	15.66	153.5	8.2
		500-600		5.3	23.6	23.2	14.0	11.7	4.8	8.7	12.3	0.66	0.42	0.10	0.14	1.32	15.17	123.3	8.7
G		600-700	gh	6.3	24.8	23.3	13.3	12.8	3.7	8.6	13.4	0.63	0.44	0.07	0.12	1.26	12.29	91.7	10.3
		700-800		11.7	17.7	22.1	13.8	13.8	5.7	9.1	17.0	1.11	0.79	0.10	0.16	2.16	15.99	94.1	13.5
		800-950		11.6	17.5	15.1	7.9	10.1	4.0	10.0	33.7	2.38	2.13	0.20	0.18	4.9	15.17	45.0	32.3
		950-1100		15.7	6.0	12.1	13.9	6.2	7.9	10.7	40.1	1.74	1.48	0.17	0.16	3.55	17.63	44.0	20.1
		1100-1400		10.6	13.2	18.5	9.9	16.5	4.5	9.9	25.7	1.87	1.30	0.11	0.16	3.44	13.54	52.7	25.4
		1400+		23.7	9.3	11.1	4.9	3.5	14.1	31.8	23.5	6.45	4.27	0.22	0.23	11.17	14.03	59.7	79.6

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe			Mn			
			H ₂ O	KCl				CBD	Ox	Pyro	CBD	Ox	Pyro	
A	0-100	1.66	5.38	4.57	0.78	680	11.5	5385	665	798	4.5	16.5	26.1	
	100-200		5.32	4.37	0.79	609	12.9	4075	1460	784	5.0	13.0	17.1	
E1	200-300	1.69	5.37	4.31	0.53	503	10.6	4245	1390	872	4.0	5.0	14.1	
	300-400		5.35	4.20	0.54	428	12.6	5625	1500	822	3.5	3.0	13.1	
E2	400-500	1.89	5.41	4.27	0.78	431	18.0	3865	1760	681	11.0	2.5	12.0	
	500-600		5.40	4.21	0.35	431	8.0	4285	1640	643	46.0	1.5	11.0	
G	600-700	1.72	5.52	4.28	0.31	330	9.3	5855	1170	584	69.0	1.5	11.0	
	700-800		5.67	4.20	0.16	295	5.4	7145	587	427	10.5	1.0	11.0	
	800-950		5.86	5.82	0.20	383	5.1	4285	369	297	2.5	5.0	11.0	
	950-1100		5.66	4.22	0.38	485	7.8	5855	692	363	30.5	1.0	11.0	
	1100-1400		5.92	4.31	0.09	234	3.6	1260	280	240	75.0	18.0	13.1	
	1400+	1.73	5.97	4.40	0.08	289	2.9	5420	249	228	47.0	61.0	15.1	

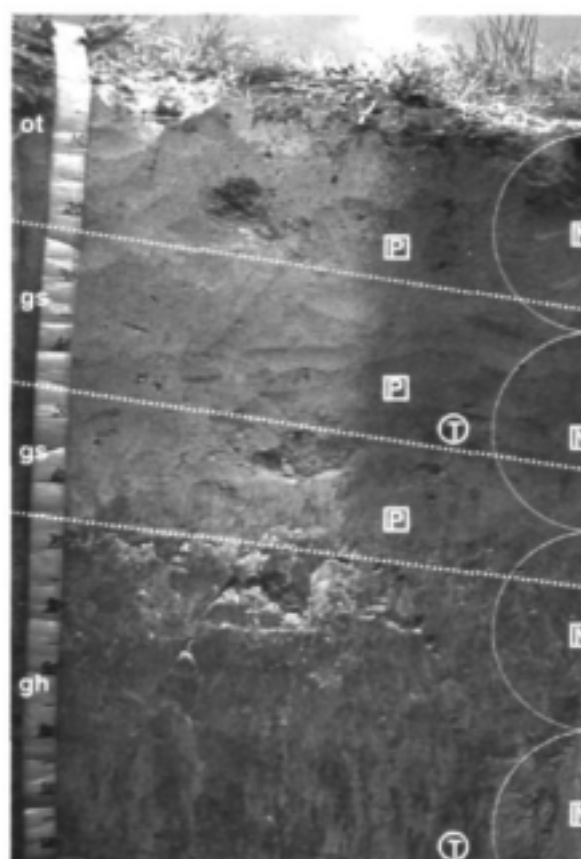


Figure 9 Profile 205 (Kroonstad 2000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

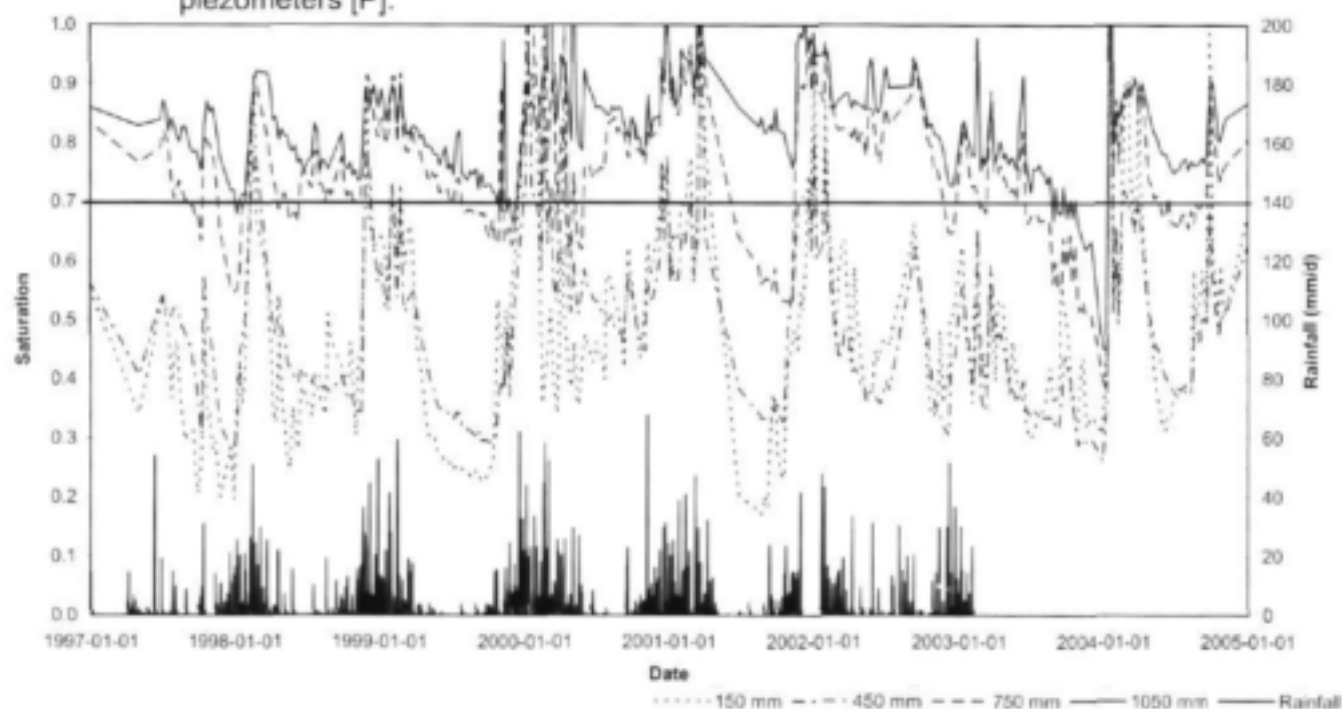


Figure 10 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 205.

Table 12 Profile description for profile 206 (Kroonstad 1000)

Profile No: 206	Soil form: Kroonstad
Mapphoto: 312548	Soil family: 1000
Latitude & Longitude: 31° 06' 07" S / 28° 20' 00" E	Surface rockiness: None
Surface stoniness: None	Occurrence of Boulders: None
Altitude: 1 281 m	Wind erosion: None
Terrain unit: Lower footslope	Water erosion: None
Slope: 7 %	Vegetation / Land use: Grassveld, closed
Slope shape: Straight	Water table: 200 mm
Aspect: Northwest	Described by: D. Scholtz & T.B. Ziem
Microrelief: 10 % mole mounds, 0.5 m high, profile between features	Date described: 18/06/2001
Parent material subsoil: Single, local colluvium	Weathering of underlying material: Advanced physical, strong chemical
Underlying material: Multistone	Alteration of underlying material: Ferruginous
Geological Group: Molteno	

Horizon	Depth (mm)	Description	Diagnostic horizons
A	0-550	Moisture status: Wet, dry colour: 10YR5/1 (100 %), moist colour: 10YR3/1 (100 %), 21.7 % clay, loam, few fine distinct 7.5YR5/8 dry, 10YR4/5 moist, iron oxide mottles, weak medium granular, hard, friable, sticky, plastic, common normal fine and very fine pores, few rusty medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s), many rusty roots, clear smooth transition.	orthic A horizon
E	550-800	Moisture status: Wet, dry colour: 10YR5/1 (95 %), 7.5YR5/8 (5 %), moist colour: 10YR2/1 (95 %), 10YR4/5 (5 %), 15.8 % clay, loam, common fine prominent 7.5YR5/8 dry, 10YR4/5 moist, iron oxide mottles, few fine prominent 10YR2/1 dry, 10YR2/1 moist, manganese mottles, apedal massive, very hard, friable, non-sticky, non-plastic, few normal fine and very fine pores, few bleached medium and coarse pores, no slickensides, no cracks, no cutans, few 2-6 mm rounded shaped stones, water absorption 1 second(s), few bleached roots, clear smooth transition.	E horizon
G	800-1100	Moisture status: Wet, dry colour: 10YR5/1 (90 %), 7.5YR5/8 (10 %), moist colour: 10YR4/1 (90 %), 10YR5/8 (10 %), 38.0 % clay, clay loam, many medium prominent 7.5YR5/8 dry, 10YR5/8 moist, iron oxide mottles, moderate coarse subangular blocky, very hard, firm, sticky, plastic, few bleached fine and very fine pores, few bleached medium and coarse pores, no slickensides, medium cracks, common silica cutans, very few 5-25 mm mixed shaped stones, water absorption 8 second(s), few bleached roots, transition not reached.	G horizon

Table 13 Soil analyses for profile 206 (Kroonstad 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
				coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
				%	%	%	%	%	%	%	cmolc/kg	cmolc/kg	cmolc/kg	cmolc/kg	cmolc/kg				
A	0-100	ot	13.3	6.9	6.8	10.1	11.5	7.4	32.9	23.2	8.91	3.27	0.29	0.33	12.81	30.99	133.6	41.3	
	100-250		15.4	7.0	6.8	7.8	15.8	13.4	27.0	23.9	9.95	2.78	0.19	0.30	13.21	19.19	80.3	68.8	
	250-350		7.2	8.1	7.3	7.8	14.0	15.8	21.9	24.6	5.91	2.06	0.15	0.27	8.39	15.77	64.1	53.2	
	350-450		2.0	9.4	8.1	9.7	13.8	22.1	17.2	18.7	3.93	1.17	0.07	0.20	5.37	15.12	60.9	35.5	
	450-550		1.5	10.1	8.1	11.7	16.0	13.3	20.0	18.1	4.21	1.16	0.07	0.27	5.7	10.66	58.9	53.5	
E	550-650	gs	2.9	10.0	9.6	9.9	16.2	17.9	17.9	15.6	3.97	0.98	0.10	0.27	5.31	9.76	62.8	54.2	
	650-750		4.3	11.5	10.0	9.9	14.9	19.2	15.7	15.9	3.07	0.92	0.11	0.24	4.34	6.96	43.8	62.4	
	750-850		4.8	10.6	9.4	10.2	15.6	23.0	16.2	17.3	2.67	1.02	0.14	0.23	4.06	6.42	37.1	63.2	
G	850-1000	gh	5.7	8.0	8.0	7.8	11.3	14.8	8.9	38.0	5.21	2.37	0.29	0.29	8.17	12.78	33.6	63.9	

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C/N	Fe			Mn		
			H ₂ O	KCl				CBD	Ox	Pyro	CBD	Ox	Pyro
			mg kg ⁻¹										
A	0-100	0.99	6.13	5.66	4.40	2648	16.6	7975	7960	3524	41.0	46.5	27.1
	100-250		6.23	5.72	2.91	2747	10.6	2290	13050	2560	15.0	35.0	25.1
	250-350		5.76	5.39	2.80	2052	13.7	5635	5635	2902	11.0	13.0	21.1
	350-450		5.82	4.78	1.26	968	13.0	2985	2700	847	9.5	9.0	18.1
	450-550		6.00	4.63	1.12	830	13.4	2275	1965	660	6.0	7.0	16.1
E	550-650	1.66	5.77	4.74	0.91	567	15.5	2285	2320	564	4.0	6.0	15.1
	650-750		5.87	4.49	0.42	274	15.3	1815	1890	398	4.0	4.5	13.1
	750-850		5.70	4.42	0.16	201	8.9	2435	1595	327	8.5	3.5	13.1
G	850-1000	1.70	5.83	4.28	0.16	264	5.9	1240	1520	407	147.0	3.5	17.1

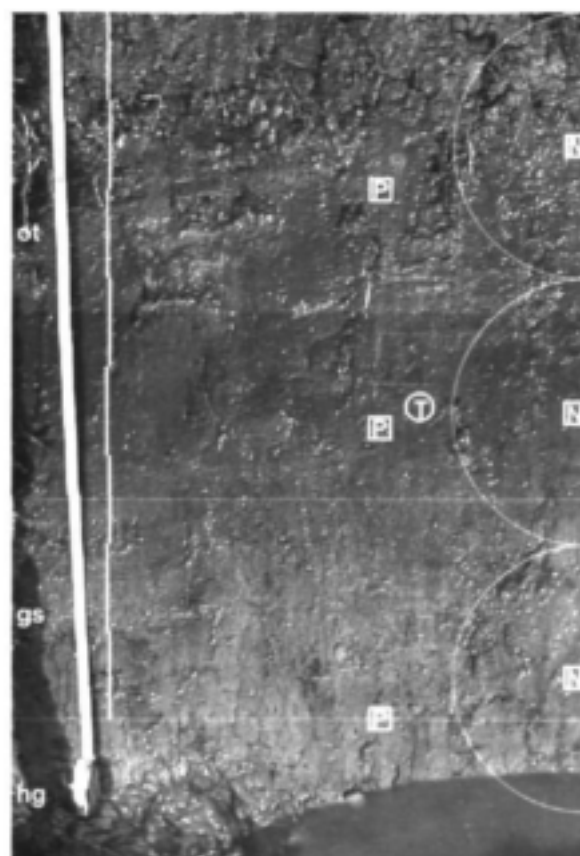


Figure 11 Profile 206 (Kroonstad 1000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

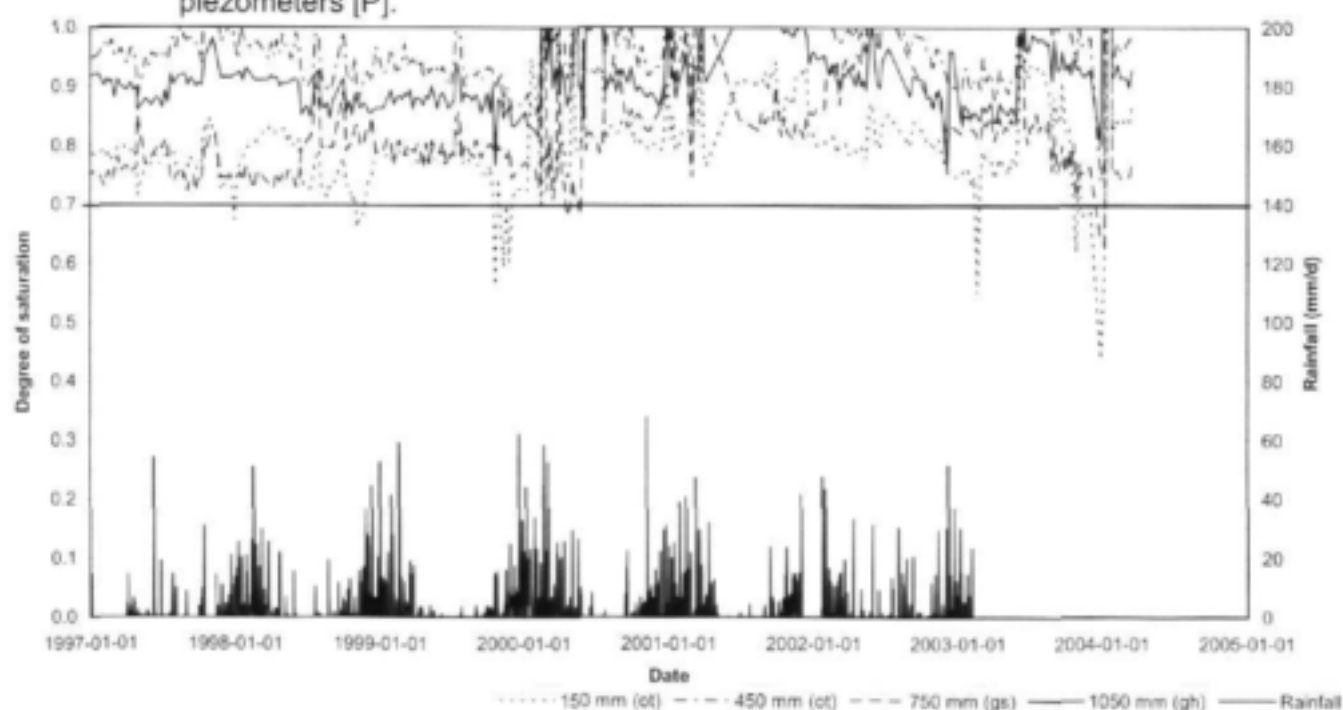


Figure 12 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 206.

Table 14 Profile description for profile 207 (Westleigh 1000)

Profile No: 207		Soil form: Westleigh	
Mapphoto: 312540		Soil family: 1000	
Latitude & Longitude: 31° 06' 10.2" / 28° 18' 49.2"		Surface rockiness: None	
Surface elevation: None		Occurrence of flooding: Occasional	
Altitude: 1 269 m		Wind erosion: None	
Terrain unit: Valley bottom		Water erosion: None	
Slope: 5 %		Vegetation / Land use: Grassveld, closed	
Slope shape: Concave		Water table: none	
Aspect: West		Described by: C. V. van Huyssteen & M. Smit	
Microrelief: 1 % mole mounds, 0.5 m height, profile between features		Date described: 19/06/2001	
Parent material: siltstone, Origin single, sand rock		Weathering of underlying material: Weak physical, weak chemical	
Underlying material: Felspathic sandstone		Alteration of underlying material: Ferruginised	
Geological Group: Murrumbidgee			

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0-300	Moisture status: moist dry colour: 10YR5/2 (100 %) moist colour: 7.5YR4/3 (100 %) 22.5 % clay, silty loam; common fine distinct 10YR5/7 dry; 10YR4/6 moist; iron oxide mottles; moderate fine subangular blocky hard, friable, slightly sticky, slightly plastic; many rusty fine and very fine pores; many rusty medium and coarse pores; no slickensides; fine cracks; no cutans; common 6-25 mm round boulders; water absorption 5 seconds; many rusty roots; clear smooth transition	offic. A horizon
B1	300-560	Moisture status: moist dry colour: 10YR5/3 (90 %) 10YR5/7 (10 %) moist colour: 7.5YR5/2 (90 %) 10YR4/6 (10 %) 23.6 % clay, silty loam; many medium distinct 10YR5/7 dry; 10YR4/6 moist; iron oxide mottles; moderate fine angular blocky hard, friable, slightly sticky, plastic; many rusty fine and very fine pores; many rusty medium and coarse pores; no slickensides; no cracks; no cutans; common 6-25 mm round boulders; water absorption 6 seconds; common bleached roots; clear smooth transition	soft, pedtic B horizon
B2	560-670	Moisture status: moist dry colour: 10YR5/1 (80 %) 10YR5/6 (20 %) moist colour: 10YR5/2 (80 %) 10YR4/6 (20 %) 19.4 % clay, silty loam; common medium prominent 10YR5/6 dry; 10YR4/6 moist; iron oxide mottles; moderate fine angular blocky hard, friable, slightly sticky, slightly plastic; common rusty fine and very fine pores; many rusty medium and coarse pores; no slickensides; no cracks; no cutans; many 2-6 mm round stones; water absorption 3 seconds; few bleached roots; clear smooth transition. Remark: B2 horizon tongues into G	soft, pedtic B horizon
G	670-1300	Moisture status: Wet dry colour: 10YR5/2 (80 %) 10YR5/6 (40 %) moist colour: 10YR1/2 (80 %) 10YR4/6 (40 %) 45.9 % clay, clay; many fine prominent 10YR5/2 dry; 10YR4/6 moist; iron oxide mottles; strong coarse prismatic, very hard, firm, very sticky, plastic; many bleached fine and very fine pores; few bleached medium and coarse pores; few slickensides; no cracks; many silica cutans; very few >250 mm angular stones; water absorption 5 seconds; no roots; transition not reached	unprofiled material with signs of wetness

Table 15 Soil analyses for profile 207 (Westleigh 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel		Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
			coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S					
			%								cmolc kg ⁻¹								
A	0-100	ot	5.3	4.3	3.8	3.8	10.2	33.9	20.5	20.9	2.29	1.17	0.31	0.18	3.94	10.44	50.0	37.7	
	100-200		2.3	3.9	3.8	3.9	11.6	31.2	20.4	23.9	1.98	1.02	0.25	0.20	3.46	10.66	44.6	32.5	
	200-300		0.9	4.7	3.7	3.3	11.7	32.3	21.0	22.8	1.58	0.90	0.17	0.23	2.88	9.08	39.8	31.7	
	300-400		0.7	5.0	3.4	3.2	11.7	35.4	15.1	23.8	1.27	0.78	0.15	0.23	2.43	9.30	39.1	26.1	
B1	400-560	sp	3.1	6.6	3.7	3.2	11.4	37.7	16.7	23.4	1.23	0.77	0.16	0.20	2.36	8.37	35.8	28.2	
B2	560-670	sp	8.2	9.3	4.1	3.8	10.5	37.8	18.5	19.4	1.18	0.79	0.15	0.20	2.33	6.74	34.7	34.6	
G	670-800	gh	29.3	4.4	3.4	3.4	10.9	29.1	7.8	41.4	2.91	1.90	0.20	0.30	6.32	10.77	26.0	49.4	
	800-900		7.7	3.8	3.1	3.2	9.1	21.5	6.0	50.4	4.83	2.86	0.23	0.39	8.30	14.68	29.1	56.5	

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C		N	C:N	Fe			Mn		
			H ₂ O	KCl	%	mg kg ⁻¹			CBD	Ox	Pyro	CBD	Ox	Pyro
A	0-100	1.58	5.35	4.29	1.61	1109	14.5	6200	1160	754	103.0	3.0	49.2	
	100-200		3.63	4.21	1.24	1031	12.1	6025	1975	811	88.5	3.0	32.1	
	200-300		5.69	4.36	0.87	770	11.3	8075	6560	796	58.5	7.0	26.1	
	300-400		5.74	4.14	0.72	694	10.3	6825	230	1098	50.0	6.5	25.1	
B1	400-560	1.63	5.71	4.07	0.46	527	8.7	7515	395	945	111.0	125.0	22.1	
B2	560-670		6.27	4.20	0.21	404	5.3	7980	405	610	183.5	110.0	20.1	
G	670-800	1.68	5.83	4.19	0.27	360	7.4	1145	2255	329	229.0	90.0	15.1	
	800-900		6.36	4.46	0.21	375	5.6	2905	2090	286	37.5	71.5	14.1	

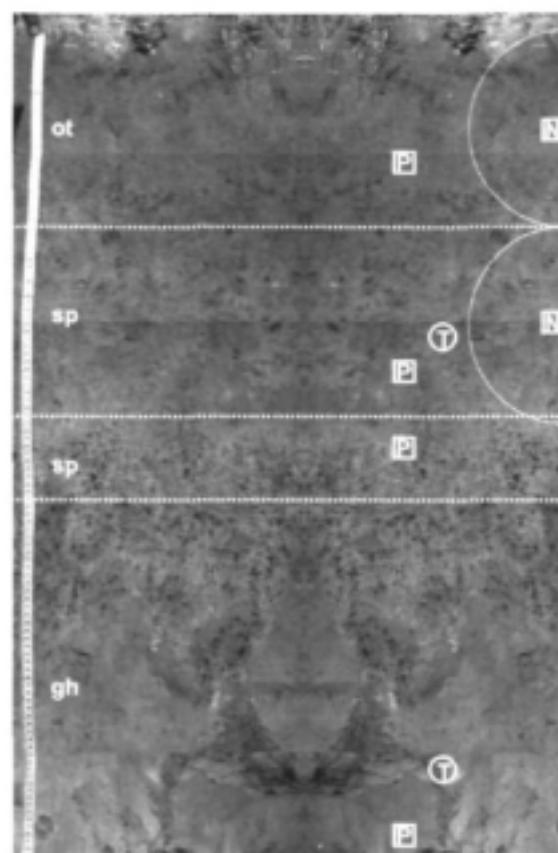


Figure 13 Profile 207 (Westleigh 1000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

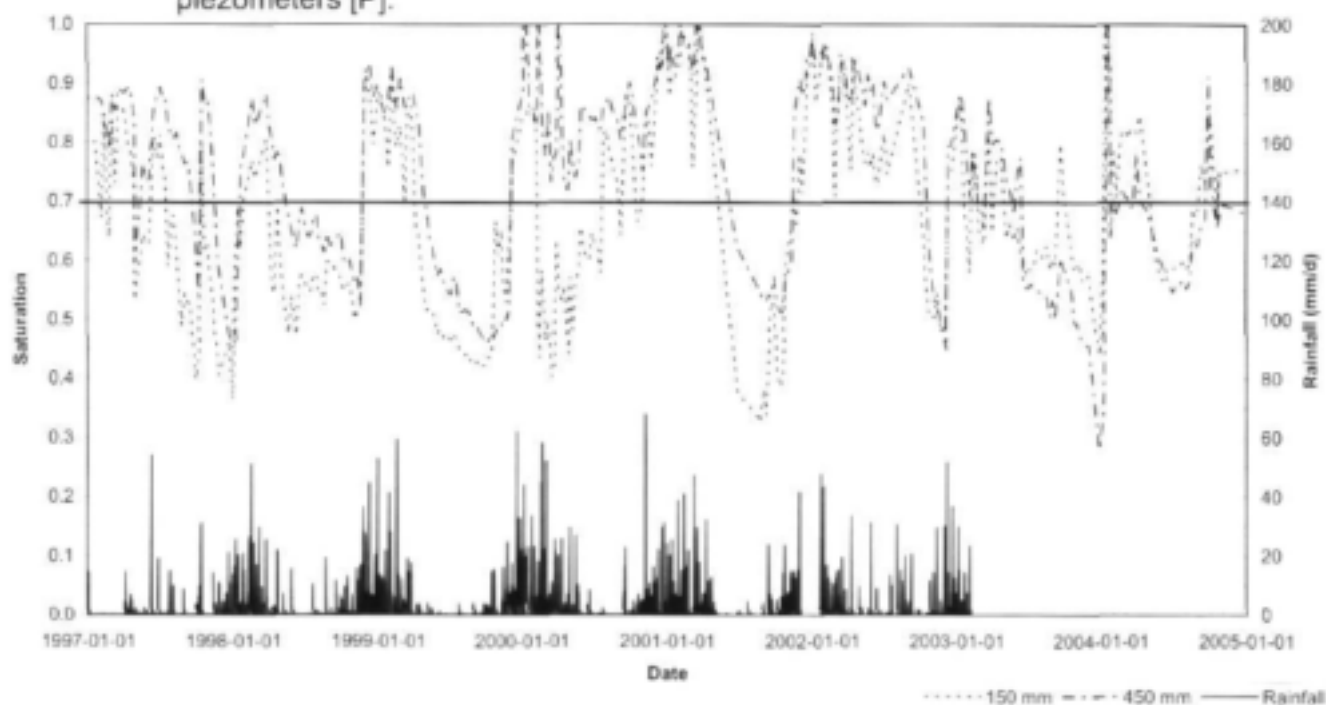


Figure 14 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 207.

Table 16 Profile description for profile 208 (Kroonstad 1000)

Profile No: 208	Soil form: Kroonstad
Mapphoto: 3128AB	Soil family: 1000
Latitude & Longitude: 31° 06' 10.2" / 28° 19' 44.8"	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 272 m	Wind erosion: None
Terrain unit: Lower footslope	Water erosion: None
Slope: 7 %	Vegetation / Land use: Grassveld, closed
Slope shape: Concave	Water table: None
Aspect: East	Described by: M. Hendry & A. G. Welkeghannas
Microrelief: None	Date described: 19/05/2001
Parent material source: Origin single: local colluvium	Weathering of underlying material: Moderate physical, moderate chemical
Underlying material: Multistone	Alteration of underlying material: Ferruginised
Geological Group: Molteno	

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 - 350	Moisture status: moist; dry colour: 10YR5/1 (100 %); moist colour: 10YR4/1 (100 %); 13.5 % clay; silty loam; common fine distinct 10YR5/5 dry; 10YR4/5 moist; iron oxide mottles; weak coarse granular; hard; friable; non-sticky; non-plastic; many rusty fine and very fine pores; few rusty medium and coarse pores; no slickensides; no cracks; no clay outcans; no coarse fragments; water absorption 1 second(s); many bleached roots; gradual smooth transition.	subsoil horizon
E	350 - 530	Moisture status: moist; dry colour: 10YR5/2 (90 %); 10YR5/5 (10 %); moist colour: 10YR4/1 (90 %); 10YR4/5 (10 %); 13.1 % clay; loam; many medium distinct 10YR5/5 dry; 10YR4/5 moist; iron oxide mottles; weak medium subangular blocky; hard; friable; non-sticky; non-plastic; many rusty fine and very fine pores; few rusty medium and coarse pores; no slickensides; no cracks; few clay outcans; no coarse fragments; water absorption 1 second(s); many bleached roots; gradual smooth transition.	E horizon
G1	530 - 800	Moisture status: moist; dry colour: 10YR3/1 (80 %); 10YR5/5 (20 %); moist colour: 10YR5/2 (80 %); 10YR4/5 (20 %); 23.7 % clay; loam; common medium distinct 10YR5/5 dry; 10YR4/5 moist; iron oxide mottles; apedal massive; very hard; firm; sticky; slightly plastic; many bleached fine and very fine pores; few dark medium and coarse pores; no slickensides; no cracks; few clay outcans; no coarse fragments; water absorption 1 second(s); common bleached roots; clear smooth transition. Remark: This horizon forms the transition between E and G.	G horizon
G2	800 - 1700	Moisture status: moist; dry colour: 10YR5/2 (70 %); 10YR5/5 (30 %); moist colour: 10YR5/2 (70 %); 10YR4/5 (30 %); 10YR3/1 (10 %); 25.1 % clay; loam; many medium distinct 10YR5/5 dry; 10YR5/5 moist; iron oxide mottles; common medium distinct 10YR4/5 dry; 10YR4/5 moist; brown mottles; few fine prominent 10YR2/1 dry; 10YR2/1 moist; manganese mottles; strong coarse prismatic; very hard; very firm; very sticky; plastic; common normal fine and very fine pores; common dark medium and coarse pores; many slickensides; no cracks; very many clay outcans; no coarse fragments; water absorption 10 second(s); few bleached roots; transition not reached.	G horizon

Table 17 Soil analyses for profile 208 (Kroonstad 1000)

Soil analyses for profile 200 (Kilobard 1000)																		
Horizon	Depth	Diagnostic horizon	Gravel	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
				coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
	mm		%	%							cmol/kg							%
A	0-100	ot	1.9	5.4	5.9	7.9	15.6	37.4	18.7	11.7	1.50	0.83	0.10	0.17	2.69	10.11	86.4	26.6
	100-200		7.7	5.7	6.0	8.4	17.1	46.4	1.7	16.3	1.50	0.78	0.10	0.22	2.59	9.08	55.7	28.5
	200-300		2.7	6.5	6.2	8.0	18.0	31.8	17.5	13.7	1.14	0.59	0.10	0.22	2.04	6.85	50.0	29.8
E	300-400	gs	3.0	6.2	6.2	7.8	16.1	32.7	20.8	12.0	0.92	0.51	0.05	0.16	1.64	5.06	42.2	32.4
	400-500		3.3	6.4	6.2	8.0	16.0	34.3	19.2	14.1	1.17	0.71	0.06	0.18	2.12	4.89	34.7	43.4
G1	500-600	gh	4.4	6.5	6.2	7.7	15.6	27.3	18.0	19.2	2.18	1.39	0.14	0.27	3.99	6.96	36.3	57.3
	600-650		2.4	6.7	6.0	7.4	14.3	26.7	16.8	21.6	2.58	1.40	0.15	0.23	4.36	7.45	34.5	58.5
	650-700		18.4	6.7	5.5	6.6	12.4	23.9	20.0	24.0	2.82	1.81	0.18	0.26	6.07	8.43	35.1	60.1
	700-800		14.6	5.6	5.2	6.1	11.3	24.3	19.4	25.5	4.04	2.55	0.25	0.33	7.17	9.62	37.7	74.5
	800-900		10.2	6.0	5.2	6.0	11.5	17.9	22.3	27.8	3.90	2.45	0.23	0.27	6.85	10.00	36.0	68.5
G2	900-1000	gh	3.8	4.4	8.0	10.1	11.9	23.6	18.4	26.4	5.06	3.11	0.26	0.35	8.77	10.93	41.4	80.2
	1000-1100		1.4	6.1	7.1	7.4	11.1	21.3	19.0	26.3	5.29	3.18	0.25	0.35	9.07	11.25	42.8	80.6
	1100-1200		10.6	13.1	9.6	11.0	14.2	16.0	12.4	22.0	4.78	2.93	0.23	0.32	8.26	9.08	41.3	91.0
	1400+		38.8	7.7	6.8	10.1	18.0	19.5	13.0	22.8	5.03	3.03	0.19	0.32	8.56	8.70	38.2	98.4

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe			Mn			Pyro	mg/kg
			H ₂ O	KCl	%	mg/kg	CBD	Ox	Pyro	CBD	Ox	Pyro			
													Mg m ⁻³		
A	0-100	1.44	5.76	4.59	1.12	806	13.9	2955	705	1185	1.5	23.5	22.1		
	100-200		5.63	4.32	0.95	659	14.5	3115	1645	705	2.0	40.0	12.0		
	200-300		5.17	4.05	0.71	631	11.2	2220	1465	649	4.5	35.0	11.0		
E	300-400	1.62	5.28	4.08	0.57	496	11.6	2360	1430	577	7.0	273.0	9.0		
	400-500		5.84	4.23	0.30	336	9.0	1820	796	521	8.0	184.0	7.0		
	500-600		6.03	4.21	0.17	233	7.1	3440	2115	361	1.5	48.0	7.0		
G1	600-650	1.75	6.26	4.25	0.11	204	5.6	4220	7185	339	20.0	10.0	7.0		
	650-700		5.52	4.65	0.07	189	3.5	4620	5920	409	32.0	7.5	7.0		
	700-800		6.48	4.55	0.11	151	7.0	7555	2260	408	109.0	4.0	8.0		
G2	800-900	1.75	6.62	4.48	0.08	176	4.6	1335	2310	348	191.5	1.0	11.0		
	900-1000		6.74	5.18	0.08	170	4.9	2605	661	296	118.0	0.5	14.1		
	1000-1100		6.77	5.02	0.06	168	3.7	7150	316	282	359.5	0.5	12.0		
	1100-1200		6.99	5.24	0.06	134	4.5	7840	218	284	15.0	31.5	10.0		
	1400+	1.74	7.13	5.43	0.02	118	1.4	4905	455	311	98.5	42.0	7.0		

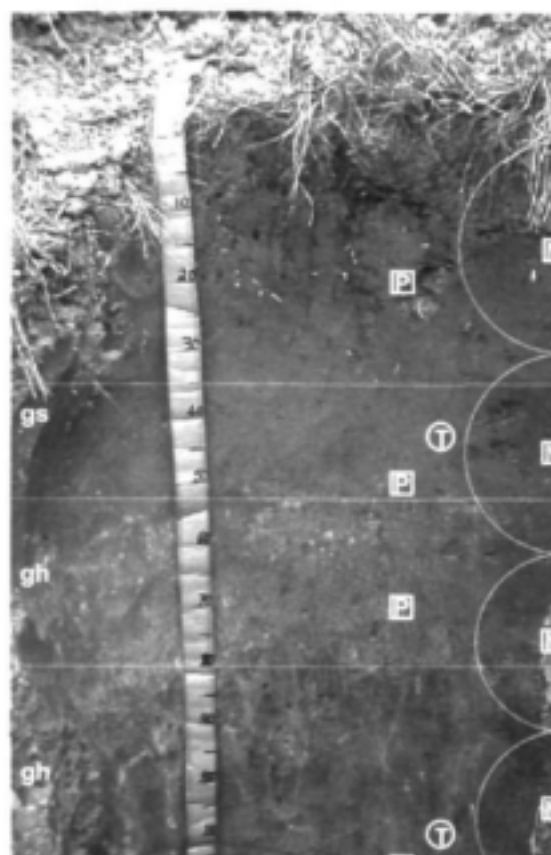


Figure 15 Profile 208 (Kroonstad 1000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

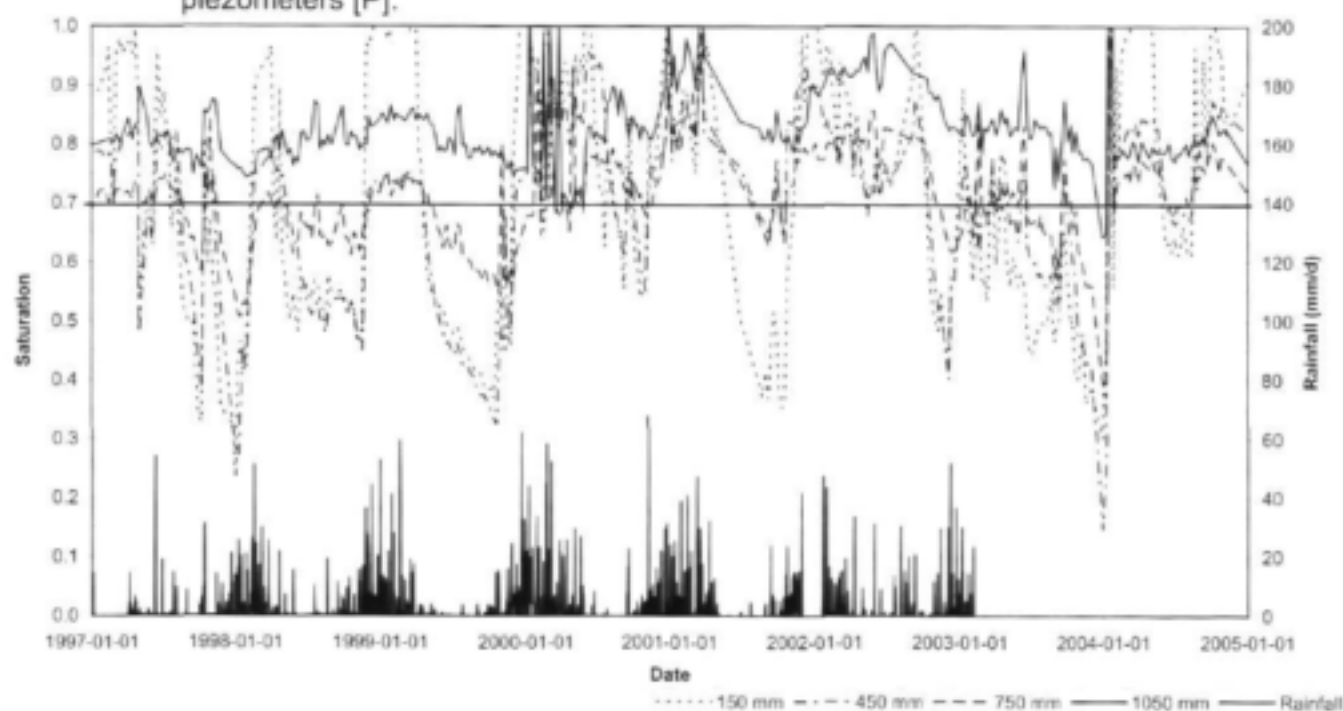


Figure 16 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 208.

Table 18 Profile description for profile 209 (Katspruit 1000)

Profile No. 209	Soil form: Katspruit
Map photo: 3125AB	Soil family: 1000
Latitude & Longitude: 31° 06' 10.3" / 28° 19' 35.8"	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 285 m	Wind erosion: None
Termin unit: Upper mesolope	Water erosion: None
Slope: 12 %	Vegetation / Land use: Grassveld, closed
Slope shape: Concave	Water table: None
Aspect: East	Described by: M. Hersley, W. Boschhoff
Microrelief: None	Date described: 19/06/2001
Parent material: solum: Origin binary, local colluvium, solid rock	Weathering of underlying material: Weak physical, weak chemical
Underlying material: Mudstone	Alteration of underlying material: Ferruginised
Geological Group: Mafeno	

Horizon	Depth (mm)	Description	Diagnostic horizons
A	0 - 450	Moisture status: moist; dry colour: 10YR5/2 (90 %), 7.5YR4/6 (10 %); moist colour: 10YR5/2 (90 %), 7.5YR4/6 (10 %); 16.3 % clay; loam; many fine distinct 7.5YR4/6 dry, 7.5YR3/4 moist, iron oxide mottles, moderate coarse granular, hard, slightly firm, non-sticky, non-plastic; many bleached and rusty fine and very fine pores; many bleached and rusty medium and coarse pores; no slickensides; fine cracks; no cutans; very few 5-25 mm moist shaded stones; water absorption 2 seconds; many bleached roots; clear smooth transition. Remark: >70 m to dolomite outcrop. Rocks in 2 layers at 700 and 900 mm.	ortho A horizon
G	450 - 1100	Moisture status: moist; dry colour: 10YR5/1 (90 %), 7.5YR5/6 (10 %); moist colour: 10YR5/1 (90 %), 7.5YR5/6 (10 %); 35.7 % clay; clay loam; many fine prominent 10YR5/6 dry, 7.5YR5/8 moist, iron oxide mottles, strong coarse granular, very hard, very firm, very sticky, plastic; common bleached fine and very fine pores; few bleached and rusty medium and coarse pores; many slickensides; medium cracks; very many clay cutans; common 75-250 mm moist shaded stones; very few 2-6 mm round manganese concretions; water absorption 6 seconds; few bleached roots; clear smooth transition. Remark: root channels are always dark gray (10YR4/1). Vertical streaking light to dark gray.	G horizon
C	1100 - 1400	Moisture status: moist; dry colour: 10YR5/1 (90 %), 7.5YR5/6 (10 %); moist colour: 10YR5/1 (90 %), 7.5YR5/6 (10 %); 35.7 % clay; clay loam; many fine distinct 7.5YR5/6 dry, 7.5YR4/6 moist, iron oxide mottles, strong coarse granular, very hard, very firm, very sticky, plastic; few bleached fine and very fine pores; few bleached and rusty medium and coarse pores; many slickensides; medium cracks; very many silica & clay cutans; many 75-250 mm moist shaded stones; water absorption 6 seconds; common bleached roots; transition not reached. Remark: C horizon is horizontally layered mudstone.	saprolite

Table 19 Soil analyses for profile 209 (Katspruit 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat %
				coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
				%							cmol, kg ⁻¹							
A	0-100	ot	3.8	3.7	3.0	10.1	25.4	23.8	17.9	16.5	2.98	1.55	0.23	0.20	4.98	9.41	57.0	52.7
	100-200		4.1	4.2	3.0	8.6	26.7	25.9	16.0	16.2	2.95	1.57	0.15	0.23	4.9	8.32	51.4	58.9
	200-300		1.8	3.8	2.9	8.5	26.9	22.6	18.9	16.2	2.75	1.52	0.16	0.22	4.68	8.81	54.4	52.9
	300-400		3.9	4.1	3.0	8.5	27.2	22.0	20.8	14.8	2.80	1.56	0.15	0.28	4.78	7.99	54.0	59.8
	400-450		17.7	4.2	3.2	8.6	25.9	23.4	16.4	17.9	2.08	1.56	0.15	0.25	4.04	5.71	31.9	70.8
G	450-500	gh	7.0	5.4	3.2	8.0	23.8	21.0	14.2	22.5	2.41	2.07	0.17	0.28	4.93	6.80	30.2	72.5
	500-600		9.0	6.5	2.9	5.6	18.6	25.6	13.7	28.8	3.22	2.51	0.19	0.32	6.24	6.42	22.3	97.2
	600-850		29.4	4.0	2.0	4.1	14.6	22.6	13.9	35.2	4.30	3.10	0.20	0.33	7.52	7.61	21.6	104.1
	850-900		27.4	1.2	0.6	1.7	8.2	25.8	12.8	47.6	10.25	6.03	0.30	0.39	16.97	13.05	27.4	130.0
	900-1000		34.5	7.0	4.8	4.1	9.7	16.7	21.0	35.7	5.97	2.94	0.27	0.36	9.54	7.72	21.6	123.6
	1000-1100		23.3	0.5	0.5	0.8	3.2	13.5	37.0	44.2	2.83	7.86	0.28	0.39	11.36	17.83	40.3	63.7

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C/N	Fe			Mn			
			H ₂ O	KCl				CBD	Ox	Pyro	CBD	Ox	Pyro	
A	0-100	1.45	5.60	4.74	1.43	866	16.5	5155	253	1069	82.0	97.5	51.2	
	100-200		5.78	4.71	0.76	671	11.3	4720	327	678	61.0	190.5	23.1	
	200-300		5.98	4.88	0.81	611	13.3	4525	296	562	48.5	134.5	17.1	
	300-400		5.93	4.66	0.57	539	10.6	6945	262	508	8.0	263.0	16.1	
	400-450		6.22	4.68	0.43	487	8.8	7180	197	468	26.0	14.0	13.1	
G	450-500	1.65	6.22	4.63	0.31	412	7.6	44940	179	375	5.5	104.0	8.0	
	500-600		6.36	4.69	0.35	350	10.0	1460	2250	314	6.0	65.5	7.0	
	600-850	1.64	6.49	4.90	0.26	378	6.9	1370	2505	300	47.5	46.5	6.0	
	850-900		6.51	5.23	0.16	389	4.1	390	2875	235	10.5	37.5	8.0	
	900-1000	1.73	6.59	5.21	0.08	351	2.3	1145	2940	288	95.5	18.0	6.0	
	1000-1100		6.64	5.35	0.08	430	1.8	7975	2775	302	18.5	5.5	8.0	



Figure 17 Profile 209 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

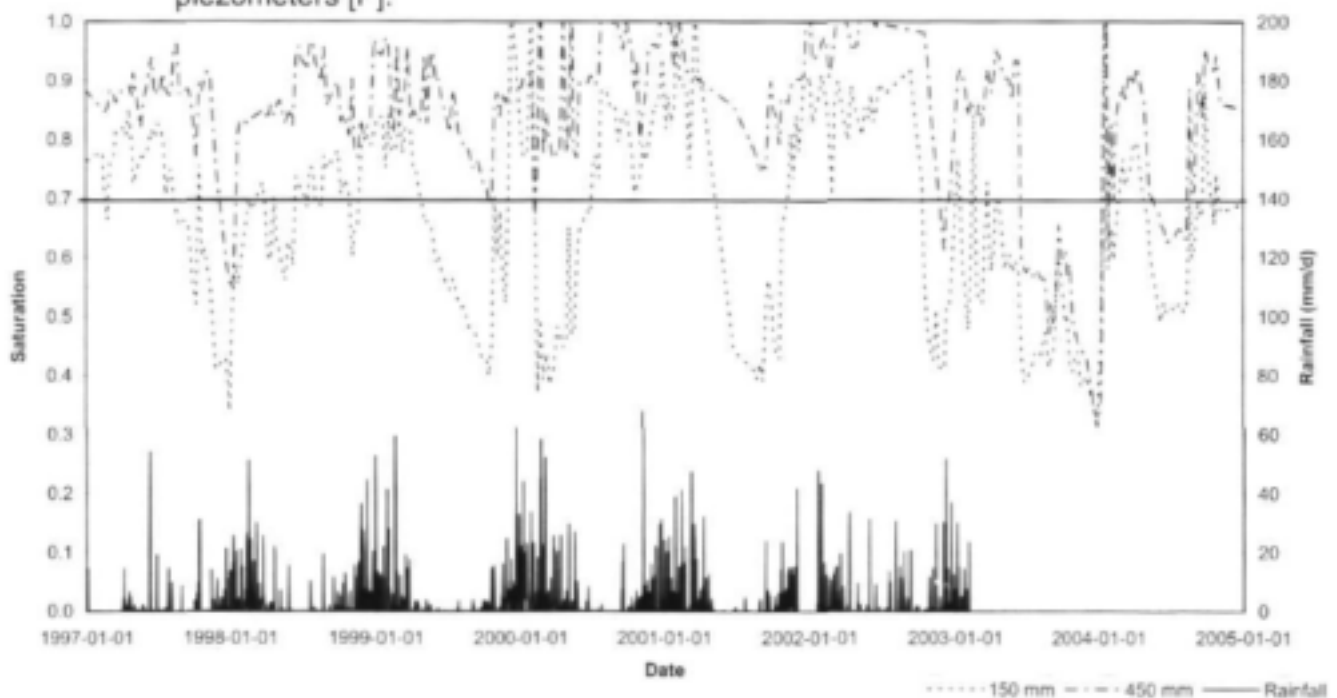


Figure 18 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 209.

Table 20 Profile description for profile 210 (Bloemdal 1100)

Profile No: 210		Soil form: Bloemdal	
Mapphoto: 312648		Soil family: 1100	
Latitude & Longitude: 31° 06' 10.5" / 28° 19' 34.9"		Surface rockiness: None	
Surface stoniness: None		Occurrence of Bedding: None	
Altitude: 1 306 m		Wind erosion: None	
Terrain unit: Upper midslope		Vegetation / Land use: Grassveld, closed	
Slope: 8 %		Water table: none	
Slope shape: Convex		Described by: M. Henckes & T.B. Zere	
Aspect: East		Date described: 15/06/2001	
Microrelief: None		Weathering of underlying material: Strong physical, strong chemical	
Parent material solon: Origin single, solid rock		Alteration of underlying material: Ferruginous	
Underlying material: Felsic sandstone			
Geological Group: Motene			

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 - 250	Moisture status: dry, dry colour: 10YR4/2 (100 %), moist colour: 10YR3/2 (100 %), 18.0 % clay, clay loam, no mottles, moderate fine subangular blocky, slightly hard, brittle, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 2 seconds; many normal roots, gradual smooth transition.	orthic A horizon
A2	250 - 530	Moisture status: dry, dry colour: 10YR4/3 (100 %), moist colour: 7.5YR3/2 (100 %), 15.7 % clay, loam, no mottles, moderate fine subangular blocky, soft, loose, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second; many normal roots, gradual smooth transition. Remark: This horizon forms the transition between orthic A horizon and B1.	orthic A horizon
B1	530 - 810	Moisture status: dry, dry colour: 7.5YR4/6 (90 %), 7.5YR4/2 (10 %), moist colour: 5YR4/6 (90 %), 7.5YR3/2 (10 %), 23.9 % clay, loam, many medium distinct 7.5YR4/2 dry, 7.5YR3/2 moist, humus mottles, weak fine subangular blocky, slightly hard, loose, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, common 2-6 mm round stones, very few 6-25 mm round boulders, water absorption 2 seconds; many normal roots, gradual smooth transition. Remark: Humus in channels between 600 and 1200 mm.	red apedal B horizon
B2	810 - 1200	Moisture status: moist, dry colour: 7.5YR6/6 (90 %), 5YR4/6 (10 %), moist colour: 5YR4/4 (90 %), 5YR4/4 (10 %), 18.0 % clay, loam, many fine distinct 7.5YR4/2 dry, 7.5YR3/2 moist, humus mottles, apedal massive, hard, friable, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, common 2-6 mm round stones, very few 6-25 mm round boulders, water absorption 3 seconds; common normal roots, gradual smooth transition. Remark: Humus in channels between 600 and 1200 mm.	red apedal B horizon
C1	1200 - 1580	Moisture status: moist, dry colour: 10YR8/4 (100 %), moist colour: 7.5YR3/4 (100 %), 17.3 % clay, coarse sandy loam, no mottles, apedal massive, hard, friable, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, very few 2-6 mm round stones, water absorption 2 seconds; few normal roots, clear smooth transition.	unspecified material with signs of wetness
C2	1580 - 1750	Moisture status: moist, dry colour: 2.5YR3/6 (100 %), moist colour: 5YR6/2 (100 %), 20.1 % clay, loam, no mottles, strong coarse prismatic, hard, firm, sticky, plastic, few normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, common silica cutans, no coarse fragments, water absorption 7 seconds; no roots, transition not reached.	saprolite

Table 21 Soil analyses for profile 210 (Bloemdal 1100)

Soil analyses for profile 210 (Bismarck 1960)																		
Horizon	Depth	Diagnostic horizon	Gravel		Texture of the fine earth						Exchangeable cations					CEC soil	CEC clay	Base sat
	mm		coSa	meSa	fiSa	viSa	Si	fSi	Cl	Ca	Mg	K	Na	S			%	
			%			%								cmol/kg				
A	0-130	ot	3.7	0.6	0.5	0.8	3.2	13.5	37.0	18.9	0.76	0.51	0.10	0.13	1.50	6.58	34.9	22.8
	130-260		6.5	29.1	12.8	6.2	7.8	11.5	12.8	19.2	0.54	0.44	0.10	0.14	1.23	6.14	32.0	20.0
	260-370		18.3	33.4	11.6	5.3	7.1	12.0	14.1	14.5	0.36	0.33	0.09	0.13	0.91	6.09	42.0	14.9
	370-550		11.1	31.9	13.3	6.3	7.2	13.2	9.2	18.8	0.24	0.23	0.10	0.14	0.72	5.44	28.9	13.1
	530-650		15.2	26.2	12.0	5.9	8.1	12.7	14.3	18.6	0.22	0.22	0.11	0.14	0.69	5.27	28.3	13.1
B1	650-750	re	9.2	27.4	12.7	6.0	7.2	23.0	7.1	16.6	0.23	0.25	0.13	0.14	0.78	5.82	35.1	13.1
	750-810		5.4	24.8	11.3	5.3	7.6	11.3	2.4	36.4	0.30	0.36	0.14	0.15	0.94	5.17	14.2	18.2
	810-910		6.8	27.4	11.6	5.4	7.5	21.3	7.5	18.5	0.28	0.35	0.13	0.16	0.91	5.60	30.3	16.3
	910-1010		7.7	26.9	11.8	5.0	7.9	12.7	15.9	17.5	0.28	0.34	0.12	0.17	0.91	5.38	30.7	16.9
	1010-1100		5.7	30.1	12.0	5.4	8.0	13.0	18.1	12.5	0.28	0.34	0.11	0.16	0.90	5.17	41.4	17.4
B2	1100-1200	re	13.8	16.0	14.4	9.4	13.0	11.9	11.1	23.5	0.59	0.88	0.07	0.16	1.71	4.51	19.2	37.9
	1200-1300		10.1	31.6	10.9	5.3	7.7	14.3	11.0	19.0	0.24	0.23	0.12	0.14	0.73	5.17	27.2	14.1
	1300-1400		9.8	30.7	13.1	5.9	8.6	14.5	7.7	18.8	0.23	0.21	0.11	0.15	0.70	2.39	12.7	29.3
	1400-1500		7.3	42.0	10.6	4.5	7.8	11.1	6.9	15.5	0.23	0.19	0.09	0.14	0.65	3.04	19.6	21.4
	1500-1600		25.5	42.2	10.7	4.4	7.0	3.2	15.8	15.7	0.23	0.21	0.11	0.16	0.71	2.83	18.0	25.1
C2	1600-1700	so	43.2	36.2	9.3	4.4	9.2	12.1	10.7	16.3	0.38	0.41	0.08	0.13	1.00	3.15	19.3	31.7
	1900-2000		33.3	26.2	10.0	4.9	8.6	13.6	12.5	23.8	1.01	0.74	0.18	0.15	2.08	7.94	33.4	26.2

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe			Mn				
	mm		H ₂ O	KCl				%	mg/kg	CBD	Ox	Pyro	CBD	Ox	Pyro
		Mg/m ³						mg/kg			mg/kg				
A	0-130	1.39	5.09	5.10	1.00	686	14.5	7020	513	1184	11.5	2.5	11.0		
	130-260		5.15	4.41	0.85	610	16.8	3860	395	1151	19.5	3.0	9.0		
	260-370		5.21	4.10	0.33	430	7.6	7880	457	1234	13.5	34.5	9.0		
	370-550		5.29	4.62	0.33	354	9.3	4150	336	1331	29.5	9.0	9.0		
	530-650		5.20	3.85	0.39	305	12.7	7145	3090	1272	48.0	105.5	11.0		
B1	650-750	1.72	5.11	3.91	0.14	247	5.5	5450	717	994	80.0	11.5	10.0		
	750-810		5.15	3.93	0.23	246	9.2	9850	1250	950	94.5	9.0	12.0		
	810-910		5.20	3.96	0.31	304	10.3	6750	1620	654	106.0	13.0	14.1		
	910-1010		5.24	3.67	0.17	230	7.4	8100	3680	390	112.0	14.0	11.0		
	1010-1100		5.22	4.04	0.10	216	4.5	13950	1575	580	112.0	18.5	15.1		
B2	1100-1200	1.70	5.60	4.14	0.12	171	6.8	8060	1830	423	118.0	37.0	13.1		
	1200-1300		5.24	4.02	0.21	169	12.3	6570	165	470	102.0	54.5	14.1		
	1300-1400		5.28	4.11	0.09	109	8.6	4280	2515	298	106.0	119.5	11.0		
	1400-1500		5.29	4.12	0.12	115	10.5	5630	1910	305	109.5	124.5	12.0		
	1500-1600		5.21	4.05	0.06	125	5.2	5385	1895	389	72.5	107.5	14.1		
C1	1600-1700	1.82	5.45	4.08	0.03	132	2.5	5660	1260	296	49.0	108.5	12.0		
	1900-2000		5.18	4.12	0.61	438	13.8	10650	2310	1025	145.5	105.0	15.1		

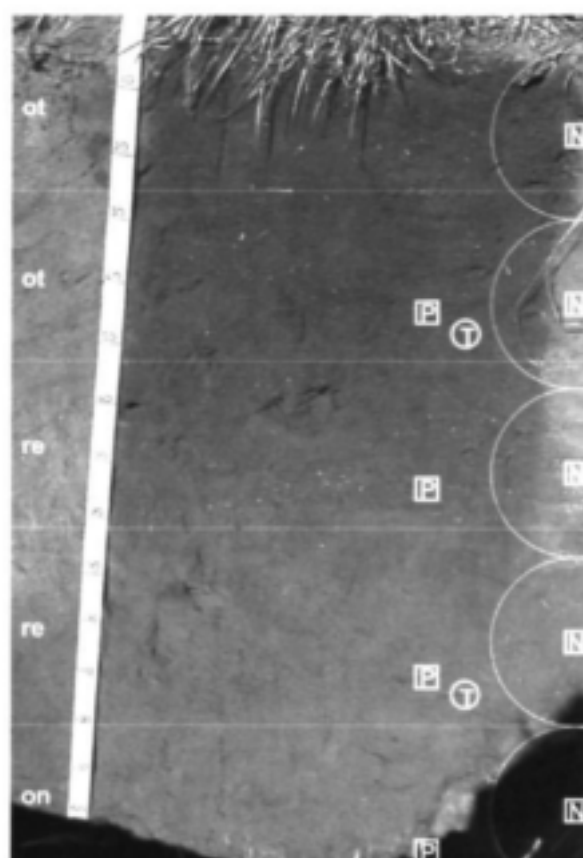


Figure 19 Profile 210 (Bloemdal 1100), indicating diagnostic horizons as well as measurement depths for tensiometers [T], neutron water meter [N] and piezometers [P].

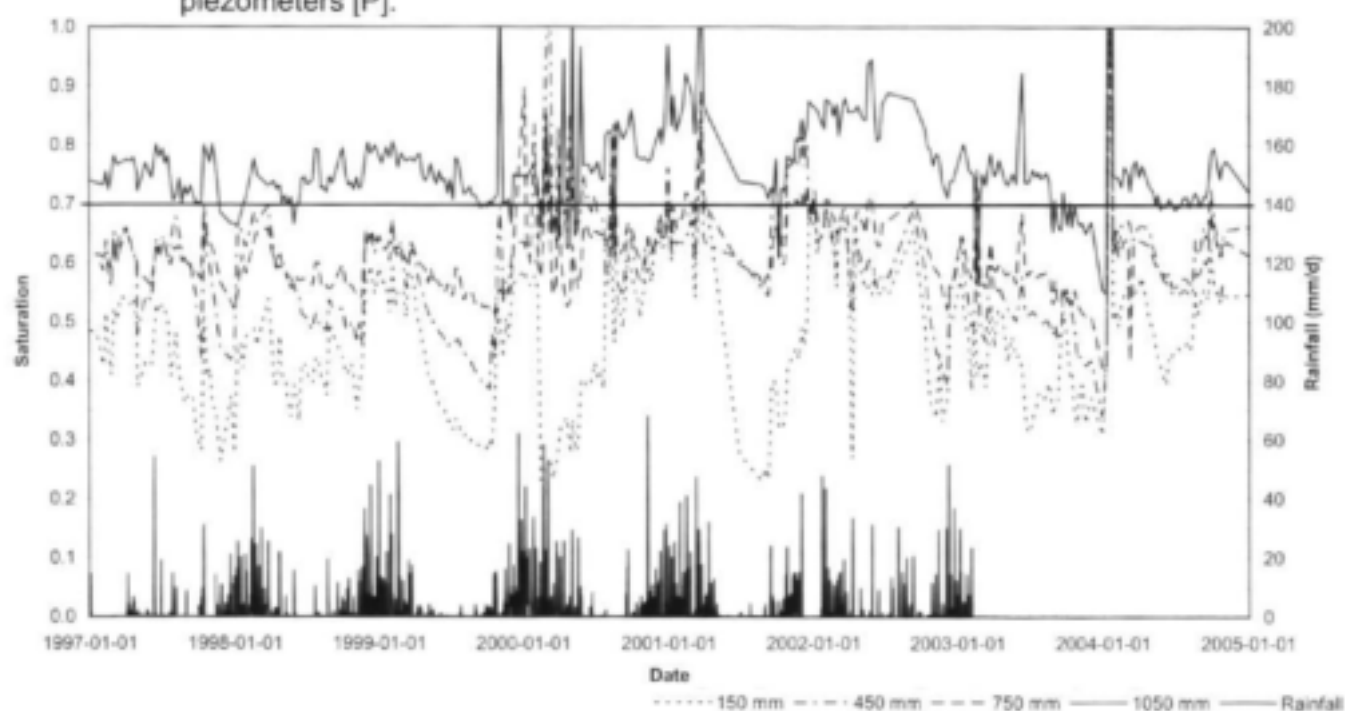


Figure 20 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 210.

Table 22 Profile description for profile 211 (Katspruit 1000)

Profile No: 211	Soil form: Katspruit
Mapphoto: 312548	Soil family: 1000
Latitude & Longitude: 31° 06' 25.3" / 28° 19' 35.5"	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1250 m	Wind erosion: None
Termin unit: Upper footslope	Water erosion: None
Slope: 5 %	Vegetation / Land use: Grassveld, covered
Slope shape: Convex	Water table: 650 mm
Aspect: North	Described by: W. Boshoff, A.G. Wiedeyshannes
Micronutrient: None	Date described: 19/06/2001
Parent material solum: Origin binary: local colluvium, solid rock	Weathering of underlying material: Strong physical, strong chemical
Underlying material: Mudstone	Alteration of underlying material: Ferruginised
Geological Group: Molteno	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0 - 150	Moisture status: moist, dry colour: 10YR7/1 (50 %), 7.5YR5/8 (50 %), moist colour: 10YR4/2 (50 %), 2.5YR4/8 (50 %), 32.4 % clay, clay loam, many fine distinct 10YR4/4 dry, 2.5YR4/8 moist, iron oxide mottles, weak coarse granular, hard, slightly firm, sticky, very plastic, common rusty fine and very fine pores, common rusty medium and coarse pores, no slickensides, fine cracks, no cutans, no coarse fragments, water absorption 3 second(s), many rusty roots, diffuse smooth transition.	orthic A horizon
G1	150 - 450	Moisture status: Wet, dry colour: 10YR7/1 (80 %), 7.5YR5/8 (20 %), moist colour: 10YR5/1 (80 %), 2.5YR4/8 (20 %), 37.5 % clay, clay loam, common fine distinct 10YR5/8 dry, 2.5YR4/8 moist, iron oxide mottles, weak fine subangular blocky, hard, slightly firm, sticky, very plastic, common rusty fine and very fine pores, common rusty medium and coarse pores, no slickensides, fine cracks, no cutans, no coarse fragments, water absorption 4 second(s), many rusty roots, gradual smooth transition.	G horizon
G2	450 - 1200	Moisture status: Wet, dry colour: 10YR7/1 (80 %), 7.5YR5/8 (20 %), moist colour: 10YR5/1 (80 %), 7.5YR5/8 (20 %), 37.5 % clay, clay loam, common fine distinct 10YR5/8 dry, 10YR5/8 moist, iron oxide mottles, weak fine subangular blocky, hard, very firm, sticky, very plastic, few rusty fine and very fine pores, few rusty medium and coarse pores, no slickensides, fine cracks, common silica cutans, very few 2-5 mm mixed stones, water absorption 10 second(s), few rusty roots, transition not reached.	G horizon

Remark: Yellow pores (channels) in all three horizons.

Table 23 Soil analyses for profile 211 (Katspruit 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat %
				coSa	meSa	fsa	vtSa	Si	SSi	Cl	Ca	Mg	K	Na	S			
				cmol/kg														
A	0-100	ot	5.5	5.7	6.0	4.2	6.3	13.9	24.9	32.6	11.63	1.95	0.33	0.23	14.34	9.68	29.7	148.2
	100-200		11.4	5.4	5.4	3.4	8.3	15.4	27.8	32.1	9.35	1.61	0.25	0.19	11.71	9.52	29.6	123.1
G1	200-300	gh	13.9	4.2	5.0	3.5	8.1	12.3	24.6	38.9	17.35	3.10	0.27	0.22	20.90	13.65	35.1	153.4
	300-400		5.2	4.4	4.9	3.5	7.8	13.0	20.8	40.9	3.06	3.67	0.27	0.23	7.24	13.43	32.8	53.9
G2	400-500	gh	2.4	4.4	4.9	3.4	7.3	12.3	33.5	32.7	4.43	4.96	0.30	0.34	10.03	13.81	42.2	72.6
	500-600		7.1	5.6	5.7	4.4	9.0	10.5	20.9	41.9	4.48	4.80	0.19	0.29	9.75	15.66	37.4	62.3

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C/N	Fe		Mn	
			H ₂ O	KCl				CBD		CBD	
			mg kg ⁻¹								
A	0-100	1.39	5.07	3.99	1.39	1070	13.0	6250		191.0	
	100-200		5.51	4.01	1.04	965	10.5	9850		243.0	
G1	200-300	1.66	5.72	4.43	0.95	891	10.6	9800		158.0	
	300-400		6.19	4.36	0.56	802	7.0	10250		181.5	
G2	400-500		5.95	4.27	0.45	650	7.0	10900		14.0	
	500-600	5.81	4.50	0.26	488	5.4	4985		13.5		

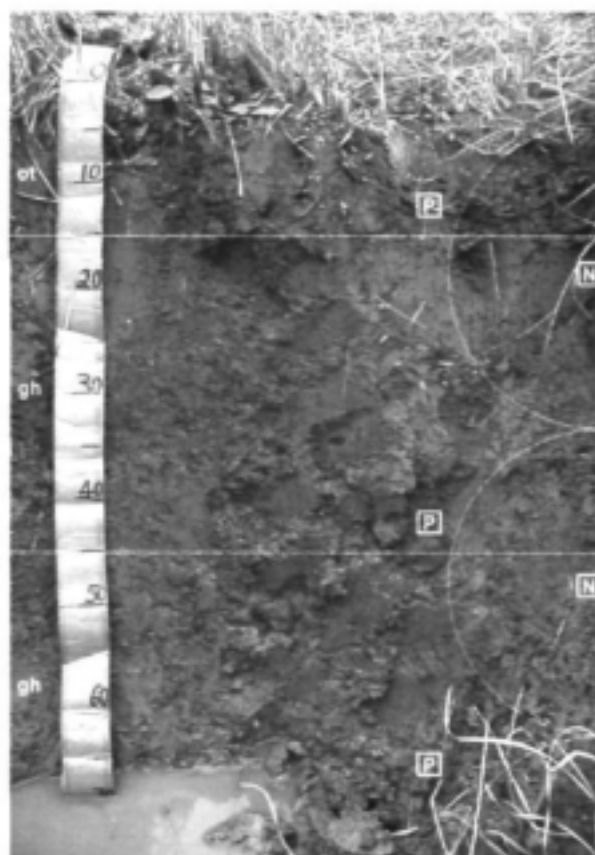


Figure 21 Profile 211 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

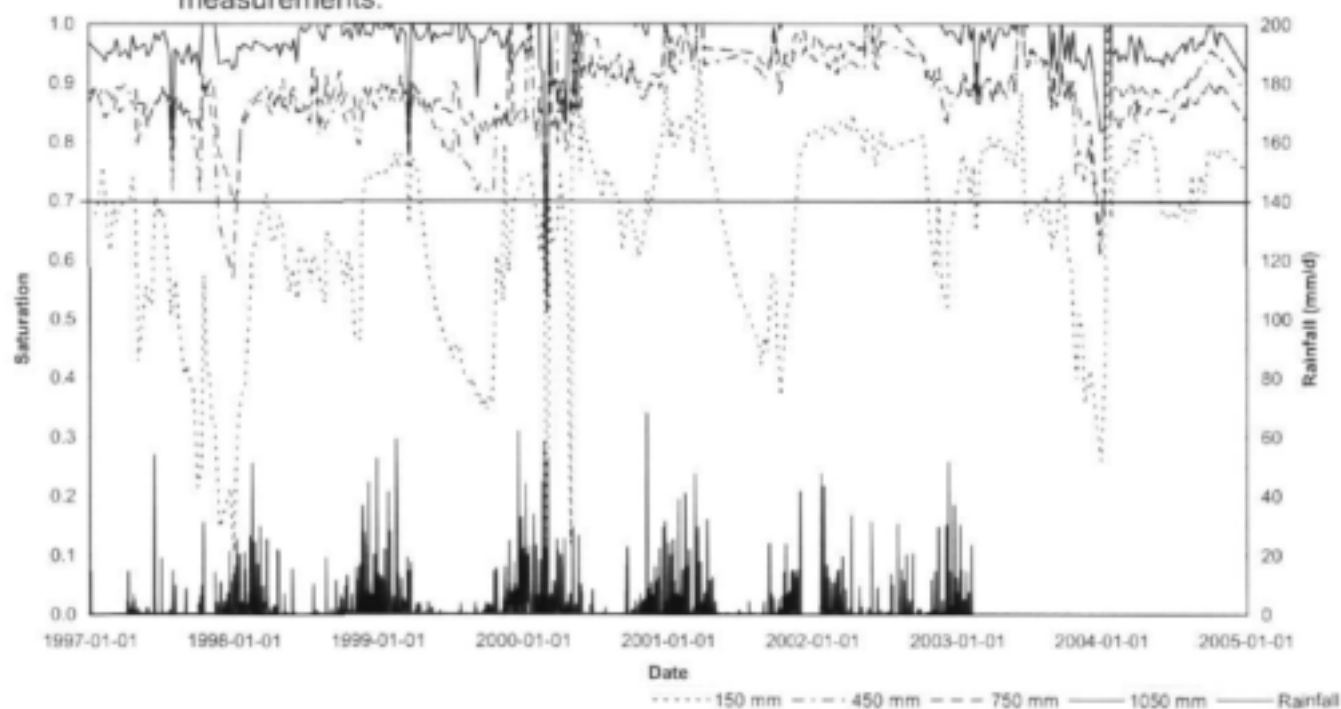


Figure 22 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 211 (Katspruit 1000).

Table 24 Profile description for profile 212 (Tukulu 1110)

Profile No: 212		Soil form: Tukulu	
Map photo: 31254E		Soil family: 1110	
Latitude & Longitude: 31° 06' 32.0" / 28° 19' 34.0"		Surface rockiness: None	
Surface stoniness: None		Occurrence of flooding: None	
Altitude: 1 315 m		Wind erosion: None	
Terrain unit: Upper midslope		Water erosion: None	
Slope: 13 %		Vegetation / Land use: Grassveld, closed	
Slope shape: Convex		Water table: None	
Aspect: North		Described by: D. Scholtz	
Microrelief: None		Date described: 19/06/2001	
Parent material solum: Origin single, solid rock		Weathering of underlying material: Strong physical, weak chemical	
Underlying material: Felsic/silicic sandstone		Alteration of underlying material: Ferruginised	
Geological Group: Mafeno			

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0-300	Moisture status: dry; dry colour: 2.5YR5/2 (100 %); moist colour: 10YR3/2 (100 %); 9.7 % clay; sandy loam; no mottles; weak fine subangular blocky slightly hard friable; sticky plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; very few 2-6 mm round stones; water absorption 3 seconds; common normal roots; gradual smooth transition.	orthic A horizon
B1	300-570	Moisture status: dry; dry colour: 10YR6/4 (90 %); 10YR5/1 (10 %); moist colour: 10YR4/4 (90 %); 10YR4/3 (10 %); 11.7 % clay; sandy loam; many medium & coarse distinct 10YR3/2 dry; 10YR3/2 moist; humus mottles; weak fine granular hard friable; sticky plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; few clay cutans; very few 2-6 mm round stones; few 5-25 mm round boulders; water absorption 3 seconds; common normal roots; diffuse smooth transition.	neocatic B horizon
B2	570-1300	Moisture status: dry; dry colour: 7.5YR6/6 (90 %); 7.5YR5/6 (10 %); moist colour: 7.5YR4/4 (90 %); 7.5YR4/3 (10 %); 18.0 % clay; fine sandy loam; common medium distinct 2.5YR5/2 dry; 2.5YR4/2 moist; reduced iron mottles; weak fine granular hard friable; sticky plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; few clay cutans; very few 2-6 mm round stones; very few 2-6 mm round boulders; water absorption 3 seconds; few normal roots; diffuse smooth transition.	neocatic B horizon
C	1300-1500	Moisture status: dry; dry colour: 7.5YR4/4 (80 %); 7.5YR6/4 (20 %); moist colour: 7.5YR4/4 (80 %); 7.5YR4/3 (20 %); 17.2 % clay; fine sandy loam; common medium distinct 2.5YR5/2 dry; 2.5YR4/2 moist; reduced iron mottles; few medium distinct 2.5YR4/3 dry; 2.5YR3/6 moist; iron oxide mottles; weak medium angular blocky hard firm non-sticky non-plastic; many normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 seconds; few normal roots; transition not reached.	unspecified material with signs of wetness

Table 25 Soil analyses for profile 212 (Tukulu 1110)

Horizon		Depth	Diagnostic horizon	Texture of the fine earth										Exchangeable cations					CEC soil	CEC clay	Base sat %
		mm		coSa	meSa	fSa	vrSa	Si	BSi	Cl	Ca	Mg	K	Na	S						
				%			%								cmol/kg						
A																					
		0-100	ot	10.0	20.7	15.6	17.9	17.9	11.2	10.0	9.0	1.04	0.56	0.19	0.13	1.92	3.64	40.5	52.8		
		100-200		10.1	20.6	17.6	17.2	17.2	8.0	11.4	10.0	0.94	0.50	0.11	0.12	1.68	2.99	29.9	56.2		
		200-300		15.9	20.4	16.7	17.5	17.5	8.9	10.4	10.0	0.92	0.54	0.12	0.11	1.69	3.04	30.4	55.4		
		300-400		16.9	26.3	17.1	17.6	17.6	6.4	9.0	9.0	0.83	0.56	0.11	0.12	1.61	3.21	35.6	50.3		
B1		400-500	ne	13.7	23.9	16.8	16.5	16.5	8.3	10.4	10.4	0.88	0.65	0.12	0.12	1.78	2.12	20.4	83.9		
		500-600		10.4	23.0	14.2	14.8	14.8	6.4	10.5	15.8	0.73	0.59	0.10	0.12	1.55	2.83	18.1	54.7		
		600-700		9.2	33.6	11.7	13.3	13.3	7.7	7.1	15.1	0.64	0.60	0.09	0.12	1.46	3.04	20.2	47.8		
		700-800		15.1	19.9	9.9	12.4	12.4	12.1	17.4	17.6	0.62	0.71	0.07	0.13	1.53	3.04	17.3	50.3		
		800-900	ne	25.5	14.9	10.2	14.0	14.0	11.7	17.2	17.2	0.61	0.65	0.07	0.13	1.47	3.10	18.0	47.5		
B2		900-1000		17.5	12.5	11.0	13.2	13.2	11.6	18.8	20.5	0.63	0.79	0.08	0.14	1.65	3.48	17.0	47.3		
		1000-1100		13.4	14.4	9.3	12.0	12.0	14.3	17.6	18.8	0.60	0.62	0.08	0.14	1.63	3.64	19.4	44.8		
		1100-1200		-	-	-	-	-	-	-	-	0.61	0.47	0.06	0.13	1.27	3.15	-	40.3		
		1200-1300	so	20.6	18.1	13.4	13.0	13.0	10.7	15.5	18.5	0.45	0.71	0.07	0.11	1.34	3.97	21.6	33.8		
C1		1300-1400		26.4	15.4	9.4	12.0	12.0	12.3	21.2	18.2	0.62	0.56	0.08	0.13	1.39	3.59	19.7	38.9		
		1400-1500		22.9	7.0	14.5	14.1	14.1	12.4	18.1	18.1	0.54	0.76	0.07	0.13	1.50	3.25	18.0	46.0		
C2		1500-1600		19.3	21.8	10.3	11.3	11.3	9.7	16.3	16.3	0.46	0.63	0.05	0.15	1.30	2.34	14.3	55.5		
		1600+	so	17.2	24.0	11.4	13.9	13.9	8.7	18.0	18.0	0.40	0.66	0.07	0.13	1.25	2.45	15.3	61.1		

Horizon	Depth	Bulk density	pH	Org C	N	C:N	Fe		Mn		
							CBD		CBD		
		mm	Mg m ³	H ₂ O	KCl	%	mg kg ⁻¹			mg kg ⁻¹	
A											
		0-100	1.52	5.32	4.44	0.79	369	21.5	4505	14.5	
		100-200		5.22	4.26	0.70	406	17.3	3910	37.0	
		200-300		5.31	4.29	0.66	332	19.8	5324	12.5	
		300-400		5.37	4.27	0.38	385	10.0	4055	12.0	
B1		400-500	1.64	5.40	4.41	0.57	270	13.9	4860	15.0	
		500-600		5.55	4.14	0.24	226	10.9	6365	25.0	
		600-700		5.44	4.06	0.15	195	7.9	7400	54.5	
		700-800		5.43	4.05	0.18	178	10.4	12800	50.5	
		800-900	1.64	5.40	4.22	0.15	187	8.0	7970	96.0	
B2		900-1000		5.43	4.22	0.27	202	13.1	8015	112.5	
		1000-1100		5.59	4.10	0.11	181	5.9	8080	133.5	
		1100-1200		-	-	-	-	-	10200	101.0	
		1200-1300	1.68	5.71	4.17	0.11	160	6.6	8050	79.0	
C1		1300-1400		5.70	4.12	0.05	173	2.8	6955	82.0	
		1400-1500		5.88	4.33	0.12	118	9.8	6970	62.5	
		1500-1600		5.74	4.24	0.05	104	4.9	12500	80.0	
C2		1600+	-	5.66	4.16	0.04	90	4.7	4505	14.5	



Figure 23 Profile 212 (Tukulu 1110), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

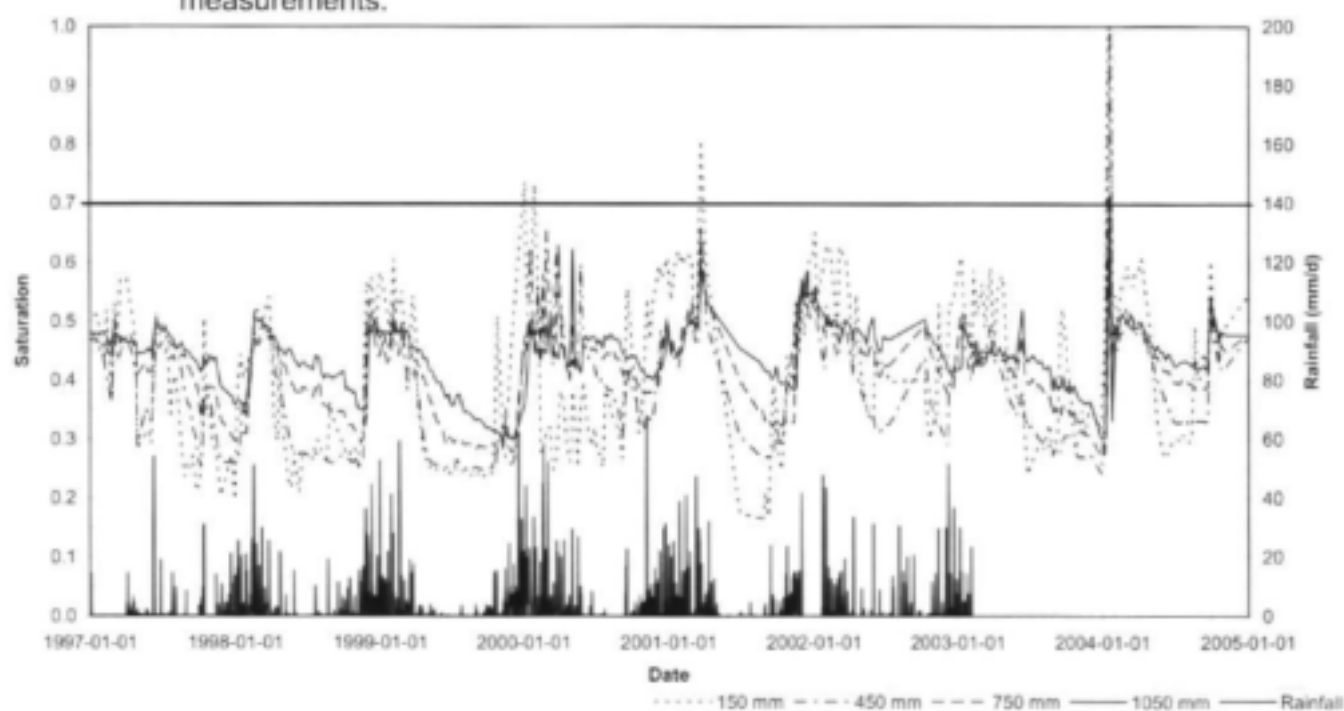


Figure 24 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 212 (Tukulu 1110).

Table 26 Profile description for profile 213 (Katspruit 1000)

Profile No: 213
Mapphoto: 3125AB
Latitude & Longitude: 31° 05' 28.5" S / 28° 15' 34.5" E
Surface stoniness: None
Altitude: 1 302 m
Terrain unit: Upper footslope
Slope: 5 %
Slope shape: Straight
Aspect: North
Microrelief: 10 % mole mounds, 0.3 m high, profile within features
Parent material column: Omg smp; local colluvium
Underlying material: Multisols
Geological Group: Moteng

Soil form: Katspruit
Soil family: 1000
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation / Land use: Grassveld, closed
Water table: None
Described by: M.L. Smit, T.B. Zeng
Date described: 19/06/2001
Weathering of underlying material: Strong physical, strong chemical
Alteration of underlying material: Ferruginised

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0 - 500	Moisture status: moist; dry colour: 10YR5/2 (100 %); wet colour: 10YR3/2 (100 %); 26.9 % clay; loam; few fine faint 10YR5/8 dry; 10YR4/6 moist; iron oxide mottles; few fine faint 5YR5/5 dry; 5YR4/6 moist; furrows mottles; moderate medium subangular blocky; hard; plastic; slightly sticky; slightly plastic; many normal fine and very fine pores; common normal medium and coarse pores; no slickensides; fine cracks; no catans; very few 2-6 mm round stones; water absorption 8 seconds; many branched roots; gradual smooth transition.	orthic A horizon
G1	500 - 810	Moisture status: moist; dry colour: 10YR6/2 (100 %); wet colour: 10YR4/1 (100 %); 29.6 % clay; clay loam; many fine prominent 10YR5/8 dry; 10YR4/6 moist; iron oxide mottles; few medium prominent 5YR3/4 dry; 5YR4/6 moist; manganese mottles; few fine distinct 10YR4/8 dry; 10YR4/6 moist; iron oxide mottles; strong coarse angular blocky; hard; very firm; sticky; plastic; few normal & branched fine and very fine pores; few normal medium and coarse pores; no slickensides; fine cracks; very many silica catans; very few 2-6 mm round stones; water absorption 15 seconds; common branched roots; diffuse smooth transition.	G horizon
G2	810 - 1500	Moisture status: moist; dry colour: 10YR6/2 (100 %); wet colour: 10YR4/1 (100 %); 26.5 % clay; loam; many fine distinct 5YR3/4 dry; 5YR3/4 moist; iron oxide mottles; few fine distinct 5YR3/4 dry; 5YR3/4 moist; mottles; many fine distinct 5YR5/1 dry; 5YR5/1 moist; reduced iron mottles; moderate coarse angular blocky; very hard; firm; sticky; plastic; few normal fine and very fine pores; no medium and coarse pores; no slickensides; fine cracks; very many silica catans; no coarse fragments; water absorption 9 seconds; few branched roots; transition not reached.	G horizon
C	1500 - 1600		Gypsite

Table 27 Soil analyses for profile 213 (Katspruit 1000)

Horizon	Depth	Diagnostic horizon	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
			Gravel								cmol kg ⁻¹							
			coSa	meSa	frSa	vrSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
			mm	%													%	
A	0-100	ot	17.2	8.4	8.6	7.3	13.0	12.2	23.9	24.0	5.51	3.33	0.33	0.17	9.34	9.30	38.7	100.4
	100-200		17.6	8.3	6.8	5.5	13.9	15.9	19.8	27.8	3.85	2.44	0.43	0.17	8.89	9.90	35.6	69.6
	200-300		4.5	5.7	7.1	6.5	14.8	14.7	25.1	25.0	3.59	2.46	0.43	0.17	5.64	8.70	34.8	76.4
	300-400		25.4	6.8	6.6	5.7	12.4	14.1	25.4	26.2	3.29	2.50	0.35	0.19	6.33	9.90	37.8	64.0
	400-500		33.0	7.6	5.9	4.9	11.5	11.6	24.6	31.3	4.69	3.10	0.33	0.23	8.34	12.18	38.9	68.5
G1	500-550	gh	44.7	7.1	6.8	5.8	11.5	10.3	22.0	34.1	4.86	4.37	0.25	0.24	9.72	10.11	29.7	96.1
	550-600		44.5	7.9	7.5	7.8	11.3	26.9	14.0	21.1	4.25	3.21	0.21	0.27	7.95	11.96	56.7	66.4
	600-700		39.7	6.2	6.8	7.4	13.3	12.2	20.9	31.9	5.08	3.55	0.24	0.22	9.10	13.38	41.9	68.0
	700-800		37.6	7.1	8.3	7.3	13.6	13.5	17.3	31.4	5.04	4.46	0.21	0.22	9.94	10.77	34.3	82.3
	800-900		43.6	9.9	12.7	6.9	9.3	10.9	17.2	30.0	4.99	4.27	0.18	0.24	9.67	10.55	35.2	91.7
G2	900-1000	gh	34.9	7.9	11.8	8.7	12.7	12.0	18.0	30.8	5.58	4.46	0.19	0.24	10.48	10.87	35.3	95.3
	1000-1100		37.2	9.6	10.2	7.4	12.7	11.9	21.4	24.8	5.44	3.12	0.20	0.26	9.02	11.53	46.5	78.2
	1100-1200		38.9	7.7	9.9	7.2	13.2	13.4	19.2	25.6	5.34	3.77	0.19	0.31	9.51	11.69	45.7	82.2
	1200-1300		49.2	7.5	8.9	7.3	13.0	13.4	22.6	25.3	4.93	3.57	0.19	0.26	8.95	10.28	40.6	87.1
	1300-1400		45.7	8.3	9.0	7.0	12.5	12.7	23.8	24.6	5.94	4.05	0.20	0.24	10.43	11.64	47.3	89.6
	1400-1500		39.3	6.7	9.2	8.2	14.4	12.9	22.7	24.7	5.59	4.29	0.21	0.22	10.31	11.04	44.7	93.4
	1500-1600		42.9	6.4	9.0	7.6	13.8	15.6	22.4	22.7	5.54	3.97	0.20	0.20	9.91	10.33	45.5	95.9
Horizon	Depth	Bulk density	pH		Org C		N	C:N	Fe		Mn							
			Mg m ⁻³		%				mg kg ⁻¹		mg kg ⁻¹		mg kg ⁻¹		mg kg ⁻¹		mg kg ⁻¹	
			H ₂ O	KCl	%	mg kg ⁻¹			CBD		CBD							
A	0-100	1.61	5.80	4.78	1.41	530	26.5	5015					160.5					
	100-200		5.46	4.35	1.46	951	15.3	6705					181.5					
	200-300		5.45	4.18	1.07	867	12.3	7825					127.5					
	300-400		5.49	4.41	0.85	747	11.4	7705					90.5					
	400-500		4.89	4.32	0.61	657	9.3	7779					53.0					
G1	500-550	1.64	5.66	4.40	0.42	572	7.4	10150					35.5					
	550-600		5.85	4.28	0.38	503	7.6	9600					55.5					
	600-700		6.12	4.32	0.24	414	5.8	2000					73.0					
	700-800		6.13	4.52	0.18	362	5.1	7910					64.0					
	800-900		6.22	4.43	0.17	363	4.7	6245					28.0					
G2	900-1000	1.73	6.30	4.61	0.13	311	4.1	2795					108.0					
	1000-1100		6.41	4.73	0.10	296	3.5	7210					113.5					
	1100-1200		6.41	4.47	0.11	310	3.4	7775					85.5					
	1200-1300		6.42	4.59	0.15	311	4.8	5765					75.0					
	1300-1400		6.45	4.74	0.09	285	3.1	5375					79.0					
	1400-1500		6.42	4.59	0.08	271	3.1	5540					88.5					
	1500-1600		6.37	4.54	0.13	271	4.9	5385					92.5					

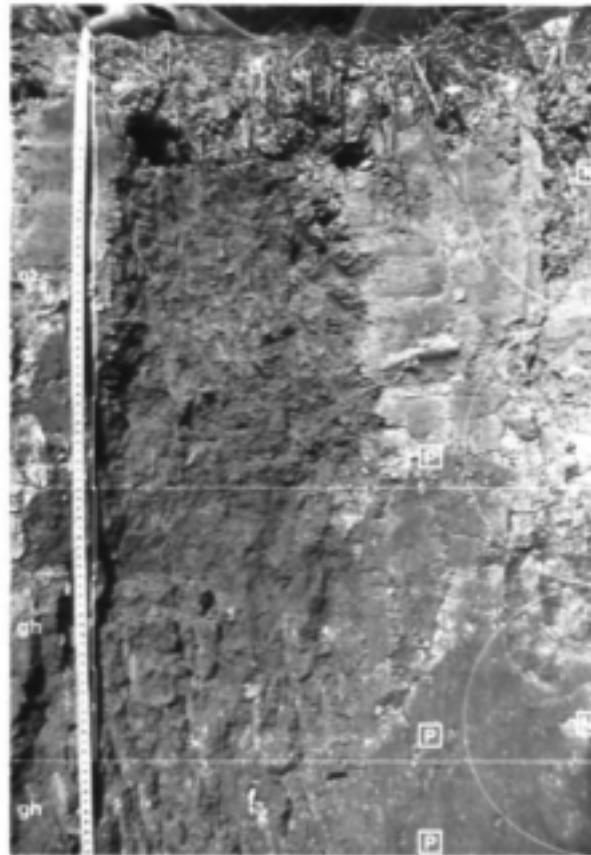


Figure 25 Profile 213 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

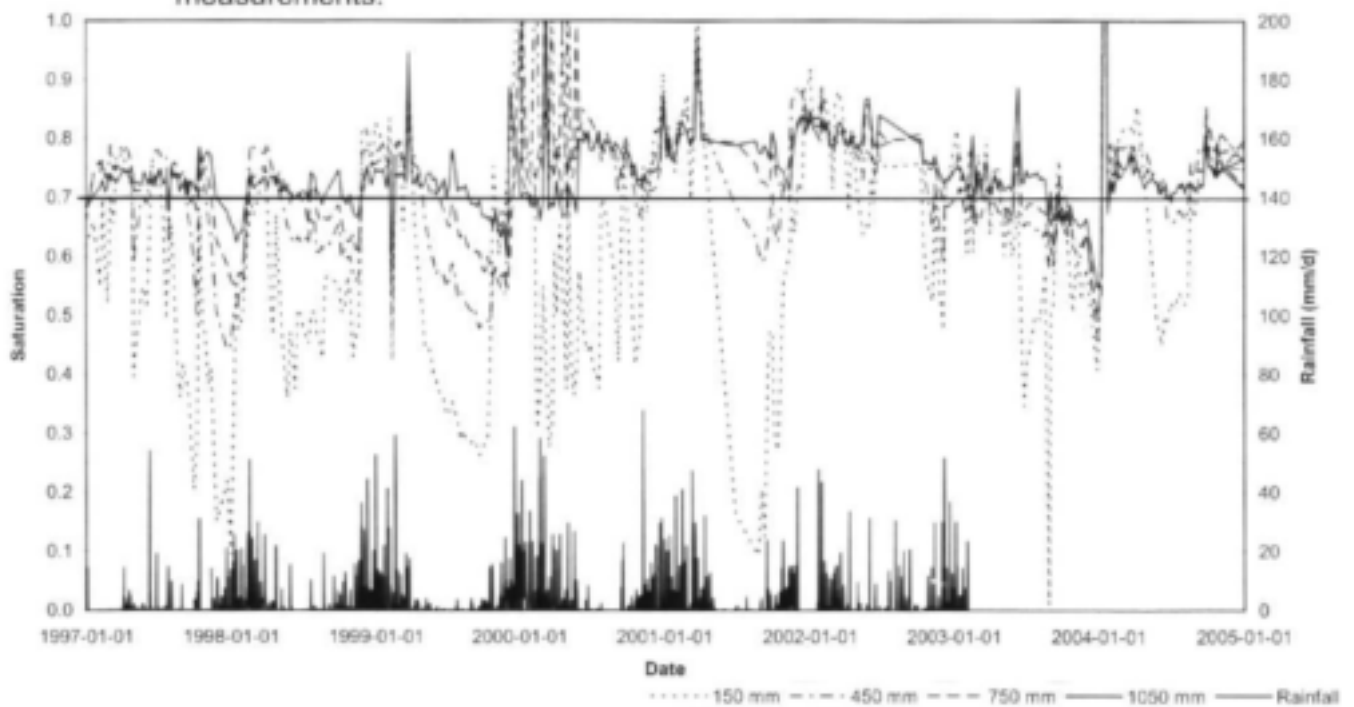


Figure 26 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 213 (Katspruit 1000).

Table 28 Profile description for profile 218 (Katspruit 1000)

Profile No: 218	Soil form: Katspruit
Mapphoto: 3125AB	Soil family: 1000
Latitude & Longitude: 31° 06' 15" E / 28° 19' 46" S	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: Frequent
Altitude: 1 275 m	Wind erosion: None
Terrain unit: Valley bottom	Water erosion: None
Slope: 2 %	Vegetation / Land use: Grass-veg, cleared
Slope shape: Concave	Water table: 400 mm
Aspect: Level	Described by: C. W. van Huyssteen
Microrelief: 20 % mole mounds, 0.3 m high, profile between features	Date described: 19/06/2001
Parent material solum: Ogr: single, silvium	Weathering of underlying material: Advanced physical, strong chemical
Underlying material: Felspathic sandstone	Alteration of underlying material: Ferruginised
Geological Group: Molomo	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A1	0 - 160	Moisture status: moist dry colour: 10YR7/1 (90 %), 10YR4/4 (10 %) moist colour: 7.5YR4/1 (90 %), 10YR4/4 (10 %) 18.6 % clay loam, few fine sand 10YR5/5 dry, 10YR4/4 moist, iron oxide mottles, few fine sand 10YR7/1 dry, 10YR5/1 moist, reduced iron mottles, moderate fine subangular blocky, slightly hard, slightly firm, non-sticky, slightly plastic, many bleached fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s), many bleached roots, gradual smooth transition. Remark: A1 possible organic horizon.	orthic A horizon
A2	160 - 350	Moisture status: moist dry colour: 10YR7/1 (90 %), 10YR4/4 (10 %) moist colour: 7.5YR4/2 (90 %), 10YR4/4 (10 %) 18.0 % clay loam, few fine sand 10YR5/5 dry, 10YR4/4 moist, iron oxide mottles, few fine sand 10YR7/1 dry, 10YR5/1 moist, reduced iron mottles, weak fine subangular blocky, slightly hard, friable, slightly sticky, slightly plastic, common bleached fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s), common bleached roots, gradual smooth transition. Remark: A2 possible E horizon.	orthic A horizon
G	350 - 750	Moisture status: wet dry colour: 10YR5/6 (80 %), 10YR5/1 (20 %) moist colour: 7.5YR5/6 (80 %), 10YR5/1 (20 %) 30.1 % clay, clay loam, many coarse prominent 10YR7/1 dry, 10YR5/1 moist, reduced iron mottles, apedal massive, hard, very firm, sticky, very plastic, few rusty fine and very fine pores, few rusty medium and coarse pores, no slickensides, few cracks, very many siliceous cutans, no coarse fragments, water absorption 10 second(s), common bleached & rusty roots, transition not reached.	G horizon

Table 29 Soil analyses for profile 218 (Katspruit 1000)

Soil analysis of profile 215 (Krasnodar, 1986)																		
Horizon	Depth	Diagnostic horizon	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
			Gravel															
	mm		coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
			%			%							cmol, kg				%	
A1	0-100	ot	3.0	10.9	12.4	10.6	12.9	13.6	17.8	20.2	4.49	2.44	0.23	0.19	7.34	7.72	38.2	95.1
	100-200		0.9	10.3	12.5	11.1	14.9	13.9	19.3	16.9	2.18	0.98	0.17	0.16	3.49	6.04	35.7	57.8
A2	200-300	ot	0.4	11.2	13.4	10.9	14.8	14.0	15.9	20.6	2.21	0.99	0.18	0.16	3.54	5.49	26.7	64.5
	300-400		1.6	11.0	12.1	10.2	13.8	14.4	22.8	19.3	3.33	1.76	0.20	0.17	5.47	6.42	41.9	85.2
	400-500	gh	15.1	9.7	10.5	8.3	10.5	12.4	14.7	32.5	6.49	3.65	0.35	0.22	10.71	12.83	39.5	83.5
	500-600		5.9	9.9	10.8	8.3	12.2	10.9	13.0	32.0	5.51	3.81	0.27	0.22	9.81	11.25	35.2	87.2
G	600-700	gh	2.9	9.0	10.1	9.3	15.8	14.2	9.9	29.7	6.77	3.97	0.28	0.21	11.24	11.31	38.1	99.3
	700-800		7.3	9.5	9.1	8.9	16.6	16.7	9.7	27.4	6.79	3.89	0.27	0.19	11.14	10.11	36.9	110.2
	800-900	gh	4.0	7.0	8.8	7.3	15.0	14.8	13.5	32.4	8.58	4.68	0.29	0.20	13.75	11.31	34.9	121.6
	900+		4.2	8.0	9.1	8.4	14.4	17.0	13.6	28.8	6.24	3.02	0.25	0.19	9.70	10.49	36.4	92.4

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
			H ₂ O	KCl				CBSD			
	mm	Mg m ⁻³			%	mg kg ⁻¹				mg kg ⁻¹	
A1	0-100	1.46	5.75	4.68	0.86	574	15.0	5440		121.0	
	100-200		5.49	4.34	0.89	707	12.6	2200		10.0	
A2	200-300	1.62	5.39	4.31	0.77	620	12.4	2270		7.0	
	300-400		5.71	4.48	0.56	471	12.0	4110		10.5	
G	400-500	1.81	5.97	4.72	0.52	463	11.3	19250		288.6	
	500-600		6.25	5.06	0.21	287	7.3	7035		254.5	
G	600-700	1.76	6.51	5.22	0.20	227	8.9	5110		102.0	
	700-800		6.96	5.69	0.18	209	8.8	6000		110.5	
C	800-900	1.76	6.99	5.93	0.17	237	7.4	6930		329.5	
	900+		6.29	4.90	0.48	497	9.6	7545		139.0	

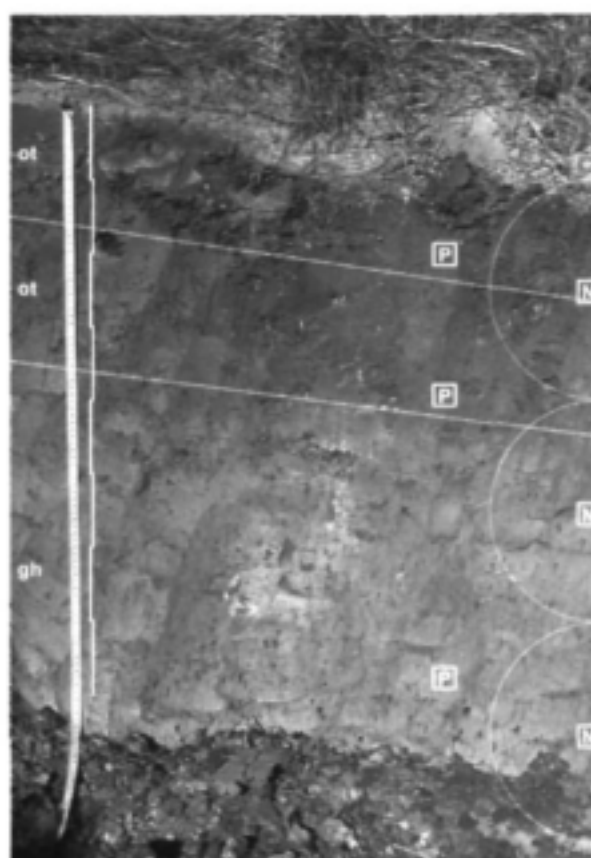


Figure 27 Profile 218 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

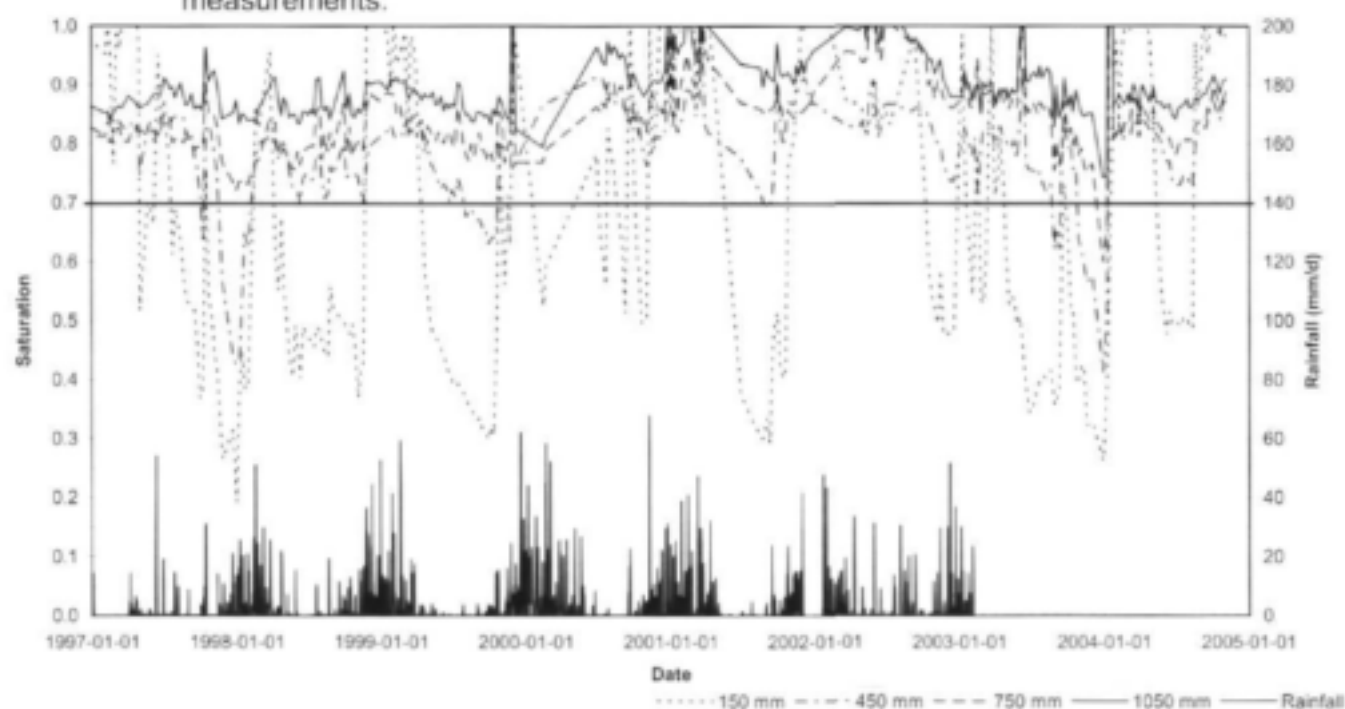


Figure 28 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 218 (Katspruit 1000).

Table 30 Profile description for profile 220 (Bloemdal 2100)

Profile No: 220 Map/photo: 3125AB Latitude & Longitude: 31° 08' 59" S / 28° 19' 38" E Surface elevation: None Altitude: 1 306 m Terrain unit: Upper midslope Slope: 13 % Slope shape: Straight Aspect: East Microrelief: None Parent material/sediment: Origin binary, local colluvium, solid rock Underlying material: Felsoparaph sandstone Geological group: Moteno		Soil form: Bloemdal Soil family: 2100 Surface rockiness: None Occurrence of flooding: None Wind erosion: None Water erosion: None Vegetation / Land use: Grassland, closed Water table: None Described by: P. A. L. le Roux & M. Smit Date described: 19/06/2001 Weathering of underlying material: Strong (physical), moderate (chemical) Alteration of underlying material: Ferruginised	
Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0 - 540	Moisture status: moist; dry colour: 10YR4/3 (90 %), 7.5YR4/5 (10 %); moist colour: 7.5YR3/2 (90 %), 7.5YR3/5 (10 %); 13.6 % clay, sandy loam, no mottles, moderate medium subangular blocky, very hard, friable, non-sticky, non-plastic, many normal fine and very fine pores, common normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 2 seconds; many normal roots, gradual smooth transition. Remarks: Red and grey colour intensity increases from 540 to 1500 mm.	offic A horizon
B	540 - 880	Moisture status: moist; dry colour: 5YR5/4 (90 %), 5YR5/6 (10 %); moist colour: 5YR4/5 (90 %), 5YR5/6 (10 %); 11.0 % clay, sandy loam, few fine prominent 5YR5/6 dry, 5YR3/2 moist, humus mottles, weak medium subangular blocky, very hard, friable, slightly sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 2 seconds; many bleached roots, clear smooth transition.	red apedal B horizon
C1	880 - 1080	Moisture status: moist; dry colour: 5YR4/5 (70 %), 5YR5/6 (20 %), 5YR7/2 (10 %); moist colour: 5YR3/4 (70 %), 5YR4/5 (20 %), 5YR5/2 (10 %); 12.8 % clay, sandy loam, common medium prominent 5YR5/6 dry, 5YR3/2 moist, humus mottles, many coarse prominent 5YR7/2 dry, 5YR5/2 moist, bleached mottles, apedal massive, very hard, firm, slightly sticky, slightly plastic, many normal fine and very fine pores, few bleached medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 2 seconds; many normal roots, clear smooth transition.	unspecified material with signs of wetness
C2	1080 - 1500	Moisture status: moist; dry colour: 5YR5/4 (85 %), 5YR4/5 (15 %); moist colour: 5YR4/5 (85 %), 5YR4/5 (15 %); 11.2 % clay, sandy loam, many fine distinct 5YR4/5 dry, 10YR5/3 moist, iron oxide mottles, many coarse prominent 7.5YR5/4 dry, 10YR5/3 moist, bleached mottles, apedal massive, very hard, firm, sticky, plastic, few normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 3 seconds; few normal roots, transition not reached.	unspecified material with signs of wetness

Table 31 Soil analyses for profile 220 (Bloemdal 2100)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					S	CEC soil	CEC clay	Base sat
				coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na					
				%							cmol/kg								
A	0-100	ot	0.6	15.7	21.2	15.9	11.9	10.2	10.1	15.2	2.10	0.71	0.30	0.12	3.22	4.95	32.6	65.1	
	100-200		0.3	21.5	23.3	13.9	9.7	7.2	7.1	14.0	1.17	0.48	0.16	0.12	1.92	4.13	29.5	46.5	
	200-300		0.2	17.1	22.0	14.7	10.3	15.1	6.2	12.9	0.99	0.47	0.08	0.12	1.66	3.53	27.4	47.0	
	300-400		0.6	22.1	23.3	14.1	10.2	8.9	7.9	12.6	0.73	0.44	0.09	0.12	1.37	2.85	22.7	48.2	
	400-500		0.4	18.0	21.6	14.6	13.0	8.2	8.7	13.2	0.69	0.44	0.09	0.12	1.34	2.94	22.2	45.7	
B	500-600	re	0.9	19.1	22.6	14.5	12.8	8.0	7.2	13.2	0.75	0.49	0.09	0.13	1.48	3.48	26.4	41.9	
	600-700		2.0	18.6	22.0	14.7	10.8	11.6	7.2	16.2	0.66	0.46	0.08	0.13	1.33	2.34	14.4	56.8	
	700-850		2.9	13.3	21.8	15.2	12.2	13.3	7.1	16.4	0.65	0.52	0.08	0.13	1.38	2.23	13.6	61.9	
C1	850-930	on	1.7	14.3	23.1	15.2	11.7	16.6	3.8	14.2	0.65	0.58	0.08	0.14	1.44	2.12	14.9	67.9	
	930-1100		0.5	15.1	23.3	14.0	11.2	17.7	5.0	10.8	0.73	0.71	0.08	0.14	1.67	2.77	25.7	60.0	
C2	1100-1200	on	1.0	14.8	21.8	15.0	9.8	24.1	3.6	10.4	1.22	1.18	0.13	0.16	2.70	4.89	47.1	55.2	
	1200-1300		4.3	14.5	21.5	13.6	10.6	19.1	7.0	12.5	1.10	0.92	0.14	0.13	2.29	4.25	34.8	52.6	
	1300-1400		2.4	13.9	21.8	13.3	9.9	16.6	11.9	10.8	1.25	1.27	0.14	0.13	2.79	4.40	40.8	63.4	

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C:N	Fe		Mn		
			H ₂ O	KCl				CBD		CBD		
A	0-100	1.73	5.60	4.77	1.06	590	18.0	4560		79.0		
	100-200		5.32	4.46	1.36	479	26.4	3380		49.5		
	200-300		5.22	4.29	0.96	372	26.7	4430		42.5		
	300-400		5.31	4.22	0.47	347	13.7	4525		40.0		
	400-500		5.32	4.25	0.41	312	13.0	4545		36.5		
B	500-600	1.79	5.34	4.22	0.58	312	18.5	5395		55.5		
	600-700		5.37	4.17	0.33	208	15.9	4480		55.5		
	700-850		5.45	4.22	0.17	116	14.3	5490		152.5		
C1	850-930	1.63	5.69	4.32	0.13	109	12.1	7955		298.0		
	930-1100		5.82	4.26	0.09	100	8.9	6235		128.5		
C2	1100-1200	1.64	5.90	4.44	0.09	133	7.1	6890		115.5		
	1200-1300		5.46	4.14	0.18	203	9.0	6065		94.5		
	1300-1400		5.50	4.31	0.25	136	18.5	7910		69.5		

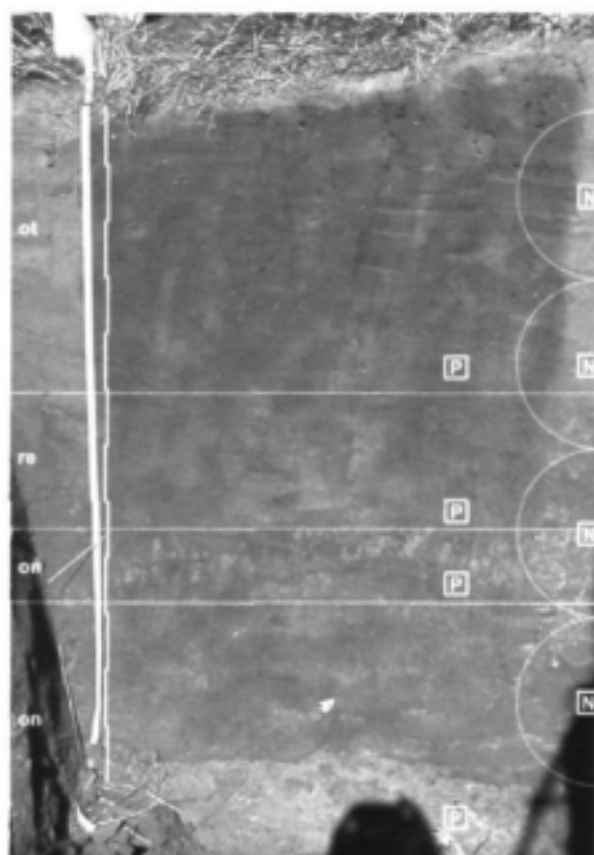


Figure 29 Profile 220 (Bloemdal 2100), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

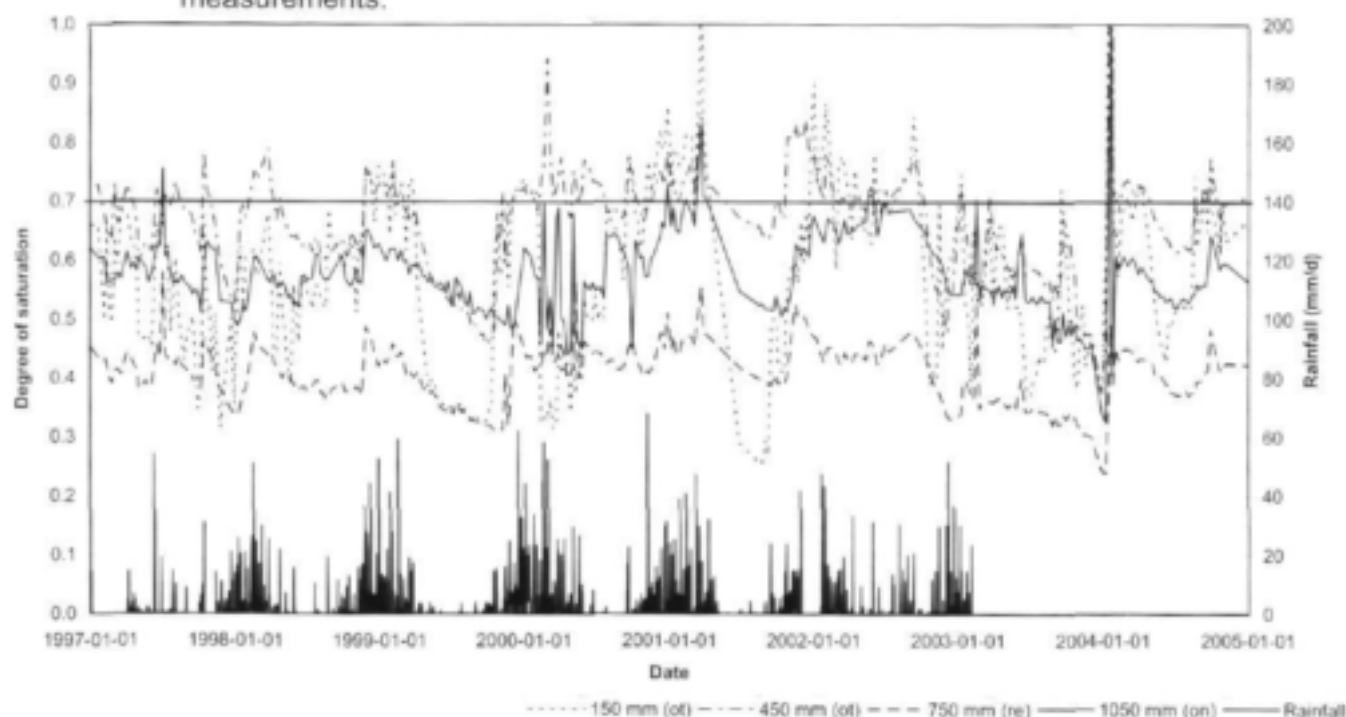


Figure 30 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 220 (Bloemdal 2100).

Table 32 Profile description for profile 221 (Hutton 2100)

Profile No: 221	Soil form: Hutton
Map/photo: 3125AB	Soil family: 2100
Latitude & Longitude: 31° 00' 00" S / 28° 19' 42" E	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 259 m	Wind erosion: None
Terrain unit: Upper footslope	Water erosion: None
Slope: 10 %	Vegetation / Land use: Grassland, closed
Slope shape: Straight	Water table: None
Aspect: East	Described by: M.L. Smit & T.B. Zinn
Macronutrient: None	Date described: 19/05/2001
Parent material/solum: Origin single, local colluvium	Weathering of underlying material: Strong physical, strong chemical
Underlying material: Mudstone	Alteration of underlying material: Fertilised
Geological Group: Moteng	

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0-250	Moisture status: dry; dry colour: 2.5YR4/6 (100 %); moist colour: 2.5YR3/4 (100 %); 16.9 % clay; loam; no mottles; weak fine granular; slightly hard; friable; slightly sticky; slightly plastic; few normal fine and very fine pores; no medium and coarse pores; no slickensides; fine cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; abrupt smooth transition.	orthic A horizon
B1	250-580	Moisture status: moist; dry colour: 7.5YR3/4 (90 %); 2.5YR4/6 (10 %); moist colour: 7.5YR3/2 (90 %); 2.5YR3/4 (10 %); 18.7 % clay; loam; no mottles; moderate medium subangular blocky; slightly hard; firm; very sticky; plastic; common normal fine and very fine pores; few normal medium and coarse pores; no slickensides; fine cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; gradual smooth transition.	red apedal B horizon
B2	580-1250	Moisture status: moist; dry colour: 2.5YR4/6 (100 %); moist colour: 2.5YR3/4 (100 %); 31.3 % clay; sandy clay loam; no mottles; weak fine crumb; slightly hard; slightly firm; sticky; plastic; common normal fine and very fine pores; common normal medium and coarse pores; no slickensides; fine cracks; no cutans; no coarse fragments; water absorption 2 second(s); many normal roots; diffuse smooth transition.	red apedal B horizon
C	1250-1800	Moisture status: moist; dry colour: 10R4/6 (100 %); moist colour: 2.5YR3/4 (100 %); 33.3 % clay; sandy clay loam; few fine prominent 2.5YR4/4 dry; 2.5YR3/4 moist; greggite iron mottles; weak fine subangular blocky; slightly hard; slightly firm; sticky; plastic; common normal fine and very fine pores; common fine medium and coarse pores; no slickensides; fine cracks; common clay cutans; no coarse fragments; water absorption 3 second(s); few normal roots; transition not reached.	unpedal material without signs of wetness

Table 33 Soil analyses for profile 221 (Hutton 2100)

Horizon	Depth mm	Diagnostic horizon	Gravel	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
			%	coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
				cmol/kg														
A	0-100	ot	24.7	12.3	13.1	9.9	10.9	16.1	16.8	17.7	1.67	0.82	0.35	0.13	2.97	5.98	33.8	49.7
	100-200		13.3	12.4	13.3	12.8	13.0	11.7	18.8	16.1	1.07	0.72	0.25	0.14	2.19	4.84	30.1	45.2
	200-300		13.2	13.9	13.3	9.9	13.4	12.2	17.8	17.0	1.04	0.73	0.20	0.14	2.12	4.11	24.2	51.6
	300-400		17.9	13.2	12.8	10.0	13.1	18.4	19.0	11.4	0.98	0.73	0.16	0.15	2.02	4.78	42.0	42.2
	400-500		10.9	12.4	10.9	11.6	13.3	14.9	12.4	21.8	0.77	0.60	0.11	0.14	1.61	4.19	19.2	38.4
B1	500-600	re	12.5	15.9	13.4	10.0	13.9	9.3	10.1	24.5	0.87	0.71	0.16	0.15	1.89	3.91	16.0	48.3
	600-700		12.9	14.8	13.1	9.9	11.6	13.3	10.3	26.1	0.92	1.45	0.17	0.17	2.71	3.91	15.0	69.1
	700-800		11.2	15.8	12.3	8.6	11.7	12.6	10.3	28.4	1.04	0.84	0.19	0.15	2.22	4.51	15.9	49.3
	800-900		9.4	14.2	13.3	8.6	11.8	11.2	8.6	32.8	1.09	1.02	0.18	0.16	2.45	5.55	16.9	44.1
	900-1000		12.1	14.7	13.2	8.5	11.5	12.0	8.2	34.2	1.28	1.22	0.20	0.17	2.88	5.87	17.2	49.0
B2	1000-1100	re	5.9	14.7	14.0	9.6	10.3	9.1	5.3	35.0	1.50	1.62	0.23	0.17	3.51	6.47	18.5	54.3
	1100-1200		9.1	16.3	15.4	10.2	10.6	9.4	3.6	31.5	1.36	1.43	0.18	0.15	3.12	5.93	18.8	52.7
	1200-1300		7.3	17.0	13.6	8.2	10.2	9.8	4.5	35.3	1.65	1.87	0.23	0.15	3.90	6.47	18.3	60.2
	1300-1400		7.0	15.9	13.3	8.3	9.9	11.3	6.9	35.2	1.58	1.74	0.24	0.13	3.69	6.69	19.0	55.2
	1400+		8.0	14.5	13.2	9.0	9.9	12.3	9.7	29.5	1.47	1.53	0.26	0.14	3.40	5.76	19.5	59.0

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn		
	mm		Mg m ³	H ₂ O				KCl	%	mg kg ⁻¹	CBD	
	mg kg ⁻¹											
A	0-100	1.64	5.40	4.46	1.15	629	18.3	5370		160.5		
	100-200		5.32	4.42	1.22	546	22.4	7095		267.0		
	200-300		5.35	4.31	1.17	457	25.6	6685		248.5		
B1	300-400	1.51	5.41	4.34	0.98	414	25.7	7610		224.0		
	400-500		5.22	4.25	0.52	276	19.0	14250		230.5		
	500-600		5.55	4.20	0.55	355	15.6	8000		251.5		
B2	600-700	1.63	5.47	4.32	0.42	219	19.2	5525		135.5		
	700-800		5.17	4.32	0.26	240	10.9	12850		238.0		
	800-900		5.32	4.47	0.20	249	7.9	16150		183.0		
B2	900-1000	1.62	5.69	4.53	0.19	262	7.4	16150		141.0		
	1000-1100		5.76	4.40	0.18	237	7.8	10650		116.0		
	1100-1200		5.67	4.51	0.11	229	4.6	9250		118.5		
C	1200-1300	1.53	5.59	4.43	0.11	237	4.6	9850		94.5		
	1300-1400		5.49	4.31	0.15	237	6.3	9600		110.5		
	1400+		5.53	4.85	0.13	317	4.0	10250		141.0		

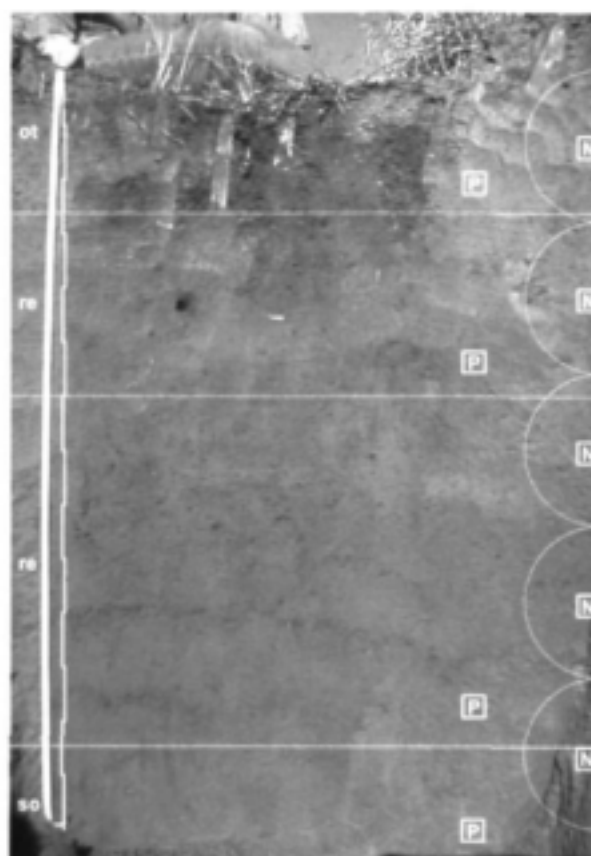


Figure 31 Profile 221 (Hutton 2100), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

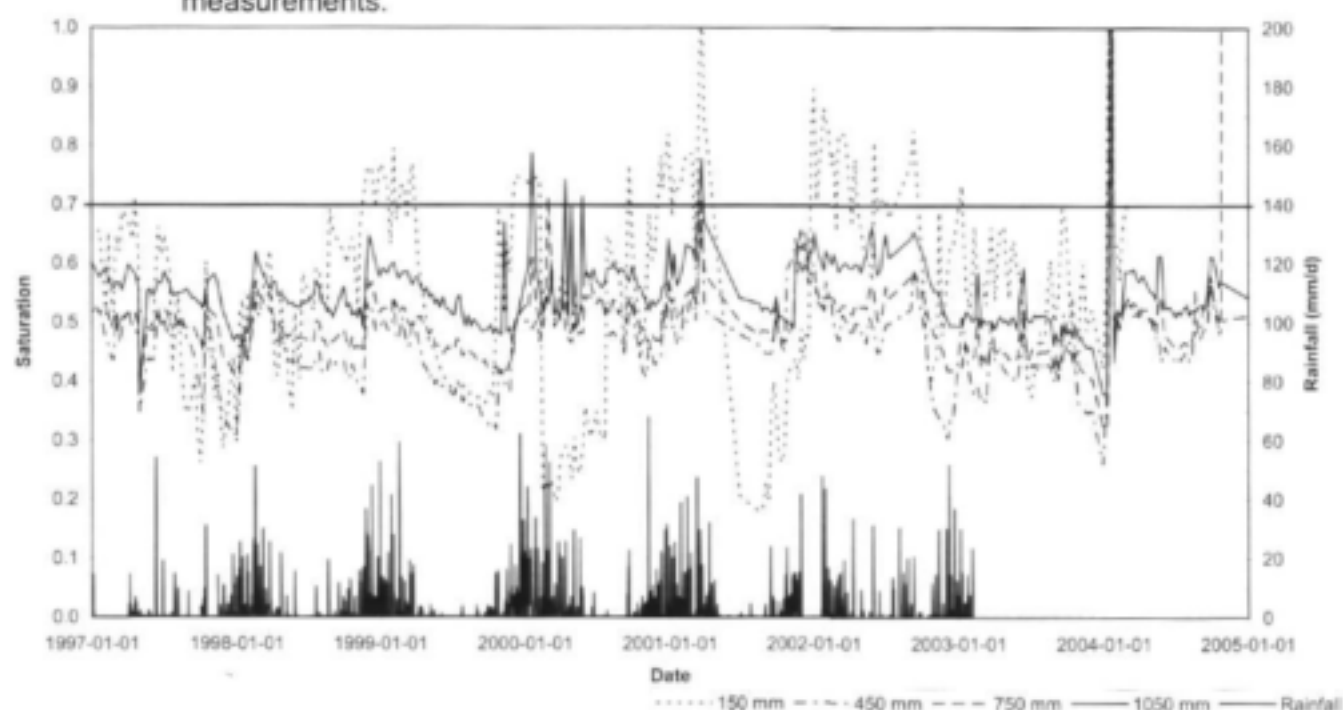


Figure 32 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 221 (Hutton 2100).

Table 34 Profile description for profile 222 (Oakleaf 1210)

Profile description for profile 222 (Capeval 1210)	
Profile No: 222	Soil type: Calical
Mapphoto: 352AB	Soil family: 1210
Latitude & Longitude: 31° 05' 59.7" S / 28° 19' 49.0" E	Surface rockiness: None
Surface stoneiness: None	Occurrence of flooding: None
Altitude: 1 268 m	Wind erosion: None
Terrain unit: Lower midslope	Water erosion: None
Slope: 10 %	Vegetation / Land use: Grassveld, cleared
Slope shape: Convex	Water table: None
Aspect: East	Described by: M. Hensley & A.G. Winklerphannes
Microrelief: None	Date described: 19/06/2001
Parent material/sediments: Origin binary, local colluvium, solid rock	Weathering of underlying material: Moderate physical, moderate chemical
Underlying material: Pindaquitic sandstone	Alteration of underlying material: Fertilised
Geological context: Mafic	

Horizon	Depth (cm)	Description	Diagnostic horizons / material
A	0 - 420	Moisture status: moist; dry colour: 7.5YR4/2 (100 %); moist colour: 7.5YR3/2 (100 %); 20-4 % clay; loam; no mottles; apedal massive; slightly hard; slightly firm; non-sticky; non-plastic; few normal fine and very fine pores; many normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); common normal roots; gradual smooth transition. Remark: Perithous prominent in B2 horizon.	orthic A horizon
B1	420 - 690	Moisture status: moist; dry colour: 5YR4/4 (90 %); 2.5YR4/4 (20 %); moist colour: 5YR3/4 (90 %); 2.5YR3/4 (20 %); 23-4 % clay; loam; few fine sand; 2.5YR4/4 dry; 2.5YR3/4 moist; iron oxide mottles; few fine distinct 10YR2/1 dry; 10YR2/1 moist; iron oxide mottles; few medium distinct 5YR4/4 dry; 5YR4/4 moist; humus mottles; weak medium subangular blocky; slightly hard; malle; non-sticky; non-plastic; few normal fine and very fine pores; many normal medium and coarse pores; no slickensides; no cracks; few clay cutans; very few 2-6 mm round stones; very few 2-6 mm round Fe & Mn concretions; water absorption 1 second(s); common normal roots; gradual smooth transition. Remark: Marked increase in gravel just above the C horizon.	neocutanic B horizon
B2	690 - 960	Moisture status: moist; dry colour: 2.5YR4/4 (90 %); 5YR4/4 (10 %); moist colour: 2.5YR3/4 (90 %); 5YR3/4 (10 %); 27-8 % clay; clay loam; common few distinct 5YR4/4 dry; 5YR3/4 moist; iron oxide mottles; few medium distinct 10YR2/1 dry; 10YR2/1 moist; humus mottles; common medium distinct 10YR2/1 dry; 10YR2/1 moist; iron oxide mottles; weak medium subangular blocky; slightly hard; malle; non-sticky; non-plastic; common normal fine and very fine pores; common normal medium and coarse pores; no slickensides; no cracks; few clay cutans; very few 2-6 mm round stones; very few 2-6 mm round Fe & Mn concretions; water absorption 1 second(s); common normal roots; clear longuing transition.	neocutanic B horizon
C	960 - 1800	Moisture status: moist; dry colour: 5YR7/8 (70 %); 5YR6/4 (30 %); moist colour: 5YR5/8 (70 %); 5YR4/4 (30 %); 20-2 % clay; loam; no mottles; apedal massive; slightly hard; malle; non-sticky; non-plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; few cracks; many clay cutans; many 25-75 mm angular stones; water absorption 1 second(s); few normal roots; transition not reached.	saprolite

Table 35 Soil analyses for profile 222 (Oakleaf 1210)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth								Exchangeable cations				S	CEC soil	CEC clay	Base sat %
				coSa	meSa	SiSa	viSa	Si	SiS	Cl	Ca	Mg	K	Na cmol kg					
A	0-100	of	0.7	11.0	10.9	8.2	13.8	18.6	15.1	20.8	3.11	1.06	0.51	0.14	4.82	7.34	35.3	65.7	
	100-200		0.9	11.4	11.4	9.7	13.1	17.4	16.0	19.9	3.15	1.10	0.26	0.14	4.64	7.29	36.6	63.7	
	200-300		0.4	11.5	10.6	7.7	14.4	16.7	19.9	19.9	2.79	1.02	0.12	0.13	4.06	6.60	30.3	61.1	
	300-400		0.6	11.8	10.8	7.7	14.8	15.6	15.0	20.8	2.58	1.01	0.11	0.14	3.84	6.25	30.1	61.4	
	400-500		1.0	10.6	11.0	7.6	14.4	15.5	16.2	22.2	1.57	0.95	0.11	0.14	2.77	6.58	25.6	42.1	
B1	500-600	ne	2.0	10.7	10.5	7.4	13.9	15.8	15.5	24.5	1.42	0.98	0.10	0.14	2.64	5.11	20.9	51.7	
	600-670		8.3	10.7	10.3	7.4	13.5	16.6	15.4	25.2	1.39	0.98	0.11	0.14	2.63	5.76	22.9	45.6	
B2	670-800	ne	7.6	7.9	9.3	7.2	13.5	16.2	15.6	28.3	1.30	1.02	0.14	0.15	2.61	5.22	18.4	50.0	
	800-960		16.2	7.5	8.4	7.7	13.5	16.0	15.0	30.0	1.05	1.25	0.15	0.15	3.41	5.65	18.8	50.3	
C	1300-1400	so	2.0	0.7	0.8	18.8	15.4	13.6	22.7	19.4	4.36	2.57	0.16	0.19	7.28	9.08	46.8	80.2	
	1400-1500		4.9	0.9	4.9	20.9	16.0	11.4	20.9	23.2	5.30	3.11	0.20	0.20	8.80	10.33	44.5	85.2	
	1500-1600		1.5	0.3	4.6	24.4	20.2	9.8	21.1	17.8	5.57	3.08	0.20	0.17	9.01	11.91	56.9	74.7	
	1600-1700		0.3	0.2	4.6	23.6	17.1	9.5	20.1	25.6	6.52	3.67	0.26	0.22	10.67	11.42	44.6	83.5	
	1700+		1.2	0.7	8.1	26.9	17.1	8.3	22.0	15.6	5.26	2.90	0.23	0.18	8.56	9.13	58.6	80.3	

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C		N	C:N	Fe		Mn	
			H ₂ O	KCl	%	mg kg ⁻¹			CBD		CBD	
A	0-100	1.56	5.46	4.62	1.39	730	19.1	7885			257.5	
	100-200		5.39	4.38	1.33	856	15.5	7915			278.5	
	200-300		5.31	4.28	1.28	878	14.6	8045			288.0	
	300-400	1.66	5.35	4.23	1.31	734	17.9	7950			276.0	
	400-500		5.34	4.47	0.74	663	11.2	16150			247.0	
	500-600		5.29	4.87	0.81	599	10.2	15150			267.5	
B1	600-670	1.60	5.19	4.36	0.51	546	9.4	15350			353.5	
	670-800		5.65	4.41	0.31	383	8.0	12300			412.5	
	800-950		5.77	4.35	0.24	365	6.5	12850			397.5	
C	1300-1400	1.57	5.96	4.41	0.25	301	8.4	13100			407.5	
	1400-1500	1.57	5.94	4.35	0.15	283	5.3	7855			720.0	
	1500-1600	-	5.91	4.46	0.14	238	6.0	6850			481.5	
	1600-1700	-	5.82	4.62	0.06	200	4.0	7485			565.0	
	1700+	-	5.97	4.61	0.05	167	3.0	4080			685.0	

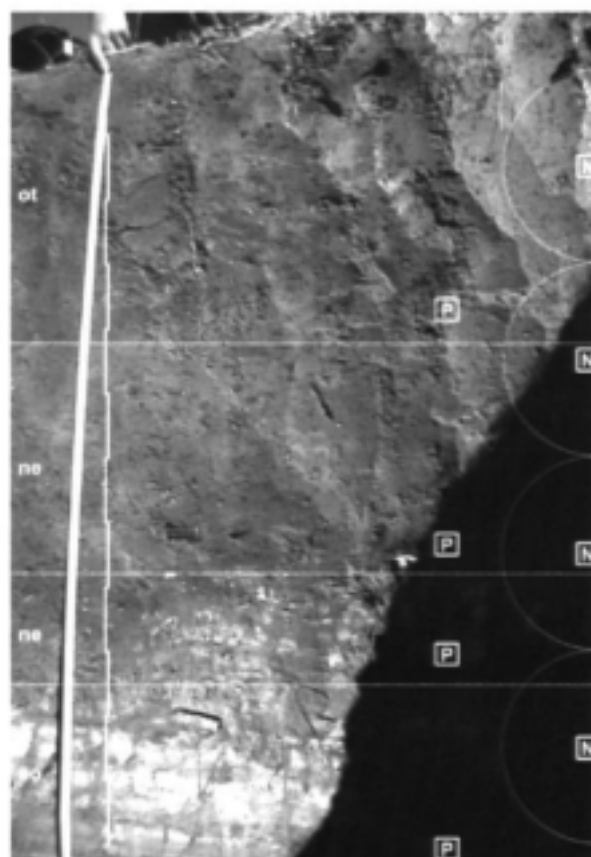


Figure 33 Profile 222 (Oakleaf 1210), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

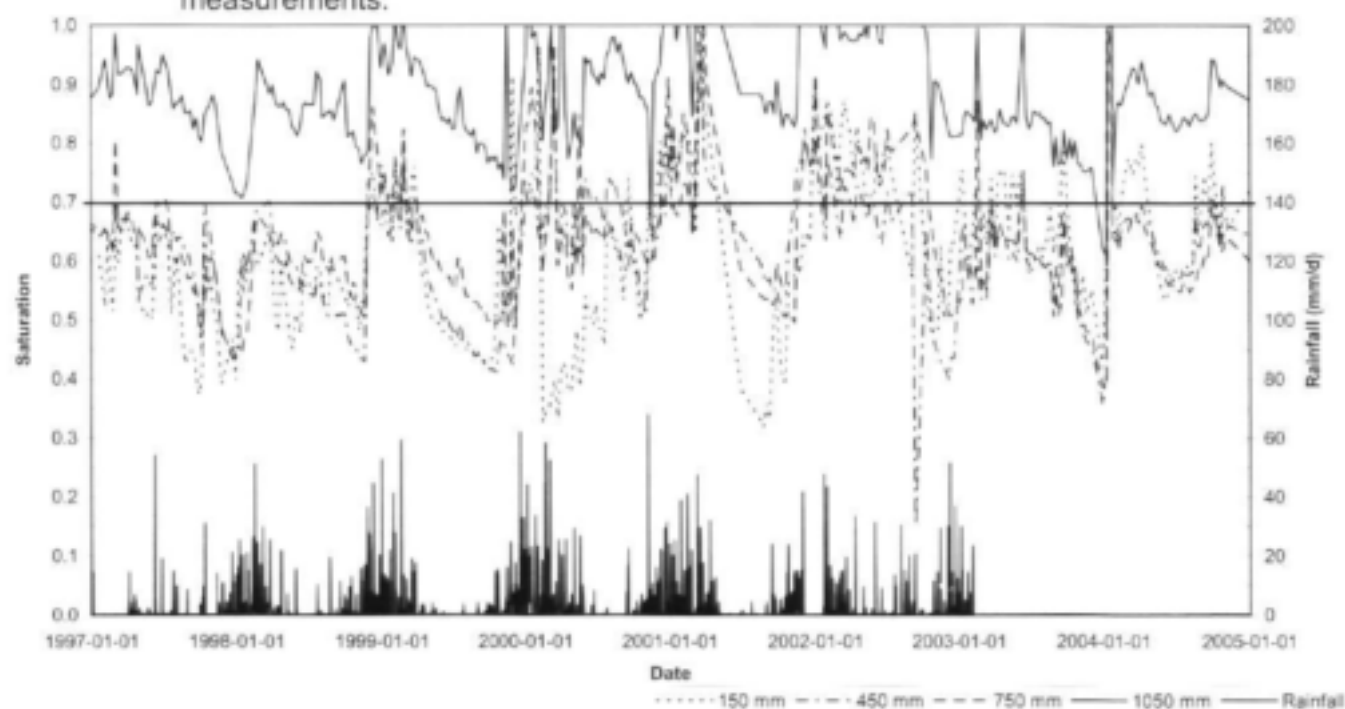


Figure 34 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 222 (Oakleaf 1210).

Table 36 Profile description for profile 225 (Longlands 1000)

Profile No: 225	Soil form: Longlands
Map/photo: 3128A8	Soil family: 1000
Latitude & Longitude: 51° 05' 57.7" / 28° 20' 07.0"	Surface thickness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1267 m	Wind erosion: None
Termin unit: Midlope	Water erosion: None
Slope: 5 %	Vegetation / Land use: Grassveld, closed
Slope shape: Concave	Water table: None
Aspect: North-west	Described by: M. Hensley & A.Q. Veldeyohannes
Microrelief: 5 % mole mounds, 0.1 m high profile between features	Date described: 19/06/2001
Parent material solum: Origin binary, local colluvium, solid rock	Weathering of underlying material: Strong physical, strong chemical
Underlying material: Feldspathic sandstone	Alteration of underlying material: Ferruginised
Geological Group: Moteng	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0-340	Moisture status: moist; dry colour: 10YR5/2 (70 %), 10YR5/4 (30 %); moist colour: 10YR5/2 (70 %), 10YR5/4 (30 %); 13.1 % clay; sandy loam; few medium faint 10YR5/4 dry, 10YR4/3 moist; humus mottles; weak medium granular, slightly hard; friable, non-sticky, non-plastic; few normal fine and very fine pores; common normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; gradual smooth transition.	orthic A horizon
E1	340-560	Moisture status: moist; dry colour: 10YR5/2 (80 %), 10YR5/6 (20 %); moist colour: 10YR4/2 (80 %), 10YR4/6 (20 %); 16.9 % clay; loam; common medium distinct 10YR5/6 dry, 10YR4/6 moist; iron oxide mottles; common medium faint 10YR5/2 dry, 10YR3/2 moist; humus mottles; apedal massive; slightly hard; friable, non-sticky, non-plastic; few rusty fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); common normal roots; gradual smooth transition.	E horizon
E2	560-840	Moisture status: moist; dry colour: 10YR7/1 (60 %), 5YR5/5 (40 %); moist colour: 10YR5/2 (60 %), 5YR4/4 (40 %); 15.0 % clay; sandy loam; common medium distinct 10YR5/6 dry, 10YR4/4 moist; iron oxide mottles; few medium faint 5YR4/6 dry, 5YR4/6 moist; iron oxide mottles; apedal massive; soft, friable, non-sticky, non-plastic; many bleached fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; common 25-75 mm mixed shaped stones; common 5-25 mm mixed shaped stones; water absorption 1 second(s); few bleached roots; clear smooth transition.	E horizon
B	840-1220	Moisture status: moist; dry colour: 5YR4/6 (60 %), 10YR5/1 (40 %); moist colour: 5YR4/6 (60 %), 10YR5/2 (40 %); 21.2 % clay; sandy clay loam; many coarse prominent 10YR5/1 dry, 10YR5/2 moist; geogenic iron mottles; many coarse prominent 5YR4/6 dry, 5YR4/6 moist; iron oxide mottles; apedal massive; hard; firm, non-sticky, non-plastic; few bleached fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; common size cutans; few 2-6 mm round Fe & Mn concretions; few 5-25 mm round Fe & Mn concretions; water absorption 1 second(s); few bleached roots; clear wavy transition.	soft pithic B horizon
C	1220-1640	Moisture status: moist; dry colour: 5YR4/6 (70 %), 10YR5/1 (20 %), 10YR2/1 (10 %); moist colour: 5YR4/6 (70 %), 10YR5/1 (20 %), 10YR2/1 (10 %); 26.2 % clay; sandy clay loam; many medium prominent 10YR5/1 dry, 10YR5/2 moist; reduced iron mottles; apedal massive; hard, slightly firm; non-sticky, non-plastic; common bleached fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; few clay cutans; very few 5-25 mm round Fe & Mn concretions; water absorption 1 second(s); few bleached roots; transition not reached; Remark: non-diagnostic lithocutanic B.	unspecified material with signs of wetness

Table 37 Soil analyses for profile 225 (Longlands 1000)

Horizon	Depth	Diagnostic horizon	Gravel	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
				coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S			
	mm		%	%	%	%	%	%	%	%	cmol/kg	cmol/kg	cmol/kg	cmol/kg	cmol/kg			%
A	0-100	ot	4.7	16.2	17.1	10.2	8.6	19.7	16.5	13.5	1.81	0.89	0.17	0.14	3.02	5.82	43.1	51.9
	100-200		2.7	16.6	17.1	10.6	8.5	17.4	16.3	13.7	1.52	0.77	0.11	0.14	2.55	6.25	45.8	40.7
	200-300		5.4	16.1	17.7	10.5	8.4	14.9	17.3	12.1	1.04	0.79	0.10	0.04	1.96	6.47	53.5	30.6
E1	300-400	ot	4.3	17.1	17.1	10.6	8.6	13.0	17.1	14.1	1.19	0.79	0.11	0.06	2.14	6.09	43.2	35.1
	400-500		4.4	15.8	17.3	10.5	8.8	9.6	17.3	17.5	1.53	0.83	0.11	0.05	2.51	5.98	34.2	42.0
	500-600		4.7	14.0	16.6	10.6	8.9	15.5	15.5	19.2	1.22	0.92	0.09	0.05	2.28	5.06	26.3	45.1
E2	600-700	gs	43.6	14.8	16.3	10.6	9.8	19.4	16.1	12.0	1.15	0.80	0.08	0.04	2.17	4.46	37.2	48.6
	700-800		51.4	14.9	18.7	11.9	11.9	9.6	14.6	17.9	0.67	0.56	0.05	0.04	1.30	2.45	13.7	53.3
	800-900		39.8	13.4	15.3	11.1	11.3	12.9	9.8	25.3	0.83	0.71	0.07	0.04	1.66	2.72	10.7	61.0
B	900-1000	sp	25.7	13.0	16.1	10.9	10.3	13.2	13.6	22.0	0.92	0.75	0.06	0.04	1.78	2.88	13.1	61.2
	1000-1100		11.1	13.6	14.9	10.7	9.6	14.2	16.4	18.7	1.32	0.94	0.07	0.05	2.37	3.48	18.6	68.2
	1100-1200		24.5	13.3	16.7	11.6	9.6	11.9	16.7	18.9	1.67	1.18	0.08	0.05	2.99	4.13	21.9	72.3
C	1200-1400	on	26.5	13.6	17.3	12.9	10.1	12.7	16.7	18.1	1.74	1.21	0.09	0.05	3.10	4.57	25.2	67.9
	1400-1600		20.9	12.3	15.7	11.2	7.8	16.3	8.0	27.6	1.85	1.32	0.09	0.06	3.32	3.86	14.0	85.9
	1600+		15.2	15.5	20.1	11.8	5.8	10.0	10.4	29.8	3.58	2.25	0.14	0.08	6.05	6.91	23.2	87.7

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
			H ₂ O	KCl	%	mg/kg		CBD		CBD	
	mm	Mg m ⁻³									
A	0-100	1.42	5.34	4.48	1.48	899	16.4	3760		63.5	
	100-200		5.32	4.38	1.22	801	15.3	3740		40.0	
	200-300		5.36	4.32	0.91	650	13.9	3195		19.0	
E1	300-400	1.65	5.43	4.34	0.96	566	17.0	8850		17.0	
	400-500		5.43	4.40	0.69	531	13.0	4030		10.0	
	500-600		5.62	4.38	0.47	445	10.5	10000		4.0	
E2	600-700	1.67	5.82	4.22	0.21	278	7.5	6700		86.8	
	700-800		5.98	4.47	0.14	138	10.4	3555		48.5	
	800-900		6.06	4.59	0.14	96	15.0	7375		149.0	
B	900-1000	1.79	6.32	4.78	0.06	112	4.1	7250		223.5	
	1000-1100		6.43	4.84	0.11	109	5.9	7100		204.0	
	1100-1200		6.52	4.95	0.09	109	8.3	10250		268.5	
C	1200-1400	1.78	6.43	4.99	0.05	98	5.0	12200		161.5	
	1400-1600		6.51	4.95	0.12	172	7.1	11500		247.5	
	1600+		6.46	4.92	0.06	192	2.7	10650		327.0	

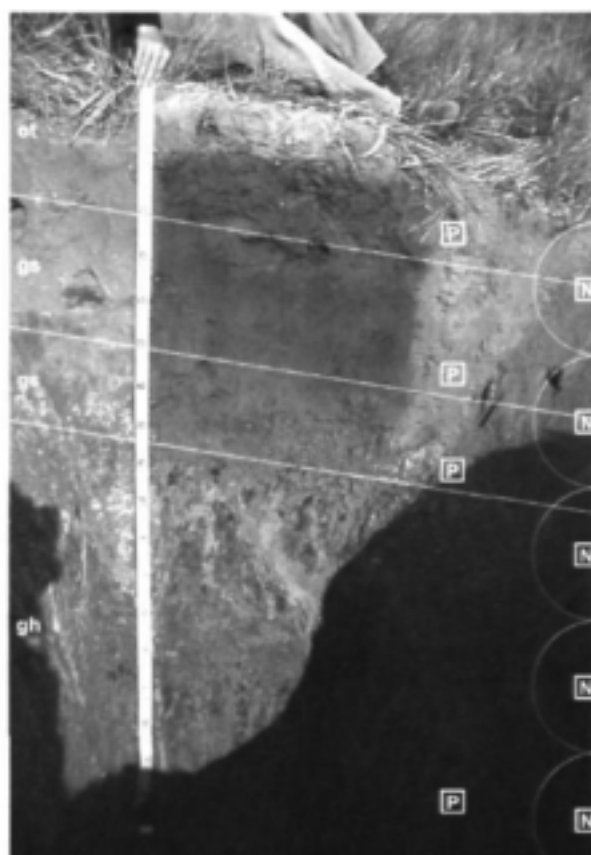


Figure 35 Profile 225 (Longlands 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

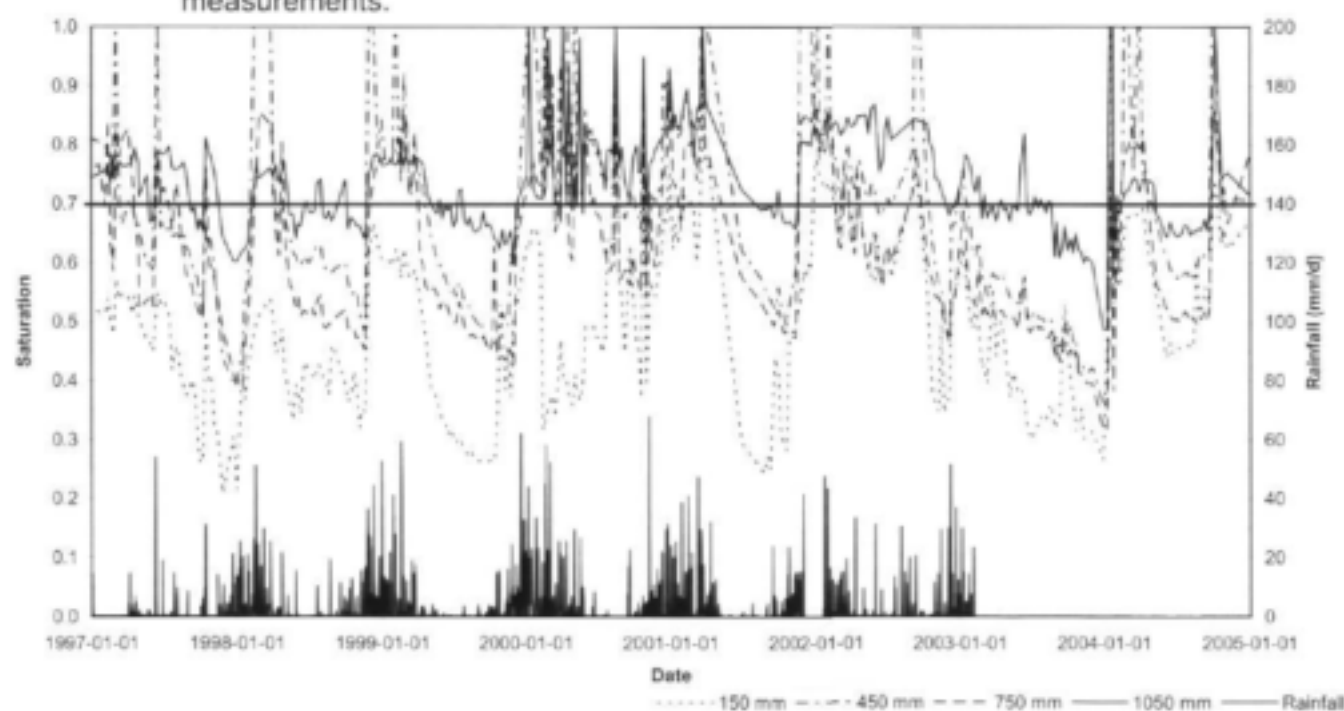


Figure 36 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 225 (Longlands 1000).

Table 38 Profile description for profile 226 (Kroonstad 1000)

Profile No: 226	Soil form: Kroonstad
Map photo: 3125A8	Soil family: 1000
Latitude & Longitude: 31° 05' 55.3" / 26° 20' 04.0"	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 274 m	Wind erosion: None
Terrain unit: Upper footslope	Water erosion: None
Slope: 4 %	Vegetation / Land use: Grassveld: closed
Slope shape: Straight	Water table: None
Aspect: West	Described by: D.A. Scholtz, W. Boschhoff
Microrelief: None	Date described: 19/06/2001
Parent material: Origin: binary, local colluvium, solid rock	Weathering of underlying material: Advanced physical, strong chemical
Underlying material: Feldspathic sandstone	Alteration of underlying material: Funguswood
Geological Group: Molteno	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0 - 200	Moisture status: Wet; dry colour: 10YR5/1 (70 %), 2.5YR4/8 (30 %); moist colour: 10YR3/1 (70 %), 2.5YR4/8 (30 %); 10.4 % clay; sandy loam; few fine distinct yellow and brown dry; 2.5YR4/8 moist; iron oxide mottles; weak fine subangular blocky; slightly hard; loose; slightly sticky; slightly plastic; many rusty fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 5 second(s); many rusty roots; diffuse smooth transition.	ortho A horizon
E1	200 - 500	Moisture status: Wet; dry colour: 10YR5/1 (90 %), 2.5YR4/8 (10 %); moist colour: 10YR3/1 (90 %), 2.5YR4/8 (10 %); 9.7 % clay; sandy loam; common medium distinct yellowish brown dry; 2.5YR4/8 moist; iron oxide mottles; apedal massive; hard; friable; non-sticky; non-plastic; many rusty fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 6 second(s); few rusty roots; clear smooth transition.	E horizon
E2	500 - 740	Moisture status: Wet; dry colour: 10YR5/1 (70 %), 7.5YR2/0 (20 %), 7.5YR5/6 (10 %); moist colour: 10YR3/1 (70 %), 7.5YR2/0 (20 %), 7.5YR5/6 (10 %); 13.2 % clay; sandy loam; many medium distinct yellowish brown dry; 7.5YR2/0 moist; iron oxide mottles; apedal massive; hard; slightly firm; slightly sticky; slightly plastic; many normal fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; very few 2-6 mm round stones; water absorption 4 second(s); few bleached roots; clear smooth transition.	E horizon
G	740 - 1000	Moisture status: Wet; dry colour: 10YR5/1 (75 %), 10YR3/1 (15 %), 7.5YR5/6 (10 %); moist colour: 10YR4/2 (75 %), 10YR3/1 (15 %), 7.5YR5/6 (10 %); 20.7 % clay; sandy clay loam; few fine prominent gray dry; 10YR3/1 moist; iron oxide mottles; moderate coarse prismatic; very hard; firm; sticky; plastic; common bleached fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; many silica cutans; no coarse fragments; water absorption 1 second(s); few bleached roots; transition not reached.	G horizon

Table 39 Soil analyses for profile 226 (Kroonstad 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth						Exchangeable cations					CEC soil	CEC clay	Base sat %
				coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na			
				%	%	%	%	%	%	%	cmol/kg	cmol/kg	cmol/kg	cmol/kg			
A	0-100	ot	0.7	15.7	20.2	11.6	10.7	14.3	18.5	10.0	4.52	2.63	0.18	0.09	7.42	7.67	96.8
	100-200		2.1	16.3	19.9	11.0	10.4	12.0	16.2	10.7	2.24	0.87	0.13	0.07	3.31	6.47	60.5
	200-300		0.6	16.3	19.9	11.8	11.7	13.4	13.8	10.2	2.02	0.68	0.13	0.06	2.90	6.52	64.0
	300-400		0.8	17.2	21.3	12.6	12.9	13.0	13.2	10.3	1.25	0.37	0.12	0.05	1.78	5.55	53.8
E1	400-500	gs	0.7	15.2	20.1	13.3	14.6	10.7	13.9	8.7	0.85	0.32	0.07	0.04	1.39	4.08	46.9
	500-600		0.6	18.3	22.2	12.6	12.0	10.0	7.5	14.3	0.85	0.35	0.05	0.03	1.29	4.24	29.7
	600-700		1.1	17.5	22.8	13.3	13.2	10.6	7.5	12.0	1.01	0.51	0.05	0.03	1.60	3.32	27.6
	700-800		1.9	17.6	21.9	12.9	13.8	9.5	8.6	18.0	0.94	0.50	0.05	0.03	1.51	3.04	16.9
G	800-900	gh	2.0	13.9	18.1	11.3	13.6	9.8	7.2	23.3	1.98	1.04	0.12	0.06	3.20	4.57	19.6
	900-1000																

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C:N	Fe		Mn	
			H ₂ O	KCl				CRD		CRD	
A	0-100	1.34	5.22	4.68	1.49	967	15.4	22625		39.5	
	100-200		5.60	4.55	1.27	948	13.4	24625		37.5	
	200-300		4.87	4.17	1.18	842	14.0	16575		14.0	
	300-400		5.02	4.01	0.87	553	14.7	13800		8.0	
E1	400-500	1.64	5.17	4.17	0.79	585	13.6	14425		8.0	
	500-600		5.31	3.98	0.35	456	7.8	9600		4.5	
	600-700		5.62	4.20	0.35	297	11.8	10050		4.0	
	700-800		5.58	4.43	0.34	404	8.4	7450		2.5	
G	800-900	1.68	5.93	4.19	0.18	204	8.8	3470		2.5	
	900-1000										

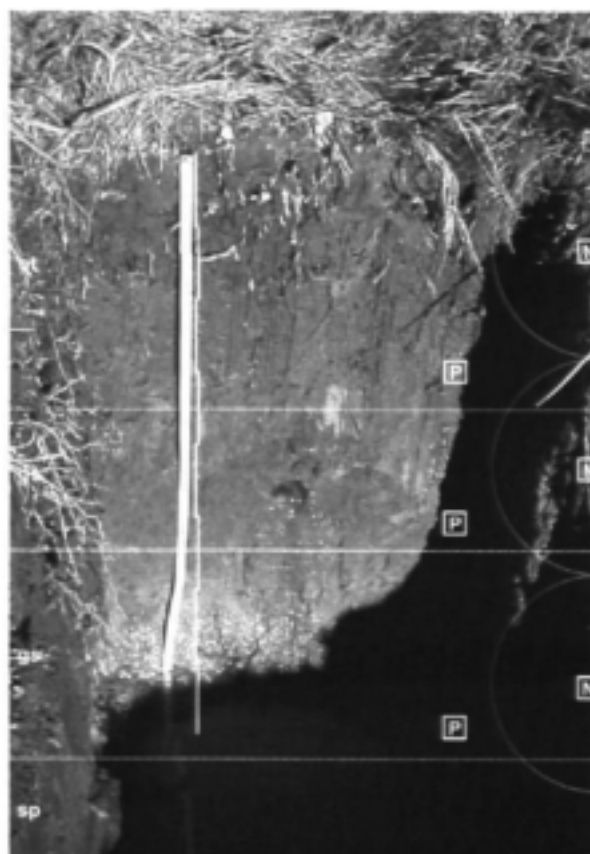


Figure 37 Profile 226 (Kroonstad 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

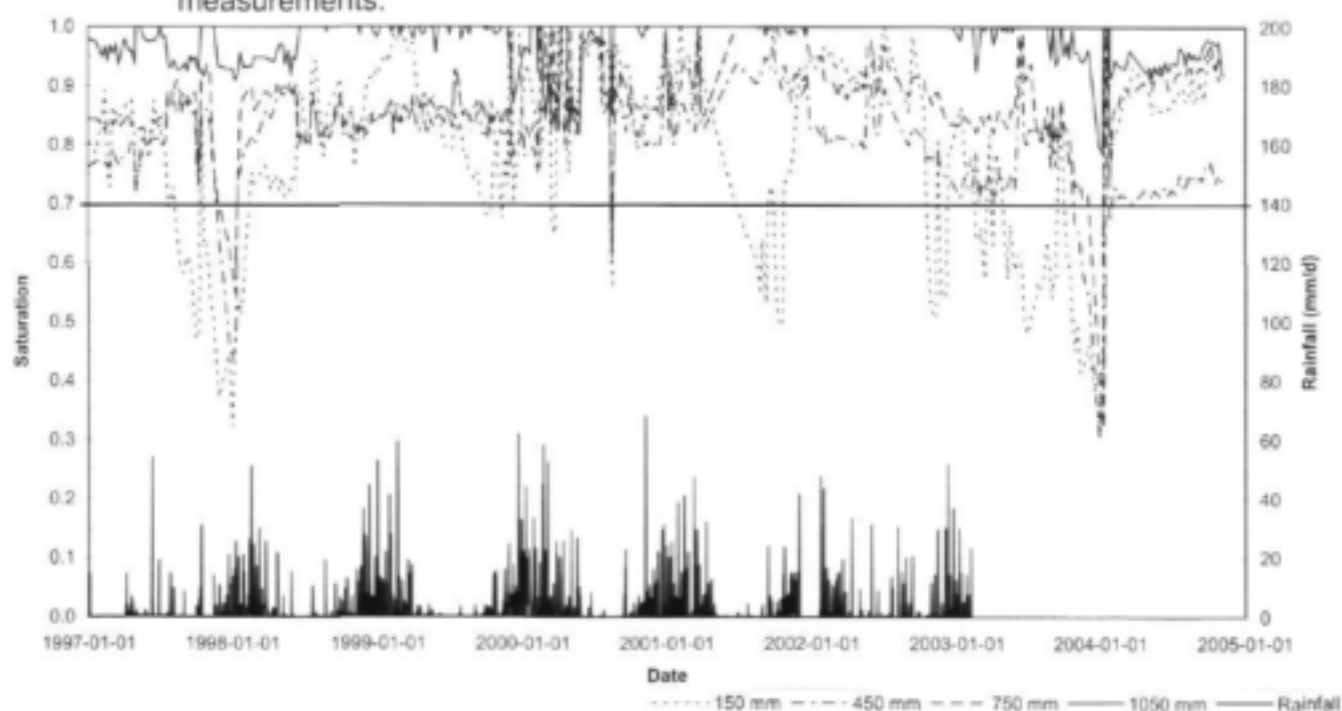


Figure 38 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 226 (Kroonstad 1000).

Table 40 Profile description for profile 229 (Kroonstad 1000)

Profile No: 229	Soil form: Kroonstad
Mapphoto: 3125AB	Soil family: 1000
Latitude & Longitude: 31° 05' 59" S / 28° 20' 09" E	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 262 m	Wind erosion: None
Terrain unit: Upper middlelope	Water erosion: None
Slope: 13 %	Vegetation (Land use): Grassveld: closed
Slope shape: Concave	Water table: 1 500 mm
Aspect: West	Described by: C. W. van Huyssteen & W. Boothe
Microclimate: None	Date described: 19/06/2001
Parent material solum: Origin binary: local colluvium: solid rock	Weathering of underlying material: Strong physical, moderate chemical
Underlying material: Felspathic sandstone	Alteration of underlying material: Ferruginous
Geological Group: Molteno	

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0 - 190	Moisture status: moist; dry colour: 5YR5/1 (100 %); moist colour: 7.5YR3/0 (100 %); 14.0 % clay; sandy loam; no mottles; moderate fine subangular blocky; loose; loose, non-sticky; non-plastic; many rusty fine and very fine pores; many rusty medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many bleached roots; gradual smooth transition	artificial horizon
E1	190 - 450	Moisture status: moist; dry colour: 5YR5/1 (90 %); 7.5YR5/4 (10 %); moist colour: 7.5YR3/0 (90 %); 7.5YR5/6 (10 %); 12.2 % clay; coarse sandy loam; common fine prominent; 7.5YR5/8 dry; 7.5YR5/6 moist; iron oxide mottles; common fine distinct; 10YR7/1 dry; 10YR5/2 moist; reduced iron mottles; moderate fine subangular blocky; slightly hard; loose, non-sticky; non-plastic; many rusty fine and very fine pores; many bleached medium and coarse pores; no slickensides; no cracks; no cutans; very few 2-6 mm round stones; water absorption 1 second(s); common bleached roots; clear smooth transition	E horizon
E2	450 - 540	Moisture status: moist; dry colour: 5YR5/1 (100 %); moist colour: 7.5YR4/0 (100 %); 11.3 % clay; sandy loam; many fine prominent; 7.5YR5/8 dry; 7.5YR5/6 moist; iron oxide mottles; weak fine subangular blocky; slightly hard; loose, non-sticky; non-plastic; many rusty fine and very fine pores; many rusty medium and coarse pores; no slickensides; no cracks; no cutans; many 2-6 mm round stones; water absorption 1 second(s); common rusty roots; clear smooth transition	E horizon
E3	540 - 1000	Moisture status: moist; dry colour: 7.5YR5/0 (85 %); 7.5YR5/8 (15 %); moist colour: 7.5YR4/0 (85 %); 7.5YR5/6 (15 %); 15.0 % clay; sandy loam; common medium prominent; 7.5YR5/8 dry; 7.5YR5/6 moist; iron oxide mottles; apical massive; hard; loose, non-sticky; non-plastic; many bleached fine and very fine pores; common bleached medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); common rusty & bleached roots; clear smooth transition	E horizon
G	1000 - 1500	Moisture status: moist; dry colour: 10YR5/1 (80 %); 7.5YR5/8 (40 %); moist colour: 10YR5/1 (80 %); 7.5YR5/6 (40 %); 25.8 % clay; sandy clay loam; few medium distinct; 7.5YR5/8 dry; 7.5YR5/6 moist; iron oxide mottles; many coarse prominent; 10YR7/1 dry; 10YR5/2 moist; reduced iron mottles; strong coarse prismatic; hard; very firm; slightly sticky; very plastic; common bleached fine and very fine pores; few bleached medium and coarse pores; no slickensides; fine cracks; common silica cutans; no coarse fragments; water absorption 10 second(s); few bleached roots; transition not reached	G horizon

Table 41 Soil analyses for profile 229 (Kroonstad 1000)

Horizon	Depth mm	Diagnostic horizon	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat			
			coSa		meSa		fSa		vtSa		Si	fSi	Cl	Ca	Mg				K	Na	S
			%	%	%	%	%	%	cmol/kg	cmol/kg											
A	0-100	ot	7.7	15.2	24.8	15.7	7.8	6.4	13.0	12.1	3.45	1.59	0.28	0.07	5.38	7.94	65.6	67.8			
	100-200		2.3	11.4	22.8	16.5	8.3	9.2	14.4	15.8	3.20	1.54	0.24	0.07	5.05	9.95	63.0	50.8			
	200-300		8.8	29.1	24.1	13.9	5.6	7.1	9.0	10.9	1.55	0.79	0.17	0.06	2.57	6.42	58.9	40.1			
E1	300-400	gs	8.0	22.3	25.4	14.8	7.8	4.2	12.5	13.4	1.40	0.77	0.12	0.05	2.35	6.14	45.9	38.2			
	400-500		9.7	24.4	28.0	14.5	6.8	7.7	10.5	11.3	1.47	0.76	0.10	0.04	2.37	3.86	34.2	61.3			
	500-600		4.9	23.3	27.0	14.0	7.2	6.1	9.3	10.2	1.45	0.74	0.09	0.04	2.33	4.51	44.2	51.7			
E2	600-700	gs	3.5	25.2	23.5	11.2	7.7	5.4	17.0	11.8	1.68	0.82	0.09	0.05	2.64	3.75	32.3	70.5			
	700-800		4.7	22.9	23.3	11.7	8.0	5.3	18.0	13.2	1.66	0.83	0.09	0.05	2.63	4.19	31.7	62.8			
	800-900		12.5	22.0	21.6	11.4	8.2	10.2	15.0	14.1	1.97	0.86	0.12	0.06	3.01	4.89	34.7	61.5			
E3	900-1000	gh	4.2	13.4	11.8	7.4	9.5	10.6	19.7	25.7	2.44	1.16	0.14	0.08	3.82	5.38	20.9	70.9			
	1000-1100		4.6	16.7	14.6	8.3	9.2	5.6	19.5	25.6	3.18	1.49	0.17	0.15	5.00	6.09	23.8	82.1			

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C	N	C:N	Fe		Mn	
			H ₂ O	KCl				%	mg kg ⁻¹	CBD	
A	0-100	1.26	5.80	4.91	2.05	1311	15.6	14075			8.5
	100-200		5.32	4.38	0.99	1473	6.7	14425			7.5
E1	200-300	1.67	5.14	4.17	0.70	875	10.3	7375			3.5
	300-400		5.53	4.14	0.78	546	14.3	21650			3.0
E2	400-500	1.69	5.55	4.17	0.45	405	11.0	18875			3.0
	500-600		5.57	4.52	0.42	311	13.4	18320			2.5
E3	600-700	1.69	5.74	4.23	0.38	249	15.1	17825			3.5
	700-800		5.69	4.33	0.44	315	13.9	20100			3.5
	800-900		5.81	4.34	0.27	272	9.9	20925			3.5
	900-1000		5.73	4.46	0.24	281	8.4	11675			5.5
G	1000-1100	1.69	5.90	4.23	0.20	243	8.3	13525			6.0

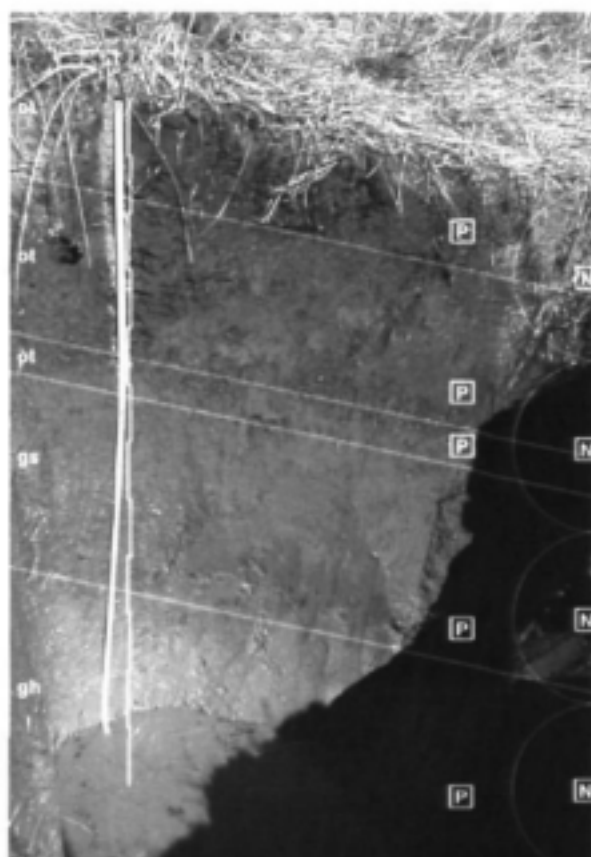


Figure 39 Profile 229 (Kroonstad 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

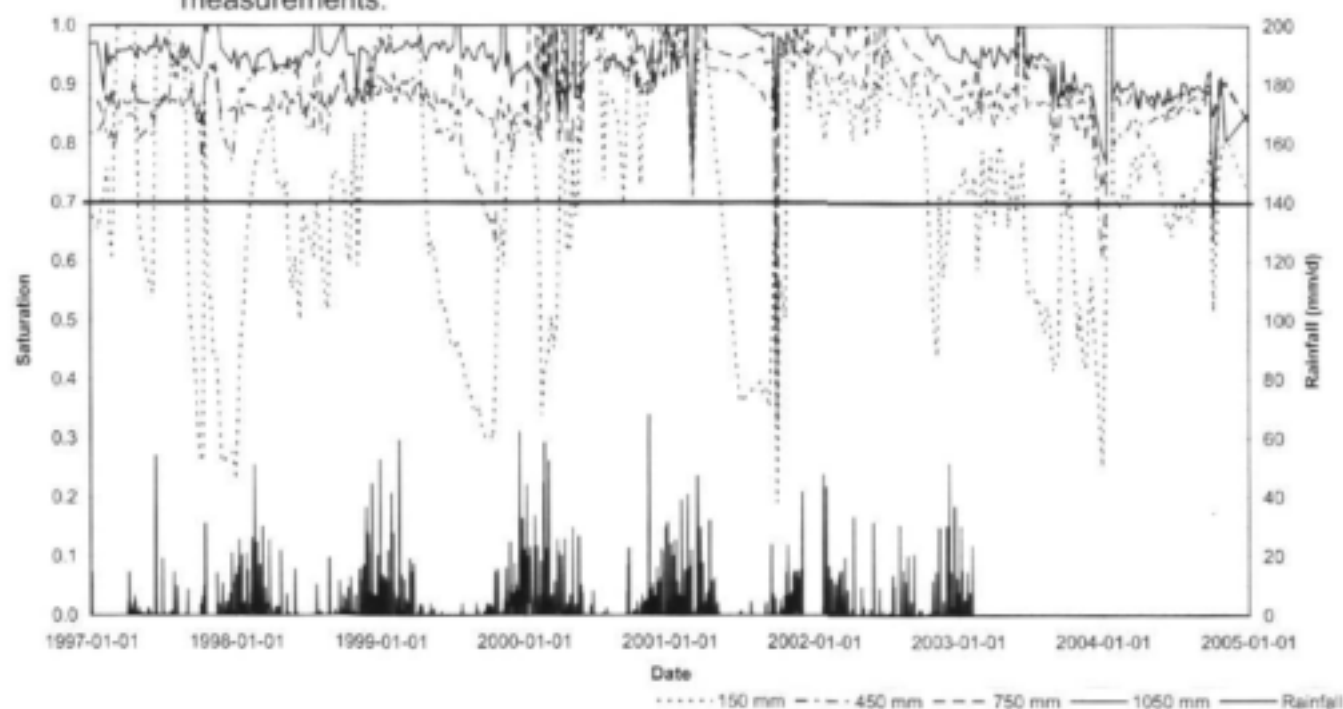


Figure 40 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 229 (Kroonstad 1000).

Table 42 Profile description for profile 230 (Westleigh 1000)

Profile No. 230 Map/photo: 3125A/B Latitude & Longitude: 31° 36' 06.5" S / 28° 10' 45.0" E Surface stoniness: None Altitude: 1274 m Terrain unit: Lower footslope Slope: 5 % Slope shape: Straight Aspect: East Microrelief: 10 % mole mounds, 0.2 m high, profile between features Parent material solon: Origin binary, local colluvium, solid rock Underlying material: Mudstone Geological Group: Molteno	Soil form: Westleigh Soil family: 2000 Surface rockiness: None Occurrence of flooding: None Wind erosion: None Water erosion: None Vegetation / Land use: Grassveld, closed Water table: none Described by: W. Boshoff, M. Gmit Date described: 19/06/2001 Weathering of underlying material: Advanced physical, strong chemical Alteration of underlying material: Ferruginised
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Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0-400	Moisture status: moist, dry colour: 7.5YR5/2 (90 %), 7.5YR5/4 (10 %); moist colour: 2.5YR4/2 (90 %), 2.5YR4/6 (10 %); 12.3 % clay; fine sandy loam; few fine faint 7.5YR5/4 dry, 7.5YR4/6 moist; iron oxide mottles; few fine faint 10YR7/8 dry, moist; iron oxide mottles; weak medium crumb; hard, loose, non-plastic, common normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); many bleached roots; gradual smooth transition.	epithic A horizon
B	400-650	Moisture status: moist, dry colour: 7.5YR7/2 (90 %), 7.5YR5/6 (20 %); moist colour: 10YR5/4 (80 %), 2.5YR4/3 (20 %); 18.1 % clay; fine sandy loam; few fine prominent 7.5YR5/6 dry, 2.5YR4/6 moist; iron oxide mottles; few fine prominent 10YR2/1 dry, moist; manganese mottles; apedal massive, very hard, friable, non-sticky, common normal fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; few 2-6 mm round stones; water absorption 2 second(s); common bleached roots; clear smooth transition; Remark: Possible E horizon 200 to 400 mm.	soft plinthic B horizon
C1	650-870	Moisture status: moist, dry colour: 10YR7/4 (90 %), 2.5YR4/6 (10 %); moist colour: 10YR5/4 (90 %), 2.5YR4/6 (10 %); 26.6 % clay; clay loam; few fine prominent 2.5YR4/6 dry, 2.5YR4/6 moist; iron oxide mottles; common fine prominent 10YR5/6 dry, moist; iron oxide mottles; apedal massive, very hard, slightly firm, non-sticky, slightly plastic; few normal fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; no cutans; few 2-6 mm round stones; water absorption 4 second(s); few bleached roots; clear smooth transition; Remark: The G1 horizon grades to soft plinthic.	unspecified material with signs of wetness
C2	870-1660	Moisture status: moist, dry colour: 10YR5/6 (70 %), 10YR6/1 (30 %); moist colour: 7.5YR5/6 (70 %), 10YR6/2 (30 %); 26.4 % clay; clay loam; few coarse prominent 10YR5/6 dry, 10YR5/2 moist; bleached mottles; few coarse prominent 10YR2/1 dry, moist; manganese mottles; strong coarse prismatic; very hard, very firm, very sticky, pasty; few normal fine and very fine pores; no medium and coarse pores; no slickensides; coarse cracks; few silica cutans; very few 5-25 mm round stones; water absorption 5 second(s); no roots; transition not reached.	unspecified material with signs of wetness

Table 43 Soil analyses for profile 230 (Westleigh 1000)

Soil analyses of profile 200 (Western 1000)																				
Horizon	Depth	Diagnostic horizon	Gravel		Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
			coSa	meSa	fSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S	cmol, kg					
	mm		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%		
A	0-100	ot	1.2	10.3	11.8	17.7	20.8	13.6	12.4	10.8	1.43	0.53	0.15	0.09	2.20	4.13	38.3	53.2		
	100-200		2.9	12.1	11.4	15.5	22.0	13.8	12.0	10.8	1.30	0.56	0.13	0.12	2.10	3.91	36.2	53.6		
	200-300		1.7	10.8	11.5	15.5	20.8	14.2	15.8	12.0	1.00	0.54	0.12	0.12	1.79	4.19	34.9	42.7		
	300-400		5.1	10.8	11.2	15.3	20.1	15.0	10.2	15.7	0.91	0.57	0.12	0.15	1.74	3.75	23.9	46.5		
B	400-500	sp	5.7	7.3	9.9	15.4	21.7	16.0	10.7	16.8	1.10	0.69	0.12	0.14	2.06	4.35	25.9	47.3		
	500-600		29.8	12.0	9.0	12.3	19.0	14.2	11.2	19.3	1.85	1.04	0.15	0.15	3.19	4.40	22.8	72.5		
C1	600-700	on	11.8	6.1	7.6	12.2	19.7	13.9	13.4	25.1	2.65	1.65	0.15	0.27	4.72	6.14	24.5	76.8		
	700-800		11.6	7.7	8.6	11.2	12.3	13.8	15.8	27.5	9.67	4.68	0.27	0.32	14.94	11.64	42.3	128.4		
	800-900		12.7	6.4	5.9	8.4	14.2	13.4	15.8	33.3	6.21	3.25	0.25	0.29	10.01	10.33	31.0	96.9		
	900-1000		13.1	6.7	6.1	7.5	11.0	14.3	21.6	29.7	8.11	4.21	0.26	0.37	12.95	10.98	37.0	117.9		
C2	1000-1100	on	5.1	6.3	6.4	8.9	13.1	13.7	21.0	28.0	7.23	4.13	0.27	0.22	11.84	12.34	44.1	95.9		
	1100-1200		9.1	4.8	6.2	9.6	13.4	14.4	18.5	30.0	8.60	4.52	0.29	0.34	13.75	12.56	41.9	109.5		
	1200-1300		9.7	6.0	5.0	11.9	11.5	13.3	17.0	29.9	8.69	4.29	0.28	0.34	13.60	12.12	40.6	112.1		
	1300-1400		5.5	5.0	6.9	13.0	15.1	17.1	13.7	29.3	9.30	3.97	0.27	0.24	13.78	12.07	41.2	114.2		
	1400-1500		12.4	5.6	9.0	11.6	11.9	15.2	19.9	27.5	9.00	4.29	0.28	0.32	13.89	12.83	45.7	108.2		
	1500-1600		15.2	16.1	6.4	9.8	13.4	14.7	15.2	22.4	3.71	2.05	0.18	0.23	6.16	6.36	28.4	96.9		
	1600-1700		5.0	4.5	6.8	11.4	13.6	25.4	5.3	30.6	9.30	4.52	0.28	0.31	14.41	11.80	38.6	122.1		
Horizon	Depth	Bulk density	pH		Org C		N	C/N	Fe		Mn									
			H ₂ O	KCl	%	mg kg ⁻¹			CBD		CBD									
	mm	Mg m ⁻³																		
A	0-100	1.62	5.26	4.40	1.18	617	19.1	20500				20.5								
	100-200		5.42	4.39	0.95	519	18.4	20725				12.5								
	200-300		5.51	4.38	0.60	447	13.4	22050				8.0								
	300-400		5.49	4.30	0.47	434	10.7	6320				11.0								
B	400-500	1.70	5.61	4.33	0.25	351	7.0	1565				21.5								
	500-600		5.75	4.33	0.22	262	8.5	9125				112.0								
	600-700		5.90	4.33	0.13	236	5.4	8575				129.0								
	700-800		6.83	4.92	0.05	248	1.9	11375				173.0								
C2	800-900	1.74	6.34	4.60	0.11	318	3.5	8050				117.0								
	900-1000		6.39	4.53	0.10	305	3.4	9625				190.0								
	1000-1100		6.52	4.59	0.05	284	1.8	8625				447.0								
	1100-1200		6.50	4.94	0.05	281	1.8	10825				401.5								
	1200-1300	1.74	6.71	4.93	0.04	239	1.7	8625				183.5								
	1300-1400		6.86	5.50	0.09	195	4.6	7500				112.5								
	1400-1500		6.85	5.32	0.01	232	0.6	7450				178.5								
	1500-1600		6.20	4.76	0.07	235	3.2	8775				54.5								
	1600-1700		6.81	5.17	0.03	200	1.3	9350				102.0								

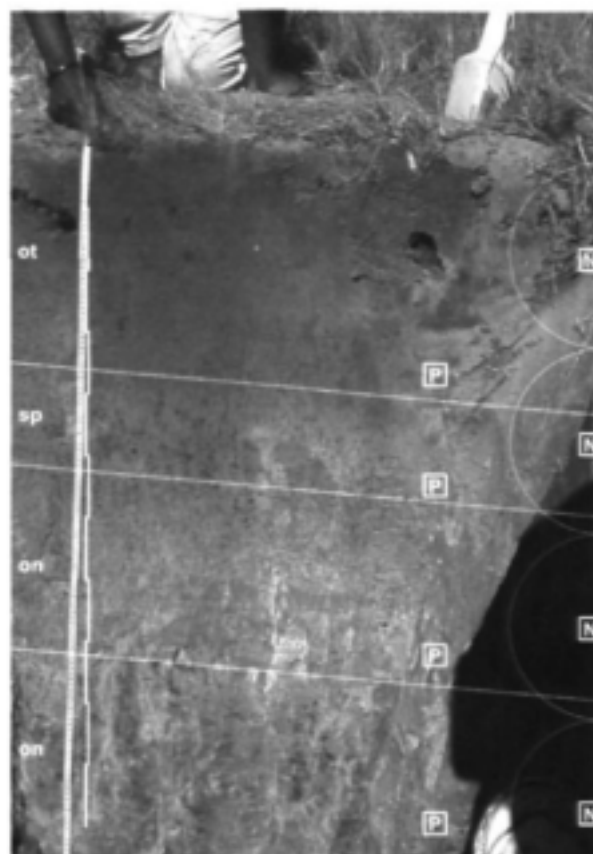


Figure 41 Profile 230 (Westleigh 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

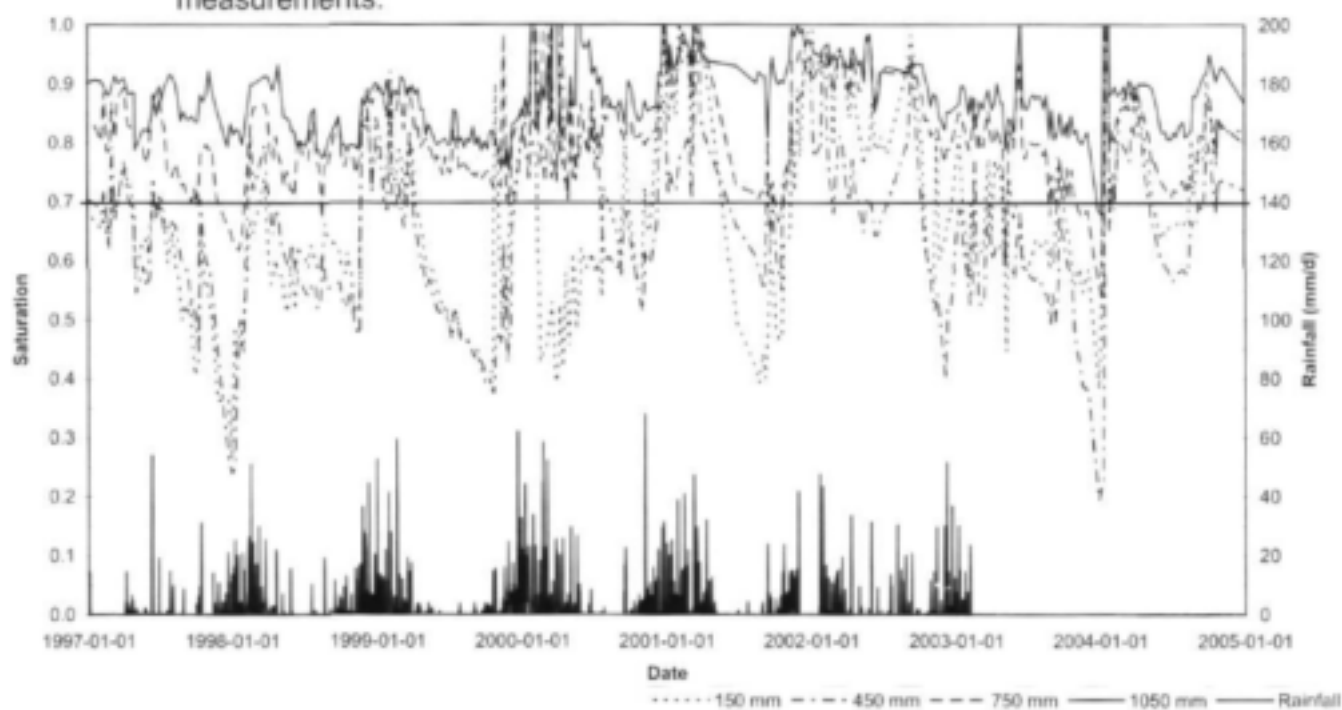


Figure 42 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 230 (Westleigh 1000).

Table 44 Profile description for profile 231 (Westleigh 2000)

Profile No: 231		Soil form: Westleigh	
Mapphoto: 3125AB		Soil family: 2000	
Latitude & Longitude: 31° 05' 58" S / 28° 19' 40" E		Surface rockiness: None	
Surface stoniness: None		Occurrence of flooding: None	
Altitude: 1 280 m		Wind erosion: None	
Terrain unit: Lower foreshore		Water erosion: None	
Slope: 10 %		Vegetation / Land use: Grassveld, closed	
Slope shape: Straight		Water table: None	
Aspect: East		Described by: M. Henson & T.B. Ziem	
Microrelief: 10 % mole mounds, 0.2 m high, profile between features		Date described: 19/06/2001	
Parent material solum: Origin binary, local colluvium, solid rock		Weathering of underlying material: Advanced physical, strong chemical	
Underlying material: Muttonstone		Alteration of underlying material: Ferruginous	
Geological Group: Molteno			

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0-300	Moisture status: moist, dry colour: 10YR5/1 (90 %), 7.5YR5/6 (10 %), moist colour: 10YR3/1 (90 %), 7.5YR4/6 (10 %), 8.9 % clay, fine sandy loam, few medium prominent 7.5YR5/6 dry, 7.5YR4/6 moist, iron oxide mottles, weak medium crumb, hard, friable, non-sticky, non-plastic, many normal fine and very fine pores, few rusty medium and coarse pores, no slickensides, no cracks, no cutans, few 6-25 mm round stones, water absorption 1 second(s), many rusty roots, clear smooth transition.	pritic A horizon
B1	300-420	Moisture status: moist, dry colour: 10YR5/1 (85 %), 7.5YR5/6 (15 %), moist colour: 10YR4/2 (85 %), 7.5YR4/6 (15 %), 17.3 % clay, few sandy loam, few medium prominent 7.5YR5/6 dry, 7.5YR4/6 moist, iron oxide mottles, apedal massive, hard, slightly firm, non-sticky, non-plastic, common normal fine and very fine pores, no medium and coarse pores, no slickensides, no cracks, no cutans, many 6-25 mm round stones, water absorption 2 second(s), common bleached roots, clear smooth transition. Remark: B1 & B2 contains weathering coarse stones. Wuldo should analyse.	soft plastic B horizon
B2	420-550	Moisture status: moist, dry colour: 10YR5/2 (85 %), 7.5YR5/6 (15 %), moist colour: 10YR5/2 (85 %), 7.5YR4/6 (15 %), 17.8 % clay, few sandy loam, many medium prominent 7.5YR5/6 dry, 7.5YR4/6 moist, iron oxide mottles, apedal massive, very hard, slightly firm, non-sticky, non-plastic, few normal fine and very fine pores, no medium and coarse pores, no slickensides, no cracks, no cutans, very few 2-6 mm round stones, water absorption 2 second(s), few bleached roots, diffuse smooth transition. Remark: This horizon is soft plastic with G characteristics.	soft plastic B horizon
C	550-1440	Moisture status: moist, dry colour: 10YR7/1 (70 %), 7.5YR5/6 (20 %), 10YR7/2 (10 %), moist colour: 2.5Y7/1 (70 %), 7.5YR5/6 (20 %), 15YR5/1 (10 %), 20.0 % clay, iron loam, many coarse prominent 7.5YR5/6 dry, 7.5YR5/6 moist, iron oxide mottles, strong coarse prismatic, very hard, very firm, slightly sticky, plastic, few bleached fine and very fine pores, no medium and coarse pores, no slickensides, coarse cracks, few siliceous cutans, no coarse fragments, water absorption 10 second(s), no bleached roots, transition not reached	unspecified material with signs of wetness

Table 45 Soil analyses for profile 231 (Westleigh 2000)

Horizon	Depth mm	Diagnostic horizon	Gravel		Texture of the fine earth						Exchangeable cations					CEC soil	CEC clay	Base sat %
			coSa	meSa	fiSa	vrSa	Si	Si	Ca	Mg	K	Na	S					
			%	%	%	%	%	%	cmol, kg	cmol, kg	cmol, kg	cmol, kg	cmol, kg					
A	0-100	ot	5.4	11.7	15.7	21.7	16.6	13.0	9.8	8.8	1.42	0.48	0.19	0.12	2.21	3.53	13.0	0.63
	100-200		5.3	14.5	15.7	20.9	16.0	13.4	7.8	8.9	1.04	0.56	0.08	0.14	1.81	3.58	11.3	0.51
	200-330		22.6	10.1	12.7	16.5	13.5	14.8	14.3	17.3	2.68	1.24	0.10	0.13	4.16	3.81	3.6	1.09
B1	330-500	sp	9.3	12.8	12.5	15.9	11.6	12.8	15.2	17.8	4.71	2.35	0.14	0.16	7.36	7.67	40.4	0.96
B2	500-600	sp	2.6	7.8	11.2	13.7	10.8	12.5	26.1	15.7	5.06	2.57	0.13	0.15	7.91	6.63	37.6	1.19
C	600-700	on	3.2	9.7	12.8	15.9	11.9	12.4	14.2	22.5	4.63	2.24	0.16	0.18	7.23	6.80	29.2	1.06
	700-800		3.1	10.0	13.2	18.1	13.4	12.7	12.2	19.6	4.54	2.17	0.15	0.15	7.01	4.84	24.2	1.45
	800-900		6.4	10.1	13.1	17.7	13.1	13.2	10.7	20.3	4.95	2.37	0.19	0.15	7.56	5.33	25.5	1.44
	900-1000		1.8	7.3	12.4	16.1	13.3	16.2	16.3	18.9	4.34	2.05	0.15	0.15	6.69	4.95	25.8	1.35
	1000-1100		1.7	9.3	12.9	15.9	13.2	14.4	14.4	20.0	3.92	2.34	0.16	0.23	6.64	7.01	33.0	0.95
	1100-1200		0.5	8.1	11.0	13.3	11.6	16.0	16.4	20.8	4.02	2.37	0.17	0.22	6.77	7.29	34.7	0.93
	1200-1300		0.4	7.9	11.6	12.4	11.7	15.8	19.8	20.8	5.38	3.81	0.23	0.25	9.88	8.48	40.6	1.14
	1300-1400		1.8	6.1	7.9	9.2	10.4	15.9	21.2	28.1	3.58	2.19	0.17	0.20	6.14	7.07	24.1	0.87

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
			H ₂ O	KCl				CBD		CBD	
	mm	Mg m ⁻³	%	mg kg ⁻¹	mg kg ⁻¹						
A	0-100	1.56	5.20	4.37	1.38	569	22.7	15200		18.0	
	100-200		5.21	4.26	1.18	591	19.6	17800		9.6	
	200-330		5.94	4.41	0.93	240	38.5	8075		92.5	
B1	330-500	1.75	5.98	4.46	0.14	236	5.8	8875		99.5	
B2	500-600		6.17	4.25	0.10	224	4.5	9450		62.5	
C	600-700	1.72	6.31	4.43	0.06	179	3.6	7025		21.0	
	700-800		6.26	4.69	0.03	138	1.9	2670		19.0	
	800-900		6.45	4.77	0.04	117	3.6	1565		9.5	
	900-1000		6.48	4.86	0.02	91	2.5	1590		4.5	
	1000-1100	1.80	6.66	4.90	0.12	86	13.8	3060		2.5	
	1100-1200		6.70	5.30	0.02	86	2.4	1735		2.5	
	1200-1300		6.67	5.19	0.01	62	1.3	1895		7.5	
	1300-1400		-	-	0.08	152	5.5	1785		5.0	

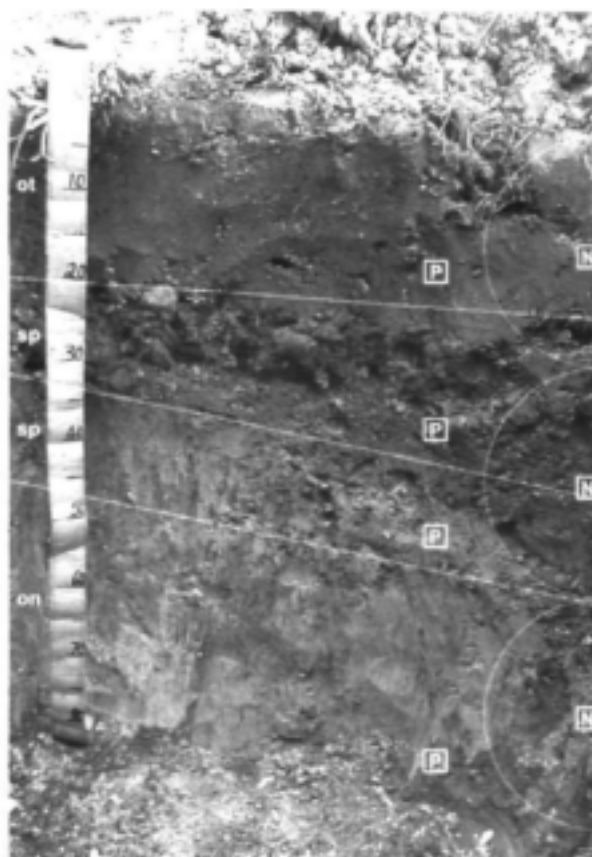


Figure 43 Profile 231 (Westleigh 2000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

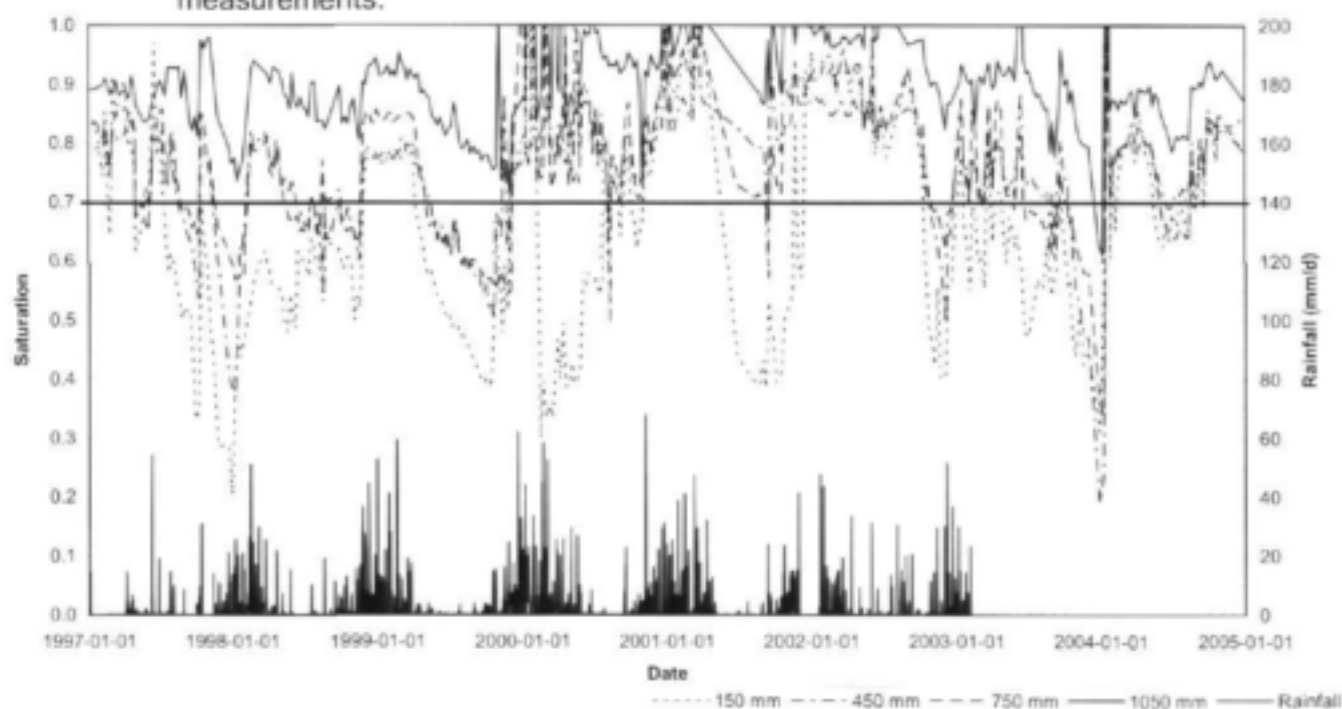


Figure 44 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 231 (Westleigh 2000).

Table 46 Profile description for profile 232 (Katspruit 1000)

Profile No: 232	Soil form: Katspruit
Map/photo: 3125AB	Soil family: 1000
Latitude & Longitude: 31° 06' 51" E / 28° 20' 14" S	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 320 m	Wind erosion: None
Terrain unit: Crest / Footslope	Water erosion: None
Slope: 6 %	Vegetation / Land use: Grass veld, closed
Slope shape: Straight	Water table: None
Aspect: West	Described by: M. Smit & A. G. Verdyghans
Microrelief: None	Date described: 15/06/2001
Parent material column: Origin single, solid rock	Weathering of underlying material: Strong physical, moderate chemical
Underlying material: Multistone	Alteration of underlying material: Fungus
Geological Group: Elliot	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A1	0 - 220	Moisture status: moist; dry colour: 10YR4/2 (85 %); 7.5YR5/6 (5 %); moist colour: 2.5YR2/2 (85 %); 5YR3/4 (5 %); 12.4 % clay; fine sandy loam; few fine sand 7.5YR5/6 dry; 5YR3/4 moist; iron oxide mottles; weak fine subangular blocky, slightly hard, loose, non-sticky, non-pastic; many bleached fine and very fine pores; many normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); many normal roots; diffuse smooth transition.	orthic A horizon
A2	220 - 500	Moisture status: moist; dry colour: 10YR5/3 (85 %); 5YR4/6 (15 %); moist colour: 2.5YR3/2 (85 %); 5YR3/4 (15 %); 10.6 % clay; fine sandy loam; common fine sand 7.5YR5/6 dry; 5YR3/4 moist; iron oxide mottles; moderate fine subangular blocky, soft, loose, non-sticky, non-pastic; many normal fine and very fine pores; many normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); many normal roots; diffuse smooth transition. Remark: Second horizon is transition from A to B.	orthic A horizon
G1	500 - 840	Moisture status: moist; dry colour: 10YR5/2 (80 %); 7.5YR5/6 (20 %); moist colour: 2.5YR4/2 (80 %); 7.5YR3/4 (20 %); 20.0 % clay; sandy clay loam; many fine sand 7.5YR5/6 dry; 5YR3/4 moist; iron oxide mottles; weak fine subangular blocky, soft, friable, slightly sticky, slightly plastic; common normal fine and very fine pores; common bleached medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); common normal roots; gradual smooth transition. Remark: Young pedithic soil - therefore structure still present.	G horizon
G2	840 - 1120	Moisture status: moist; dry colour: 10YR5/1 (80 %); 10R4/6 (20 %); moist colour: 2.5YR5/2 (80 %); 10R4/6 (20 %); 20.8 % clay; sandy clay loam; common fine sand 7.5YR5/6 dry; 10R4/6 moist; iron oxide mottles; apertal massive; very hard, firm, sticky, plastic; few normal fine and very fine pores; few bleached medium and coarse pores; few slickensides; no cracks; common slick cutans; no coarse fragments; water absorption 5 second(s); few bleached roots; clear smooth transition.	G horizon
G3	1120 - 1360	Moisture status: moist; dry colour: 10YR7/2 (70 %); 7.5YR5/6 (30 %); moist colour: 2.5YR5/4 (70 %); 7.5YR5/6 (30 %); 21.4 % clay; sandy clay loam; many fine sand 7.5YR5/6 dry; 7.5YR4/6 moist; iron oxide mottles; apertal massive; very hard, friable, non-sticky, non-pastic; common normal fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); few bleached roots; clear smooth transition.	G horizon
G4	1360 - 1500	Moisture status: moist; dry colour: 10YR5/2 (90 %); 10YR6/4 (10 %); moist colour: 10YR5/2 (90 %); 10YR4/6 (10 %); 14.2 % clay; fine sandy loam; common fine sand 10R4/6 dry; 10R4/6 moist; iron oxide mottles; apertal massive; very hard, very firm, sticky, plastic; common bleached fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 7 second(s); no roots; transition not reached.	G horizon

Table 47 Soil analyses for profile 232 (Katspruit 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
				coSe	meSe	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
				%	%	%	%	%	%	%	cmol/kg	cmol/kg	cmol/kg	cmol/kg	cmol/kg				
A1	0-100	ot		0.8	14.3	16.7	22.5	14.6	14.0	10.4	6.0	1.75	0.68	0.21	0.19	2.84	8.70	145.0	32.6
	100-200		0.6	11.7	14.5	15.6	9.5	11.2	16.7	18.7	1.04	0.48	0.16	0.17	1.84	6.63	35.5	27.8	
A2	200-300	ot		0.6	11.4	14.6	16.1	10.2	14.8	12.2	18.5	1.32	0.55	0.22	0.18	2.27	8.26	44.7	27.5
	200-330		45.3	11.2	15.5	20.2	16.1	5.8	11.5	18.9	0.88	0.45	0.09	0.20	1.62	4.78	25.3	33.8	
	300-400		0.8	10.4	13.9	15.6	10.6	10.7	15.5	20.4	1.02	0.50	0.21	0.20	1.93	8.37	41.0	23.1	
	400-500		0.3	10.8	13.9	16.4	10.6	10.8	15.5	20.4	0.84	0.49	0.16	0.20	1.69	7.78	38.1	21.8	
G1	500-600	gh		0.6	10.0	13.6	15.6	10.5	14.6	11.7	21.6	0.69	0.45	0.14	0.17	1.46	8.81	40.8	16.5
	600-750		0.7	9.1	13.3	16.1	11.0	10.3	16.1	22.3	0.67	0.50	0.12	0.19	1.48	5.82	26.1	25.4	
	700-800		0.5	26.3	20.6	12.8	8.1	6.7	8.4	16.1	0.77	0.56	0.12	0.18	1.63	6.52	40.5	25.0	
	750-800		2.7	9.0	13.4	15.7	11.1	7.7	16.8	22.7	0.36	0.39	0.07	0.17	1.01	4.13	18.2	24.4	
G3	800-950	gh		2.1	9.5	14.3	17.0	11.5	12.8	12.0	20.8	0.88	0.67	0.12	0.18	1.85	6.42	30.8	28.8
	1100-1200		3.1	6.9	18.4	19.9	8.1	6.4	18.1	21.4	2.56	1.71	0.24	0.24	4.75	8.97	41.9	52.9	
G4	1200-1500	gh		1.3	5.0	31.2	30.2	7.3	4.2	6.0	14.2	1.08	0.80	0.11	0.16	2.15	5.06	35.6	42.6

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C:N	Fe		Mn	
			H ₂ O	KCl				CBD		CBD	
A1	0-100	1.50	5.15	4.29	1.05	578	18.2	520		6.0	
	100-200		5.19	4.26	1.37	903	15.1	1740		9.5	
	200-300		5.17	4.03	1.25	834	15.0	1390		51.5	
A2	200-330	1.61	5.29	4.28	0.90	569	15.8	2360		40.5	
	300-400		5.22	3.97	1.03	619	16.7	1750		1.0	
	400-500		5.20	3.91	0.76	675	11.2	1695		32.0	
G1	500-600	1.67	5.21	3.94	0.75	601	12.5	2550		15.0	
	600-750		5.28	3.91	0.49	413	11.8	2680		7.5	
	700-800		5.44	3.83	0.29	364	8.0	2335		4.5	
G3	750-800	1.67	5.11	3.85	0.17	296	5.9	3355		2.0	
	800-950		5.23	3.97	0.25	213	11.5	2850		5.5	
	1100-1200		5.64	3.95	0.18	286	6.1	8145		3.0	
G4	1200-1500		5.48	4.04	0.09	84	10.4	8050		3.0	

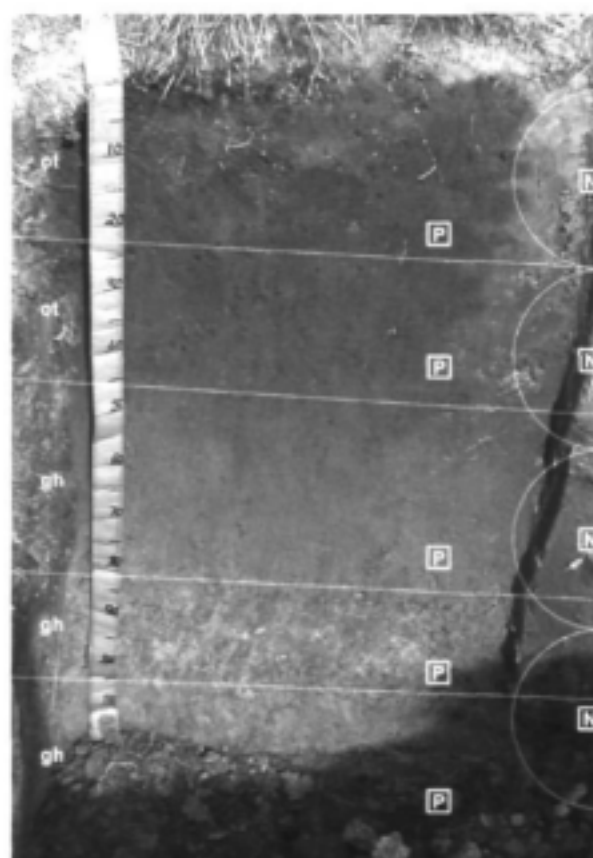


Figure 45 Profile 232 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

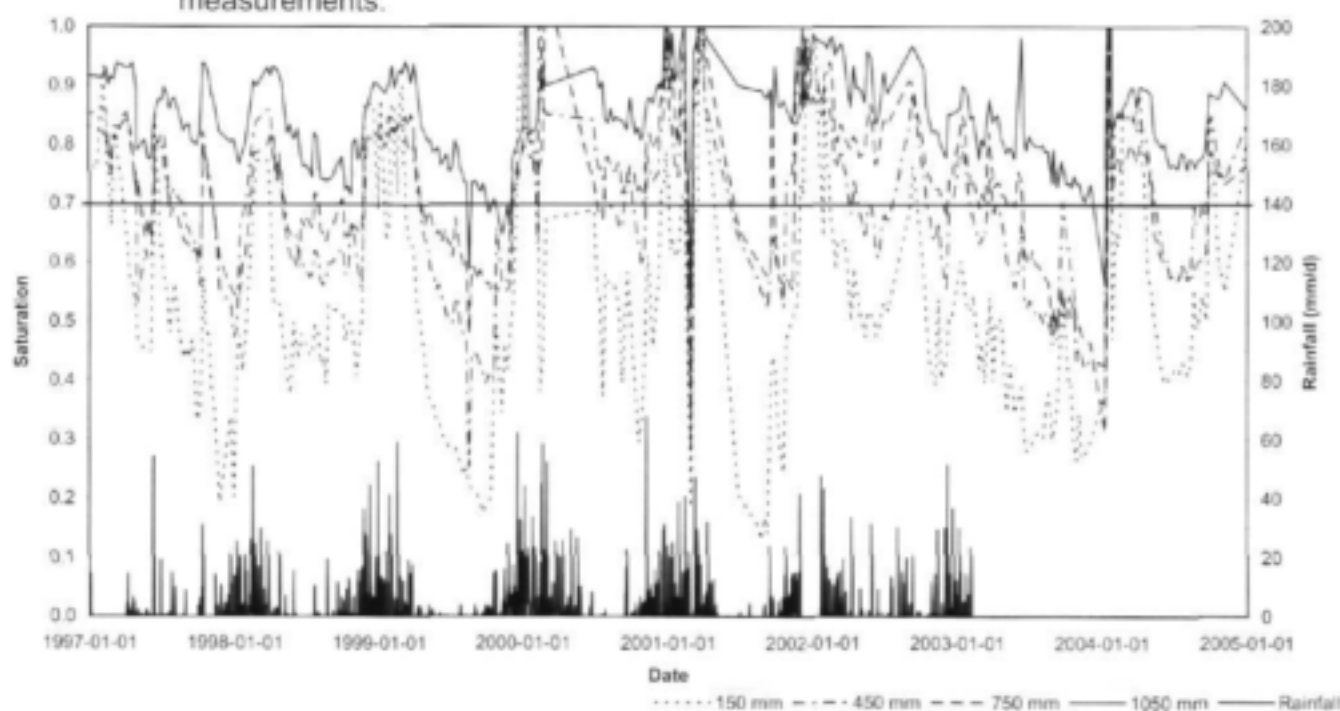


Figure 46 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 232 (Katspruit 1000).

Table 48 Profile description for profile 233 (Pinedene 2100)

Profile No: 233
Mapphoto: 312548
Latitude & Longitude: 31° 06' 02.1" / 28° 20' 16.9"
Surface stoniness: None
Altitude: 1 326 m
Terrain unit: Footslope
Slope: 10 %
Slope shape: Concave
Aspect: West
Microrelief: None
Parent material column: Origin binary, local colluvium, solid rock
Underlying material: Mudstone
Geological Group: Elliot

Soil type: Pinedene
Soil family: 2100
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation / Land use: Grassveld, closed
Water table: None
Described by: D. Schults & T.B. Zere
Date described: 19/06/2001
Weathering of underlying material: Strong physical, strong chemical
Alteration of underlying material: Ferruginised

Horizon	Depth (mm)	Description	Diagnostic horizons / material		
A	0 - 300	Moisture status: moist; dry colour: 10YR4/2 (95 %); 7.5YR5/4 (5 %); moist colour: 10YR3/2 (95 %); 7.5YR3/2 (5 %); 10.4 % clay; sandy loam; common medium fast 7.5YR5/4 dry; 7.5YR3/2 moist; humus mottles; apedal massive; hard; friable; non-sticky; non-plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no catans; no coarse fragments; water absorption 1 second(s); common normal roots; gradual smooth transition.	arctic A horizon		
B1	300 - 500	Moisture status: moist; dry colour: 10YR4/2 (80 %); 7.5YR5/6 (40 %); moist colour: 10YR3/2 (80 %); 7.5YR4/6 (40 %); 11.0 % clay; sandy loam; many medium fast 10YR5/6 dry; 7.5YR4/6 moist; humus mottles; apedal massive; hard; friable; non-sticky; non-plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no catans; no coarse fragments; water absorption 1 second(s); common normal roots; gradual smooth transition.	yellow-brown horizon	apedal	B
B2	500 - 600	Moisture status: moist; dry colour: 10YR5/4 (80 %); 10YR5/2 (20 %); moist colour: 10YR4/4 (80 %); 10YR3/2 (20 %); 9.6 % clay; sandy loam; many coarse fast 10YR5/2 dry; 10YR3/2 moist; humus mottles; apedal massive; hard; friable; non-sticky; non-plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no catans; no coarse fragments; water absorption 1 second(s); few normal roots; clear smooth transition.	yellow-brown horizon	apedal	B
C1	600 - 1040	Moisture status: moist; dry colour: 10YR5/2 (90 %); 2.5YR5/8 (10 %); moist colour: 10YR4/2 (90 %); 2.5YR4/8 (10 %); 34.4 % clay; clay loam; many coarse prominent 2.5YR5/8 dry; 2.5YR4/8 moist; geogenic mottles; many medium prominent 2.5YR5/8 dry; 2.5YR4/8 moist; iron oxide mottles; strong coarse prismatic; very hard; very firm; sticky; very plastic; few branched fine and very fine pores; few normal medium and coarse pores; many slickensides; fine cracks; very many clay catans; very few 2-6 mm round stones; water absorption 4 second(s); few normal roots; gradual smooth transition.	unspecified material with signs of wetness		
C2	1040 - 1570	Moisture status: moist; dry colour: 5YR5/6 (80 %); 10YR5/1 (40 %); moist colour: 5YR4/6 (80 %); 10YR5/2 (40 %); 28.0 % clay; clay loam; many coarse prominent 10YR5/1 dry; 10YR5/2 moist; geogenic mottles; many coarse prominent 10YR5/1 dry; 10YR5/2 moist; iron oxide mottles; apedal massive; very hard; very firm; sticky; very plastic; few branched fine and very fine pores; few normal medium and coarse pores; few slickensides; no cracks; few clay catans; no coarse fragments; water absorption 4 second(s); few normal roots; transition not reached.	unspecified material with signs of wetness		

Table 49 Soil analyses for profile 233 (Pinedene 2100)

Horizon		Depth	Diagnostic horizon	Texture of the fine earth										Exchangeable cations					CEC soil	CEC clay	Base sat
		mm		Gravel									cmol kg ⁻¹								
					%	coSa	meSa	fSa	vSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
A		0-100	ot	-	21.6	22.0	18.7	9.6	7.8	8.7	9.8	1.56	0.56	0.15	0.17	2.45	5.27	53.8	46.4		
		100-200		1.7	16.0	21.7	21.0	11.6	9.9	9.4	9.6	1.33	0.52	0.12	0.17	2.13	5.22	54.4	40.8		
		200-300		2.5	15.9	22.8	19.3	11.2	9.6	10.2	11.7	0.86	0.48	0.13	0.17	1.64	4.89	41.8	33.5		
B1		300-400	ye	3.6	15.2	20.6	19.6	13.9	8.4	8.4	10.9	0.71	0.44	0.13	0.17	1.44	4.62	42.4	31.3		
		400-500		3.3	15.5	21.3	21.1	13.7	8.3	7.4	11.0	0.54	0.40	0.13	0.16	1.23	4.95	45.0	24.8		
B2		500-600	ye	13.4	14.2	22.9	20.9	12.2	9.5	8.3	9.6	0.51	0.46	0.14	0.16	1.24	3.75	39.1	33.2		
		600-650		11.1	13.1	21.3	22.5	13.3	10.4	8.2	10.0	0.52	0.42	0.11	0.15	1.19	4.35	43.5	27.5		
C1		650-700	on	9.4	7.5	9.9	11.8	10.0	10.0	17.0	31.2	2.10	1.51	0.34	0.19	4.15	12.18	39.0	34.0		
		700-800		11.4	9.9	9.4	10.0	8.7	9.6	12.5	37.3	1.84	1.75	0.27	0.22	4.08	14.08	37.8	29.0		
		800-900		5.8	9.1	9.4	10.5	9.3	9.7	2.9	47.2	2.65	1.83	0.29	0.23	5.00	14.73	31.2	33.9		
		900-1000		8.0	7.4	9.5	11.4	10.8	10.6	3.7	46.2	2.27	1.55	0.23	0.22	4.26	13.32	28.8	32.0		
C2		1000-1100	on	2.6	10.1	10.1	11.7	10.4	10.3	12.9	33.8	2.22	1.61	0.25	0.22	4.29	13.32	39.4	32.2		
		1100-1200		4.0	7.8	9.8	12.6	12.0	10.2	19.2	27.3	2.21	1.56	0.23	0.22	4.21	12.51	45.8	33.7		
		1200-1300		6.1	8.3	10.0	13.4	12.6	11.0	15.0	27.0	1.40	1.71	0.20	0.23	3.53	10.77	39.9	32.8		
		1300-1400		4.2	10.6	10.7	13.7	12.2	11.6	11.6	26.6	1.30	1.58	0.18	0.20	3.26	12.61	47.4	25.9		
		1400-1500		4.3	7.8	11.6	14.7	13.1	13.2	11.0	25.5	1.43	1.52	0.18	0.20	3.33	13.27	52.0	25.1		

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn		C8D		C8D		C8D		C8D			
			H ₂ O	KCl				%	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹
A		0-100	1.59	5.31	4.52	1.14	508	22.4	2850												
		100-200		5.33	4.25	0.81	556	14.6	5090												
		200-300		5.25	4.24	0.60	439	13.7	4990												
B1		300-400	1.62	5.32	3.95	0.44	326	13.4	3845												
		400-500		5.31	4.09	0.31	222	14.0	3420												
B2		500-600	1.61	5.27	4.04	0.15	194	7.6	3335												
		600-650		5.15	4.06	0.20	449	4.4	3310												
C1		650-700	1.66	5.31	3.71	0.38	358	10.7	3250												
		700-800		5.27	3.84	0.25	371	6.7	7910												
		800-900		5.26	3.74	0.38	367	10.4	5285												
		900-1000		5.47	3.52	0.17	269	6.2	5015												
C2		1000-1100	1.66	5.11	3.84	0.17	227	7.7	3840												
		1100-1200		5.47	3.57	0.15	256	6.9	2900												
		1200-1300		5.51	3.74	0.08	264	3.2	4800												
		1300-1400		5.50	3.69	0.11	170	6.7	4135												
		1400-1500		5.49	3.77	0.09	175	6.1	5670												

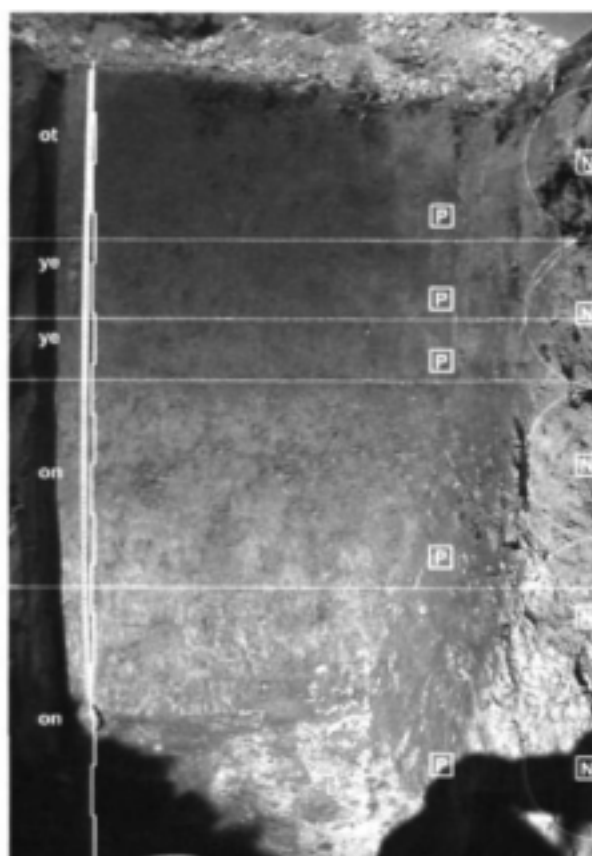


Figure 47 Profile 233 (Pinedene 2100), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

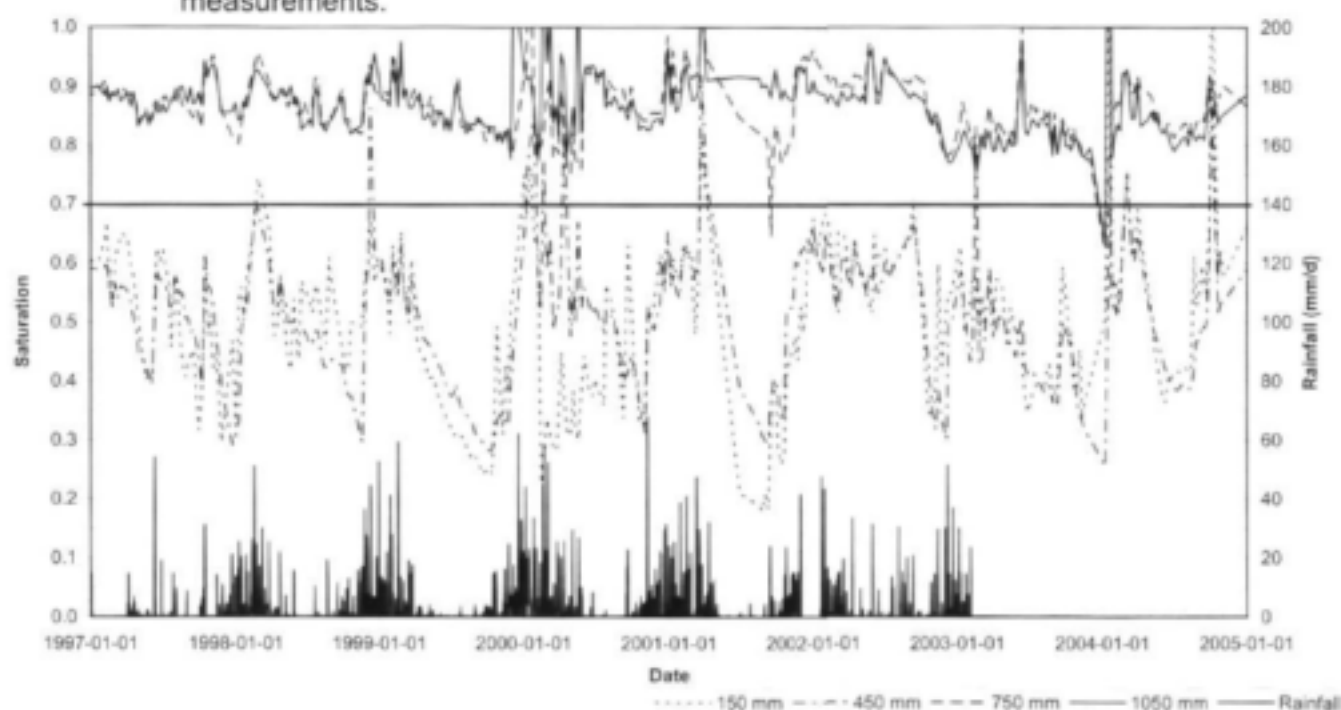


Figure 48 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 233 (Pinedene 2100).

Table 50 Profile description for profile 234 (Avalon 2100)

Profile No: 234	Soil form: Avalon
Map photo: 312842	Soil family: 2100
Latitude & Longitude: 31° 36' 02.8" / 28° 26' 18.2"	Surface rockiness: None
Surface elevation: None	Occurrence of flooding: None
Altitude: 1 333 m	Wind erosion: None
Terrain unit: Midslope	Water erosion: None
Slope: 11 %	Vegetation / Land use: Grassveld, closed
Slope shape: Concave	Water table: None
Aspect: West	Described by: M. Smit & A.G. Veldyphannes
Microrelief: None	Date described: 1996/2001
Parent material source: Origin single, local colluvium	Weathering of underlying material: Strong physical, moderate chemical
Underlying material: Felspathic sandstone	Alteration of underlying material: Ferruginised
Geological Group: Ebur	

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A	0 - 500	Moisture status: moist, dry colour: 10YR4/2 (95 %), 10YR4/3 (5 %), moist colour: 10YR3/2 (95 %), 10YR4/3 (5 %), 9.8 % clay, coarse sandy loam, no 10YR4/5 dry, 10YR3/2 moist, humus mottles, apedal massive, hard, friable, non-sticky, non-plastic, few normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s); many normal roots, gradual smooth transition.	orthic A horizon
B1	500 - 880	Moisture status: moist, dry colour: 10YR5/4 (90 %), 10YR4/2 (10 %), moist colour: 10YR4/4 (90 %), 10YR3/2 (10 %), 14.3 % clay, coarse sandy loam, common medium distinct 10YR4/2 dry, 10YR3/2 moist, humus mottles, apedal massive, hard, friable, non-sticky, non-plastic, few normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s); many normal roots, gradual smooth transition.	yellow-brown apedal horizon
B2	880 - 1070	Moisture status: moist, dry colour: 10YR5/4 (85 %), 10YR5/5 (10 %), 10YR5/2 (5 %), moist colour: 10YR5/4 (85 %), 10YR4/5 (10 %), 10YR3/2 (5 %), 17.1 % clay, sandy loam, common medium distinct 10YR5/4 dry, 10YR5/5 moist, humus mottles, apedal massive, hard, friable, non-sticky, non-plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s); common normal roots, gradual smooth transition.	yellow-brown apedal horizon
B3	1070 - 1300	Moisture status: moist, dry colour: 10YR7/3 (90 %), 10YR6/1 (10 %), moist colour: 10YR5/6 (90 %), 10YR5/5 (10 %), 18.7 % clay, loam, common fine distinct 10YR5/1 dry, 10YR5/6 moist, iron oxide mottles, common fine distinct 10YR5/1 dry, 10YR5/6 moist, iron oxide mottles, apedal massive, very hard, friable, very sticky, plastic, many normal fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s); few bleached roots, clear smooth transition.	soft pedithic B horizon
C1	1300 - 1500	Moisture status: moist, dry colour: 10YR5/1 (70 %), 2.5YR4/6 (30 %), moist colour: 10YR5/2 (70 %), 10YR4/6 (30 %), 15.1 % clay, loam, common fine distinct 2.5YR4/6 dry, 10YR4/6 moist, iron oxide mottles, many fine prominent 2.5YR4/6 dry, 10YR4/6 moist, iron oxide mottles, moderate coarse prismatic, very hard, very firm, very sticky, very plastic, few bleached fine and very fine pores, few bleached medium and coarse pores, many slickensides, no cracks, common clay & cutans, very few 2-6 mm round Fe & Mn concretions, water absorption 4 second(s); very few bleached roots, abrupt smooth transition.	unpedified material with signs of wetness
C2	1500 - 1800	Moisture status: moist, dry colour: 10YR7/1 (80 %), 10YR5/6 (40 %), moist colour: 10YR5/4 (50 %), 10YR4/6 (40 %), 15.1 % clay, loam, many coarse distinct 10YR5/6 dry, 10YR4/6 moist, iron oxide mottles, moderate coarse prismatic, very hard, very firm, very sticky, very plastic, few bleached fine and very fine pores, few bleached medium and coarse pores, many slickensides, no cracks, common clay & cutans, no coarse fragments, water absorption 1 second(s); no roots, transition not reached.	unpedified material with signs of wetness

Table 51 Soil analyses for profile 234 (Avalon 2100)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth %							Exchangeable cations cmol _c kg ⁻¹					CEC soil	CEC clay	Base sat %	
				coSa	meSa	fSa	vtSa	Si	fSi	Cl	Ca	Mg	K	Na	S				
A	0-100	ot		1.9	31.0	22.0	9.8	5.5	7.8	14.5	6.3	1.42	0.61	0.20	0.13	2.36	6.14	57.5	38.4
	100-200			0.9	34.5	22.9	9.1	5.3	6.8	12.0	8.8	0.84	0.54	0.16	0.16	1.70	5.11	58.1	33.2
	200-300			0.7	32.7	22.7	9.4	5.5	6.9	9.9	12.0	0.54	0.44	0.14	0.16	1.28	8.26	68.9	15.5
	300-400			1.9	36.9	23.1	8.9	5.1	6.1	10.8	0.37	0.31	0.11	0.13	0.92	7.12	66.0	12.9	
	400-500			0.9	42.1	20.3	8.1	5.2	5.5	7.6	10.9	0.35	0.28	0.09	0.14	0.86	7.78	71.3	11.1
B1	500-600	ye		0.9	29.5	22.6	10.2	6.7	7.9	9.5	13.0	0.26	0.35	0.07	0.16	0.84	7.72	59.4	10.9
	600-700			1.8	29.6	19.8	11.1	7.4	12.0	4.0	16.0	0.37	0.48	0.08	0.19	1.12	4.97	28.5	24.2
	800-900			1.7	18.3	17.7	15.1	11.3	18.5	4.8	13.9	0.35	0.39	0.07	0.13	0.95	3.64	26.2	26.0
B2	900-1000	ye		5.8	16.6	18.5	16.1	12.2	10.0	7.8	17.7	0.37	0.47	0.06	0.18	1.08	3.70	20.9	29.2
	1000-1100			6.3	14.5	17.1	16.2	12.1	10.8	13.1	18.5	1.20	0.56	0.11	0.17	2.04	5.98	36.2	34.1
B3	1100-1300	sp		2.1	4.8	5.4	16.2	14.2	10.6	25.7	18.7	0.91	0.48	0.10	0.17	1.67	5.27	28.2	31.7
C	1300-1400	on		8.0	1.0	4.7	18.0	12.9	9.1	36.2	15.1	0.85	0.58	0.10	0.18	1.71	4.19	27.7	40.0

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
	mm	Mg m ⁻³	H ₂ O	KCl	%	mg kg ⁻¹		CBD		CBD	
A	0-100	1.58	5.25	4.44	1.51	702	21.6	5125		4.5	
	100-200		5.13	4.21	1.12	541	20.7	6285		7.0	
	200-300		5.05	3.97	0.74	564	13.2	5855		5.0	
	300-400		5.28	3.91	0.71	378	18.7	5245		5.0	
	400-500		5.26	3.84	0.31	284	10.7	7855		8.0	
B1	500-600	1.64	5.30	3.97	0.35	188	18.7	3155		15.5	
	600-700		5.36	3.87	0.32	153	20.6	5500		8.5	
	800-900		5.48	3.85	0.13	198	6.5	6005		7.0	
B2	900-1000	1.65	5.49	3.84	0.15	87	17.1	3555		6.5	
	1000-1100		5.53	3.92	0.14	62	22.3	6055		6.5	
B3	1100-1300	1.71	5.76	3.93	0.25	343	7.2	5375		6.0	
C	1300-1400		5.73	3.97	0.24	272	8.7	6250		7.0	

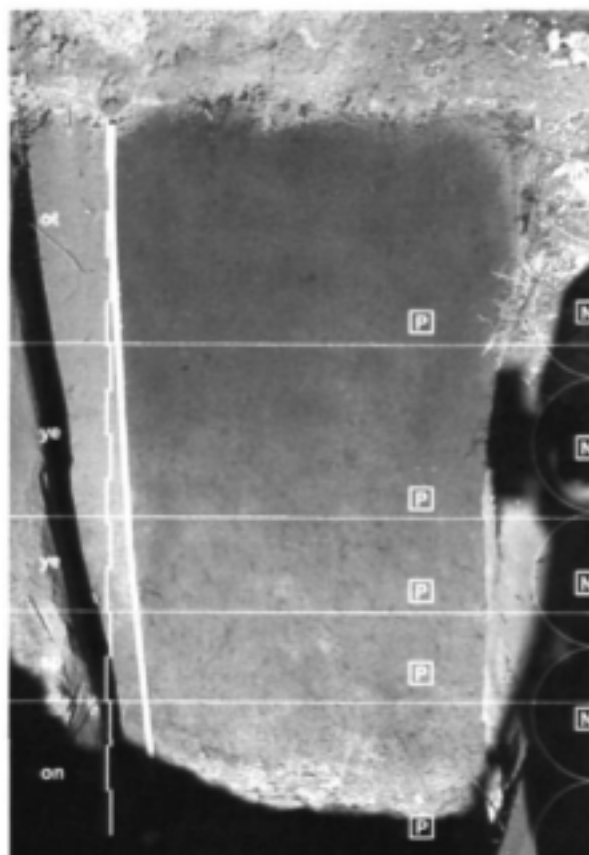


Figure 49 Profile 234 (Avalon 2100), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

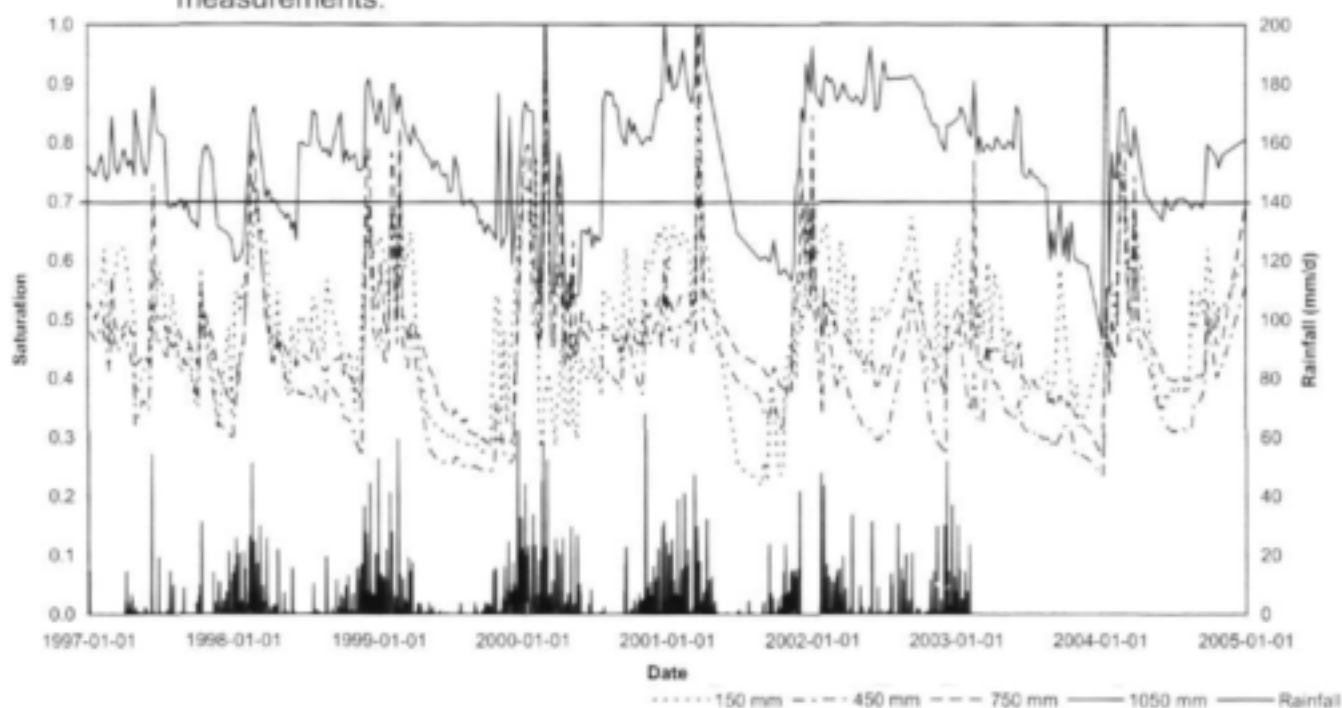


Figure 50 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 234 (Avalon 2100).

Table 52 Profile description for profile 235 (Katspruit 1000)

Profile No: 235	Soil form: Katspruit
Mapphoto: 3125A/B	Soil family: 1000
Latitude & Longitude: 31° 05' 57" S / 28° 20' 02" E	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 274 m	Wind erosion: None
Terrain unit: Lower footslope	Water erosion: None
Slope: 3 %	Vegetation / Land use: Grassveld, wooded
Slope shape: Straight	Water table: None
Aspect: West	Described by: P.A.L. le Roux & W. Boshoff
Microrelief: 1 % mole mounds, 0.2 m height, profile between features	Date described: 19/06/2001
Parent material solon: Origin single, solid rock	Weathering of underlying material: Advanced physical, strong chemical
Underlying material: Feldspathic sandstone	Alteration of underlying material: Ferruginised
Geological Group: Moteng	

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A1	0-250	Moisture status: moist; dry colour: 10YR5/2 (80 %), 2.5YR4/6 (20 %); moist colour: 10YR4/2 (80 %), 2.5YR3/4 (20 %); 10.1 % clay; fine sandy loam; common fine distinct 7.5YR5/6 dry, 2.5YR3/4 moist; iron oxide mottles; apedal massive; soft; loose; non-sticky; non-plastic; many normal fine and very fine pores; common normal medium and coarse pores; no slickensides; no cracks; no cutans; very few 2-6 mm round stones; water absorption 1 second(s); many normal roots; diffuse smooth transition; Remark: Stone line in bottom of A2 horizon.	orthic A horizon
A2	250-490	Moisture status: moist; dry colour: 10YR5/2 (70 %), 5YR5/8 (30 %); moist colour: 10YR4/1 (70 %), 5YR4/4 (30 %); 11.4 % clay; fine sandy loam; common fine prominent 7.5YR4/6 dry, 5YR4/4 moist; iron oxide mottles; apedal massive; slightly hard; friable; slightly sticky; non-plastic; common bleached fine and very fine pores; common bleached medium and coarse pores; no slickensides; no cracks; no cutans; very few 2-6 mm round stones; water absorption 4 second(s); many rusty roots; abrupt wavy transition; Remark: rusty root coating only in A2.	orthic A horizon
G1	490-780	Moisture status: moist; dry colour: 10YR5/1 (50 %), 5YR5/8 (40 %); moist colour: 10YR5/1 (50 %), 5YR4/6 (40 %); 29.5 % clay; sandy clay loam; common fine prominent 2.5YR5/6 dry, 5YR4/6 moist; iron oxide mottles; strong coarse prismatic; very hard; very firm; sticky; plastic; common normal fine and very fine pores; few bleached medium and coarse pores; no slickensides; no cracks; few silica cutans; very few 2-6 mm round stones; water absorption 15 second(s); common normal & bleached roots; clear wavy transition; Remark: Mottles is red in G1 and yellow in G2.	G horizon
G2	780-1200	Moisture status: moist; dry colour: 10YR5/1 (50 %), 5YR5/8 (40 %); moist colour: 10YR5/1 (50 %), 5YR4/6 (40 %); 35.8 % clay; clay loam; common fine prominent 10YR5/1 dry, 10YR5/1 moist; silica mottles; strong coarse prismatic; very hard; very firm; very sticky; very plastic; common normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; few silica cutans; very few 2-6 mm round stones; water absorption 20 second(s); few normal & bleached roots; transition not reached; Remark: Mottles is red in G1 and yellow in G2.	G horizon

Table 53 Soil analyses for profile 235 (Katspruit 1000)

Horizon	Depth (mm)	Diagnostic horizon	Texture of the fine earth								Exchangeable cations					CEC soil	CEC clay	Base sat
			coSa	meSa	fsa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S	cmol/kg			
A1	0-100	ot	3.2	13.6	14.8	20.0	14.3	15.8	11.6	10.2	0.97	0.68	0.10	0.19	1.94	4.30	42.1	45.3
	100-200		7.5	15.3	15.4	19.5	14.3	19.8	7.3	10.0	0.50	0.60	0.07	0.18	1.35	5.00	50.0	27.0
A2	200-300	ot	7.8	15.4	14.2	18.4	14.4	15.6	12.2	11.0	2.33	2.05	0.21	0.24	4.83	13.05	118.6	37.0
	300-400		8.6	11.7	14.3	19.5	17.0	12.5	10.5	11.1	3.15	2.40	0.25	0.26	6.05	12.67	114.1	47.8
G1	400-500	gh	24.8	12.8	14.7	19.9	15.3	18.5	10.0	12.2	1.66	0.71	0.18	0.17	2.72	8.75	71.8	31.1
	500-650		7.9	14.7	12.0	12.4	9.8	9.8	7.2	32.0	3.99	2.34	0.24	0.27	6.85	10.17	31.8	67.3
G2	650-850	gh	4.7	11.5	11.1	16.8	12.1	7.4	11.1	27.0	3.68	2.56	0.19	0.25	6.68	9.25	34.3	72.1
	850-1150		6.3	15.0	12.9	9.9	8.6	9.0	13.0	30.0	0.51	0.52	0.22	0.24	1.49	11.47	38.2	13.0
G2	1150-1400	gh	3.4	7.8	9.1	5.5	5.1	12.4	22.2	36.3	0.51	0.56	0.27	0.23	1.58	10.93	28.5	14.5
	1500+		5.8	10.9	11.6	7.0	10.4	5.7	15.4	39.0	1.75	0.72	0.17	0.21	2.86	8.92	22.9	32.1

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
								CBD		CBD	
	mm	Mg m ⁻³	H ₂ O	KCl	%	mg kg ⁻¹		mg kg ⁻¹			
A1	0-100	1.68	5.45	4.34	1.29	6.79	19.0	6770		6.0	
	100-200		5.53	4.17	0.82	6.22	13.1	6620		7.0	
	200-300		5.47	4.21	0.83	4.97	12.7	6880		6.5	
A2	300-400	1.70	5.51	3.98	0.61	4.01	15.3	7085		6.5	
	400-500		5.52	4.03	0.45	3.66	12.4	1550		6.5	
	500-650		5.87	4.13	0.26	3.92	6.6	7200		6.5	
G1	650-850	1.74	6.32	4.14	0.12	2.25	5.4	4290		8.0	
	850-1150		6.51	4.49	0.06	2.04	3.0	4380		13.0	
G2	1150-1400	1.73	6.77	4.82	0.05	1.94	2.4	4780		14.0	
	1500+		7.00	5.29	0.02	1.62	1.5	4155		16.0	

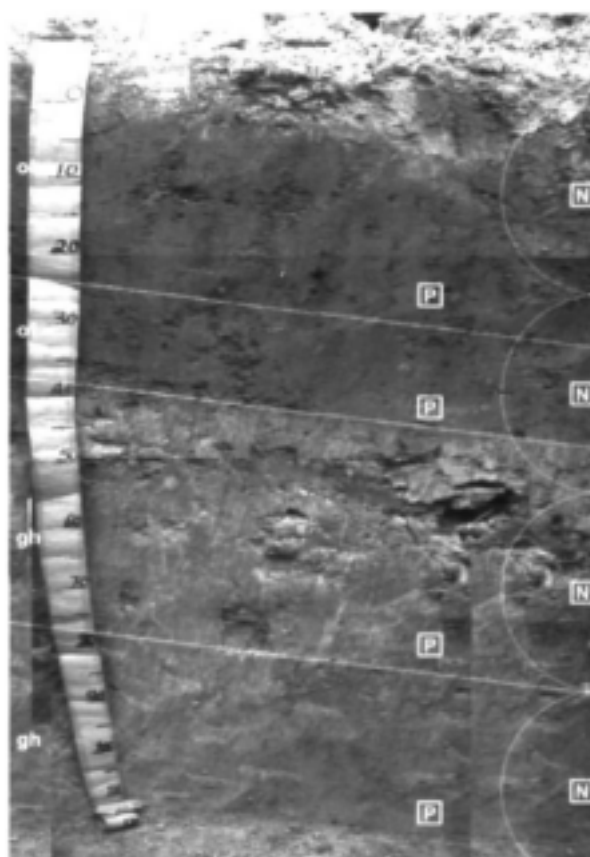


Figure 51 Profile 235 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

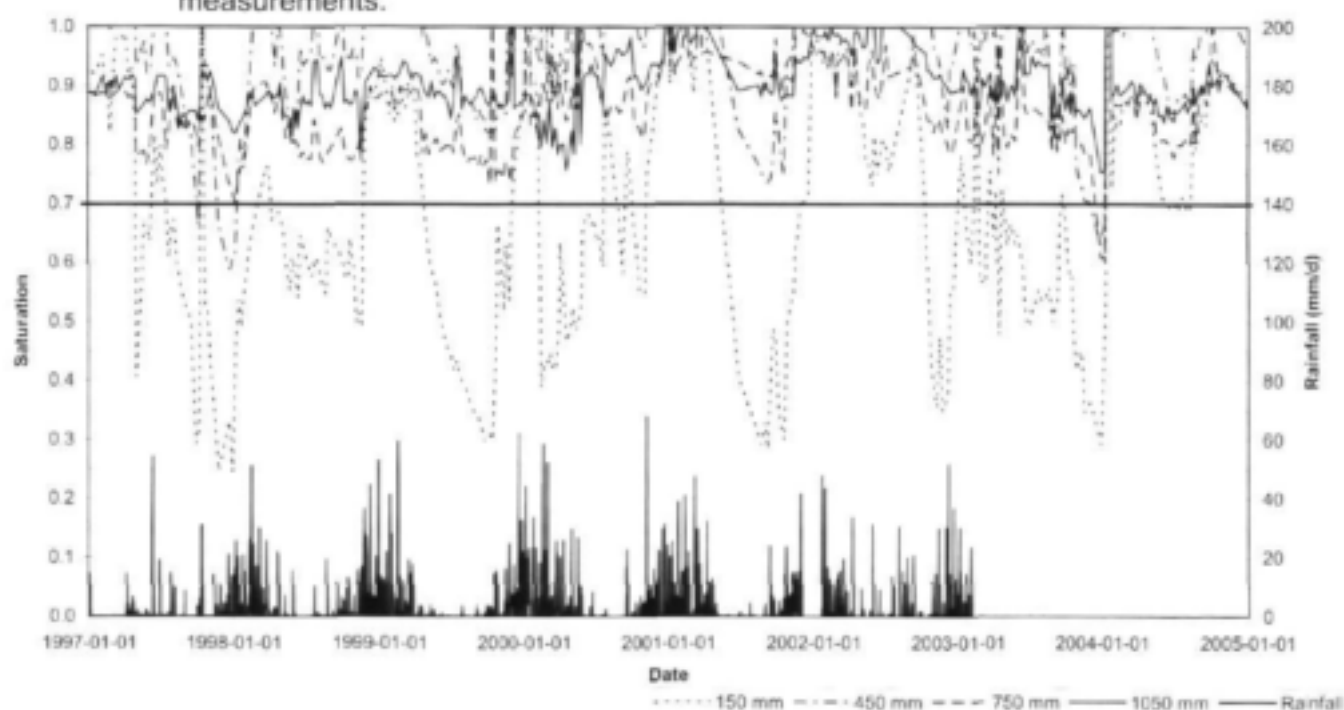


Figure 52 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 235 (Katspruit 1000).

Table 54 Profile description for profile 236 (Katspruit 1000)

Profile No: 236	Soil form: Katspruit
Mapphoto: 3128AB	Soil family: 1000
Latitude & Longitude: 31° 01' 59.8" / 28° 20' 06.1"	Surface rockiness: None
Surface stoniness: None	Occurrence of flooding: None
Altitude: 1 283 m	Wind erosion: None
Terrain unit: Mafic	Water erosion: None
Slope: 5 %	Vegetation / Land use: Grassveld, closed
Slope shape: Straight	Water table: None
Aspect: West	Described by: M. Hensley & M. Smit
Microbiot: None	Date described: 19/06/2001
Parent material (soil): Origin single, solid rock	Weathering of underlying material: Advanced physical, strong chemical
Underlying material: Mafic	Alteration of underlying material: Ferruginised
Geological Group: Moteng	

Horizon	Depth(mm)	Description	Diagnostic horizons / material
A	0 - 500	Moisture status: Wet, dry colour: 10YR5/2 (70 %), 5YR4/6 (30 %) moist colour: 10YR3/1 (70 %), 5YR3/4 (30 %) 15.2 % clay, sandy loam, common fine dotted 5YR4/4 dry, 5YR3/4 moist, iron oxide nodules, weak fine granular, slightly hard, friable, slightly sticky, slightly plastic, few fully fine and very fine pores, few normal medium and coarse pores, no slickensides, no cracks, no cutans, no coarse fragments, water absorption 1 second(s); many normal roots, abrupt smooth transition.	other A horizon
G1	500 - 970	Moisture status: Wet, dry colour: 10YR5/1 (80 %), 10YR5/6 (40 %) moist colour: 10YR5/1 (80 %), 5YR5/6 (40 %) 34.0 % clay, clay loam, many medium prominent 10YR5/6 dry, 5YR5/6 moist, iron oxide nodules, common fine prominent 2.5YR5/6 dry, 2.5YR4/6 moist, iron oxide nodules, strong coarse prismatic, very hard, very firm, sticky, very plastic, few normal fine and very fine pores, few bleached medium and coarse pores, few slickensides, no cracks, very many clay cutans, very few 2-6 mm round stones, very few 6-25 mm round stones, water absorption 10 second(s); few bleached roots, gradual smooth transition.	G horizon
G2	970 - 1650	Moisture status: Wet, dry colour: 10YR7/1 (80 %), 10YR5/6 (20 %) moist colour: 10YR5/1 (80 %), 10YR4/6 (20 %) 28.5 % clay, clay loam, common medium prominent 2.5YR5/6 dry, 2.5YR4/6 moist, iron oxide nodules, few fine prominent 10YR2/1 dry, 10YR2/1 moist, iron oxide nodules, special massive, very hard, very firm, sticky, very plastic, few normal fine and very fine pores, no medium and coarse pores, no slickensides, no cracks, common clay cutans, few 6-25 mm round stones, water absorption 10 second(s); no normal roots, transition not reached.	G horizon

Table 55 Soil analyses for profile 236 (Katspruit 1000)

Horizon	Depth mm	Diagnostic horizon	Gravel %	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
				coSa	meSa	fsa	vsSa	Si	fsi	Cl	Ca	Mg	K	Na	S			
				%							cmol/kg							
A	0-100	at	7.2	18.4	21.4	18.1	12.0	10.3	6.7	10.0	1.22	0.56	0.13	0.13	2.05	5.93	59.3	34.6
	100-200		9.7	21.1	21.7	16.5	12.5	8.3	9.1	9.8	0.72	0.41	0.09	0.14	1.37	4.78	48.8	28.6
	200-300		9.8	19.9	22.2	17.0	13.3	8.6	9.0	6.9	0.58	0.30	0.06	0.16	1.11	4.62	67.0	24.0
	300-370		7.9	18.6	21.8	16.8	14.7	12.6	5.9	9.0	0.76	0.51	0.07	0.14	1.48	3.81	42.3	38.9
	370-400		7.7	19.5	21.1	16.5	14.3	7.6	8.2	13.0	0.82	0.54	0.07	0.11	1.53	4.64	35.7	33.0
G1	400-500	gh	5.1	3.4	4.4	11.1	13.7	17.1	10.5	42.6	1.00	0.53	0.08	0.14	1.76	3.91	9.2	45.0
	500-700		8.6	3.3	7.2	19.4	12.8	16.1	9.4	33.4	4.62	2.60	0.32	0.30	7.84	14.52	43.5	54.0
	700-800		21.7	11.9	10.6	10.1	8.6	7.5	13.1	36.3	4.75	3.89	0.25	0.30	9.19	15.80	43.5	58.2
	800-1000		33.0	19.5	9.4	7.9	6.4	7.5	14.1	32.3	5.35	4.05	0.24	0.28	9.93	11.85	36.7	83.8
G2	1000-1200	gh	2.8	3.4	6.5	11.5	14.4	12.3	18.8	31.2	6.61	4.84	0.24	0.27	11.96	15.56	49.9	76.9
	1200-1400		4.1	1.6	7.0	20.5	17.7	9.9	14.4	25.7	9.29	6.35	0.24	0.29	16.17	17.83	69.4	90.7
C	1400+	so	-	-	-	-	-	-	-	-	6.73	4.33	0.24	0.25	11.55	16.26	-	71.0

Horizon	Depth mm	Bulk density Mg m ⁻³	pH		Org C %	N mg kg ⁻¹	C:N	Fe		Mn	
			H ₂ O	KCl				CBD		CBD	
A	0-100	1.63	5.51	4.20	0.89	522	17.0	6140		15.5	
	100-200		5.72	4.02	0.97	473	20.5	4970		12.0	
	200-300		5.79	4.01	0.85	469	13.9	3060		10.5	
	300-370		5.36	4.06	0.45	419	10.8	1735		10.0	
	370-400		5.70	4.09	0.50	457	11.0	1895		9.5	
G1	400-500	1.71	5.72	4.15	0.47	550	8.5	1785		11.5	
	500-700		6.11	4.21	0.13	279	4.7	6230		11.0	
	700-800		6.24	4.25	0.12	270	4.3	7565		9.5	
	800-1000		6.19	4.13	0.05	203	2.5	7545		12.0	
G2	1000-1200	1.76	6.53	4.48	0.05	193	2.4	5020		12.5	
	1200-1400		6.62	5.16	0.01	152	1.0	7205		9.0	
C	1400+										

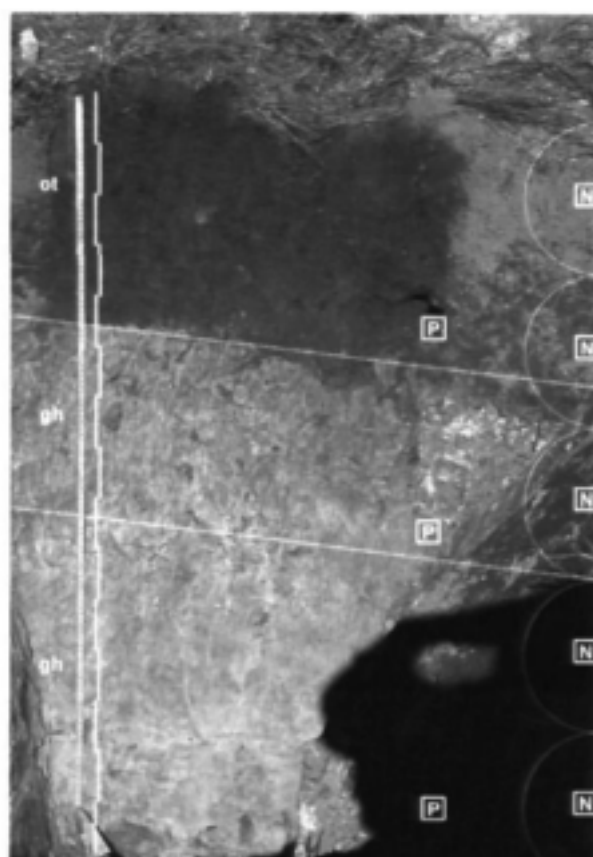


Figure 53 Profile 236 (Katspruit 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

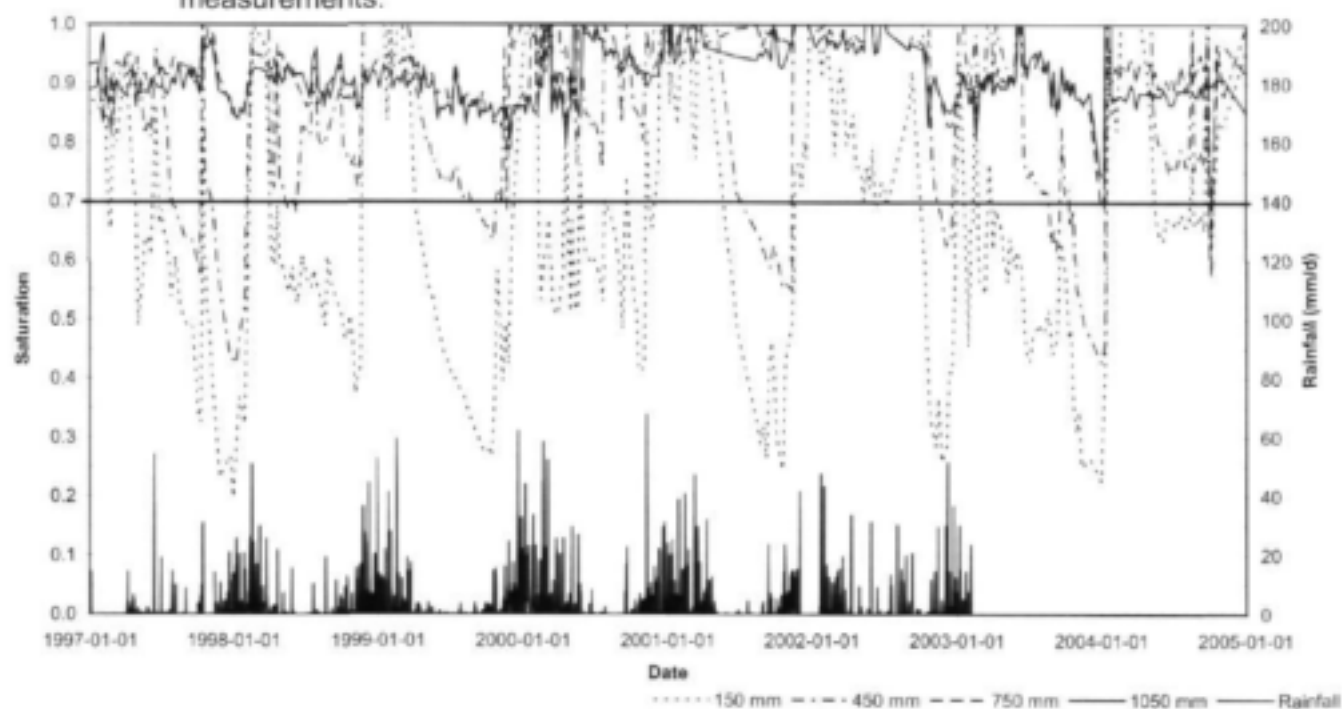


Figure 54 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 236 (Katspruit 1000).

Table 56 Profile description for profile 237 (Westleigh 1000)

Profile No: 237
Mapphoto: 3125AB
Latitude & Longitude: 31° 06' 00" S / 28° 20' 08" E
Surface stoniness: None
Altitude: 1 280 m
Terrain unit: U2011 midslope
Slope: 10 %
Slope aspect: GSWW
Aspect: West
Microrelief: none
Parent material column: Origin binary: local colluvium: solid rock
Underlying material: Mutton
Geological Group: Mutton

Soil form: Westleigh
Soil family: 1000
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation / Land use: Grassveld: closed
Water table: none
Described by: C W van Huyssteen, W Boshoff
Date described: 19/06/2001
Weathering of underlying material: Strong physical: weak chemical
Alteration of underlying material: Ferruginised

Horizon	Depth (mm)	Description	Diagnostic horizons / material
A1	0 - 200	Moisture status: moist; dry colour: 10YR4/1 (80 %); 5YR4/5 (20 %); moist colour: 7.5YR3/0 (80 %); 5YR3/0 (20 %); 8.4 % clay; sandy loam; few fine fast 5YR4/5 dry; 5YR3/0 moist; iron oxide mottles; moderate fine granular hard, friable; non-sticky; plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); common normal roots; clear smooth transition.	orthic A horizon
A2	200 - 500	Moisture status: moist; dry colour: 10YR5/2 (70 %); 5YR4/5 (30 %); moist colour: 7.5YR3/0 (70 %); 5YR3/0 (30 %); 9.6 % clay; sandy loam; common fine fast 5YR4/5 dry; 5YR3/0 moist; iron oxide mottles; common medium fast 5YR4/5 dry; 5YR3/0 moist; iron oxide mottles; weak fine subangular blocky; hard; friable; slightly sticky; plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); common rusty roots; clear smooth transition.	orthic A horizon
B1	500 - 760	Moisture status: moist; dry colour: 10YR5/2 (80 %); 7.5YR4/5 (40 %); moist colour: 7.5YR3/0 (80 %); 7.5YR4/5 (40 %); 40.2 % clay; clay; many coarse distinct 7.5YR4/5 dry; 7.5YR4/5 moist; iron oxide mottles; common medium distinct 7.5YR4/5 dry; 7.5YR4/5 moist; iron oxide mottles; weak fine angular blocky; hard; friable; non-sticky; plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); few bleached roots; clear smooth transition.	soft plastic B horizon
B2	760 - 1100	Moisture status: moist; dry colour: 10YR7/2 (80 %); 10YR5/5 (40 %); moist colour: 7.5YR5/5 (80 %); 10YR5/5 (40 %); 4.4 % clay; clay; coarse sand; many medium prominent 10YR5/5 dry; 10YR5/5 moist; iron oxide mottles; weak fine angular blocky; very hard; friable; slightly sticky; plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 1 second(s); few bleached roots; clear smooth transition.	soft plastic B horizon
B3	500 - 1100	Moisture status: moist; dry colour: 10YR7/1 (80 %); 10YR5/5 (40 %); moist colour: 7.5YR5/5 (80 %); 10YR5/5 (40 %); 5.4 % clay; sandy loam; common medium distinct 10YR5/5 dry; 10YR5/5 moist; iron oxide mottles; weak fine angular blocky; very hard; friable; slightly sticky; plastic; few normal fine and very fine pores; few normal medium and coarse pores; no slickensides; no cracks; no cutans; no coarse fragments; water absorption 2 second(s); few bleached roots; diffuse wavy transition. Remark: The B1 horizon occurs in the left hand side of the profile and wedges out to the middle of the profile. It has a lighter texture than the B2 or B3 horizons. The B3 horizon occupies the same depth as the B1 and B2 horizons.	soft plastic B horizon
C	1100 - 1800	Moisture status: moist; dry colour: 10YR5/5 (40 %); 10YR5/1 (40 %); 2.5YR4/5 (20 %); moist colour: 7.5YR5/5 (40 %); 10YR5/1 (40 %); 2.5YR4/5 (20 %); 23.2 % clay; sandy clay loam; many fine prominent 2.5YR4/5 dry; 2.5YR4/5 moist; greggite mottles; many coarse prominent 10YR5/1 dry; 10YR5/1 moist; reduced iron mottles; strong coarse prismatic; very hard; firm; slightly sticky; very plastic; no fine and very fine pores; no medium and coarse pores; no slickensides; no cracks; many siliceous cutans; no coarse fragments; water absorption 10 second(s); few bleached roots; transition not reached.	unprofiled material with signs of wear

Table 57 Soil analyses for profile 237 (Westleigh 1000)

Horizon	Depth	Diagnostic horizon	Gravel	Texture of the fine earth							Exchangeable cations					CEC soil	CEC clay	Base sat
	mm		%	ccSa	meSa	fsSa	vfSa	Si	fSi	Cl	Ca	Mg	K	Na	S			%
cmol/kg																		
A	0-100	ot	3.2	19.8	27.8	19.1	7.0	10.5	6.7	7.4	1.52	0.73	0.13	0.15	2.54	8.36	86.0	39.9
	100-200		2.1	22.5	27.7	17.5	8.9	7.2	9.2	9.3	1.03	0.57	0.10	0.15	1.85	8.06	84.4	36.5
B1	200-300		2.3	23.5	28.4	17.5	6.8	5.7	8.3	8.7	0.77	0.51	0.09	0.14	1.52	4.50	51.7	33.7
	300-400	sp	4.9	19.7	30.0	18.8	7.3	5.4	8.0	9.6	0.61	0.44	0.10	0.14	1.29	5.45	56.8	23.7
	400-500		7.0	22.1	28.1	18.5	8.0	8.7	4.3	10.4	0.46	0.39	0.07	0.14	1.06	5.00	48.1	21.2
B2	500-600		-	4.7	7.1	12.5	13.4	15.4	3.9	40.2	5.10	2.60	0.28	0.30	8.28	11.87	29.5	69.7
	600-700	sp	2.4	21.7	30.6	19.7	7.6	6.3	6.0	8.4	0.53	0.44	0.05	0.13	1.16	3.21	38.2	36.2
	700-800		5.0	22.6	27.3	18.1	8.8	7.0	8.5	7.3	0.37	0.30	0.03	0.13	0.83	3.03	41.6	27.4
B3	800-900	sp	11.9	25.9	29.6	17.8	9.2	5.8	6.9	4.4	0.26	0.21	0.03	0.13	0.63	1.85	42.0	33.9
C	1100-1200		17.8	22.6	25.5	15.4	8.8	8.0	13.0	5.4	0.55	0.47	0.05	0.14	1.21	2.03	37.7	69.4
	1200-1400	on	23.5	15.1	15.8	10.8	8.3	10.2	14.8	23.2	1.39	1.12	0.13	0.14	2.78	4.68	20.2	69.4

Horizon	Depth	Bulk density	pH		Org C	N	C:N	Fe		Mn	
	mm	Mg m	H ₂ O	KCl	%	mg kg		CBD		CBD	
mg kg											
A	0-100	1.52	5.40	4.35	1.43	722	19.7	4110		12.0	
	100-200		5.65	4.31	0.97	598	16.2	5110		19.5	
	200-300		5.59	4.16	0.80	603	13.3	5600		20.5	
B1	300-400		5.44	4.05	0.55	458	11.9	5860		9.5	
	400-500	1.65	5.25	4.12	0.45	312	14.3	6235		8.5	
	500-600		5.96	4.34	0.26	388	7.1	7045		81.8	
	600-700		5.42	4.43	0.18	231	7.0	6265		19.5	
	700-800	1.74	5.48	4.51	0.07	112	6.6	6145		47.0	
B3	800-900		5.73	4.33	0.05	63	9.7	8240		72.5	
G	1100-1200	1.78	5.95	4.15	0.06	57	11.1	1740		155.5	
	1200-1400	1.79	5.91	4.14	0.08	127	6.2	4110		12.0	

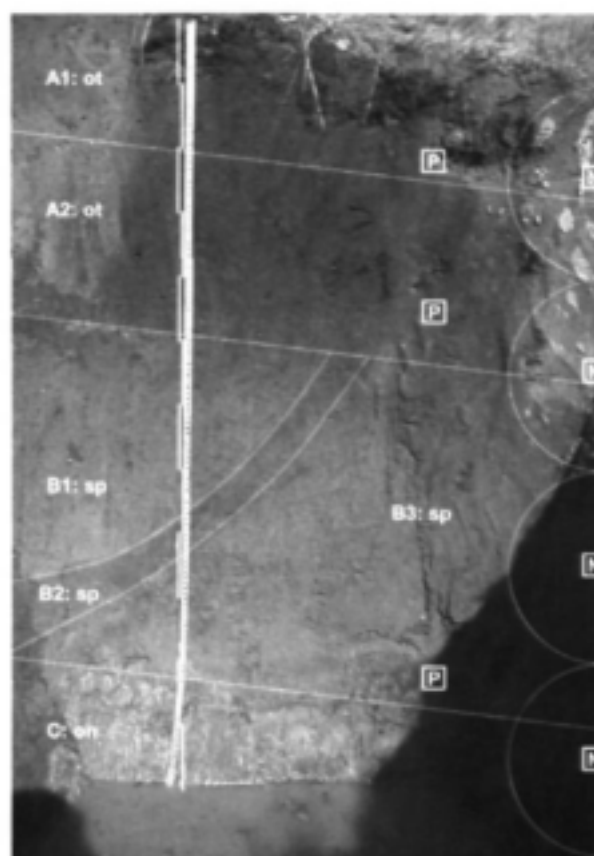


Figure 55 Profile 237 (Westleigh 1000), indicating diagnostic horizons as well as measurement depths for neutron water meter [N] and piezometers [P] measurements.

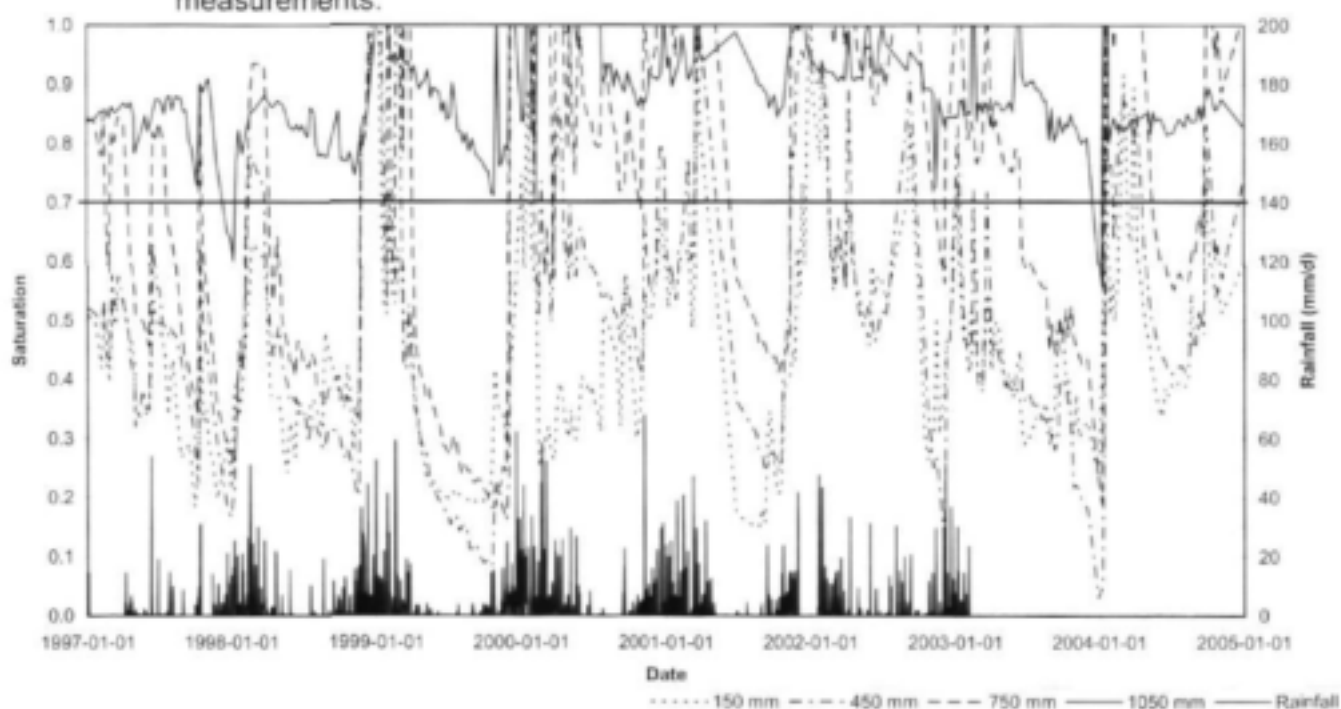


Figure 56 Degree of water saturation and daily rainfall from 1 January 1997 until 31 December 2004 for profile 237 (Westleigh 1000).

Appendix B

Annual duration, frequency and duration of $s > 0.7$ events
for profiles 201 to 237, over 7 years

Table 1 Annual duration of $s > 0.7$, for profiles 201 to 237, calculated from weekly neutron water meter data from 01/07/1997 until 30/06/2003

Profile No.	Depth (mm)	Diag horizon	97/98	98/99	99/00	00/01	01/02	02/03	Total	Mean	Median	Std. dev
(days year ⁻¹)												
201	160	ot	1	8	85	6	0	0	100	3.5	16.7	33.6
	460	gs	20	36	142	28	8	0	234	24.0	39.0	52.1
	760	sp	45	80	169	99	85	35	513	82.5	85.5	47.7
202	190	ot	0	1	1	2	0	0	4	0.5	0.7	0.8
	490	ye	0	4	9	5	0	0	18	2.0	3.0	3.7
	790	ye	189	241	184	361	226	289	1490	233.5	248.3	67.2
	1090	on	365	365	324	365	365	365	2149	365.0	358.2	16.7
	1390	on	365	365	299	365	365	365	2124	365.0	354.0	26.9
203	190	ot	1	1	0	1	0	0	3	0.5	0.5	0.5
	490	ne	1	7	18	13	2	1	42	4.5	7.0	7.1
	790	ne	1	8	20	13	3	3	48	5.5	8.0	7.3
	1090	on	32	45	130	228	192	139	766	134.5	127.7	77.9
	1390	on	11	29	127	203	181	73	624	100.0	104.0	79.4
204	220	ot/gs	22	127	164	137	61	45	556	94.0	92.7	57.4
	520	sp	80	135	189	200	112	95	811	123.5	135.2	49.6
	820	gh	155	276	122	335	226	355	1469	251.0	244.8	94.6
	1120	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
205	230	ot	19	38	104	71	23	4	259	30.5	43.2	37.5
	530	gs	39	52	171	119	41	1	423	46.5	70.5	62.4
	830	gh	172	286	197	320	233	255	1463	244.0	243.8	55.1
	1130	gh	352	365	330	365	365	365	2142	365.0	357.0	14.2
	1430	gh	365	365	366	365	365	365	2184	365.0	364.0	3.0
206	170	ot	337	267	307	319	332	306	1868	313.0	311.3	25.1
	470	gs	361	363	366	365	365	365	2185	365.0	364.2	1.8
	770	gs	365	365	361	365	365	365	2186	365.0	364.3	1.6
	1070	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
207	180	ot	89	123	211	273	197	196	1089	196.5	181.5	65.8
	480	sp	228	158	76	302	231	256	1251	229.5	208.5	80.0
208	205	ot	102	147	213	256	218	144	1080	180.0	180.0	57.9
	505	gs	134	97	33	192	265	131	852	132.5	142.0	79.6
	805	gh	83	133	16	288	273	198	991	165.5	165.2	107.5
	1105	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1405	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
209	230	ot	103	213	213	324	232	141	1226	213.0	204.3	76.8
	530	ot/gh	306	365	195	253	365	263	1747	284.5	291.2	67.3
210	190	ot	0	1	1	4	1	0	7	1.0	1.2	1.5
	490	ne	4	16	161	127	52	39	399	45.5	66.5	63.3
	790	ne	39	50	186	228	131	86	720	108.5	120.0	75.8
	1090	on	286	365	337	363	357	357	2045	357.0	340.8	38.0
	1390	on	166	91	173	310	358	153	1251	169.5	208.5	102.6
211	200	ot/gh	43	140	206	230	223	292	1134	214.5	189.0	86.5
	500	gh	300	361	342	365	365	365	2098	363.0	349.7	25.9
	800	gh	349	365	260	339	365	365	2043	357.0	340.5	40.9
	1100	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
212	200	ot	2	3	7	4	1	0	17	2.5	2.8	2.5
	500	ne	0	0	2	1	0	0	3	0.0	0.5	0.8
	800	ne	0	4	5	2	0	0	11	1.0	1.8	2.2
	1100	ne	0	4	3	2	0	0	9	1.0	1.5	1.8
	1400	on	0	5	13	7	3	0	28	4.0	4.7	4.9
213	180	ot	39	97	191	179	162	192	860	170.5	143.3	62.1
	480	ot/gh	157	149	200	286	236	264	1292	218.0	215.3	56.3
	780	gh	212	198	19	293	343	159	1224	205.0	204.0	112.8
	1080	gh	294	307	118	339	365	365	1788	323.0	298.0	92.9
	1380	gh	351	344	345	365	365	365	2135	358.0	355.8	10.3
218	200	ot	87	143	225	254	243	177	1129	201.0	188.2	65.0
	500	gh	247	310	250	287	297	331	1722	292.0	287.0	33.3
	800	gh	337	365	354	365	329	365	2115	359.5	352.5	15.9
	1100	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1400	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
220	175	ot	33	68	180	153	88	73	595	80.5	99.2	55.8
	475	ot	105	106	207	210	193	110	931	151.5	155.2	53.1
	775	re	0	0	0	0	0	0	0	0.0	0.0	0.0
	1075	on	6	0	0	121	14	8	149	7.0	24.8	47.4
	1375	on	280	321	71	320	360	279	1631	300.0	271.8	102.9
221	140	ot	19	92	191	141	105	81	629	98.5	104.8	58.0
	440	re	0	1	48	1	0	0	50	0.5	6.3	19.4
	740	re	0	0	92	4	0	0	96	0.0	16.0	37.3
	1040	re	0	5	127	115	5	17	269	11.0	44.8	59.4
	1340	on	0	11	20	121	6	8	166	9.5	27.7	46.2

Profile No.	Depth (mm)	Diag. horizon	97/98	98/99	99/00	00/01	01/02	02/03	Total	Mean	Median	Std. dev.
(days year ⁻¹)												
222	180	ot	54	98	157	167	174	175	869	170.5	144.8	56.0
	480	ne	10	48	169	181	97	63	568	80.0	94.7	66.3
	780	ne	41	109	185	256	223	143	957	164.0	159.5	78.6
	1080	on	365	365	365	358	365	365	2184	365.0	364.0	3.0
225	220	ot	5	37	43	95	38	12	230	37.5	38.3	31.7
	520	ot/gs	46	145	164	268	198	112	933	154.5	155.5	75.5
	820	gs	92	130	161	214	112	40	749	121.0	124.8	59.5
	1120	sp	203	188	180	357	273	237	1438	220.0	239.7	67.0
	1420	so	240	180	118	365	359	270	1532	255.0	255.3	97.7
226	190	ot	126	357	297	290	246	200	1516	268.0	252.7	81.4
	490	gs	310	365	363	355	365	357	2115	360.0	352.5	21.2
	790	gh	328	365	270	338	365	365	2031	351.5	338.5	37.2
	1090	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1390	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
229	225	ot	162	197	219	305	248	258	1389	233.5	231.5	50.1
	525	ot/gs	358	365	319	329	359	365	2095	358.5	349.2	20.0
	825	gs	365	365	347	325	359	365	2126	362.0	354.3	16.0
	1125	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
230	150	ot	42	111	206	207	223	185	974	195.5	182.3	71.0
	450	sp	70	94	60	129	166	67	586	82.0	97.7	41.9
	750	gh	263	354	243	339	285	357	1841	312.0	306.8	49.5
	1050	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1350	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
231	150	ot	50	136	214	250	207	174	1031	190.5	171.8	71.1
	450	sp	177	167	102	280	348	253	1327	215.0	221.2	89.0
	750	gh	163	173	81	309	314	246	1306	214.5	217.7	89.8
	1050	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1350	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
232	230	ot	48	100	162	120	74	32	536	87.0	89.3	48.1
	530	sp	157	141	198	256	166	164	1082	165.0	180.3	41.5
	830	sp	121	162	173	339	233	296	1324	203.0	220.7	84.2
	1130	gh	365	365	304	358	365	365	2122	365.0	353.7	24.5
233	190	ot	3	16	54	18	1	1	93	9.5	15.5	20.3
	490	ye	14	26	78	41	5	9	173	20.0	28.8	27.4
	790	on	365	365	366	365	360	365	2186	365.0	364.3	2.2
	1090	on	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1390	on	365	365	366	365	365	365	2191	365.0	365.2	0.4
234	210	ot	20	28	80	27	5	4	164	23.5	27.3	27.6
	510	ot	29	35	97	23	6	0	190	26.0	31.7	34.7
	810	ye	35	52	128	52	22	5	294	43.5	49.0	42.7
	1110	ye	119	359	204	361	220	354	1617	267.0	269.5	102.9
	1410	sp/on	256	365	282	361	220	365	1649	321.5	308.2	63.9
235	185	ot	68	154	201	218	203	147	991	177.5	185.2	55.5
	485	ot	301	365	364	365	353	365	2113	364.5	352.2	25.5
	785	ot/gh	357	365	346	365	365	365	2163	365.0	360.5	7.8
	1085	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1385	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
236	190	ot	62	132	190	180	192	116	872	156.0	145.3	51.7
	490	ot/gh	134	351	178	304	227	305	1499	265.5	249.8	84.0
	790	gh	365	365	277	339	365	365	2076	365.0	348.0	35.4
	1090	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
	1390	gh	365	365	366	365	365	365	2191	365.0	365.2	0.4
237	210	ot	16	55	110	57	51	26	315	53.0	52.5	32.8
	510	ot/sp	44	89	192	179	110	79	693	99.5	115.5	58.4
	810	sp	79	131	165	310	226	323	1234	195.5	205.7	98.3
	1110	sp	342	365	366	365	365	365	2168	365.0	361.3	9.5
	1410	on	365	365	366	365	365	365	2191	365.0	365.2	0.4

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

Profile No.	Depth (mm)	Diag. horizon	97/98	98/99	99/00	00/01	01/02	02/03	Mean	Median	Std. dev
(events year ⁻¹)											
201	160	ot	1	3	11	1	0	0	2.7	1.0	4.2
	460	gs	3	10	11	7	2	0	5.5	5.0	4.5
	760	sp	2	7	5	4	1	2	3.5	3.0	2.3
202	190	ot	0	1	1	2	0	0	0.7	0.5	0.8
	490	ye	0	4	9	5	0	0	3.0	2.0	3.7
	790	ye	8	9	2	1	1	6	4.5	4.0	3.6
	1090	on	1	1	4	1	1	1	1.5	1.0	1.2
	1390	on	1	1	3	1	1	1	1.3	1.0	0.8
203	190	ot	1	1	0	1	0	0	0.5	0.5	0.5
	490	ne	1	6	17	10	2	1	6.2	4.0	6.4
	790	ne	1	8	20	12	3	3	7.8	5.5	7.2
	1090	on	4	5	9	3	3	5	4.8	4.5	2.2
	1390	on	2	5	9	6	7	4	5.5	5.5	2.4
204	220	ot/gh	5	2	4	6	3	2	3.7	3.5	1.6
	520	sp	4	2	5	4	4	5	4.0	4.0	1.1
	820	gh	5	6	3	1	1	2	3.0	2.5	2.1
	1120	gh	1	1	1	1	1	1	1.0	1.0	0.0
205	230	ot	4	8	11	14	7	3	7.8	7.5	4.2
	530	gs	3	6	8	10	9	1	6.2	7.0	3.5
	830	gh	10	12	9	1	2	10	7.3	9.5	4.6
	1130	gh	2	1	4	1	1	1	1.7	1.0	1.2
	1430	gh	1	1	1	1	2	1	1.2	1.0	0.4
206	170	ot	10	20	12	9	8	11	11.7	10.5	4.3
	470	gs	2	2	1	1	1	1	1.3	1.0	0.5
	770	gs	1	1	5	1	1	1	1.7	1.0	1.6
	1070	gh	1	1	1	1	1	1	1.0	1.0	0.0
207	180	ot	10	5	6	9	11	15	9.3	9.5	3.6
	480	sp	4	2	2	2	1	9	3.3	2.0	2.9
208	205	ot	6	1	1	3	5	13	4.8	4.0	4.5
	505	gs	5	12	4	7	7	8	7.2	7.0	2.8
	805	gh	7	7	2	6	4	8	5.7	6.5	2.3
	1105	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1405	gh	1	1	1	1	1	1	1.0	1.0	0.0
209	230	ot	12	10	6	5	2	10	7.5	8.0	3.8
	530	ot/gh	4	1	4	2	1	3	2.5	2.5	1.4
210	190	ot	0	1	1	3	1	0	1.0	1.0	1.1
	490	ne	3	7	8	16	14	3	8.5	7.5	5.5
	790	ne	5	9	6	14	18	4	9.3	7.5	5.6
	1090	on	5	1	5	2	2	2	2.8	2.0	1.7
	1390	on	6	13	6	5	2	4	6.0	5.5	3.7
211	200	ot/gh	6	7	7	10	4	8	7.0	7.0	2.0
	500	gh	6	2	9	1	1	1	3.3	1.5	3.4
	800	gh	4	1	1	1	1	1	1.5	1.0	1.2
	1100	gh	1	1	1	1	1	1	1.0	1.0	0.0
212	200	ot	1	2	6	3	1	0	2.2	1.5	2.1
	500	ne	0	0	2	1	0	0	0.5	0.0	0.8
	800	ne	0	4	5	2	0	0	1.8	1.0	2.2
	1100	ne	0	4	3	2	0	0	1.5	1.0	1.8
	1400	on	0	5	13	6	3	0	4.5	4.0	4.8
213	180	ot	6	10	11	10	12	17	11.0	10.5	3.6
	480	ot/gh	7	3	12	9	4	25	10.0	8.0	8.0
	780	gh	10	6	1	6	3	8	5.7	6.0	3.3
	1080	gh	4	6	2	1	1	1	2.5	1.5	2.1
	1380	gh	3	4	3	1	1	1	2.2	2.0	1.3
218	200	ot	5	3	3	4	5	13	5.5	4.5	3.8
	500	gh	5	11	12	5	10	6	8.2	8.0	3.2
	800	gh	5	1	4	1	2	1	2.3	1.5	1.8
	1100	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1400	gh	1	1	1	1	1	1	1.0	1.0	0.0
220	175	ot	6	11	14	14	18	8	11.8	12.5	4.4
	475	ot	18	18	14	17	20	12	16.5	17.5	2.9
	775	re	0	0	0	0	0	0	0.0	0.0	0.0
	1075	on	1	0	0	3	1	1	1.0	1.0	1.1
	1375	on	7	6	5	4	2	8	5.3	5.5	2.2
221	140	ot	6	14	16	11	9	11	11.2	11.0	3.5
	440	re	0	1	14	1	0	0	2.7	0.5	5.6
	740	re	0	0	11	2	0	0	2.2	0.0	4.4
	1040	re	0	1	2	6	1	2	2.0	1.5	2.1
	1340	on	0	1	2	3	1	1	1.3	1.0	1.0

Profile No.	Depth (mm)	Diag. horizon	97/98	98/99	99/00	00/01	01/02	02/03	Mean	Median	Std. dev.
			(events year ⁻¹)								
222	180	ot	12	10	8	7	10	16	10.5	10.0	3.2
	480	ne	4	10	7	9	18	5	8.8	8.0	5.0
	780	ne	6	7	6	5	3	6	5.5	6.0	1.4
	1080	on	1	1	1	2	1	1	1.2	1.0	0.4
225	220	ot	2	6	9	16	14	4	8.5	7.5	5.6
	520	ot/gs	1	1	6	12	5	7	5.3	5.5	4.1
	820	gs	6	1	3	6	3	2	3.5	3.0	2.1
	1120	sp	4	5	6	2	3	5	4.2	4.5	1.5
	1420	so	3	1	6	1	2	4	2.8	2.5	1.9
226	190	ot	17	2	10	2	6	9	7.7	7.5	5.7
	490	gs	3	1	4	7	1	8	4.0	3.5	3.0
	790	gh	2	1	3	2	1	1	1.7	1.5	0.8
	1090	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1390	gh	1	1	1	1	1	1	1.0	1.0	0.0
229	225	ot	7	8	3	4	1	13	6.0	5.5	4.3
	525	ot/gs	2	1	8	2	2	1	2.7	2.0	2.7
	825	gs	1	1	7	4	2	1	2.7	1.5	2.4
	1125	gh	1	1	1	1	1	1	1.0	1.0	0.0
230	150	ot	6	19	9	8	6	20	11.3	8.5	6.4
	450	sp	5	5	2	8	11	5	6.0	5.0	3.1
	750	gh	6	3	5	1	5	2	3.7	4.0	2.0
	1050	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1350	gh	1	1	1	1	1	1	1.0	1.0	0.0
231	150	ot	7	6	4	8	5	16	7.7	6.5	4.3
	450	sp	5	8	10	8	3	12	7.7	8.0	3.3
	750	gh	3	4	2	6	7	7	4.8	5.0	2.1
	1050	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1350	gh	1	1	1	1	1	1	1.0	1.0	0.0
232	230	ot	3	5	5	12	11	5	6.8	5.0	3.7
	530	sp	10	2	6	7	4	8	6.2	6.5	2.9
	830	sp	3	3	3	4	2	8	3.8	3.0	2.1
	1130	gh	1	1	4	2	1	1	1.7	1.0	1.2
	1430	gh	1	1	1	2	1	1	1.2	1.0	0.4
233	190	ot	2	4	8	5	1	1	3.5	3.0	2.7
	490	ye	7	6	10	11	4	6	7.3	6.5	2.7
	790	on	1	1	1	1	2	1	1.2	1.0	0.4
	1090	on	1	1	1	1	1	1	1.0	1.0	0.0
	1390	on	1	1	1	1	1	1	1.0	1.0	0.0
234	210	ot	5	8	13	10	4	3	7.2	6.5	3.9
	510	ot	4	7	21	6	2	0	6.7	5.0	7.5
	810	ye	6	8	20	14	8	1	9.5	8.0	6.6
	1110	ye	5	2	7	1	1	3	3.2	2.5	2.4
	1410	sp/on	9	1	8	1	1	1	3.5	1.0	3.9
235	185	ot	12	3	5	6	9	14	6.2	7.5	4.3
	485	ot	5	1	3	1	3	1	2.3	2.0	1.6
	785	ot/gh	4	1	2	1	1	1	1.7	1.0	1.2
	1085	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1385	gh	1	1	1	1	1	1	1.0	1.0	0.0
236	190	ot	3	2	3	5	10	10	5.5	4.0	3.6
	490	ot/gh	9	4	18	2	2	2	6.2	3.0	6.4
	790	gh	1	1	2	1	1	1	1.2	1.0	0.4
	1090	gh	1	1	1	1	1	1	1.0	1.0	0.0
	1390	gh	1	1	1	1	1	1	1.0	1.0	0.0
237	210	ot	5	9	12	5	7	5	7.2	6.0	2.9
	510	ot/sp	1	3	2	7	4	4	3.5	3.5	2.1
	810	sp	3	1	15	4	1	3	4.5	3.0	5.3
	1110	sp	2	1	1	1	1	1	1.2	1.0	0.4
	1410	on	1	1	1	1	1	1	1.0	1.0	0.0

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

Profile No.	Depth (mm)	Diag. horizon	97/98	98/99	99/00	00/01	01/02	02/03	Mean	Median	Std. dev
(days event ⁻¹)											
201	160	ot	1.0	2.7	7.7	6.0	0.0	0.0	2.9	1.8	3.3
	460	gs	6.7	3.6	12.9	4.0	4.0	0.0	5.2	4.0	4.3
	760	sp	22.5	11.4	33.8	24.8	85.0	17.5	32.5	23.6	26.8
202	190	ot	0.0	1.0	1.0	1.0	0.0	0.0	0.5	0.5	0.5
	490	ye	0.0	1.0	1.0	1.0	0.0	0.0	0.5	0.5	0.5
	790	ye	23.6	26.8	92.0	361.0	226.0	48.2	129.6	70.1	136.2
	1090	on	365.0	365.0	81.0	365.0	365.0	365.0	317.7	365.0	115.9
	1390	on	365.0	365.0	99.7	365.0	365.0	365.0	320.8	365.0	108.3
203	190	ot	1.0	1.0	0.0	1.0	0.0	0.0	0.5	0.5	0.5
	490	ne	1.0	1.2	1.1	1.3	1.0	1.0	1.1	1.0	0.1
	790	ne	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	0.0
	1090	on	8.0	9.0	14.4	76.0	64.0	27.8	33.2	21.1	29.6
	1390	on	5.5	5.8	14.1	33.8	25.9	18.3	17.2	16.2	11.2
204	220	ot/gs	4.4	63.5	41.0	22.8	20.3	22.5	29.1	22.7	20.5
	520	sp	20.0	67.5	37.8	50.0	28.0	19.0	37.1	32.9	18.9
	820	gh	31.0	46.0	40.7	335.0	226.0	177.5	142.7	111.8	124.4
	1120	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
205	230	ot	4.8	4.8	9.5	5.1	3.3	1.3	4.8	4.8	2.7
	530	gs	13.0	8.7	21.4	11.9	4.6	1.0	10.1	10.3	7.1
	830	gh	17.2	23.8	21.9	320.0	116.5	25.5	87.5	24.7	120.0
	1130	gh	176.0	365.0	82.5	365.0	365.0	365.0	286.4	365.0	125.3
	1430	gh	365.0	365.0	366.0	365.0	179.0	365.0	334.2	365.0	76.0
206	170	ot	33.7	13.4	25.8	35.4	41.5	27.8	29.6	30.8	9.8
	470	gs	180.5	181.5	366.0	365.0	365.0	365.0	303.8	365.0	95.1
	770	gs	365.0	365.0	72.2	365.0	365.0	365.0	316.2	365.0	119.5
	1070	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
207	180	ot	8.9	24.6	35.2	30.3	17.9	13.1	21.7	21.3	10.2
	480	sp	57.0	79.0	38.0	151.0	231.0	28.4	97.4	68.0	78.7
208	205	ot	17.0	147.0	213.0	85.3	43.6	11.1	86.2	64.5	80.0
	505	gs	26.8	8.1	8.3	27.4	37.9	16.4	20.8	21.6	11.9
	805	gh	11.9	19.0	8.0	48.0	68.3	24.8	30.0	21.9	23.4
	1105	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1405	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
209	230	ot	8.6	21.3	35.5	64.8	116.0	14.1	43.4	28.4	40.9
	530	ot/gh	76.5	365.0	48.8	126.5	365.0	87.7	178.2	107.1	146.8
210	190	ot	0.0	1.0	1.0	1.3	1.0	0.0	0.7	1.0	0.6
	490	ne	1.3	2.3	20.1	7.9	3.7	13.0	8.1	5.8	7.3
	790	ne	7.8	5.6	31.0	16.3	7.3	21.5	14.9	12.0	10.0
	1090	on	53.2	365.0	67.4	181.5	178.5	178.5	170.7	178.5	111.8
	1390	on	27.7	7.0	28.8	62.0	179.0	38.3	57.1	33.5	62.3
211	200	ot/gh	7.2	20.0	29.4	23.0	55.8	36.5	28.6	26.2	16.5
	500	gh	50.0	180.5	38.0	365.0	365.0	365.0	227.3	272.8	159.0
	800	gh	87.3	365.0	280.0	339.0	365.0	365.0	296.9	352.0	110.5
	1100	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
212	200	ot	2.0	1.5	1.2	1.3	1.0	0.0	1.2	1.3	0.7
	500	ne	0.0	0.0	1.0	1.0	0.0	0.0	0.3	0.0	0.5
	800	ne	0.0	1.0	1.0	1.0	0.0	0.0	0.5	0.5	0.5
	1100	ne	0.0	1.0	1.0	1.0	0.0	0.0	0.5	0.5	0.5
	1400	on	0.0	1.0	1.0	1.2	1.0	0.0	0.7	1.0	0.5
213	180	ot	6.5	9.7	17.4	17.9	13.5	11.3	12.7	12.4	4.4
	480	ot/gh	22.4	49.7	16.7	31.8	59.0	10.6	31.7	27.1	19.1
	780	gh	21.2	33.0	19.0	48.8	114.3	19.9	42.7	27.1	36.9
	1080	gh	73.5	51.2	59.0	339.0	365.0	365.0	208.8	206.3	162.1
	1380	gh	117.0	86.0	115.0	365.0	365.0	365.0	235.5	241.0	142.3
218	200	ot	17.4	47.7	75.0	63.5	48.6	13.6	44.3	48.1	24.5
	500	gh	49.4	28.2	20.8	57.4	29.7	55.2	40.1	39.6	15.7
	800	gh	67.4	365.0	88.5	365.0	164.5	365.0	235.9	264.8	145.1
	1100	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1400	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
220	175	ot	5.5	6.2	12.9	10.9	4.9	9.1	8.2	7.7	3.2
	475	ot	5.8	5.9	14.8	12.4	9.7	9.2	9.6	9.4	3.5
	775	re	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1075	on	6.0	0.0	0.0	40.3	14.0	8.0	11.4	7.0	15.1
	1375	on	40.0	53.5	14.2	80.0	180.0	34.9	67.1	46.8	59.4

Profile No.	Depth (mm)	Diag horizon	97/98	98/99	99/00	00/01	01/02	02/03	Mean	Median	Std dev
(days event)											
221	140	ot	3.2	6.6	11.9	12.8	11.7	7.4	8.9	9.5	3.8
	440	re	0.0	1.0	3.4	1.0	0.0	0.0	0.9	0.5	1.3
	740	re	0.0	0.0	8.4	2.0	0.0	0.0	1.7	0.0	3.3
	1040	re	0.0	5.0	63.5	19.2	5.0	8.5	16.9	6.8	23.7
	1340	on	0.0	11.0	10.0	40.3	6.0	8.0	12.6	9.0	14.2
222	180	ot	4.5	9.8	24.6	23.9	17.4	11.2	15.2	14.3	8.1
	480	re	2.5	4.8	24.1	20.1	5.4	12.6	11.6	9.0	8.9
	780	re	6.8	15.6	30.8	51.2	74.3	23.8	33.8	27.3	25.0
	1080	on	365.0	365.0	366.0	179.0	365.0	365.0	334.2	365.0	76.0
225	220	ot	2.5	6.2	4.8	5.9	2.7	3.0	4.2	3.9	1.7
	520	ot/gh	46.0	145.0	27.3	22.3	39.6	16.0	49.4	33.5	48.1
	820	gs	15.3	130.0	53.7	35.7	37.3	20.0	48.7	36.5	42.1
	1120	sp	50.8	37.6	30.0	178.5	91.0	47.4	72.5	49.1	56.0
	1420	so	80.0	180.0	19.7	365.0	179.5	67.5	148.6	129.8	123.8
226	190	ot	7.4	178.5	29.7	145.0	41.0	22.2	70.6	35.4	72.2
	490	gs	103.3	365.0	90.8	50.7	365.0	44.6	189.9	97.0	152.8
	790	gh	164.0	365.0	90.0	169.0	365.0	365.0	253.0	267.0	125.8
	1090	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1390	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
229	225	ot	23.1	24.6	73.0	76.3	248.0	19.8	77.5	48.8	87.4
	525	ot/gh	179.0	365.0	39.9	164.5	179.5	365.0	215.5	179.3	127.1
	825	gs	365.0	365.0	49.6	81.3	179.5	365.0	234.2	272.3	149.5
	1125	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
230	150	ot	7.0	5.8	22.9	25.9	37.2	9.3	18.0	16.1	12.6
	450	sp	14.0	18.8	30.0	16.1	15.1	13.4	17.9	15.6	6.2
	750	gh	43.8	118.0	48.6	339.0	57.0	178.5	130.8	87.5	114.5
	1050	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1350	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
231	150	ot	7.1	22.7	53.5	31.3	41.4	10.9	27.8	27.0	17.9
	450	sp	35.4	20.9	10.2	35.0	116.0	21.1	39.8	28.0	38.6
	750	gh	61.0	43.3	40.5	51.5	44.9	35.1	46.0	44.1	9.1
	1050	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1350	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
232	230	ot	16.0	20.0	32.4	10.0	6.7	6.4	15.3	13.0	10.0
	530	sp	15.7	70.5	33.0	36.6	41.5	20.5	36.3	34.8	19.4
	830	sp	40.3	54.0	57.7	84.8	116.5	37.0	65.0	55.8	30.4
	1130	gh	365.0	365.0	76.0	179.0	365.0	365.0	285.8	365.0	126.9
	1430	gh	365.0	365.0	366.0	182.0	365.0	365.0	334.7	365.0	74.8
233	190	ot	1.5	4.0	6.8	3.6	1.0	1.0	3.0	2.6	2.3
	490	ye	2.0	4.3	7.8	3.7	1.3	1.5	3.4	2.9	2.5
	790	on	365.0	365.0	366.0	365.0	180.0	365.0	334.3	365.0	75.6
	1090	on	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1390	on	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
234	210	ot	4.0	3.5	6.2	2.7	1.3	1.3	3.2	3.1	1.8
	510	ot	7.3	5.0	4.6	3.8	3.0	0.0	4.0	4.2	2.4
	810	ye	5.8	6.5	6.4	3.7	2.8	5.0	5.0	5.4	1.5
	1110	ye	23.8	179.5	29.1	361.0	220.0	118.0	155.2	148.8	127.8
	1410	sp/on	28.4	365.0	35.3	361.0	220.0	365.0	229.1	290.5	162.6
235	185	ot	5.7	51.3	40.2	36.3	22.6	10.5	27.8	29.4	17.9
	485	ot	60.2	365.0	121.3	365.0	117.7	365.0	232.4	243.2	146.9
	785	ot/gh	89.3	365.0	173.0	365.0	365.0	365.0	287.0	365.0	123.6
	1085	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1385	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
236	190	ot	20.7	66.0	83.3	36.0	19.2	11.6	38.1	28.3	23.5
	490	ot/gh	14.9	87.8	9.9	152.0	113.5	152.5	88.4	100.6	63.8
	790	gh	365.0	365.0	138.5	339.0	365.0	365.0	322.9	365.0	90.9
	1090	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
	1390	gh	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4
237	210	ot	3.2	6.1	9.2	11.4	7.3	5.2	7.1	6.7	2.9
	510	ot/sp	44.0	29.7	96.0	25.6	27.5	19.8	40.4	28.6	28.4
	810	sp	26.3	131.0	11.0	77.5	226.0	107.7	96.6	92.6	78.3
	1110	sp	171.0	365.0	366.0	365.0	365.0	365.0	332.8	365.0	79.3
	1410	on	365.0	365.0	366.0	365.0	365.0	365.0	365.2	365.0	0.4

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Hydraulic properties of stony soils

Van Deventer PW; Bennie ATP; Hatting JM

The hydraulic conductivity of the soil used in this investigation, decreased with increasing stone contents until it reached a specific threshold stone content and then increased for higher stone contents due to the formation of preferential flow paths around the stones. Because of the limited number of tests (21) of this study, the stone contents where preferential flow started to become important was ill-defined between 40 and 70%). Therefore it was suggested that the threshold value can be taken at a stone content of about 50%.

The water retention of the experimental soil decreased with an increase in stone content. The pore sizes did not decrease proportionally with the stone content, in fact the ratio between large and small pores actually increased with stone content. The relatively good hydraulic conductivity of stony soils compared to their low porosity can be attributed to a higher percentage of large pores. However, the absence of small pores, especially in the range 10µm to 0.6µm, reduces the water-holding capacity of stony soils.

The soil matrix used in this study had a strong crusting tendency and surface crusting largely controlled the infiltration rate. For any given stone content crusting was prevented at slope angles steeper than 25°, through the combined effect of less effective rainfall and the dissipation of raindrop energy by the stones. For a constant slope angle (10°) the infiltration rate decreased rapidly for stone contents higher than 30% by volume. This study once again confirmed that stones have an ambivalent effect on runoff generation. Stones promote runoff by concentrating rainwater or reducing the infiltration of the soil but it can also dissipate raindrop energy and thereby protecting the soil from forming crusts. The major effect of stones was the reduction of infiltration and thereby increasing runoff. Stones can play a role in erosion control but the decision to use stones or not should be based on other factors as well.

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