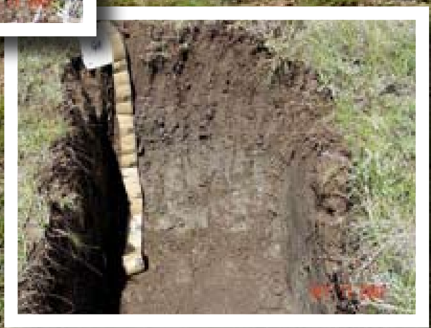
A Procedure for an Improved Soil Survey Technique for Delineating Land Suitable for Rainwater Harvesting

M Hensley, PAL le Roux, J Gutter & MG Zerizghy



TT 311/07

Water Research Commission

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EXECUTIVE SUMMARY

Infield rainwater harvesting (IRWH) has been proved to be an effective crop production technique to improve rainwater productivity in certain semi-arid areas of South Africa. This is of particular importance for uplifting subsistence farmers. To ensure that this technique is applied successfully in semi-arid areas, it is essential that it is only applied on soils which have suitable characteristics. This need calls for efficient and cost effective intensive soil surveys – eventually over very large areas of South Africa. Traditionally, and before certain modern technological facilities were available, intensive soil surveys (scales around 1:10 000 and larger) were generally conducted using a relatively expensive grid pattern. Our hypothesis is that by employing modern and innovative techniques, in association with predictive mapping based on comprehensive pedological knowledge and experience, it should be possible to develop a more effective survey technique for identifying land suitable for IRWH. The aim of this project was to test this hypothesis.

The land type survey (scale 1: 250 000), with results now available for the whole of South Africa, provides a valuable framework within which to conduct intensive soil surveys. Comprehensive appreciation of this fact is of primary importance in the process of developing a cost-effective intensive soil survey technique to identify areas suitable for IRWH. The first step in this process is the subdivision of the land type into soilscapes on 1:50 000 maps. Examples of three land types which have been subdivided in this way are presented, viz. Dc17, Db37 and Ca22. The proposed steps to follow this first one, leading up to the intensive survey, are outlined.

The procedure followed to develop an improved soil survey technique was one of trial and error while carrying out soil surveys of two Dc17 Soilscapes, viz. No 58 Gladstone (2 721 ha), and No 6 Feloane/Potsane (1 599 ha). The soil surveys revealed that the area of good land for IRWH on soilscapes 58 and 6 amounted to 1 177 and 183 ha, respectively.

The procedures used to carry out the soil surveys are described in detail in the interim and in this final report. The following are the main advanced, modern and

innovative techniques that were employed: a geographical positioning system (GPS) instrument which uses satellites to instantly provide the coordinate of any position; a computer programme “3dMapper” (Terrain Analytics, 2004) to facilitate predictive mapping; the intensive application of pedological expertise to facilitate predictive mapping; a simple steel penetrometer to make rapid determinations of soil depth; a simplified soil profile description form; the choice of a carefully chosen threshold value for the depth to which observations need to be made to evaluate the suitability of soils for IRWH.

A preliminary step by step procedure for an improved soil survey technique for identifying land suitable for IRWH is presented. Because of the exploratory nature of this study and the limited area which was studied, it is not possible at this stage to determine in a reliable way the financial benefits compared to a conventional grid type survey. Recommendations are made regarding future needs in connection with this subject.

ACKNOWLEDGEMENTS

The Key Strategic Area: Water Utilisation in Agriculture of the Water Research Commission is gratefully acknowledged for initiating and funding this research project. The support and guidance of Dr Gerhard Backeberg in this regard is appreciated.

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1. INTRODUCTION

1.1 Motivation

Subsistence farmers in rural semi-arid areas with low cropping potential are a category of poor people in South Africa that the Government urgently wants to assist. Their well-being is jeopardized by a low income and inadequate food security. To address this problem a number of research projects, managed and funded by the Water Research Commission (WRC), have been launched during the last ten years by the ARC-Institute for Soil Climate and Water (ISCW) located at Glen. The focus of the projects was initially on developing a crop production technique, specifically suited to the natural resource conditions prevailing in the Thaba Nchu region, by which rain water productivity (RWP) could be significantly improved. The recent “more crop per drop” statement by the Secretary General of the United Nations Kofi Annan, aptly expresses the worldwide need to strive for the achievement of this objective. Success was achieved at Glen with the in-field rainwater harvesting (IRWH) technique, locally termed “matangwane”. The second phase consisted of propagating the technique amongst the subsistence farmers around Thaba Nchu. Success in this regard was also achieved, shown by the fact that large numbers of households in the region now successfully use IRWH to grow maize and vegetables in their backyards. The time is now ripe for expanding the application of IRWH to the relatively large unused cropland areas available to these subsistence farmers. The need then arises to identify and delineate the portion of each village area that is suitable for IRWH. Because of the relatively small area of cropland allocated to each household it is essential that the soil survey be conducted on an intensive basis, at a scale of at least 1: 10 000, but preferably larger. Intensive soil surveys at this scale, carried out using the traditional grid technique, are costly. It was hypothesised that it should be possible to develop a more effective survey procedure to select suitable land for IRWH by maximising the application of tacit knowledge and employing modern and innovative technology. Aware of this need, the WRC initiated the research project to test this hypothesis.

1.2 Objectives

General

To develop a cost effective procedure to obtain a detailed soil map at a scale of 1:10 000 or larger on which land suitable for rainwater harvesting is delineated.

Specific

1.2.1 To demonstrate the subdivision of land types into component soilscapes.

1.2.2 To carry out detailed soil surveys on selected soilscapes using innovative techniques for making and recording observations. These techniques should contribute towards decreased costs compared to traditional soil surveys.

1.2.3 To use predictive mapping to apply expert knowledge and reduce fieldwork.

1.2.4 To involve local subsistence farmers in the soil survey operations with the aim of developing their knowledge of the production potential of the soils they cultivate.

1.2.5 To synthesize the experience gained during the achievement of objectives 1.2.1, 1.2.2 and 1.2.3 into a proposed generic procedure for delineating land suitable for rainwater harvesting in South Africa.

1.3 The land type database

The land types delineated for the whole of South Africa by the ARC-ISCW (Land Type Survey Staff, 2002) provide a framework within which to conduct intensive soil surveys. Comprehensive appreciation of this fact is a fundamental first step towards developing a cost-effective intensive soil survey technique to identify areas suitable for IRWH. To serve as clarification some information is provided below about the three land types involved in this project. Detailed land type information for the whole of South Africa is now easily available (http://www.agis.agric.za). The main soils present in each land type have been identified, and are presented in tabular form in what is called the "inventory". Their estimated spatial distribution in the landscape is described in terms of what can be described as a toposequence. In addition, the estimated area of each soil or group of similar soils occurring on each terrain morphological unit, is presented in the inventory. Examples are presented in Table 1 for land type Dc 17 – important for this project, and Tables 2 and 3 for Db37 and Ca22, respectively, also involved in this project. The total area of these land types are 239 080 ha, 94 220 ha and 156 400 ha, respectively. The term toposequence used above is described by Tables 1, 2 and 3, with the relevant quantitative estimates of the soil distribution pattern presented by the data.

Although these three land types are adjacent to each other and similar in a number of ways, there are also specific differences. These differences are revealed firstly by comparing the terrain form sketches at the bottom of Tables 1, 2 and 3. The differences are clearly visible during a field visit. Dc17 is characterized by an abundance of dolerite intrusions which have produced many hills, an uneven topography and a relatively large portion of the total area with slopes too steep for cultivation. This portion consists of around 16% of the total area (Table 1). The altitude above mean sea level (a.m.s.l.) varies from between 1 350m to around 1 600m, making this a class A4 terrain type (Table 1) in terms of the criteria specified by the Land Type Survey Staff (2000). In Db37 dolerite intrusions are far less than in Dc17. The topography is characterized by long gentle slopes, with only about 3% of the area estimated as being too steep for cultivation (Table 2). The terrain type is described as A3 with the major part of the area occurring between altitudes a.m.s.l. of 1 380 m and 1 500 m. Ca22 has very gently undulating topography as clearly shown in the terrain sketch. Altitudes vary from 1 300 m to a maximum of 1 390 m, making this an A2 terrain type.

Regarding soil differences between the three land types, the frequency of dolerite intrusions plays a major role. Dolerite provides base rich parent material for soil formation thereby promoting the genesis of margalitic topsoils. Hence also the Dc designation for Dc17, indicating that significant areas of margalitic soils with vertic and melanic A horizons occur, estimated to amount to around 20% of the total area (Table 1). Because of there being relatively little dolerite the Db designation is appropriate for Db37, confirming that soils with margalitic topsoils do not occupy significantly large areas. The estimated portion is about 4% (Table 2).

Table 1 Soil and terrain form inventory of land type data Dc17 (Land Type Survey Staff, 2002)

LAND TYPE : Dc17
CLIMATE ZONE : 46S
Area : 239080 ha

Occurrence (maps) and areas:
2826 Winburg (4750 ha) 2926 Bloemfontein (234330 ha)

Inventory by:
J.F Eloff & A.T.PBennie
Modal Profiles:
P605 P607

Estimated area unavailable for agriculture: 4080 ha

Terrain unit		1	1(1)	2	3	3(1)	4	5
% of land type	:	6	12	1	12	40	20	9
Area (ha)	:	14345	28690	2391	28690	95632	47816	21517
Slope (%)	:	2-8	1-2	90-150	12-45	2-3	0-2	0-3
Slope length (m)	:	50-500	100-700	100-400	100-600	300-1000	250-800	50-300
Slope shape	:	Z-Y	Z-Y	Z	X	Z-Y	Z	X-Z
MB0, MB1 (ha)	:	0	27255	0	0	92763	47816	18505
MB2 - MB4 (ha)	:	14345	1434	2391	28690	2869	0	3012

Soil series or land classes	Depth	MB	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	Total ha	Total %	Clay content (%) A	E	B21	Hor	Texture Class	Limiting material
Soil-rock complex :	(mm)																							
Rock		4:	10042	70			2391	100	18648	65							31080	13						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36,	100-250	3:	2152	15					4304	15							6455	2.7	10-20		15-25	A	LmfiSa-SaLm	R,so
Milkwood Mw11, Glengazi Bo31 Rashseni Bo21, Glendale Sd21	250-350	3:	1148	8					2869	10							4017	1.7	25-50		35-55	A	fiSaClL m-SaCl	R,vp,vr
Swartland Sw31, Sterkspruit Ss26,	100-250	3:	1004	7					2869	10							3873	1.6	10-20		40-50	B	fiSaCl	Vp,pr,
Swartland Sw31,Nyoka Sw41, Omdraai Sw42	100-250	0:			14345	50					33471	35	16736	35	3443	16	67994	28.4	15-30		40-60	B	fiSaCl-Cl	Vp
Shepperdvale Va42,Lidley Va 41, Arniston Va31	100-300	0:			7172	25					19126	20	14345	30	3443	16	44086	18.4	15-30		45-60	B	fiSaCl-Cl	Vp
Milkwood Mw11,Grythorne Mw21	300-600	0:									19126	20	9563	20	3873	18	32563	13.6	40-55			A	fiSaCl-Cl	R
Glengazi Bo31,Bonheim Bo41	250-400	0:									9563	10	3347	7	2582	12	15492	6.5	40-55		45-60	A	fiSaCl-Cl	Vp
Estcourt Es36,Enkeldoom Es33	200-350	0:									4782	5	2391	5	646	3	7818	3.3	12-25	10-20	45-60	E	LmfiSa-SaLm	Pr
Sterkspruit Ss26,	100-300	0:			5738	20					1913	2					7651	3.2	15-30		45-60	A	fisaLm-SaClLm	Pr
Gelykvlakte Ar20	400-900	0:									4782	5	1434	3	1076	5	7292	3.1	40-60			A	fiSaCl-Cl	R
Mispah Ms10,Williamson Gs	100-300	0:			1434	5					2869	3					4303	1.8	10-15			A	fisaLm-SaClLm	R,so
Dundee Du10, Limpopo Oa46,	600-1200	0													3443	16	3443	1.4	15-35		25-35	B	fiSaClL m	
Stream beds		4													3012	14	3012	1.3						

MB = Mechanical limitations, MB0 = no limitation, MB1 = many stones but ploughable, MB2 = large stones and boulders, unplaughable, MB3 = very shallow soils on rock, MB4 = lack of soil
Slope shapes: X = concave, Y = convex, Z = straight
Depth limiting material: vp = pedocutanic B horizon, pr = prismacutanic B horizon, R = rock, so = saprolite

Terrain type A4

Geology: Sandstone, shale and mudstone of the Beaufort group with dolerite intrusions.

Terrain form sketch

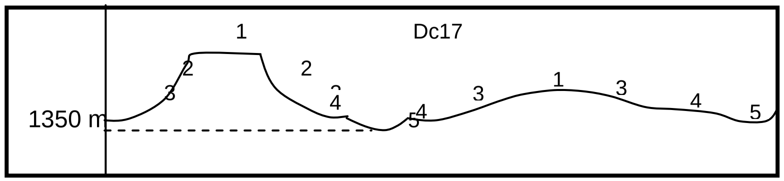


Table 2 Soil and terrain form inventory for Land Type Db37 (Land Type Survey Staff, 2002).

LAND TYPE / *LANDTIPE* : Db37
CLIMATE ZONE *KLIMAATSONE* : 46S
Area *Oppervlakte* : 94220 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 2220 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte :*
2826 Winburg (65720 ha) 2926 Bloemfontein (28500 ha)

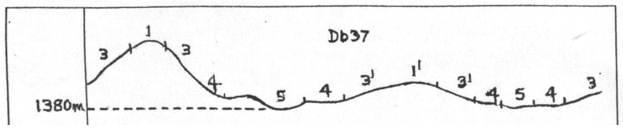
Inventory by *Inventaris deur :*
J F Eloff & A T P Bennie

Modal Profiles *Modale profiele :*
P472 P473 P474 P475 P476
P608 P609 P610
48 49 50

Terrain unit ***Terreineenheid***	1	1(1)	3	3(1)	4	5
% of land type *% van landtipe*	1	11	3	52	23	10
Area *Oppervlakte (ha)*	942	10364	2827	48994	21671	9422
Slope / *Helling (%)*	1 - 2	0 - 2	6 - 35	1 - 3	0 - 2	0 - 1
Slope length *Hellingslengte (m)*	200 - 700	20 - 50	500 - 1500	50 - 300	400 - 1000	50 - 300
Slope shape *Hellingsvorm*	Z-Y	Z-Y	Z	Z	Z	Z-X
MB0, MB1 (ha)	0	10364	0	48994	21671	8009
MB2 - MB4 (ha)	942	0	2827	0	0	1413

Soil series or land classes ***Grondseries of landklasse***	**Depth** ***Diepte*** **(mm)**	**MB**	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	**Total** ***Totaal*** ha	%	**Clay content %** ***Klei-inhoud %*** A	E	B21	Hor	**Texture** ***Tekstuur*** Class / *Klas*	**Depth limiting material** ***Diepte-beperkende materiaal***
Soil-rock complex																						
Grond-rotskompleks:																						
Rock/Rots		4	659	70			1979	70							2638	2.8						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36	100-250	3	188	20			424	15							612	0.7	10-25		15-30	A	LmfiSa-SaClLm	R,so
Glendale Sd21, Milkwood Mw11, Glengazi Bo31	250-400	2	94	10			424	15							518	0.6	20-45		35-50	B	fiSaCl	R,vp
Sheppardvale Va42	100-250	0							19598	40	14086	65	1413	15	35097	37.3	20-30		55-65	B	Cl	vp
Lindley Va41, Arniston Va31	100-250	0			5182	50			17148	35	2601	12	471	5	25402	27.0	12-25		40-55	B	fiSaCl-Cl	vp
Nyoka Sw41, Omdraai Sw42, Swartland Sw31	100-200	0							4899	10	3251	15	754	8	8904	9.5	12-30		40-65	B	fiSaCl-Cl	vp
Rietvlei We12	300-450	0			4664	45			1470	3					6134	6.5	12-30		20-35	A	fiSaLm-SaClLm	sp
Dundee Du10, Jozini Oa36	>1200	0											4711	50	4711	5.0	15-45			A	fiSaLm-SaCl	
Bluebank Kd16, Kroonstad Kd13	450-600	0							2940	6	1084	5	283	3	4306	4.6	15-25	10-20	40-60	E	fiSaLm	G
Milkwood Mw11, Glengazi Bo31	300-450	0							2450	5	650	3	377	4	3477	3.7	35-50		40-55	A	fiSaCl	R,vp,sp
Soetmelk Av36	500-700	0			518	5			490	1					1008	1.1	12-25		20-35	B	fiSaClLm	sp
Stream beds/Stroombeddings		4											1413	15	1413	1.5						

Terrain type /*Terreintipe :* A3
Terrain form sketch /*Terreinvormskets*



Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Sandstone, shale and mudstone of the Beaufort Group, with dolerite intrusions.

Geologie Sandsteen, skalie en moddersteen van die Groep Beaufort, met dolerietindringings.

Table 3 Soil and terrain form inventory of land type data Ca22 (Land Type Survey Staff, 2002)

LAND TYPE / *LANDTIPE* .... : **Ca22**
CLIMATE ZONE *KLIMAATSONE* .... : 45S
Area *Oppervlakte* .... : 156400 ha
Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 5000 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte :*
2826 Winburg (68290 ha) 2926 Bloemfontein (88110 ha)

Inventory by *Inventaris deur :*
J F Eloff

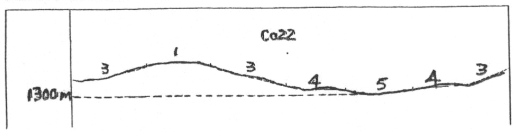
Modal Profiles *Modale profiele :*
P459 P460 P480 P592 P595
P596 P597
32 35 36 37

Terrain unit *Terreineenheid*	:	1	3	4	5
% of land type *% van landtipe*	:	22	53	18	7
Area *Oppervlakte (ha)*	:	34408	82892	28152	10948
Slope / *Helling (%)*	:	0 - 2	2 - 8	1 - 3	0 - 4
Slope length *Hellingslengte (m)*	:	100 - 900	500 - 1500	200 - 700	50 - 400
Slope shape *Hellingsvorm*	:	Y	Y-Z	Y-Z	Z-X
MB0, MB1 (ha)	:	29591	78747	28152	10948
MB2 - MB4 (ha)	:	4817	4145	0	0

Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Soil-rock complex																		
Grond-rotskompleks:																		
Rock/Rots		4	1032	3	1658	2					2690	1.7						
Glendale Sd21, Milkwood Mw11, Skilderkrans Sw11	100-250	0	344	1	829	1					1173	0.8	15-30		35-55	B	fiSaClLm-Cl	R,vr
Mispah Ms10, Williamson Gs16, Shorrocks Hu36	100-250	3	344	1	829	1					1173	0.8	10-18			A	LmfiSa-SaLm	R,so
Waterval Va11, Craven Va21	100-350	0	12043	35	20723	25	7038	25			39804	25.5	12-20		45-55	B	fiSaCl-Cl	vp
Amiston Va31, Lindley Va41, Chalumna Va32, Sheppardvale Va42	100-300	0	8602	25	19065	23	9009	32	2737	25	39413	25.2	12-25		45-60	B	fiSaCl-Cl	vp
Rietvlei We12, Sibasa We13	200-500	0	6193	18	12434	15	3660	13			22287	14.3	10-25		25-40	A	fiSaLm-SaClLm	sp
Milkwood Mw11, Graythorne Mw21, Gelykvlakte Ar20	300-900	0			4974	6	2252	8	3832	35	11057	7.1	40-55			A	fiSaCl-Cl	R
Soetmelk Av36	400-800	0	688	2	5802	7	1971	7			8461	5.4	8-15		18-25	B	fiSaLm-SaClLm	sp
Shorrocks Hu36	300-1000	0	1720	5	6631	8					8352	5.3	8-15		18-25	B	fiSaLm-SaClLm	R
Sterkspruit Ss26	100-250	0			4145	5	3378	12			7523	4.8	20-30		55-70	A	fiSaClLm	pr
Mispah Ms10, Williamson Gs16	100-250	3	3441	10	1658	2					5099	3.3	10-18			A	LmfiSa-SaLm	R,so
Bainsvlei Bv36	400-800	0			4145	5	845	3			4989	3.2	8-15		18-25	B	fiSaLm-SaClLm	sp
Dundee Du10, Killarney Ka20, Mutale Oa47	300-1200+	0							4379	40	4379	2.8	10-30			A	LmfiSa-SaClLm	gc

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)
Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Terrain type /*Terreintipe* : A2
Terrain form sketch / *Terreinvormskets*



Geology: Sandstone, shale and mudstone of the Beaufort Group, with dolerite intrusions.

Geologie Sandsteen, skalie en moddersteen van die Groep Beaufort, met dolerietindringings.

In the case of Ca22 dolerite intrusions are also relatively infrequent. The fraction of the total area with margalitic topsoils is estimated to be 7% (Table 3). If deep enough the margalitic soils are good for IRWH because of their high water holding capacity and relatively low infiltration rate. The latter promotes runoff into the basins of the IRWH system.

A common soil distribution characteristic of the three land types is the dominance of duplex soils. The main forms are Swartland and Valsrivier, estimated to occupy 48%, 74% and 51% of the total areas of Dc17, Db37 and Ca22, respectively (Tables 1, 2 and 3). Included in these estimates will be duplex soils of the Sepane form describe in the improved 1991 classification scheme. Sepane is a soil of particular importance for IRWH because of its morphological characteristic of signs of wetness, generally here in clay rich material below the pedocutanic B horizon. The presence of signs of wetness proves that it has the high water storage capacity important for IRWH. The occurrence of duplex soils with an E-horizon (e.g. Estcourt, Klapmuts, Kroonstad and Katspruit forms) at the lower end of the toposequence is also a characteristic feature of these three land types.

1.4 Expanding the land type database to facilitate intensive soil surveys

An exercise of this nature was conducted by Tekle (2004) on land type Dc17. The first step consisted of subdividing Dc17 into 66 soilscapes on topocadastral maps of scale 1:50 000. A soilscape was defined as follows by Tekle (2004): "A mapping unit consisting of a portion of land mapable at a scale of 1:50 000 in such a way that it facilitates the identification of arable land. It consists of a hillslope or combination of hillslopes, with a characteristic pedosequence of which the lower boundary is a drainage line and the upper boundary a crest. In areas of low relief it may include the watershed between two drainage lines". The subdivisions are shown in Figure 1. The 66 soilscapes were then divided into 6 groups each with similar characteristics. The characteristics considered were related to suitability of the land for IRWH and were as follows: extent of dolerite intrusions, discernable on the 1: 50 000 maps as rough and steep areas; area made unsuitable for cultivation due to township development; extent of the area with low slopes (slopes <3%). This can be considered as a first preliminary and useful step in predictive mapping. It was found that nine soilscapes with a total area of 88 000 ha had negligible land suitable for IRWH.

The next step consisted of selecting specific soilscapes for more detailed studies on the soil distribution pattern in the toposequences of selected hillslopes. This provided valuable information for the next step which consisted of estimating the area of land suitable for IRWH on each soilscape, and hence the estimated total IRWH area for Dc17. The project conditions did not allow detailed testing of these estimates. The present project enables testing in the case of soilscape Nos. 58 and 6 located as shown Figure 1.

The procedure we envisage at present as being a suitable one to expand the land type database to facilitate intensive soil surveys is as follows:

- subdivide the land type into soilscapes on 1:50 000 maps;
- divide the soilscapes into groups with similar terrain form;
- for each group select representative hillslopes;
- make an intensive study of the toposequence of representative hillslopes employing the full potential of predictive soil mapping;
- formulate a hypothesis regarding the soil distribution pattern;
- test the hypothesis on similar unstudied hillslopes;
- improve the hypothesis and test again etc.;
- use the results and experience gained to facilitate intensive soil surveys on each soilscape of the particular land type.

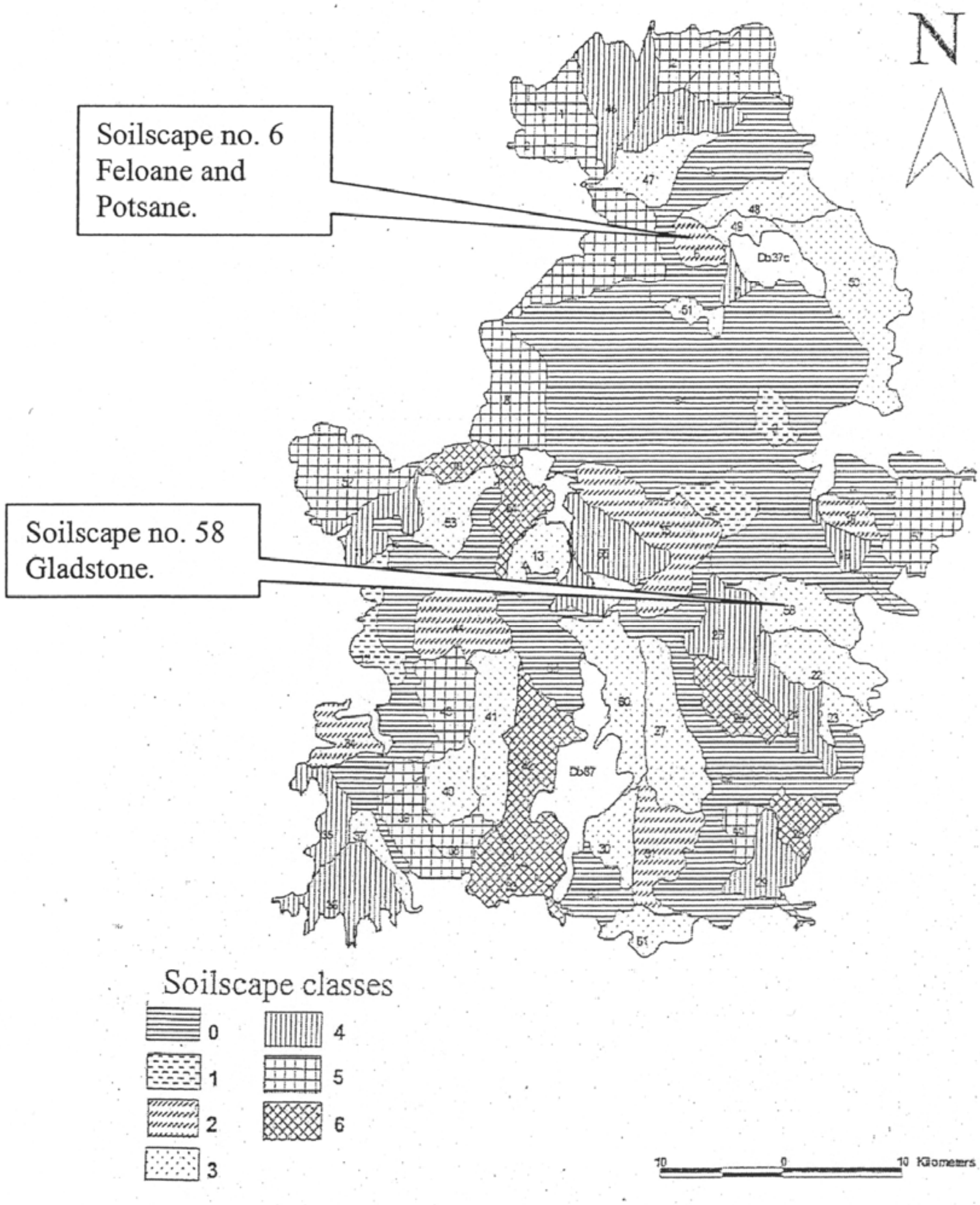


Figure 1 Soilscapes of Land Type Dc17.

2. PROCEDURE ADOPTED TO DEVELOP AN IMPROVED SOIL SURVEY TECHNIQUE

Our hypothesis states, "that it should be possible to reduce the costs of intensive soil surveys by developing an appropriate procedure employing modern and innovative technology that will meet the current objectives". There are a number of soil survey activities that need to be considered when developing a strategy to reduce costs and yet produce a good quality soil map that meets the objectives of the survey. The following are important: selecting a map scale; deciding on the number and kind of observation points that will be needed; selecting a procedure for sitting and recording the location of the observation points; deciding on how to make the observations and to what depth they should be made; deciding on how the results of the survey will be presented.

The procedure we followed was developed by trial and error. We just continued soil surveying, striving to adapt and improve on each of the different activities as we went. The trials and the errors we made are described in detail in the two preliminary reports and are presented in an edited form in Appendix 9. Only the conclusions based on our current understanding will be presented here. It is likely that the recommendations presented could change as experience is accumulated. This is an ongoing venture. The fundamental guiding principle guiding us is the conviction that predictive soil mapping is a valid and fruitful procedure, and that it should be exploited as far as possible to facilitate and improve soil surveys for a variety of purposes. Central to this concept is the truth that soils are distributed in the landscape in a defined pattern determined by the five factors of soil formation, parent material, climate, topography, time and the biological factor (Jenny, 1941). In a particular land type, by definition, the range of variation in each of these factors is restricted to a specific macro-climate, specific limited macro-parent material, similar age, similar biological factors and specific topographical form. This is what makes it pedologically valid in the land type survey to specify particular kinds of soils on particular terrain morphological units in the inventory (e.g. Table 1). The view of Hudson (1992) that the science of soil surveying is based on the landscape paradigm provides sound philosophical support for this procedure, and also for our contention regarding the validity of predictive soil mapping and its potential value for improving soil survey procedures.

The focus of predictive soil mapping (PSM) here is on an intensive study of the variation of soil distribution patterns on representative hillslopes (i.e. representative toposequences) in a particular land type, and then using the results to facilitate intensive soil surveys at large scales.

Two aspects have received attention. Firstly, learning to employ the computer programme “3D Mapper”, and secondly an attempt to develop a model to predict the distribution of soils in selected soilscapes of land type Dc17. The results of the efforts are presented in Chapter 4. The computer programme “3dMapper” is a recent development from the University of Wisconsin aimed at aiding and streamlining predictive mapping. Because of limited time and experience it was not possible to exploit the full potential of this valuable programme during this project. For the same reasons it has also not been possible in this project to harness the PSM model described in Chapter 4.

3. SUBDIVISION OF LAND TYPES Dc17, Db37 AND Ca22 INTO SOILSCAPES

The subdivisions were made on 1:50 000 maps in accordance with the definition of a soilscape. The delineations were then transferred to 1:250 000 maps. Results are presented on the attached map which is a combination of 2826 Winburg and 2926 Bloemfontein. Land type Ca22 consists of five portions, only two of which (Ca22d and Ca22e) are on the 1:250 000 map 2926 Bloemfontein, constituting an area of 88 110 ha. In our planning it was erroneously not realised that there were three other distant portions of Ca22 constituting an area of 68 290 ha. The result is that only the 88 110 ha of Ca22 on 2926 Bloemfontein has been subdivided into soilscapes. It is logical to assume that the predicted soil distribution pattern as shown in Table 3 will be the same on this portion as on the excluded portions.

Some details about the average areas of the soilscapes in the three land types are given in Table 4.

Table 4 Land type areas, number of soilscapes, and average area per soilscape for land types Dc17, Db37 and Ca22; and estimated percentage arable in each land type by Eloff (1984)

Land type	Total area (ha)	No of soilscapes	Average area per soilscape (ha)	Estimated arable %
Dc17	239 080	66	3 622 (2752)*1	10
Db37	94 220	51	1 847	15
Ca22	156 400 (88110)	40	2 203*2	60

*1 Calculation based on the large area of 82 222 ha of 9 unsuitable soilscapes being excluded

*2 Based on the 88 110 ha on which the soilscapes were delineated

The data in Table 4 indicates that in this semi-arid region soilscapes as we see them have an average area of around 2 500 ha. Because the aridity index for these three land types is very similar, the differences in arability estimated by Eloff (1984) can be attributed mainly to the influence of topography. In addition to the most favourable topography, Ca22 has the extra benefit of windblown sand from the west increasing the depth and quality of the surface soil.

The soilscape delineations on land type Dc17, Db37 and Ca22 are presented in electronic format on the CD that accompanies this report. The data for Dc17 is from Tekle (2004).

The land type areas presented on the CD are slightly different from those presented in Table 4 for the following reasons: Dc17 and Db37, discrepancies (less than 2%) are due to duplicate measurements by different operators; Ca22, discrepancy due to portions of the land type occurring in the Bloemfontein Municipal area being excluded in the area subdivided into soilscapes.

4. COMPUTER AIDED PREDICTIVE SOIL MAPPING: PRELIMINARY EFFORTS

4.1 Subdivision of soilscape 58 of land type Dc17 into characteristic hillslopes

The aim of this exercise was to reduce fieldwork by optimising the application of available information and technology. Available resources include land type data, computer modelling and expert knowledge.

Applying land type information

Both the land type and the soilscape survey are based on the correlation between the distribution pattern of soil in the landscape and topographical form. As this information is accumulated by individual observations it should be possible to apply this principle to hillslopes. The land type and soilscape surveys were done at scales of 1:250 000 and 1:50 000, respectively. The outcome was associations of soils. Associations are combinations of soils in a map unit that occur in the same landscape but do not have similar suitability for common land uses (Soil Conservation Staff, 1981). To make land type information useful for land use application a consociation soil map (soils of similar suitability for common land uses grouped in map units) must be produced. The scale must be larger than 1:50 000 but the limits are uncertain.

Terrain morphological units (TMU's)

To optimise the contribution of land type information in subdividing Soilscape 58 the soilscape was divided into TMU's. The first attempt was to define the TMU's on orthophoto maps. This was found to be difficult. Map contours gave a good indication of the relief but the contribution was insufficient as we could not decide on the boundaries of the TMU's as defined in the land type inventory.

The application of the computer model 3dMapper for terrain analysis of Soilscape 58 of Land Type Dc17 made it possible to apply more tools to identify the TMU's (Figure 2). The slope neighbourhood was set at 150 m and contours displayed at 3 m intervals (10 ft). Slope classes (Figure 3) and profile curvature (Figure 4) was set on 1% intervals for maximum sensitivity. After several trials plan curvature was set for maximum ability to distinguish between hillslopes (Figure 5). All other settings were kept standard. The slope, profile and planform curvature layers were applied alternatively in search for patterns in hillslope characteristics.

The ridge or divide, (TMU1) of the soilscape is best shown by planform curvature. To determine the position of TMU 1 the planform layer was applied. The extent of TMU 1 was interpreted with the slope layer applied. TMU 1 shows up as a convex (dark yellow planform curvature), nearly level (slope 0-1% pink and 1-2% blue) area on the ridges with a convex (dark to light blue) profile curvature. Switching these three layers on alternatively and simultaneously, facilitated the drawing of lines between the TMU's. There was uncertainty regarding much the land type information stipulating that the TMU's 1(1), 2, 3(1), 4 and 5 made up 12%, 1%, 30%, 20% and 9% of the land type respectively. A brief field visit helped in this respect. The photo background and the 3 dimension ability of 3dMapper helped to distinguish between TMU's 1(1) and 4(1) in the landscape.

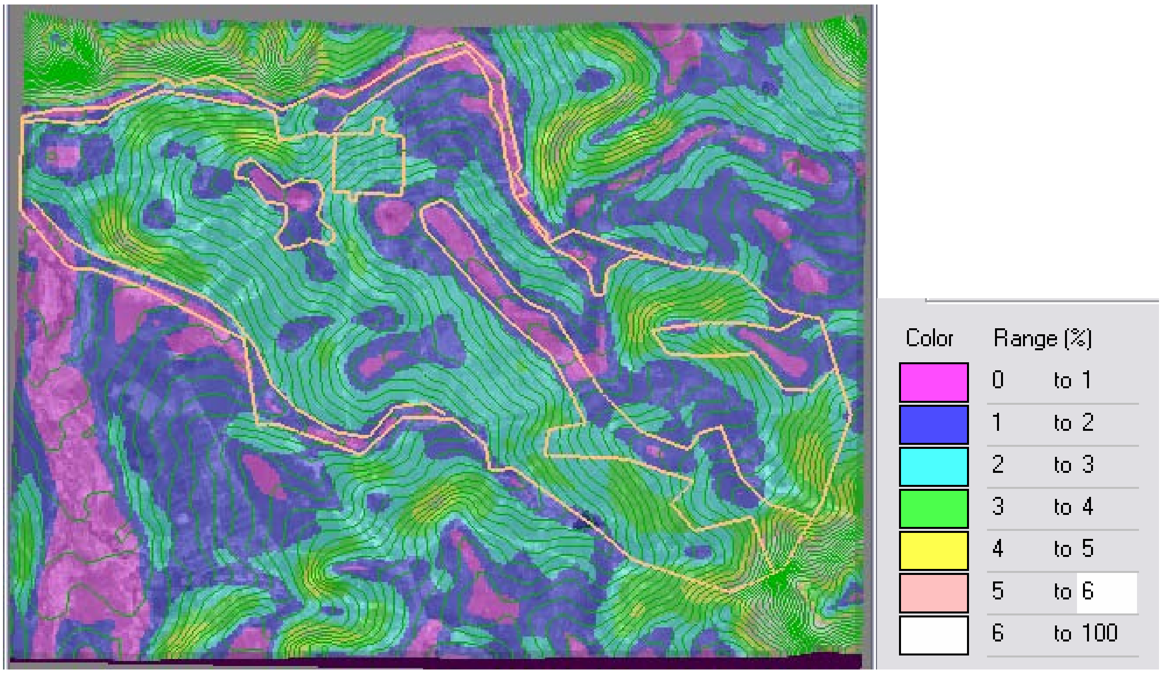


Figure 2 TMU's 1, 3(1) plus 4 and 5 of Soilscape 58 identified with 3dMapper. The slope layer is applied in this image and the slope classes are presented in the legend.

Hillslopes

The same settings as were used for delineating TMU's were applied to determine typical hillslopes. Additional to land type information, the frequency of the occurrence of certain soils, learned during the brief field visit, was applied. Predicted results are presented in Table 5 with subdivisions a – f, each for a specific kind of hillslope with a predictive soil distribution pattern. The soil described as Swartland (Gladstone) has signs of wetness in the C horizon. It is proposed to name this the Gladstone series of the Amandel family of the Swartland form.

Table 5 Distribution of soils in characteristic hillslopes of soilscape 58

a) The rock/Mispah//Glenrosa hillslope

TMU	Soil	% of Ss	Slope (%)	Profile curvature	Planform curvature
3	Rock/Mispah		4 to 12	3 to -1	40 to -40

b) The Sw/SwG*/Es hillslope

TMU	Soil	% of Ss	Slope (%)	Profile	Planform
1	Swartland		1 to 2	1 to -1	-10 to -100
3	Swartland (Gladstone)*		1 to 4	1 to -1	40 to -40
5	Estcourt		1 to 2	1 to -1	100 to 40

*Refers to soils of the Swartland form with signs of wetness, i.e. Gladstone series.

Note: The banks of the rivulet at the lower end of the toposequence probably contain *in situ* weathered material, or very old deposits, resulting in soils of the Estcourt form rather than of the Dundee or Oakleaf forms to occur.

c) The Sw-Ar/SwG-Ar/Es hillslope

TMU	Soil	% of Ss	Slope (%)	Profile	Planform
1	Swartland Arcadia		0 to 3	1 to -1	
3	Swartland (Gladstone) Arcadia		2 to 3	1 to -1	
5	Estcourt		0 to 1	1 to -1	

Note: The occurrence of vertic soils is suggested due to a dolerite influence. The banks of the rivulet at the lower end of the pedosequence probably contain in-situ weathered material, or very old deposits, resulting in soils of the Estcourt form rather than of the Dundee or Oakleaf forms to occur.

d) The SwG / SwG /Du hillslope

TMU	Soil	% of Ss	Slope (%)	Profile	Panform
1	Swartland (Gladstone)		1 to 0	1 to -1	-10 to -100
3	Swartland (Gladstone)		2 to 3	1 to -1	100 to -100
5	Dundee		0 to 2	1 to -1	100 to 40

Note: The banks of the rivulet at the lower end of the toposequence probably contain recent deposits resulting in soils of the Dundee or Oakleaf forms to occur.

e) The Sw/ SwG /Du hillslope

TMU	Soil	% of Ss	Slope (%)	Profile	Panform
1	Swartland		0 to 2	1 to -1	-10 to -100
3	Swartland (Gladstone)		1 to 3	1 to -1	-40 to 40
5	Dundee		0 to 2	1 to -1	40 to 100

Note: The banks of the rivulet at the lower end of the toposequence probably contain recent deposits resulting in soils of the Dundee or Oakleaf forms to occur.

f) The Sw/Ms-Gs/Du hillslope

TMU	Soil	% of Ss	Slope (%)	Profile	Panform
1	Swartland		0 to 2	1 to -1	-40 to -100
3	Mispah Glenrosa		2 to 5	1 to -1	10 to -40
5	Dundee		0 to 2	1 to -1	40 to 100

Note: The banks of the rivulet at the bottom end of the toposequence probably contain recent deposits resulting in soils of the Dundee or Oakleaf forms to occur.

Discussion

The slope of the land in Soilscape 58 varies between 0% and 12% (Figure 3). The slope of the majority of the land is <3% and small areas have a slope between 3 and 4%. The near level areas, on the crest, are 500 to 1 000 m wide and probably play a major role in soil formation. Where depressions occur and internal drainage takes place the soils may be deep and have signs of wetness in the subsoil. Soils of the Swartland, Valsrivier and Swartland (Gladstone) forms may occur in this sequence of frequency, on sites favoured for soil formation and erosion restriction. Where dolerite occurs the Valsriviers may be associated/replaced by Arcadias and Swartland (Gladstone).

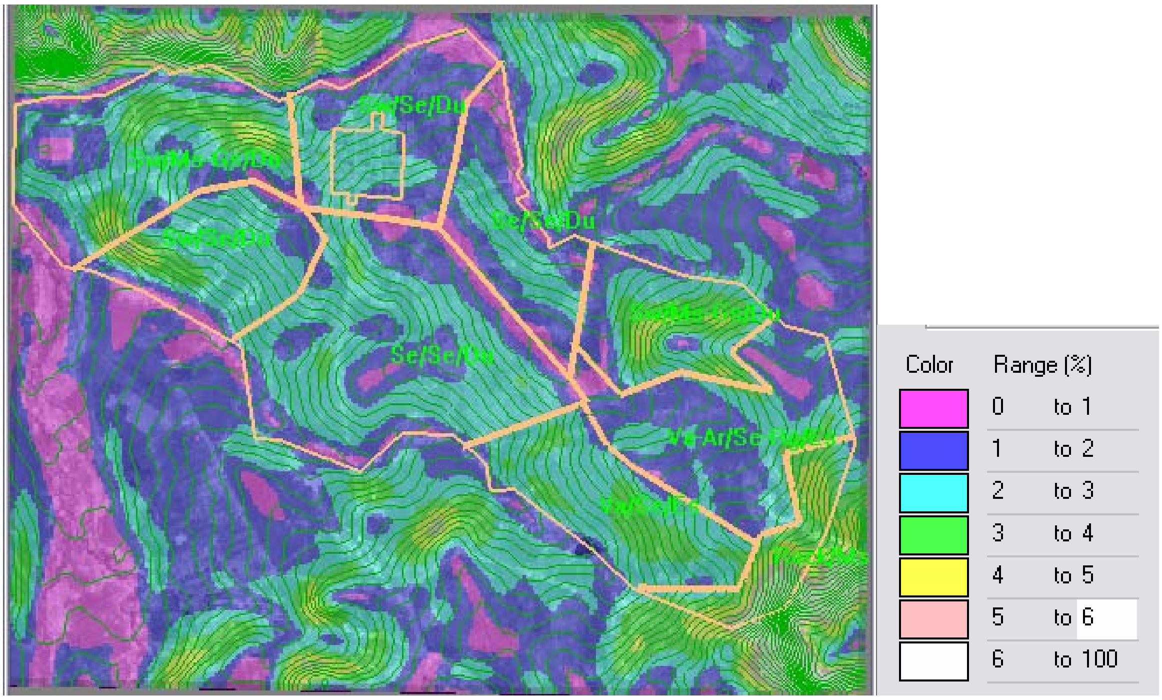


Figure 3 Hillslopes of Soilscape 58, and the slope classes on each hillslope.

The mid- and footslopes have a slope of 2% to 3%. Although erosion plays a role on slopes the more important factor on this position of the landscape is probably the profile wetness. The wetness of the profile is probably more affected by the planform curvature and position in the landscape. More concave topography and a lower position downslope probably aids in profile wetness and soil profile development. Profile curvature probably plays a small role as there is very light profile curvature in this soilscape as the downward slopes are nearly straight (Figure 4). It has a gently undulating topography.

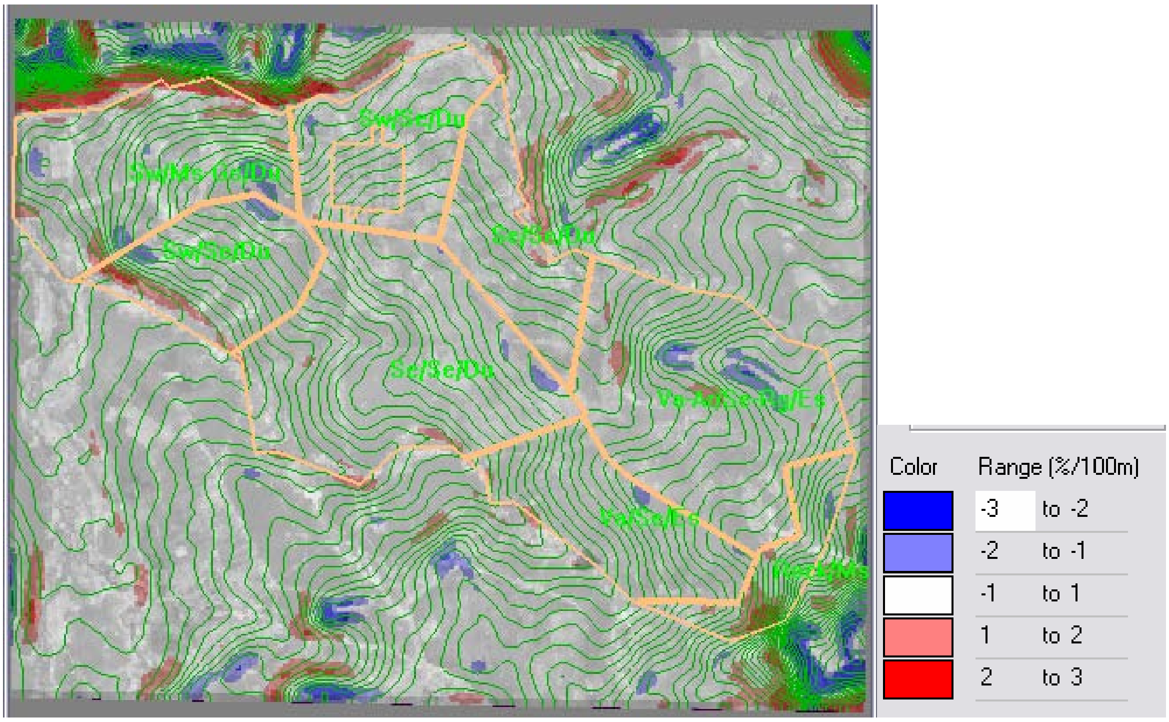


Figure 4 Profile curvature of Soilscape 58

On the SwG/SwG/Du hillslopes (Table 5) topographical features are assumed to have made a maximum contribution to pedogenesis resulting in optimum profile wetness and soil formation.

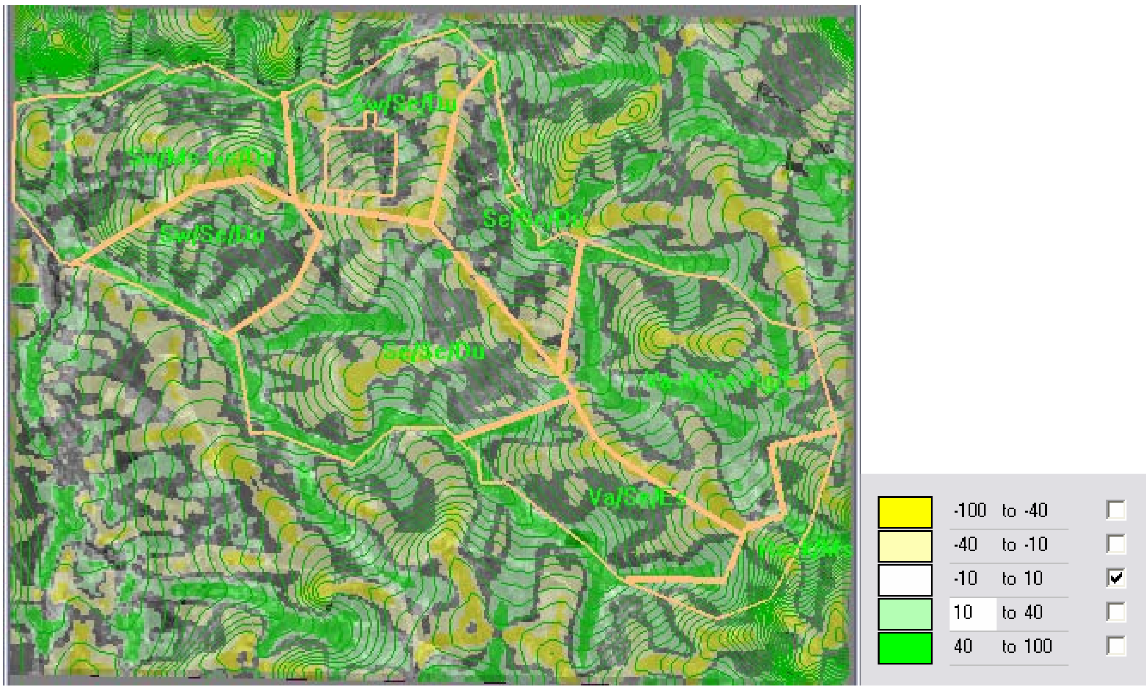


Figure 5 Planform curvature of Soilscape 58. The class -10 to 10 is transparent and shows up as the background photo image.

The position of dolerite sills and dykes may help to improve prediction. In drier positions the dolerite may result in shallow soils (Mispah/Glenrosa or Mayo/Milkwood), while Swartland soils are found on the Karoo sandstones and mudstones. In progressively wetter areas Arcadia soils may replace Swartland and Swartland (Gladstone) soils.

4.2 Using Predictive Soil Mapping To Develop A Model For Predicting Soil Types In Land Type Dc 17

4.2.1 Introduction

4.2.1.1 Motivation

In nature soils are different (Warrick and Nielsen, 1980). What may appear to be the same to the layman may have great variations in the physical and chemical properties which characterize a soil. Since these variations may have a significant impact on the kind of land use that can be employed on different soils, studying the variation is an important exercise in soil science. Because soil is an important attribute of land, it greatly dictates the suitability of land for a particular land use. For this reason soil surveys are important procedures that open a window through which one can study the nature of soils and classify them. Accordingly, Soil Survey Division Staff (1993) depicts soil surveys as describing the characteristics of soils, classifying them according to a standard, mapping them, and making predictions about their behaviour. They furthermore elucidate that soil surveys take into consideration the current use of the soils and their responses to different managements. In this way they predict future effects.

Through the ages, soil survey techniques have been evolving. Soil survey techniques may differ depending on the purpose of the investigation, and the kind and intensity of field examination. The intensity can range from an extensive survey with a low density of observations to a detailed study with a high density of observations and detailed investigation of soil properties. Because of this, there is no way of setting criteria for an all-purpose soil survey. However, the literature provides generalizations regarding the kinds of soil survey that are conducted in conjunction with specific purposes. This is mainly done to standardize the kind (high or low level) and the intensity of field examination. In reality, soil survey criteria have, in the past, been largely subjective depending greatly on tacit knowledge, i.e. knowledge gained by experience (Hudson, 1992). The effect of this subjectivity is two-fold. In the case of experienced surveyors it promotes customization of the practice to suit the purpose. In case of inexperienced surveyors, it might lead to inefficiency. The inefficiency might manifest itself either as a gathering of insufficient information or excessive information. To deal with such inconsistencies it would be advantageous to have an objectively developed soil survey procedure in which the inputs required are matched with the desired outputs.

At present the major sources of soil spatial information and the mapping thereof is coming from conventional soil surveys (Zhu *et al*., 2001). However, Scull *et al*. (2005) state that many researchers agree that the traditional soil survey method is not yielding the data required by modern users and there is therefore a need for change. To effect such a change, great endeavour has been put into soil studies in order to make quantitative assessments and measurements. This shift towards quantitativeness has different advantages. Firstly the quantification and measurements need to be linked to laws and theories in science. Secondly, dealing with quantitative terms enables the use of mathematical and statistical tools to express relationships, thereby enabling easier and accurate modelling of the processes (Jenny, 1941).

A review done by *Geoderma* regarding the development of research undertaken in soil science and published in the same paper, attests to the shift indicated above. In explaining the boost observed in publishing pedometrics research, it was shown that a 6 fold increase, i.e. from 3% to 18%, occurred over 3 decades. For this reason the review asserted that “more qualitative soil genesis and morphological studies have decreased to make way for the increase in more quantitative studies” (Hartenmink *et al.*, 2001).

Although there has been continuous change and reshaping as to how surveys are conducted and reported, a marked shift has been observed following the introduction of digital analyses. As in any other discipline technological advancement has been put to good effect to simplify the analyses done and to improve the accuracy of the variables used. The technological advance achieved in geographic information systems (GIS) and related fields has in particular given spatial analysis and representation a boost. Similarly soil survey has benefited because such advances in GIS have enabled candid representation of the spatial variability of soils.

4.2.1.2 Hypothesis and objectives

Hypothesis

Since there is a strong relationship between relief and soil in a particular climate zone with a particular geology, terrain attributes can be used to predict soil distribution within a particular land type

Objectives

- To predict the spatial distribution of soils within a selected soilscape of land type Dc17 with an acceptable level of accuracy
- To investigate soil prediction in relation to suitability of land for in-field rain water harvesting

4.2.2 Literature review

4.2.2.1 Defining Predictive soil mapping (PSM*)*

PSM is an important contribution to soil surveying that has been brought about by the technological advances. In practice, PSM is associated with digital soil mapping which is geared towards producing digital maps of soil types and soil properties. This procedure relies heavily on computer support and different software applications used to process the observations (data) used as a basis of inference. Since this procedure is still in its infancy, no formal delineation of scope is available. Definitions have nevertheless been given by practitioners. The following definition helps to clarify the procedure. Scull *et al.* (2003) defined PSM as "the development of a numerical or statistical model of the relationship among environmental variables and soil properties, which is then applied to a geographic data base to create a predictive map". This definition is a comprehensive one that indicates three major activities. Firstly, it uses the key words "numerical and statistical", which basically have to deal with the quantification of variables of interest, such as environmental variables. Secondly, it brings in the "relationship among environmental variables and soil properties" to emphasize that the establishment of the relationships between the environmental variables and the soil are important as models of the factors of soil formation. Lastly, the key words "geographic data base" reveals the importance of spatial distribution in the procedure, serving to depict soil as a continuum. In addition to what is stated in the definition Scull (2002) accentuates the incorporation of expert systems as one of the main requirements of PSM.

4.2.2.2 Advantages of PSM

Why was PSM developed and what are the advantages it offers? The change introduced to soil surveying is due to dissatisfaction with traditional procedures. These stem from inefficiencies of varying sorts. One of these is that conventional soil surveys are often more costly and labour and time consuming than they need be (Zhou *et al.*, 2004). Webster (1977) suggested that where observations are excessively expensive and time consuming, more easily observed characteristics and cheaper means of making observations should be devised. This emphasizes the value of PSM which uses proxy and ancillary information to infer about soil classes and soil properties and their distribution in the landscape. This serves to decrease costs. PSM furthermore uses variables that can easily be quantitatively measured, allowing predictions to be done consistently and objectively. An additional advantage of PSM is its role in facilitating soil mapping. The outputs of traditional soil surveys are maps having polygon delineations of soil types which are assumed to be uniform within. In reality the homogeneity of soils in a landscape depends on the scale of the study. However, even at large scales soils vary continuously and there is need for a mapping system that represents this variation. PSM, utilizing the developments achieved in GIS, can present this continuous soil variation in an appropriate way. PSM uses geographic data types that discretize the surface of study area into smaller grids, in which the value allocated to every grid cell (pixel) can be individually recorded and depicted. By so doing it also provides a means of controlling the resolution of the map produced.

4.2.2.3 Progress with PSM

4.2.2.3.1 Introduction

Fuelled by the need for a better soil survey method, different PSM models have been developed. The development of such models is an ongoing process which is continuously being shaped by the introduction of new techniques. This makes PSM an interesting area of research. Depending on the techniques employed and areas of emphasis, progress can be grouped into statistical methods, geostatistical methods, artificial intelligence and expert systems. None of the models prepared by only one of these means can be considered to be the best. This is mainly due to the fact that each method has merits suited for a particular objective. Therefore a combination which exploits the merits of each one promises to be the best option.

At least 3 reviews have been done recording progress with PSM (McBratney *et al.* 2000, Scull *et al*. 2003, and McBratney *et al*. 2003). They provide good coverage of the subject. Only important developments and studies similar to ours will be considered here.

The work that pioneered the use of digital applications based on theories was done by Jenny (1941). He focused on the process of soil formation (pedogenesis), recognized the role of soil forming factors, and expressed this in the form of mathematical equations (equations 1 and 2). At that particular time, and for decades to follow, an acceptable way of quantifying the factors was not available. The equation nevertheless served as a launching pad for research. The important formulation done by Jenny (1941) not only described soil type as a function of the five soil forming factors (equation 1), but also introduced the concept of focussing on the influence of varying a particular factor of formation while keeping the others constant (equation 2). Equation 2 here, for example, shows soil variation as a function of climate. This concept might have been developed to mimic a normal experimental procedure in science, which observes the effect of one factor while keeping others constant. The problem with this procedure with regard to soil formation is that the process takes place over a very long time. Nevertheless this concept served to provide the foundation for the assumption made in PSM.

$$S = f\,(cl, o, r, p, t, \ldots) \qquad (1)$$

$$S = f\,(cl)_{o, r, p, t, \ldots} \qquad (2)$$

Where S = soil properties (type)

cl = Climate
o = Organisms
r = Topography
p = Parent material
t = Time

The major assumption that stems from the above equations, which is reflected in most of PSM models, is that soil pedosequences in a particular relatively small area tend to be similar. The underlying assumption is that in a relatively small area there is not much variation in the soil forming factors, apart from topography, to bring about soil variation. This is presumably what Hudson (1992) refers to as the “landscape paradigm” which plays such an important role in soil surveys.

Although the equation represents the theory of soil formation explicitly, it is mathematically unsolvable (Scull *et al*., 2003). For this reason no remarkable advances were made soon after Jenny’s publication in 1941. It was only during the 1960’s that research in pedometrics started to blossom (Webster, 1994). This development was fuelled by the introduction of new statistical techniques in soil science. This research was further promoted by advances achieved in geostatistics. Geostatistics is a technique that addresses variation as a function of spatial factors. McBratney *et al*. (2003) noted that this shift to include spatial factors was necessitated for two reasons. First, there was a need to map the results, and secondly, to use Jenny’s equations for prediction purposes all the factors need to be quantified. This is a difficult task.

Because of the difficulty of quantifying the soil forming factors, ways of modelling these factors became important. Among the five soil forming factors direct measurement of climate and relief is relatively easy. Parent material can easily be expressed nominally or as dummy variable, i.e. as absent or present. The influence of organisms and time are not easy to measure directly. Even if direct measurement is not easy, surrogate or proxy variables can be used to represent them. In cases where such quantification is very difficult, approximation by local experts who have good knowledge of the area can be used (Zhu *et al*., 2001).

Since one of the objectives of PSM is to solve the difficulty of obtaining data during surveying, using readily available data sources is a valid option. To serve this objective, easily measured attributes like topographic, climatic and geological parameters have been used to model the relationship between these environmental attributes and the soil. In addressing this issue Zhu *et al*. (2001) states that the choice of environmental variables can be done depending on data availability and significance in impacting pedogenesis. This means that among the available representative variables the ones that provide ease of measurement and use are utilized in model build up. Such variables can then be used to model the relationship with the soil and used as the basis for prediction.

Much of the work done has focussed on modelling variations in relief in relation to variations in soils. Scull *et al*. (2003) provides a list of research that has been done on digital soil mapping. Among the listed studies, 15 of them used terrain attributes to model the relationship between the environment and the soil. Among those 15 studies 8 of them used terrain attributes only. Such wide use of terrain attributes to model the relationship between soils and their environment accentuates the significance of terrain attributes in explaining pedogenesis.

4.2.2.3.2 Digital terrain modelling

Digital terrain modelling in general terms provides a quantification of landform shape, connectivities and adjacencies that define external landscape geomorphometry, and water flow patterns (Gessler *et al*., 2000). Rossiter, (2005) termed this procedure a promising approach for prediction and noted that it stems from the fact that soil distribution and geomorphology are strongly related. This procedure is also considered by McKenzie & Ryan (1999) to display good potential for generating environmental variables that reflect geomorphic, climatic and hydrological processes. This means that using such variables would not only represent the relief part of soil forming factors but also other factors that vary with changing topography.

Digital terrain analysis as a tool in PSM can help to achieve different goals. McKenzie *et al*. (2000) enumerate the following end results that can be realized:

- “Generate high-resolution environmental information of direct use in land evaluation (slope, net radiation etc)
- Create explicit environmental stratifications for survey design
- Provide quantitative spatial predictions of individual soil properties”

With the current developments in GIS digital terrain modelling is done by analysing digital elevation models (DEM). A DEM is a digital model of landform data represented as point elevation values. Such models can be produced by scanning or digitizing existing contour lines or other isarithms (Demers, 2005). It can also be produced from electronic data that is gathered by remote sensing (Burrough and McDonell, 1998).

Using DEMs as an input into a GIS makes it possible to produce sets of digital parameters that are representative of the terrain. The set of parameters might include first and second derivatives of the terrain attributes (Wilson and Gallant, 2000). Among the common ones are: slope angle, aspect, plan and profile curvatures, flow direction, contours, viewshed, stream link, topographic wetness index, etc.

4.2.2.3.3 Statistical applications in PSM

Statistical methods have been the basis for the introduction of automated prediction in soil science. Application of statistics in PSM can be seen as coming in two forms (Hengl and Heuvelink, 2004). The first one is the use of ordinary multivariate analysis which is widely used in all the sciences. The second one is the use of geostatistics, a statistical application that takes into consideration the relationship that datasets display as a function of spatial proximity and differences. These methods in PSM have been used to interpolate the values of soil properties in areas where measurements have not been taken from field samples (Scull *et al*. 2003). Such use of statistical methods facilitates standardization of spatial predictions invariably done in conventional soil surveys. In these surveys, since sampling can only represent a small fraction of the total area (around 0.01%), conceptual prediction and interpolation is generally done subjectively by the operator. Using geostatistical techniques of interpolation enables consistent interpolation and mapping. The use of geostatistics in soil science has been the major focus of pedometrics since its development in the 1960’s.

Multivariate statistics has been used to model the relationship between the soil and environmental variables. Different techniques have been used in soil science. The statistical methods used include: multiple linear regression, generalized linear models (GLM), general additive models, multivariate discriminant analysis, principal component regression and multiple logistic regression. McBratney *et al*. (2003) provides a list of predictive studies with specification of methods used, factors of prediction and the predicted property. Among these techniques a method that can also be used to predict nominal variables (like soil classes) is discriminant analysis. It has been used successfully to predict soil classes from data obtained by conventional soil surveys (Webster and Burrough, 1974). Kravchenko *et al*. (2002) also used discriminant analysis to predict soil drainage classes.

4.2.3 Procedure

The study area is located in land type Dc17, located in the Free State province about 90 km East of Bloemfontein in the vicinity of Thaba Nchu. Within this land type two separate soilscapes were studied, viz. Gladstone and Potsane. Data from Gladstone was used to develop, train and test a model. It covers an area of 3 410 ha which is currently mainly used for grazing. Samples from Potsane were used to validate the model. The area from which the validation sample points were collected covers 140 ha, which is only part of Potsane. Since both areas are located in a same land type, they share the same macro climate and macro geology.

Soil survey

A standard soil survey was conducted on Gladstone by digging 140 soil pits to expose test profiles (TP's). These TP's were operator-selected points to be representative of the study area. GPS readings of every TP was recorded for the purpose of mapping and further spatial analysis. Profiles were properly described and soil forms identified according to South African soil classification system (Soil classification working group, 1991).

GIS and statistical modelling

All the terrain analysis done in GIS was based on SRTM (Shuttle Radar Topography Mission) point data with a resolution of 3 arc sec, corresponding to a pixel size of approximately 90 m. A digital elevation model (DEM) of the study area was derived in ArcMap 9.1 from the SRTM data and it was rescaled to a resolution of 30m by 30m pixel. The DEM was used to generate terrain attributes, i.e.: slope (percent), aspect, profile and plan curvature, flow direction and flow accumulation. The last two attributes and slope were used to further derive an important characteristic of relief, i.e. wetness index. The wetness index was calculated using the following formula (Burrough & McDonnell, 1998):

$$\text{Wetness Index} = \ln (A_S / \tan \beta)$$

Where: A_S = upslope area (m^2)

β = Slope in degrees

In calculating the wetness index, the upslope area was calculated by using flow accumulation (number of contributing pixels) multiplied by the pixel (grid) size of the raster. In so doing to avoid “No data” caused by computation of the natural logarithm of zero, where the number of contributing pixels is zero, a value of 1 is added for every pixel. With this procedure the minimum area will be an area of a single pixel. TMU, terrain morphological unit, was also derived from the DEM with the application of expert knowledge and the utilization of specialized mapping and three-dimensional visualization software, “3dMapper™” (Terrain Analytics, 2004).

In order to utilize the point information obtained from the standard soil survey, each soil pit observation was plotted using coordinates obtained from the GPS reading. Initially, the relief characteristics that are derived from the DEM were calculated as surfaces (raster datasets). All the terrain attributes were treated with a smoothing technique - filter (a neighbourhood tool in ArcMap) - to avoid data anomalies. With the help of the points representing soil pit observations, the terrain attribute values for each point was extracted and stored in a database on which further statistical analysis was performed. Before any modelling drive was set into motion, descriptive statistics of the extracted terrain attribute values were computed. The descriptive statistics were studied to observe if there was an obvious pattern and if there existed a visible relationship with the soil type.

To model the relationship between terrain attributes and soil type found in a particular relief, the following different statistical methods were considered: multiple regression, logistic regression, generalized linear model (GLM), clustering and discriminant analysis. Discriminant analysis was found to be appropriate and was used in the study. Discriminant analysis has an advantage over the other techniques in that the dependent variable does not need to be continuous, and it can therefore handle discrete variables like soil type. Basically discriminant analysis finds a set of prediction equations based on independent variables that are used to classify individuals into groups. And particularly in this study, discriminant analysis is used to find a decision rule in which soil type (or group of soil types) at a point can be predicted based on terrain attributes.

In developing the discriminant functions, soil type (soil form) was used as the dependent variable (grouping variable), and aspect, slope, profile curvature, plan curvature, wetness index and TMU where used as the independent variables. Among the 140 TP's six were excluded from analysis to avoid anomalies and 134 of those were used as the training data in the analysis. Each TP can be considered as a sample in statistical terms. An NCSS statistical package was used to run the data obtained from GIS to perform the discriminant analysis. The package provides the discriminant functions or sets of linear equations pertaining to each classification group. By combining the effect of all the topographical variables employed, discriminant analysis calculated the degree of likelihood (probability) of each data point to belong to each soil class. This probability is what is commonly known as posterior probability. A TP is assigned to a soil class for which it has the highest posterior probability. A classification matrix was also constructed to find out the percentage of groups correctly classified. The percentage of correctly classified is calculated dividing the number of sample correctly classified by total sample frequency.

To provide further explanation relevant to the purpose of study, the soil types were combined into appropriate groups and another set of discriminant functions were developed. Three soil groups were established based on the properties shared by the soil types. The first soil group included the shallow soils; Gs, My, Sw with depth less than 700mm. The second group was made of the deep soils; Ar, Bo, Rg, Se, Va, Sw with depth more than 700mm. The third group included the wet soils; Du and Es. Soil types which did no fit in the above categories were excluded from the analysis. With the above groups as dependent variables and with slope, aspect, plan curvature, profile curvature, wetness index and TMU as the independent variables, discriminant analysis was carried out. For ease of use the discriminant analysis was run on a SAS statistical package. As with the previous discriminant analysis, the posterior probability for each TP was calculated, a classification matrix was constructed, and the hit ratio (percentage of correctly classified groups) was computed.

The result of the discriminant analysis done on these soil groups was further validated in three phases. Firstly, *cross validation* was done on same set of data that was used to develop the discriminant functions. Cross validation is based on the principle of “leave one out”, or what is commonly known as “Jack knifing”. Taking one sample out at a time, the group into which this sample belongs is predicted using the remaining set. Secondly, the discriminant function is tested on the same study area but with new data sets of samples taken randomly on areas delineated as “suitable for in-field rain water harvesting (IRWH)” by an expert. Thirdly, the discriminant analysis was tested on different data sets from another study-area, Potsane, which is in the same land type.

4.2.4. Results and Discussion

The class level information (Table 6) reveals the makeup of the TP’s used for calibration in modelling the prediction of soil type. The frequency shows the relative representation of each soil form in the total number of TP’s or samples. In the first instance of the discriminant analysis run, the chance of encountering any of the soils was set to be equal by assigning them same prior probability. Thus the main determinant in this instance was the discriminant function derived in the process. The classification matrix constructed (Table 7) provides the predictive classification of the samples. The number of samples classified into a soil type and the percentage it makes out of the group is provided. From the classification done on the calibration samples one can see that regardless of the proportion there are samples for each soil type (diagonal shading) that are correctly classified. But cross validation reveals that, this result is not as good as it appears. The percentage correctly classified on the calibration samples make only 30.6%. This proportion is further magnified in the results obtained from cross validation (Table 8), only 20.2% were actually correctly classified.

Class Level Information				
SOIL_TYPE	**Frequency**	**Weight**	**Proportion**	**Prior probability**
Ar	7	7.0000	0.052239	0.083333
Bo	11	11.0000	0.082090	0.083333
Du	1	1.0000	0.007463	0.083333
Es	7	7.0000	0.052239	0.083333
Gs	2	2.0000	0.014925	0.083333
My	4	4.0000	0.029851	0.083333
Rg	12	12.0000	0.089552	0.083333
Se	49	49.0000	0.365672	0.083333
Ss	4	4.0000	0.029851	0.083333
Sw	33	33.0000	0.246269	0.083333
Va	3	3.0000	0.022388	0.083333
Va/Se	1	1.0000	0.007463	0.083333

Table 6 – Training sample makeup information, soil form abbreviations are from Soil classification working group (1991).

From the cross validation result (Table 8) the soil types that scored into the category of correctly classified are Ar, Bo, Es, My, Rg, Se, and Sw. From this result it is obvious that the proportion of representation in the training sample had an effect. This is further amplified by considering the percentage each of the soil types mentioned above make within the correctly classified category. The biggest contribution is made by Se and Sw.

The results from the second exercise i.e. prior probability set in relation to sample proportion, shows that it enables an increase in hit ratio to be achieved (Table 9). Such setting of prior probability is used if the sampling done is thought to be representative of the actual distribution. Here it can be noted, comparatively speaking, the sample proportion does provide more information than the plain assumption that “all soil classes have the same probability of occurrence”. Thus with prior probability set to sample proportion,

Number of Observations and Percent Classified into SOIL_TYPE													
From SOIL_TYPE	**Ar**	**Bo**	**Du**	**Es**	**Gs**	**My**	**Rg**	**Se**	**Ss**	**Sw**	**Va**	**Va/Se**	**Total**
Ar	2 28.57	1 14.29	0 0.00	0 0.00	0 0.00	1 14.29	0 0.00	2 28.57	0 0.00	0 0.00	1 14.29	0 0.00	7 100.00
Bo	1 9.09	2 18.18	0 0.00	1 9.09	1 9.09	1 9.09	2 18.18	1 9.09	1 9.09	0 0.00	1 9.09	0 0.00	11 100.00
Du	0 0.00	0 0.00	1 100.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1 100.00
Es	0 0.00	0 0.00	0 0.00	4 57.14	0 0.00	0 0.00	1 14.29	1 14.29	0 0.00	0 0.00	1 14.29	0 0.00	7 100.00
Gs	0 0.00	0 0.00	0 0.00	0 0.00	1 50.00	0 0.00	1 50.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	2 100.00
My	0 0.00	0 0.00	0 0.00	0 0.00	2 50.00	1 25.00	0 0.00	0 0.00	0 0.00	0 0.00	1 25.00	0 0.00	4 100.00
Rg	1 8.33	1 8.33	0 0.00	0 0.00	0 0.00	0 0.00	4 33.33	1 8.33	3 25.00	0 0.00	2 16.67	0 0.00	12 100.00
Se	5 10.20	2 4.08	1 2.04	4 8.16	3 6.12	1 2.04	8 16.33	10 20.41	3 6.12	2 4.08	3 6.12	7 14.29	49 100.00
Ss	0 0.00	0 0.00	0 0.00	0 0.00	1 25.00	0 0.00	0 0.00	1 25.00	2 50.00	0 0.00	0 0.00	0 0.00	4 100.00
Sw	1 3.03	4 12.12	0 0.00	2 6.06	4 12.12	4 12.12	2 6.06	1 3.03	3 9.09	12 36.36	0 0.00	0 0.00	33 100.00
Va	1 33.33	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1 33.33	0 0.00	0 0.00	0 0.00	1 33.33	0 0.00	3 100.00
Va/Se	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	1 100.00	1 100.00
Total	11 8.21	10 7.46	2 1.49	11 8.21	12 8.96	8 5.97	19 14.18	17 12.69	12 8.96	14 10.45	10 7.46	8 5.97	134 100.00
Prior probabilities	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	

Table 7 – Classification matrix for soil type - Discriminant analysis done on calibration samples. (*Equal prior probability*)

Number of Observations and Percent Classified into predicted soil type													
From SOIL_TYPE	**Ar**	**Bo**	**Du**	**Es**	**Gs**	**My**	**Rg**	**Se**	**Ss**	**Sw**	**Va**	**Va/Se**	**Total**
Ar	1 14.29	2 28.57	0 0	0 0	0 0	1 14.29	0 0	2 28.57	0 0	0 0	1 14.29	0 0	7 100
Bo	1 9.09	2 18.18	0 0	1 9.09	1 9.09	1 9.09	2 18.18	1 9.09	1 9.09	0 0	1 9.09	0 0	11 100
Du	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 100	1 100
Es	0 0	0 0	0 0	2 28.57	0 0	0 0	1 14.29	1 14.29	0 0	1 14.29	1 14.29	1 14.29	7 100
Gs	0 0	0 0	0 0	0 0	0 0	1 50	1 50	0 0	0 0	0 0	0 0	0 0	2 100
My	0 0	0 0	0 0	0 0	2 50	1 25	0 0	0 0	0 0	0 0	1 25	0 0	4 100
Rg	1 8.33	1 8.33	1 8.33	1 8.33	0 0	0 0	3 25	0 0	3 25	0 0	2 16.67	0 0	12 100
Se	5 10.2	2 4.08	1 2.04	4 8.16	3 6.12	1 2.04	8 16.33	9 18.37	3 6.12	3 6.12	3 6.12	7 14.29	49 100
Ss	0 0	0 0	0 0	0 0	1 25	0 0	2 50	1 25	0 0	0 0	0 0	0 0	4 100
Sw	0 0	4 12.12	1 3.03	2 6.06	4 12.12	4 12.12	2 6.06	2 6.06	5 15.15	9 27.27	0 0	0 0	33 100
Va	1 33.33	0 0	0 0	0 0	0 0	1 33.33	1 33.33	0 0	0 0	0 0	0 0	0 0	3 100
Va/Se	0 0	0 0	0 0	1 100	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 100
Total	9 6.72	11 8.21	3 2.24	11 8.21	11 8.21	10 7.46	20 14.93	16 11.94	12 8.96	13 9.7	9 6.72	9 6.72	134 100
Prior probabilities	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	

Table 8 – Classification matrix for soil type – Cross validation summary using linear discriminant function (*Equal prior probability*)

a hit ratio of 49.3% was achieved on the calibration data (Table 9), but decreasing to 44.7% with cross validation done on the training data. This hit ratio was for the overall sample, and might seem to be an impressive improvement over the first exercise in which the prior probabilities were assumed to be equal. Yet, observing the classification matrix, the hit ratio didn't improve for all soil classes, rather the soils types that are well represented are the ones that have dramatically increased. This means that the major soil types among the samples have an increased hit ratio at the expense of the other classes (specifically the minority soil types).

Despite the improvement achieved by changing the prior probabilities assigned to each soil type, from equal to proportional to sample frequency, the hit ratio did not achieve 50%. A closer study of the classification matrix for soil type reveals which samples are classified into which class. This makes it possible to regroup the soil types (*defined in procedure*) in a way that can facilitate achievement of the objective of investigating soil distribution prediction in relation to suitability to IRWH.

The results show that prediction done on appropriate groups of soil types brings the level of accuracy to an acceptable range. With no prior knowledge regarding the proportion of the soil groups, that is prior probability set equal for each group, 56.9% of the calibration data was correctly classified. The cross validation done on the training data supports the result with a similar score, 51.5%. Since additional information regarding the suitability to IRWH was available from expert analysis, extra points were used to validate the result. On the samples extracted from areas suitable to IRWH, 58.3% were correctly classified.

Number of Observations and Percent Classified into predicted soil type													
From SOIL_TYPE	**Ar**	**Bo**	**Du**	**Es**	**Gs**	**My**	**Rg**	**Se**	**Ss**	**Sw**	**Va**	**Va/Se**	**Total**
Ar	0 0	1 14.29	0 0	0 0	0 0	0 0	0 0	6 85.71	0 0	0 0	0 0	0 0	7 100
Bo	0 0	0 0	0 0	0 0	0 0	0 0	2 18.18	4 36.36	0 0	5 45.45	0 0	0 0	11 100
Du	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 100	0 0	0 0	0 0	0 0	1 100
Es	0 0	0 0	0 0	1 14.29	0 0	0 0	0 0	5 71.43	0 0	1 14.29	0 0	0 0	7 100
Gs	0 0	0 0	0 0	0 0	0 0	0 0	1 50	0 0	0 0	1 50	0 0	0 0	2 100
My	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 25	0 0	2 50	1 25	0 0	4 100
Rg	0 0	1 8.33	0 0	0 0	0 0	0 0	1 8.33	8 66.67	0 0	2 16.67	0 0	0 0	12 100
Se	0 0	0 0	0 0	0 0	0 0	0 0	2 4.08	39 79.59	0 0	8 16.33	0 0	0 0	49 100
Ss	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 50	0 0	2 50	0 0	0 0	4 100
Sw	0 0	0 0	0 0	0 0	0 0	0 0	0 0	12 36.36	2 6.06	19 57.58	0 0	0 0	33 100
Va	1 33.33	0 0	0 0	0 0	0 0	0 0	1 33.33	1 33.33	0 0	0 0	0 0	0 0	3 100
Va/Se	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 100	0 0	0 0	0 0	0 0	1 100
Total	1 0.75	2 1.49	0 0	1 0.75	0 0	0 0	7 5.22	80 59.7	2 1.49	40 29.85	1 0.75	0 0	134 100
Prior probability	0.05224	0.08209	0.00746	0.05224	0.01493	0.02985	0.08955	0.36567	0.02985	0.24627	0.02239	0.00746	

Table 9– Classification matrix for soil type – Cross validation summary using linear discriminant function (*prior probability proportional to sample size*)

To utilize the information carried by the sample proportion, a prior probability that is equal to the proportion of samples was considered. It yielded a dramatic increase in classification accuracy. The discriminant classification done on the training samples provided 83% accurately classified, and cross validation yielded 80%. The improvement is further magnified by the validation test done on samples extracted from areas suitable to IRWH. From 168 samples the discriminant classification identified 159 as suitable to IRWH, which works out at 94% accuracy.

Using the sample proportion as prior probability therefore provided a striking improvement in prediction accuracy. Here again, however, the overall improvement achieved is not proportional for all the soil groups. This means that only those groups making out a large proportion of the training sample have a high probability of being predicted correctly. For instance, since the deeper soils make the majority in the training samples, the results show that the validation test done on areas suitable to IRWH yielded a very high accuracy. The accuracy percentage for the smaller groups is very low, i.e. for the lithosols (shallow soils) and the wet soils.

To deal with this issue one can adjust the prior probability assigned to each group and monitor the changes effected. This might involve making tradeoffs between percentage of overall accuracy and class accuracy. To observe the effect of such adjustment, prior probabilities of 20%, 50%, and 30% (Table 9) based on the information observed in the samples (the proportion is arbitrarily selected) were used. In comparison with the prior probability set proportional to sample, the change in prior probability more than doubled the accuracy of the minor groups while at the same time it reduced that of the major group and effected a reduced overall accuracy, i.e. yielding accuracies of 74.6%, 66.2%, and 78% for training samples, cross validation and test areas suited to IRWH, respectively (Table 9). The decrease in overall accuracy was considerable, i.e. more than 15%. Thus one should be cautious about changing the prior probability. Using the sample proportion appears here to yield the best results. This also makes sense from a practical point of view. Poor predictions on very small areas of poor soils is obviously relatively unimportant compared to good predictions on large areas of good soils (group 2).

Soil group and overall accuracy					
Instances of different prior probabilities		Group three	Group two	Lithosols	Overall accuracy
Equal	Calibration samples	66.67	53.77	73.33	56.92
	Cross validation	55.56	49.06	66.67	51.53
	Area Suited to IRWH	-	58.33	-	58.33
	Prior Probability	33.333	33.333	33.333	
Proportional to sample	Calibration samples	22.22	98.11	2.31	83.07
	Cross validation	11.11	97.17	0.00	80.0
	Area Suited to IRWH	-	94.64	-	94.64
	Prior Probability	6.923	81.538	11.538	
Self assigned priors	Calibration samples	55.56	76.42	22.31	74.61
	Cross validation	44.44	71.70	40.00	66.15
	Area Suited to IRWH		77.98		77.98
	Prior Probability	20	50	30	

Table 10 – Summary of soil group prediction accuracy in Gladstone

The results of the validation test done on Potsane are presented in Table 11 and summarized in Table 12. As with the exercises considered earlier, the results from this test shows that prior knowledge on the dominance of soil groups is important. Land type data provides valuable information in this respect. The estimated percentages of the soils on each TMU are clearly presented in the land type inventories now available for the whole of South Africa. Since group 2 contains the soils that are suitable for IRWH it is their prediction that is important. The validation test shows that the model predicts these with an accuracy of 85% which is very satisfactory. Poor prediction accuracy of 12.5% for the Lithosols is relatively unimportant from a practical point of view.

(a)

Number of Observations and Percent Classified into Soil Group				
From	Group three	Group two	Lithosols	Total
Group two	6 23.08	11 42.31	9 34.62	26 100.00
Lithosols	1 12.50	5 62.50	2 25.00	8 100.00
Total	7 20.59	16 47.06	11 32.35	34 100.00
Prior probability	0.3333	0.33333	0.33333	

(b)

Number of Observations and Percent Classified into soil Group				
From	Group three	Group two	Lithosols	Total
Group two	0 0.00	22 84.62	4 15.38	26 100.00
Lithosols	1 12.50	6 75.00	1 12.50	8 100.00
Total	1 2.94	28 82.35	5 14.71	34 100.00
Prior probability	0.06923	0.81538	0.11538	

Table 11 – Classification matrices for Potsane TP's: (with prior probability (a) equal and (b) proportional to sample size)

Instances of prior probability	Percent correctly classified		
	Group two	Lithosols	Overall
Equal	42.31	25.00	38.23
Proportional to training samples	84.62	12.50	67.65

Table 12 – Summary of soil group prediction accuracy in Potsane.

Model Description

The outcome of linear discriminant analysis is a set of linear equations representing each soil group, i.e. the linear discriminant function (Equation 3). This enables allocation of a new sample into the groups. The equation is written in the following format:

$$y = a_1 * x_1 + a_2 * x_2 + \cdots + a_n * x_n + c \qquad (3)$$

Where: y = discriminant function value

$x_1 \ldots x_n$ = discriminant parameters

$a_1 \ldots a_n$ = coefficients of each parameter

c = constant

The form of equation 3 used in the current exercise is presented as equation 4. The coefficients applicable to each parameter for each soil group are recorded in Table 13.

$$Y = a_1*aspect + a_2*slope + a_3*pr.curv. + a_4*Plan.Curv + a_5*W.Index + a_6*TMU + c \qquad (4)$$

Where: *Aspect* = aspect

Slope = Slope percentage

Pr.curv. = Profile Curvature

Plan.Curv= Plan curvature

W.Index = wetness index

TMU = terrain morphological unit

$a_1, a_2, \ldots a_6$ = respective coefficient for each parameter which are given in Table 13 for each soil group

c = Constant given in Table 13 for each soil group

	Coefficients for the Linear Discriminant parameters for soil groups		
	Soil Groups		
Discriminant parameter	**Group three**	**Group two**	**Lithosols**
Constant	-129.89064	-118.14603	-120.42008
Aspect	-0.01437	-0.00711	-0.01280
Slope percentage	8.90258	9.47557	10.50828
Profile curvature	9.00758	0.54166	-5.07036
Plan Curvature	242.86567	227.02217	239.56904
Wetness Index	18.27012	17.64132	17.71761
TMU	-0.70304	-1.78664	-2.65654

Table 13 – Coefficients for different discriminant parameters which define the linear discriminant function for different soil groups (prior probability equal to sample proportion)

In order to use this model for prediction, one has to obtain (as was done in the current exercise) actual values for the coefficients for each of the parameters given in Table 13 for any point on a map. The parameters aspect, slope percentage, profile curvature, and wetness index can be obtained from a DEM by running a simple procedure in a GIS. The values that are obtained from ArcMap (GIS software) can be used directly as an input to the model. To obtain a value for the TMU parameter, expert knowledge is necessary. Using visualization software like 3dMapper™ (TERRAIN ANALYTICS, 2004) enables identifying different TMU's from a DEM and orthophoto map. Substituting values for the coefficients of each parameters enables one to obtain the discriminant function (Equation 4) and calculate the discriminant function value.

Allocating any point on a map to a soil group is done by calculating the discriminant function value for each equation representing each soil group. The soil group with the highest discriminant function value is the group into which the point is allocated. The discriminant function value expresses the probability of correctness of allocation.

4.2.5 Conclusion

- There is considerable potential in modelling digital terrain attributes in order to predict the distribution of soils in a land type. With careful application of relevant statistical methods acceptable accuracy can be obtained.
- Having seen the different results obtained by changing the probabilities, it is clear that prior knowledge of the soil distribution in an area (from land type data or reconnaissance studies) greatly improves the accuracy of the discriminant functions.
- There is a greater probability of dominant soils being correctly classified when the prior probability is set according to sample frequency proportion.
- For prediction in a new locality, care must be exercised to make sure that there exists similarity in environmental factors influencing soil formation. This is taken care of to a great extent when working within a land type.

5. SOIL SURVEY RESULTS

5.1 Introduction

The surveys were conducted on 1:10 000 ortho photo maps. Four types of observations were made:

(a) visual, used to identify the boundaries of areas clearly unsuitable for IRWH, locations fixed by GPS;

(b) depth to rock determinations up to 900 mm depth (e.g. stony, eroded, or steep areas), made with a steel penetrometer (Figure 6), locations fixed either by GPS for each observation of by the position at 100 m intervals (measured by a rope length) in a downslope row of which the start was fixed by GPS;

(c) test pits located at strategic points in selected toposequences, locations fixed by GPS, profiles described in sufficient detail to make a reliable decision regarding suitability for IRWH (good, moderate or unsuitable);

(d) modal profiles selected at the end of the survey of the most important soils, locations fixed by GPS, profiles described in detail and samples taken and analysed.

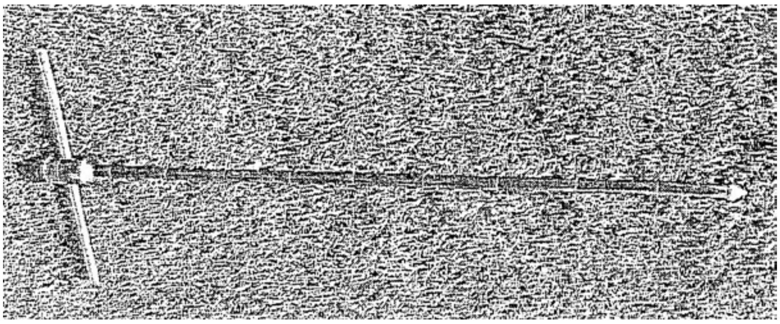


Figure 6 Penetrometer developed for determining soil depth to bedrock.

Although making a soil survey of particular soilscapes was not the main objective of this project, the resultant maps should nevertheless be useful for the subsistence farmers who have the use of this land. It is encouraging to hear that the Water Research Commission is already taking steps to fund other projects aimed at removing obstacles in the way of implementing the process of expansion of IRWH from backyards to croplands.

An important step towards streamlining the soil survey procedure was to clarify the criteria for determining suitability for IRWH. In all the controlled IRWH field experiments so far (Hensley *et al*. 2000 and Botha *et al.* 2003) the effective rooting depth of the soils has been around 1 200 mm of more, of which about 800 mm was generally high water holding capacity soil underlain by about 400 mm of saprolite weathered to varying degrees. However, many observations from results obtained in backyards, together with the interpretation of soil water extraction data obtained in the controlled field experiments, indicate that specific kinds of slightly shallower soils may also produce satisfactory results with IRWH. Because of the nature of the IRWH system it is of critical importance that the soil should have high water storage capacity. A drainage restricting horizon towards the bottom of the rootzone, e.g. "signs of wetness" below a pedocutanic horizon as in Sepane form, is considered to be advantageous for IRWH. After discussions with Prof L D van Rensburg and Dr J J Botha, the following criteria were adopted for these surveys:

- good (G) for IRWH = effective rooting depth (erd) > 900 mm;
- moderate (M) for IRWH = erd 700-900 mm;
- unsatisfactory for IRWH = erd < 700 mm (Sh), stony areas (St) eroded areas (Er), or areas with hydromorphic soils such as Estcourt, Klapmuts, Kroonstad and Katspruit forms (H).

5.2 Soilscape 58 Gladstone

The location of soilscape 58 can be seen in Figure 1. It is located about 95 km east of Bloemfontein and 20 km south of Thaba Nchu. It has a total area of 2721 ha. The major portion forms part of the Gladstone village area, the boundaries of which stretch beyond the borders of soilscape 58. Kundhlande *et al.* (2004) describe the Gladstone village as consisting of a total of 3 410 ha, of which 60, 378 and 2 972 ha are considered to be residential, arable and grazing land, respectively. The people of the village have shown great interest in IRWH and many employ the technique successfully in their backyard gardens (Botha, personal communication 2006). This is one of the reasons for choosing this soilscape for an intensive soil survey – in view also of the objective of some degree of capacity building and stimulating the interest of the local people.

The boundaries of the soilscape were transferred from the 1:50 000 maps used by Tekle (2004) to 1:10 000 ortho-photo maps. All further field and laboratory work for the survey were conducted on the following 1:10 000 maps: 2926 BD11 Noga's Post; 2926 BD12 Gladstone; 2926BD13 Eureka; 2926BD18 Vlakplaats.

The location of test profiles (total of 140) and penetrometer observation sites (total of 1427) are shown on the maps which accompany this report. Test pits are shown on the map with a dot surrounded by a circle, a TP number, and the abbreviation for the soil form. Penetrometer observations are shown by a dot only. All the dots on the map do not have numbers, because this creates too much "noise". For all penetrometer observations <700 mm deep the observation number and depth is recorded, since these indicate shallow soil. Where observations were 900 mm, numbers are given infrequently – but sufficiently frequently to enable the location of any observation to be traced. Detailed information about test pits and penetrometer observations is presented in Appendices 1 and 2.

The results have been interpreted and used to identify the areas of soilscape 58 that are suitable for IRWH. They are shown on the maps that accompany this report. Excluded areas are those where the soil is considered to be shallow, i.e. < 700 mm (marked as Sh on the maps), stony areas (marked as St on the maps); areas with only scattered patches of satisfactory soil (Sst on the maps); eroded areas (Er on the maps); the village areas (clearly visible on the maps).

The total area considered to be good for IRWH on soilscape 58 amounts to 1177 ha. These areas are marked with a G on the maps. Important soils in this class are of the Sepane (Photo No. 3), Swartland, Arcadia, Rensburg and Bonheim forms. The total area considered to be moderately suitable amounts to 254 ha, and is marked with M in the maps. The M areas are characterized by the effective rooting depth being too shallow (i.e. 700-900 mm), or where the effective rooting depth is >700 mm but the water holding capacity of the deeper layers is low. The latter occurs on some soils of the Swartland form with well weathered mudstone or sandstone saprolite at 600 mm. Soils considered to be unsuitable for IRWH are those belonging to the Mizpah, Glenrosa, Mayo, Klapmuts and Estcourt forms, and shallow members of the Swartland form.

The characteristics of the important soils on Gladstone are presented in the form of the profile descriptions and analytical data for six modal profiles in Appendix 3. Three of these profiles viz. Nos. 57, 61 (Photo No. 1) and 62 are classified as Arcadia form Rustenburg family, and considered to be good for IRWH. These are dark grey to black clay soils with clay % generally >50%. Below about 300 mm their structure is strong, with slickensides and many clay cutans. Effective rooting depth is estimated to be at least 1 200 mm, with considerable $CaCO_3$ towards the bottom of the profile. These soils are expected to respond very well to IRWH. Their water holding capacity is very high and they are well known for their naturally high fertility status. Profile No 76 represents the Swartland form (Amandel family – wet phase) soils evaluated as good for IRWH. Characteristic features are the high clay (62-65%), strongly structured B1 and B2 horizons with slickensides in the B2; and the pale coloured saprolitic C horizon well weathered and suitable for roots up to around 900 mm. Profile No. 47 is an example of the Swartland form (Amandel family – wet phase) soils evaluated as moderate for IRWH. The soil has similar features to No 76 excepting that the underlying saprolite is less hospitable for root development. Profile No 49, Klapmuts form (Photo No. 2), is considered unsuitable for IRWH because of the hydromorphic E horizon at 250 mm which is expected to seriously impair root development. Under IRWH hydromorphy will be exacerbated due to the water regime in the basin area being far higher than under natural conditions.

In the title of this report the term “rainwater harvesting” is used. This term includes “infield-rainwater harvesting” (IRWH), and “ex-field rainwater harvesting” (ERWH). The latter describes a technique whereby water from an adjacent uncultivated “catchment” area is transported to the IRWH area and distributed there, possibly in a herringbone layout, to provide additional water for crops. An ideal site for ERWH is available immediately to the east of Gladstone village, in the tree surrounded old land area and next to it on its west side. Much runoff water from the village could be conveyed there and distributed in an effective way into the basin areas of the IRWH system laid out in a herringbone pattern with the collection basins sloping slightly away from a central supply channel. The location of this mostly “good” area so close to the village makes this strategy particularly attractive.

5.3 Soilscape 6 Feloane/Potsane

The location of soilscape no. 6 can be seen in Figure 1. Tekle (2004) gives the total as 1211 ha, and estimates the arable portion as 678 ha. Soilscape no. 6 includes a large part of the areas belonging to the Feloane and Potsane villages. Kundhlande *et al.* (2004) give the total areas of these villages as 1318 ha and 970 ha, respectively; with estimated arable areas of 80 and 110 ha, respectively. As the boundaries of the village areas are not clearly defined on the available map supplied by the Free State Department of Agriculture, it is not possible to check the different areas presented. Our measurements made on 1:10 000 maps gave the total area of soilscape 6 as 1 599 ha. The reason for the discrepancy between our result and that of Tekle (2004) is not known.

Field work was carried out on the 1:10 000 maps 2926 BA15 Feloane and 2926BB11 Tiger River. The location of the test profiles (total of 115) and penetrometer observation sites (total of 117) are shown on the maps which accompany this report, using the same legend as for the Gladstone map. Detailed information about test profiles and penetrometer observations are presented in appendices 4 to 7. Information for the Potsane and Feloane villages is presented separately because these two are separate social entities.

Feloane

All the potentially arable land of this village which falls into soilscape 6 is situated between the irrigation canal from the Feloane dam and the Korannaspruit (Map 2926 BA15 Feloane). The area involved is 400 ha. The soil survey results give 62 ha classed as good, and 30 ha classed as moderate for IRWH, with the remaining 308 ha considered as unsuitable. A fruitful development strategy for the good soils would be to augment IRWH with supplementary irrigation from the presently unused canal. The most suitable sites for such a development would the two polygons containing test pits (TP's) 72 to 77, and 7 to 10, respectively, on the eastern side; and the strip along the west side stretching from TP41 down to TP50. It should also be possible to develop an ERWH system effectively on the latter strip. A deep gully eroded down the middle of this area, starting below the canal at 29°6,925'S and 26°43,402'E, proves that there is a large amount of runoff reaching this area from the hillslope above TP41. The main soils in this western strip are fairly deep high water holding capacity Arcadia soils very suitable for ERWH.

There are two areas of good soils close to the stream, around TP65 and around TP's54/61. The latter is jeopardised to some extent by a site between TP's58 and 59 where the stream floods over its banks when very full. This could easily be remedied by a low training bank along the stream. Another overflow point occurs in the sharp bend north of TP63. This has evidently been the cause of the hydromorphic "sloop" formation stretching from TP63 to TP52, and back into the stream at the depression visible on the map 300 m west of TP52. This strip should not be used for the usual crops grown here. It may be possible to grow rice on such a site, and possibly also on the wet area around TP5.

Details about soil profile and penetrometer observations are presented in Appendices 4 and 5. Modal profile descriptions and their analytical data are presented in Appendix 3. Two modal profiles were selected to represent important soils on the Feloane part of soilscape 6. Profile No. 3 (Photo No. 4) is typical of the shallow, wet phase Swartland soils rated as moderate for IRWH and provisionally named Gladstone series. The profile has a characteristic Orthic A horizon with a clear transition to typical, strong structured high clay, pedocutanic B horizon overlying slightly weathered sandstone with signs of wetness at 850 mm. Profile No. 54, Tukulu form, represents the "good" soils in the NW corner. It is a deep sandy clay loam with signs of wetness towards the bottom of the profile at 1 200 mm. This soil should respond very well to IRWH.

Potsane

The areas classed as good and moderate were 121 ha and 18 ha, respectively. The main contribution to the former are the two fairly large portions on either side of the "private farm" marked on the map, and immediately below the east-west dolerite ridge which forms the southern boundary of soilscape 6. Arcadia and Bonheim form soils are dominant in these two areas. An opportunity to develop an ERWH system presents itself in the "good" area close to Potsane village. The valley line immediately to the east of TP's 205-208 clearly carries much runoff water from the indentation in the dolerite ridge south of Potsane village. It should be possible to channel this water into a herringbone IRWH system spread out over the whole "good" area west of TP206.

Details about soil profile and penetrometer observations are presented in Appendices 6 and 7, and details about the one modal profile (No. 201 Photo No. 5) representative of the Potsane soils is presented in Appendix 3. It is Arcadia form with similar characteristics to the Arcadias of Gladstone excepting that in this case there is weathered mudstone at 700 mm. Because of the particularly high water holding capacity this soil should respond well to IRWH.

6. PROPOSED IMPROVED SOIL SURVEY TECHNIQUE FOR DELINEATING LAND SUITABLE FOR RAINWATER HARVESTING

This proposal emanates from the experience gained on only two separate soil surveys. It should be considered as a preliminary proposal for there are aspects which could probably be improved significantly as more experience is gained. To facilitate easy application, and possible improvement at a later stage, the proposed technique will be presented in a step by step format. It will be assumed that the survey is being carried out in an area inhabited by subsistence farmers, as in the case of the present survey, where labourers will be available and also to their advantage to earn some money and learn something about their soils.

Step 1: Study the relevant land type inventory, climate data and modal profiles together with the 1:250 000 land type map. Study all relevant reports and literature to try to understand pedogenesis on the land type as well as possible.

Step 2: Obtain the necessary data needed to operate 3dMapper.

Step 3: Delineate soilscapes on 1:50 000 maps on that part of the land type where intensive soil surveys are envisaged.

Step 4: Transfer the soilscape boundaries to 1:10 000 orthophoto maps, but preferably to 1:5 000 orthophoto maps with 1 m contours.

Step 5: Make a detailed reconnaissance visit to the area. It is assumed that the necessary social arrangements regarding right of access etc., will have been made beforehand. Make as many visual observations as possible, keeping the characteristic land type toposequence clearly in mind. Record the observations by GPS and plot them immediately using 3dMapper, loaded on a portable laptop computer, and on the 1:10 000 map when necessary. Identify representative hillslopes, and steep, stony, eroded and marshy areas, and also areas that most probably have shallow soils where test pits can be replaced by penetrometer observations. This reconnaissance survey should facilitate predictive mapping a great deal and help to formulate an effective strategy for the soil survey. This step should be undertaken by an experienced pedologist, together with the assistants who will undertake most of the field work. It is estimated that generally about one day will be needed for this exercise for about every 2 500 ha of a land type similar to Dc17. This is the approximate average area of one soilscape on Dc17.

Step 6: Carry out a predictive mapping exercise with 3dMapper on the whole soilscape, results to be compared later with the field data and used to identify difficult areas needing special attention.

Step 7: Selection of sites for test pits (TP's). Phase 1. Select representative toposequences on each of the hillslopes, and appropriate sites for TP's on each toposequence. All the knowledge gained by the pedologists in Step 1 needs to be mobilised during this step to facilitate predictive mapping. All the benefits offered by 3dMapper need to be employed intensively. Mark the sites using 3dMapper and on the 1:10 000 maps and determine their coordinates.

Step 8: "Flags" consisting of ± 1 ½ m lengths of 8 gauge wire, with a small piece of white or red material tied at one end to a loop in the wire, are needed to mark out in the field the sites identified in Step 6. A technical assistant with a suitable vehicle and GPS is needed for this task. Depending on the distance from base and on the terrain, it should be possible to peg out between about 40 and 80 sites per day.

Step 9: Decide on the depth to which TP's must be dug. For rating the suitability of soils for IRWH in a semi-arid land type like Dc17 it is considered that TP's dug to a depth of 900 mm are satisfactory. For detailed soil classification purposes a profile may need to be 1.5 m deep in some soils. However, since the main objective here is evaluation for IRWH in a cost effective way, a profile depth of 900 mm is adequate. The most important characteristics needed for classification purposes will generally be revealed within this depth. The following horizons, common in semi-arid areas, are examples: E, pedocutanic B, prismacutanic B, vertic, melanic, shallow soft plinthic B as in Westleigh form, lithocutanic B, neocutanic B, red apedal B, yellow-brown apedal B.

Step 10: Enlist labourers to dig the TP's, arranging appropriate payment per TP completed satisfactorily to the specified depth. Give to each one about 20 small metal plates marked with a distinctive number allocated specifically to each digger. These should be left in each completed TP, and should be collected at the end of each week by a technical assistant to determine payment.

Step 11: Proceed with the digging of TP's. The technical assistant with his vehicle is needed to facilitate this task. He can at the same time continue with the task of pegging out new sites well in advance of the diggers.

Step 12: Describing the profiles. A suitable time-saving form (Appendix 8) has been developed for this purpose. It is considered to provide sufficient information for IRWH evaluation. Only the data called for on the form need to be filled in. An experienced pedologist should preferably be involved from the start to set the standard for filling in the form, while training an assistant. It is essential that all the items receive diligent attention in order to produce a reliable soil map. Additional comments e.g. distance to stony areas nearby, details about signs of wetness, surface features that may be important for arability, signs of flooding, classification problems, etc. should also be made, when necessary, on the form. Having a defined standard set for profile descriptions, the bulk of the field work can be done by a less experienced pedologist or experienced technical assistant. Regular quality control should be exercised by the experienced pedologist in the field and in the laboratory.

Step 13: Employing penetrometer observations. The representative toposequences and toposequence TP's will soon reveal a characteristic soil pattern on each hillslope. The best way to augment observations by means of cheaper and faster penetrometer observations will become clear. The experienced pedologist should guide the policy in this connection. These observations can be made by a reliable technical assistant. Each observation should be located by GPS.

Step 14: Selection of sites for additional TP's. Phase 2. By the time the relatively low density Phase 1 TP's have been described and plotted on 3dMapper and on the 1:10 000 maps, the soil distribution pattern on each hillslope should be relatively clear. Make the best possible use of the knowledge and skills gained during Phase 1 to select sufficient additional TP sites and penetrometer observation sites to produce a good quality soil map.

Step 15: Final observations and drawing the soil map. Complete the Phase 2 observations, plot them, and draw the soil map. Identify modal profiles, describe and take samples for analysis. Measure the areas of each map unit and present a soil map on paper for the local inhabitants and extension officers, and in digital form. Prepare a report on the survey.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 The presentation in section 6 of a proposed improved soil survey procedure indicates that the objective of the project has been achieved. However, it needs to be kept in mind that considerable improvements on the proposed procedure will probably become possible in the future.

7.2 A map scale of 1:5 000 with 1 m contours is recommended.

7.3 Predictive mapping needs to be optimized. In this connection the following aspects are important:

(a) detailed understanding of pedogenesis in the particular land type, soilscape and hillslope;

(b) maximising the contribution of 3dMapper;

(c) effective employment of (a) and (b) during field work.

7.4 Procedures for making observations in the field:

(a) the speedy, low-cost penetrometer should be used wherever appropriate;

(b) test pits will always be necessary to provide essential information regarding profile morphology, and especially in the case of IRWH, to enable efficient evaluation of shallow underlying saprolite;

(c) because of (b), an effective but abbreviated procedure for recording the essential details of soil profiles is necessary – such as presented in Appendix 8.

(d) the proposed threshold depth of determination for observations is 900 mm for the purposes of identifying IRWH land in a semi-arid area.

(e) a mechanical auger mounted on a suitable vehicle would be a great advantage.

7.5 The services of a reliable, experienced technical assistant to conduct most of the laborious field work will make a large contribution to reducing costs and ensuring an efficient survey.

7.6 These surveys can provide valuable employment for local people and at the same time make them aware of the suitability of the soils of their village areas. There is some potential for a certain amount of capacity development among the younger fairly well educated people in the villages. This has been attempted during these surveys, and could be exploited further during future soil surveys of this nature.

7.7 The GPS instrument is of great value.

7.8 There is uncertainty about the evaluation of certain relatively shallow hydromorphic soils for IRWH, e.g. soils of the following forms: Swartland (shallow, wet phase, now named Gladstone series); Westleigh; shallow members of Avalon, Bloemdal, Bainsvlei and Pinedene, and the sandy members of these four forms. Research is needed to solve this problem.

7.9 Developing cost-effective soil survey procedures for different purposes should be considered as an ongoing task that should produce rich rewards in the future.

7.10 There is a current WRC project aimed at sorting out tribal cropland allocations in the Potsane and Gladstone Villages, and possibly other villages in the Thaba Nchu region. The project has been awarded to Umhlaba Consulting Group Pty Ltd. of East London, with Mr Siyabu Manona the active consultant. This is considered to be an important initiative set in motion by the WRC. Until this task has been efficiently completed, expansion of IRWH from homestead gardens to croplands in an ordered way will not be possible. These two activities are mutually dependant. It is of little value to spend time sorting out cropland allocations on land that is unsuitable for cultivation. It is also unnecessary, at least for the immediate future, to expand survey activities to identify IRWH land in excess of the area which the villagers wish to develop. In the Thaba Nchu region every village will also require a certain area to provide grazing for their stock. A certain amount of land use planning, before survey activities begin, would therefore be advantageous. It is recommended that these considerations receive attention in the planning of the expansion of IRWH to croplands.

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Photos of representative soils


Photo no 1 (Arcadia)


Photo no 2 (Klapmuts)

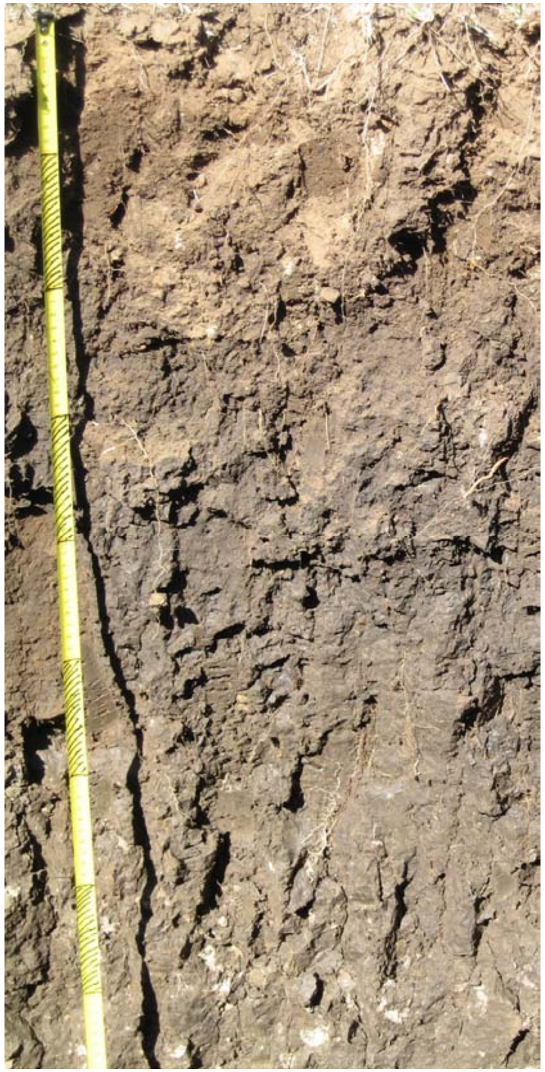
Photo no 3 (Sepane)

Photo no 4 (Swartland gladstone)

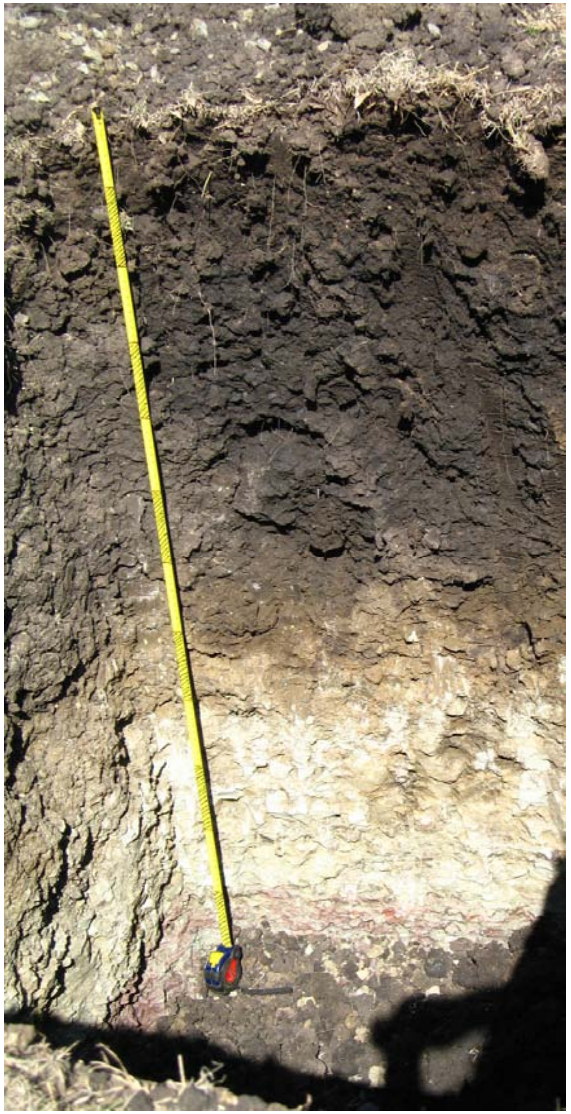

Photo no 5 (Arcadia)

Appendix 1 : Details of test pits - Gladstone

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
1	21.854	50.777	Ar	1300+	good
2	21.789	50.740	Ar	1500+	good
3	21.724	50.697	Bo	1450+	good
4	21.669	50.664	Bo	1300+	good
5	21.615	50.631	Bo	1400	good
6	21.574	50.606	Bo	1400	good
7	21.519	50.583	Bo	1500	good
8	21.476	50.556	Ss	1000	good
9	21.431	50.526	Se	1100	good
10	21.384	50.505	Se	1400	good
11	21.333	50.470	Rg	1200	good
12	21.311	50.461	Rg	1000	good
13	21.285	50.444	Du	1200	good
14	21.256	50.428	Se	1200	good
15	21.662	49.581	Se	1100	good
16	21.480	49.539	Se	1200	good
17	21.427	49.534	Se	900+	good
18	21.702	49.591	Se	400-500	unsuitable
19	21.799	48.456	Va	500	moderate
20	21.834	48.605	Ss	700	moderate
21	21.873	48.759	Es	250	unsuitable
22	21.896	48.859	Sw	900	good
23	21.919	48.952	Sw	1100	unsuitable
24	21.943	49.081	Sw	500	unsuitable

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
25	**22.647**	**49.306**	**Se**	**900+**	**good**
26	**22.597**	**49.348**	**Se**	**800+**	**good**
27	**22.496**	**49.434**	**Se**	**1000+**	**good**
28	**22.360**	**49.545**	**Sw**	**900+**	**good**
29	**22.292**	**49.612**	**Se**	**1000+**	**good**
30	**22.232**	**49.656**	**Se**	**1000+**	**good**
31	**22.330**	**50.217**	**Rg**	**1200**	**good**
32	**22.184**	**50.814**	**Ss**	**1100**	**good**
33	**22.224**	**50.635**	**Sw**	**1200**	**good**
34	**22.273**	**50.459**	**Sw**	**1200**	**good**
35	**21.892**	**47.463**	**Ve**	**1200**	**good**
36	**21.841**	**47.659**	**Ve**	**1100**	**good**
37	**21.801**	**47.814**	**Se**	**1100**	**good**
38	**21.811**	**47.991**	**Se**	**1000**	**good**
39	**21.774**	**48.210**	**Gs**	**300**	**unsuitable**
40	**21.781**	**48.296**	**Es**	**300**	**unsuitable**
41	**22.793**	**49.446**	**Se**	**1100**	**good**
42	**22.728**	**49.550**	**Se**	**1100**	**good**
43	**22.645**	**49.713**	**Se**	**1200**	**good**
44	**22.552**	**49.866**	**Se/Sw**	**900**	**good**
45	**22.488**	**49.964**	**Rg**	**900**	**good**
46	**22.412**	**50.078**	**Se**	**900**	**good**
47	**22.102**	**50.970**	**Sw**	**750**	**moderate**
48	**22.046**	**51.073**	**Se**	**1200**	**good**
49	**21.980**	**51.182**	**Km**	**250**	**unsuitable**

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
50	**22.523**	**51.093**	**Sw**	**1100**	**good**
51	**22.413**	**51.236**	**Sw**	**1000**	**good**
52	**22.330**	**51.341**	**Sw**	**650**	**unsuitable**
53	**22.299**	**51.382**	**Es**	**270**	**unsuitable**
54	**22.269**	**51.420**	**Es**	**250**	**unsuitable**
55	**22.225**	**51.481**	**Se**	**1000**	**good**
56	**22.606**	**50.948**	**Sw**	**1100+**	**good**
57	**22.675**	**50.714**	**Ar**	**1200**	**good**
58	**22.738**	**50.544**	**Se**	**1000**	**good**
59			**no test pit**		
60	**22.766**	**51.255**	**Bo**	**1200+**	**good**
61	**22.822**	**51.068**	**Ar**	**1000+**	**good**
62	**22.877**	**50.921**	**Ar**	**1100+**	**good**
63	**22.973**	**50.765**	**Rg**	**1400+**	**good**
64	**23.010**	**50.575**	**Ar**	**1200**	**good**
65	**23.062**	**50.419**	**Rg**	**1300+**	**good**
66	**23.130**	**50.244**	**Rg**	**600**	**unsuitable**
67	**23.170**	**50.161**	**Rg**	**900+**	**good**
68	**23.206**	**49.989**	**Rg**	**1000+**	**good**
69	**23.451**	**49.932**	**Se**	**1000+**	**good**
70	**22.763**	**50.759**	**Ss**	**1100**	**moderate**
71	**22.741**	**50.941**	**Rg**	**1200**	**good**
72	**22.689**	**51.091**	**Bo**	**1200**	**good**
73	**22.554**	**51.004**	**My**	**1100**	**unsuitable**
74	**22.538**	**51.709**	**Se**	**900+**	**good**

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
75	**22.646**	**51.647**	**Sw**	**570**	**unsuitable**
76	**22.774**	**51.567**	**Sw**	**900**	**moderate**
77	**22.915**	**51.472**	**Sw**	**650**	**moderate**
78	**23.001**	**51.401**	**Sw**	**1000**	**unsuitable**
79	**23.078**	**51.306**	**Se**	**830**	**good**
80	**23.168**	**51.218**	**Se**	**1100**	**good**
81	**23.258**	**51.121**	**Se**	**1100**	**good**
82	**23.342**	**51.032**	**Se**	**1000+**	**good**
83	**23.049**	**51.571**	**Sw**	**1000**	**unsuitable**
84	**23.181**	**51.710**	**Sw**	**1000**	**moderate**
85	**23.267**	**51.764**	**Ar**	**900**	**good**
86	**23.405**	**51.874**	**Ar**	**1000**	**good**
87	**23.488**	**51.942**	**My**	**600**	**unsuitable**
88	**23.593**	**52.070**	**Sw**	**800**	**moderate**
89	**23.668**	**52.151**	**Se**	**1000**	**good**
90	**23.710**	**52.037**	**Sw**	**1100**	**good**
91	**23.776**	**51.878**	**Bo**	**850**	**good**
92	**23.846**	**51.718**	**Se**	**1000**	**good**
93	**23.895**	**51.608**	**Sw**	**1100**	**good**
94	**22.863**	**52.098**	**Sw**	**700**	**moderate**
95	**22.879**	**52.029**	**Sw**	**800**	**moderate**
96	**22.954**	**52.075**	**My**	**650**	**unsuitable**
97	**23.151**	**52.174**	**Se**	**1200**	**good**
98	**23.262**	**52.261**	**Se**	**1200**	**good**
99	**23.384**	**52.366**	**Se**	**1200**	**good**

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
100	23.511	52.480	Se	1000	good
101	23.635	52.591	Sw	900	good
102			no test pit		
103	23.938	52.850	Sw	1000	unsuitable
104			no test pit		
105			no test pit		
106	23.974	52.764	Sw	800	moderate
107	23.913	52.651	Sw	600	unsuitable
108			no test pit		
109	23.844	52.465	Se	1100	good
110	23.910	52.305	Se	650	good
111	23.983	52.150	Bo	1200	good
112	24.065	52.009	Se	1000	good
113			no test pit		
114			no test pit		
115	23.231	52.707	Se	1100	good
116	23.160	52.806	Se	1100	good
117			no test pit		
118	22.932	52.944	Sw	500	unsuitable
119	22.875	52.831	Gs	400	unsuitable
120	22.699	52.733	Sw	500	unsuitable
121	22.616	52.643	Se	1200	good
122	22.533	52.537	Se	1200	good
123	22.488	52.469	Rg	1000	good
124	21.511	50.464	Sw	1100	good

Test pit No.	Co-ordinates S (29°) & __ min	E(26°) & __ min	Soil form	Effective rooting depth (mm)	Value for IRWH
125	**21.451**	**50.320**	**Va/Se**	**1100**	**good**
126	**21.587**	**50.290**	**Sw**	**550**	**unsuitable**
127	**21.428**	**50.173**	**Se/Sw**	**1100**	**good**
128	**21.565**	**50.149**	**Se/Sw**	**900**	**good**
129	**21.488**	**49.822**	**Se/Sw**	**800**	**good**
130	**21.700**	**50.870**	**Sw**	**750**	**good**
131	**21.612**	**50.850**	**Sw**	**800+**	**good**
132	**21.542**	**50.932**	**Sw**	**800+**	**good**
133	**21.602**	**51.000**	**Sw**	**800+**	**good**
134	**21.792**	**51.004**	**SW**	**750**	**good**
135	**21.729**	**51.086**	**Sw**	**900**	**good**
G1	**21.991**	**50.887**	**My**	**550**	**unsuitable**
G2	**21.930**	**50.897**	**Bo**	**700**	**unsuitable**
G3	**21.848**	**50.907**	**Bo**	**750**	**unsuitable**
G4	**21.783**	**50.882**	**Sw**	**750**	**moderate**
G5	**21.700**	**50.870**	**Sw**	**750**	**good**
G6	**21.612**	**50.850**	**Sw**	**800+**	**good**
G7	**21.512**	**50.852**	**Sw**	**750**	**good**
G8	**21.348**	**50.851**	**Sw**	**750**	**good**
G9	**21.271**	**50.858**	**Sw/Se**	**750**	**good**
G10	**21.197**	**50.856**	**Se**	**750**	**good**
G11	**21.131**	**50.856**	**Es**	**350**	**unsuitable**
G12	**21.973**	**51.011**	**Sw**	**600**	**unsuitable**
G13	**21.940**	**52.331**	**Es**	**500**	**unsuitable**

Note: Profiles marked G are from Tekle (2004)

Appendix 2 : Details of penetrometer observations - Gladstone

Observation No.	Effective depth (mm)	Observation No.	Effective depth (mm)
201	400	253	900
202	800	254	800
203	800	255	900
204	700	256	800
205	700	257	700
206	800	258	900
207	700	259	900
208	800	260	900
209	800	261	900
210	900	262	900
211	800	263	900
212	800	264	900
213	700	265	900
214	900	266	900
215	900	267	900
216	800	268	900
217	800	269	900
218	800	270	900
219	800	271	900
220	900	272	900
221	900	273	700
222	800	274-325	No Numbers
223	800	326	800
224	800	327	900
225	800	328	700
226	800	329	600
227	800	330	800
228	800	331	900
229	800	332	900
230	800	333	900
231	800	334	600
232	700	335	700
233	900	336	800
234	800	337	300
235	900	338	800
236	900	339	400
237	800	340	200
238	900	341	900
239	900	342	500
240	800	343	900
241	800	344	900
242	800	345	900
243	700	346	900
244	700	347	500
245	700	348	900
246	800	349	900
247	800	350	800
248	800	351	900
249	800	352	900
250	800	353	400
251	800	354-369	No Numbers
252	900	370	900

Observation No.	Effective depth (mm)
371	900
372	900
373	900
374	800
375	700
376	800
377	<700
378	900
379	900
380	900
381	900
382	900
383	900
384	900
385	<700
386	900
387	900
388	<700
389	800
390	800
391	900
392	900
393	900
394	900
395	900
396	<700
397	900
398	900
399	900
400	900
401	900
402	900
403	900
404	900
405	900
406	900
407	900
408	800
409	<700
410	900
411	800
412	900
413	900
414	900
415	900
416	900
417	600
418	900
419	800
420	800
421	900
422	900
423	900
424	900
425	700

Observation No.	Effective depth (mm)
426	700
427	600
428	600
429	No Numbers
430	900
431	800
432	<700
433	<700
434	800
435	900
436	900
437	800
438	700
439	700
440	800
441	300
442	200
443	100
444	600
445	800
446	800
447	700
448	500
449	300
450	700
451	800
452	500
453	600
454	600
455	700
456	400
457	600
458	700
459	800
460	800
461	800
462	700
463	600
464	700
465	900
466	900
467	900
468	800
469	800
470	700
471	600
472	800
473	900
474	900
501	600
502	900
503	800
504	800
505	700
506	400

Observation No.	Effective depth (mm)
507	900
508	800
509	900
510	900
511	900
512	900
513	900
514	900
515	900
516	900
517	900
518	800
519	900
520	700
521	900
522	600
523	900
524	300
525	700
526	800
527	800
528	800
529	800
530	400
531	800
532	900
533	800
534	200
535	400
536	700
537	600
538	500
539	800
540	800
541	900
542	900
543	300
544	700
545	300
546	700
547	600
548	700
549	800
550	300
551	900
552	800
553	800
554	800
555	600
556	>700
557	>700
558	500
559	600
560	>700
561	>700
562	>700
563	>700
564	>700
565	>700
566	>700
567	>700
568	500
569	>700
570	>700
571	>700
572	>700
573	>700
574	>700
575	>700
576	>700
577	>700
578	>700
579	>700
580	>700
581	>700
582	>700
583	>700
584	>700
585	>700
586	>700
587	>700
588	>700
589	>700
590	>700
591	400
592	700
593	600
594	600
595	700
596	600
597	600
598	500
599	700
600	700
601	700
602	600
603	800
604	300
605	900
606	500
607	800
608	900
609	900
610	900
611	900
612	800
613	900
614	900
615	800
616	900

Observation No.	Effective depth (mm)	Observation No.	Effective depth (mm)
617	400	850	900
618	600	851	800
619	800	852	900
620	900	853	900
621	900	854	600
622 - 800	No Numbers	855	800
801	900	856	900
802	900	857	900
803	900	858	800
804	900	859	900
805	900	860	900
806	900	861	900
807	900	862	900
808	900	863	900
809	900	864	900
810	900	865	800
811	900	866	700
812	900	867	900
813	900	868	900
814	900	869	900
815	900	870	900
816	900	871	900
817	900	872	900
818	900	873	800
819	900	874	900
820	900	875	900
821	900	876	900
822	900	877	900
823	900	878	900
824	800	879	800
825	900	880	900
826	900	881	900
827	900	882	600
828	800	883	600
829	900	884	800
830	900	885	900
831	900	886	900
832	900	887	800
833	900	888	800
834	900	889	900
835	900	890	900
836	900	891	900
837	900	892	900
838	900	893	900
839	900	894	900
840	900	895	900
841	900	896	900
842	900	897	900
843	900	898	900
844	900	899	800
845	900	900	800
846	600	901	800
847	800	902	900
848	900	903	800
849	900	904	900

Observation No.	Effective depth (mm)
905	900
906	800
907	600
908	700
909	800
1000	900
1001	900
1002	800
1003	800
1004	900
1005	900
1006	900
1007	900
1008	900
1009	700
1010	800
1011	900
1012	900
1013	900
1014	900
1015	900
1016	900
1017	900
1018	900
1019	900
1020	900
1021	900
1022	700
1023	800
1024	900
1025	900
1026	900
1027	900
1028	900
1029	900
1030	900
1031	900
1032	900
1033	900
1034	900
1035	900
1036	900
1037	900
1038	800
1039	800
1040	900
1041	900
1042	900
1043	900
1044	900
1045	900
1046	900
1047	900
1048	900
1049	900

Observation No.	Effective depth (mm)
1050	900
1051	900
1052	900
1053	900
1054	700
1055	800
1056	900
1057	900
1058	900
1059	<700
1060	800
1061	900
1062	900
1063	900
1064	900
1065	900
1066	900
1067	900
1068	900
1069	900
1070	900
1071	900
1072	900
1073	900
1074	900
1075	800
1076	900
1077	700
1078	900
1079	900
1080	900
1081	<700
1082	900
1083	900
1084	900
1085	900
1086	800
1087	900
1088	800
1089	900
1090 - 1099	No numbers
1100	900
1101	900
1102	800
1103	900
1104	900
1105	900
1106	900
1107	800
1108	900
1109	900
1110	800
1111	900
1112	900
1113	900

Observation No.	Effective depth (mm)	Observation No.	Effective depth (mm)
1114	900	1169	900
1115	900	1170	900
1116	900	1171	900
1117	900	1172	900
1118	800	1173	900
1119	700	1174	900
1120	800	1175	800
1121	900	1176	800
1122	800	1177	900
1123	<700	1178	900
1124	900	1179	900
1125	900	1180	800
1126	800	1181	900
1127	900	1182	800
1128	900	1183	700
1129	900	1184	800
1130	900	1185	900
1131	800	1186	800
1132	800	1187	900
1133	700	1188	900
1134	800	1189	800
1135	900	1190	700
1136	900	1191	900
1137	900	1192	900
1138	900	1193	800
1139	900	1194	900
1140	800	1195	900
1141	900	1196	800
1142	900	1197	900
1143	900	1198	900
1144	900	1199	900
1145	800	1200	900
1146	900	1201	900
1147	900	1202	900
1148	900	1203	900
1149	900	1204	900
1150	900	1205	900
1151	700	1206	900
1152	800	1207	800
1153	900	1208	800
1154	900	1209	900
1155	700	1210	900
1156	800	1211	800
1157	900	1212	900
1158	900	1213	700
1159	800	1214	900
1160	900	1215	700
1161	900	1216	700
1162	900	1217	900
1163	900	1218	800
1164	900	1219	900
1165	900	1220	900
1166	900	1221 - 1294	No numbers
1167	900	1295	800
1168	900	1296	900

Observation No.	Effective depth (mm)
1297	800
1298	800
1299	900
1300	800
1301	800
1302	800
1303	900
1304	900
1305	900
1306	700
1307	700
1308	800
1309	800
1310	600
1311	700
1312	800
1313	900
1314	800
1315	800
1316	900
1317 - 1400	No numbers
1401	>700
1402	>700
1403	>700
1404	>700
1405	>700
1406	600
1407	400
1408	>700
1409	>700
1410	>700
1411	>700
1412	>700
1413	>700
1414	>700
1415	>700
1416	>700
1417	>700
1418	>700
1419	>700
1420	>700
1421	>700
1422	>700
1423	>700
1424	>700
1425	>700
1426	>700
1427	>700
1428	>700
1429	>700
1430	>700
1431	>700
1432	>700
1433	>700
1434	>700

Observation No.	Effective depth (mm)
1435	>700
1436	>700
1437	>700
1438	>700
1439	>700
1440	>700
1441	>700
1442	>700
1443	>700
1444	>700
1445	>700
1446	>700
1447	>700
1448	>700
1449	>700
1450	>700
1451	>700
1452	>700
1453	>700
1454	>700
1455	>700
1456	>700
1457	>700
1458	>700
1459	>700
1460	500
1461	600
1462	>700
1463	>700
1464	>700
1465	>700
1466	>700
1467	>700
1468	>700
1469	>700
1470	>700
1471	>700
1472	>700
1473	>700
1474	>700
1475	>700
1476	>700
1477	>700
1478	>700
1479	>700
1480	>700
1481	>700
1482	>700
1483	>700
1484	>700
1485	>700
1486	>700
1487	>700
1488	>700
1489	>700

Observation No.	Effective depth (mm)
1490	>700
1491	>700
1492	>700
1493	>700
1494	600
1495	>700
1496	>700
1497 - 1519	No Numbers
1520	900
1521	900
1522	900
1523	900
1524	900
1525	900
1526	900
1527	900
1528	900
1529	900
1530	900
1531	900
1532	900
1533	900
1534	900
1535	No Number
1536	900
1537	900
1538	900
1539	900
1540	900
1541	900
1542	900
1543	900
1544	900
1545	900
1546	900
1547	900
1548	900
1549	900
1550	900
1551 - 1700	No numbers
1701	900
1702	800
1703	800
1704	900
1705	900
1706	900
1707	100
1708	400
1709	500
1710	700
1711	700
1712	800
1713	900
1714	900
1715	900

Observation No.	Effective depth (mm)
1716	700
1717	800
1718	800
1719	900
1720	800
1721	900
1722	900
1723	600
1724	700
1725	800
1726	900
1727	900
1728	900
1729	900
1730	900
1731	700
1732	800
1733	900
1734	900
1735	900
1736	900
1737	900
1738	700
1739	600
1740	400
1741	800
1742	800
1743	900
1744	900
1745	900
1746	900
1747	900
1748	900
1749	900
1750	600
1751	400
1752	200
1753	600
1754	800
1755	800
1756	400
1757	300
1758	700
1759	800
1760	900
1761	900
1762	900
1763	900
1764	900
1765	900
1766	900
1767	500
1768	500
1769	300
1770	700

Observation No.	Effective depth (mm)
1771	800
1772	900
1773	900
1774	900
1775	900
1776	700
1777	800
1778	900
1779	900
1780	900
1781	900
1782	900
1783	600
1784	800
1785	900
1786	900
1787	900
1789	900
1790	700
1791	800
1792	900
1793	900
1794	900
1795 - 1800	No Numbers
1801	400
1802	500
1803	600
1804	900
1805	900
1806	900
1807	900
1808	900
1809	900
1810	900
1811	900
1812	900
1813	600
1814	400
1815	300
1816	700
1817	800
1818	900
1819	900
1820	900
1821 - 1829	No Numbers
1830	500
1831	400
1832	600
1833	900
1834	900
1835	800
1836	800
1837	700
1838	900
1839	900

Observation No.	Effective depth (mm)
1840	600
1841	400
1842	300
1843	800
1844	800
1845	900
1846	900
1847 - 1860	No Numbers
1861	600
1862	900
1863	900
1864	900
1865	900
1866	200
1867	600
1868	900
1869	900
1870	900
1871	800
1872	800
1873	900
1874	900
1875	900
1876	800
1877	800
1878	900
1879	900
1880 - 1900	No Numbers
1901	600
1902	700
1903	600
1904	700
1905	900
1906	900
1907	900
1908	800
1909	900
1910	900
1911	900
1912	900
1913	900
1914	800
1915	900
1916	800
1917	800
1918	900
1919	900
1920	900
1921	900
1922	900
1923	900
1924	900
1925	800
1926	800
1927	700

Observation No.	Effective depth (mm)
1928	600
1929	400
1930	500
1931	900
1932	800
1933	900
1934	900
1935	900
1936	900
1937	900
1938	900
1939	900
1940	900
1941	800
1942	900
1943	900
1944	900
1945	900
1946	900
1947	800
1948	800
1949	900
1950	900
1951	900
1952	900
1953	800
1954	800
1955	900
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1971	900
1972	900
1973	900
1974	800
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1976	900
1977	900
1978	800
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1981	800
1982	800
1983	900
1984	900
1985	800
1986	900
1987	900
1988	900
1989	800
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1991	700
1992	600
1993	800
1994	900
1995	900
1996	900
1997	900
1998	900
1999	900
2000	900
2001	900
2002	900
2003	600
2004	700
2005	400
2006	800
2007	800
2008	900
2009	900
2010	900
2011	900
2012	900
2013	900
2014	900
2015	900
2016	900
2017	<700
2018	900
2019	900
2020	900
2021	700
2022	800
2023	900
2024	900
2025	900
2026	800
2027	400
2028	800
2029	900
2030	900
2031	900
2032	900
2033	900
2034	900
2035	700
2036	600
2037	800

Observation No.	Effective depth (mm)
2038	900
2039	900
2040	900
2041	900
2042	900
2043	900
2044	900
2045	900
2046	900
2047	800
2048	900
2049	900
2050	900
2051	700
2052	600
2053	800
2054	800
2055	900
2056	900
2057	900
2058	900
2059	900
2060	900
2061	900
2062	900
2063	800
2064	900
2065	900
2066	900
2067	900

Appendix 3 : Modal profiles and analytical data

Profile no: 47	**Soil form:** Swartland
Map 1:10 000: 2926BD12 Gladstone	**Soil family:** 1122 Amandel (wet phase)
Latitude & Longitude: S29° 22.101' E26° 50.971'	**Surface rockiness:** None
Surface stoniness: Class 2-10, angular, stones	**Occurrence of flooding:** None
Altitude:1517	**Wind erosion:** None
Terrain unit: 3U	**Water erosion:** Slight
Slope %: 2.4	**Vegetation/Land use:** Abandoned field
Slope shape: Straight: LL	**Water table:** None
Aspect: East	**Described by:** M Hensley & PAL le Roux
Micro relief: None	**Date described:** 9/2006
Parent material solum: Binary; underlying rock mu; local colluvium, dolerite	**Weathering of underlying material:** Moderate
Geological group: Beaufort	**Alteration of underlying material.** Calcified
	Evaluation for IRWH: Moderate

Horizon	Depth (mm)	Description:	Diagnostic horizon
A	-200	Dry; undisturbed; **dry colour:** 10YR(3/4); **moist colour:** 10YR(2/1); clay; weak, medium, subangular blocky; dry-hard; many roots; clear, smooth boundary	Orthic
B1	-500	Dry; undisturbed; **dry colour:** 5YR(3/2); **moist colour:** 5YR(2,5/1); clay; strong, coarse, angular blocky; dry-very hard; common, clay cutans; 3 sec water absorption; very few, coarse gravel fragments; many roots; gradual, smooth boundary	Pedocutanic
B2	-750	Moist; undisturbed; **dry colour** 2,5Y(5/2); **moist colour:** 2,5Y(4/4); clay; few, medium, distinct, black Fe oxide mottles; moist-firm; moderate free lime; few slickensides; many, clay cutans; 3 sec water absorption; common roots; gradual, tonguing boundary	Pedocutanic
C	-950	Undisturbed; mudstone and stones **dry colour** 10YR5/3; (E colour), faintly mottled; mudstone and stones(dolerite and quartzite); MB 2-3; clay soil illuviated in tongues into the saprolite; few roots.	Saprolite

Comment: PI % B2 = 29,9

Hor. Sample no. 47	Exchangeable cations & CEC ($cmol_c\ kg^{-1}$)							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
200	24.00	1.40	7.60	0.30	33.30	26.70	65.12	124.72	7.3	6.1	2	2	13	25	5	9	41
500	24.00	1.40	4.90	0.30	30.60	25.00	41.67	122.40	7.4	6.3	2	2	8	13	1	11	60
750	33.00	0.90	8.60	1.70	44.20	8.40	12.92	526.19	7.9	7.0	3	2	4	14	3	9	65

Profile no: 62	**Soil form:** Arcadia
Map 1:10 000: 2926BD12 Gladstone	**Soil family:** 1120 Rustenburg
Latitude & Longitude: S29°22.876' E26° 50.923'	**Surface rockiness:** None
Surface stoniness: None	**Occurrence of flooding:** None
Altitude:1515	**Wind erosion:** None
Terrain unit: 3L-4	**Water erosion:** None
Slope %: 1.6	**Vegetation/Land use:** Abandoned field
Slope shape: Concave CL (defined)	**Water table:** None
Aspect: West	**Described by:** M Hensley
Micro relief: None	**Date described:** 06/09
Parent material solum: Binary; local colluvium (dolerite DR); underlying rock; mudstone	**Weathering of underlying material:** Moderate (Chemical & Physical)
Geological group: Beaufort	**Alteration of underlying material:** Calcified
	Evaluation for IRWH: Good

Horizon	Depth (mm)	Description.	Diagnostic horizons
A1	-200	Moist; **dry colour:** 7,5 YR(3/2); **moist colour:** 10YR(3/3); clay; moderate, medium, subangular blocky; moist- very firm; normal macropores and cracks; few clay cutans; many roots; diffuse, smooth boundary	Vertic
A2	-450	Moist; **dry colour:** 10YR(3/2); **moist colour:** 10YR(3/3); clay; strong coarse angular blocky; moist- very firm; few, normal macropores and cracks; slight free lime; few slickensides; few roots; gradual smooth boundary	Vertic
C	-900	Moist; **dry colour** 10YR8/2; **moist colour:** 10YR7/8; clay; few, medium, faint grey, reduced Fe oxide mottles and brown geogenic mottling; moist- very firm; normal macropores and cracks; moderate free lime; few slickensides; many clay cutans; few roots	C

Comment: The dry colour of the C horizon is grey as defined for E. However it is also similar to the light brown mudstone which occurs locally. Long term water content measurements would be needed to decide between Ar and Rg. Only faint signs of saprolite at 900mm - brown colours. Pi of A1 = 29.5, A2 = 31.4.

Hor. Sample no. 62	Exchangeable cations & CEC (cmol$_c$ kg^{-1})							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
200	21.00	0.90	11.90	2.30	36.10	25.70	51.40	140.47	7.7	6.3	0	1	11	16	20	0	50
450	48.00	1.10	9.40	0.20	58.70	24.20	37.81	242.56	8.0	6.9	1	1	6	19	2	9	64
900	25.00	6.30	10.00	0.10	41.40	24.60	37.27	168.29	8.1	7.1	1	1	5	13	15	0	66

Profile no: 49
Map 1:10 000: 2926BD13 Gladstone
Latitude & Longitude: S29° 21.980' E26° 51.180'
Surface stoniness: None
Altitude:1507
Terrain unit: 4U
Slope %: 2,1
Slope shape: Concave- CL
Aspect: East
Micro relief: None
Parent material solum: Binary, underlying rock Fs; local colluvium DR
Geological group: Beaufort

Soil form: Klapmuts
Soil family: 1120 Napier
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Slight
Vegetation/Land use: Abandoned field
Water table: None
Described by: M Hensley
Date described: 9/2006
Weathering of underlying material: Moderate (Chemical and Physical)
Alteration of underlying material. Ferruginised
Evaluation for IRWH: Hydromorphic - unsuitable

Horizon	Depth (mm)	Description:	Diagnostic horizon
A	-250	Moist; undisturbed; **dry colour:** 10YR(5/4); **moist colour:** 10YR(3/4); fine sandy loam; apedal, massive; friable; few normal macropores and cracks; 1 sec water absorption; many roots; gradual smooth boundary	Orthic
E	-350	Moist; undisturbed; **dry colour:** 7,5YR(7/2); **moist colour:** 5YR(6/2); fine sandy clay loam; apedal, massive; friable; few normal macropores and cracks; very few sesquioxide concretions/nodules; very few medium, round coarse fragments; 1 sec water absorption; many roots; abrupt, wavy boundary	E
B1	-750	Moist; undisturbed; **dry colour** 7,5YR(5/2); **moist colour:** 7,5YR(4/0); clay; strong, coarse, angular blocky; moist-very firm; few, rusty, fine macropores and cracks; few slickensides; common, clay cutans; 5 sec water absorption; few roots; many, medium, distinct, red and black, oxidized Fe oxides mottles and many, medium, distinct, grey, reduced Fe oxides mottles.	Pedocutanic
C	-850	Weathered feldspathic sandstone	Saprolite

Comment: Black marks on the ped faces in B1 may be illuvial humus

Hor. Sample no. 49	Exchangeable cations & CEC (cmol$_c$ kg^{-1})							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
250	5.00	0.30	1.50	0.30	7.10	6.10	33.89	116.39	6.3	5.1	1	2	15	58	6	2	18
350	5.00	0.60	1.50	0.30	7.40	6.50	28.26	113.85	6.6	5.6	7	4	18	34	3	9	23
750	12.00	0.60	6.80	1.60	21.00	19.60	28.82	107.14	6.7	4.9	0	1	4	19	1	6	68

Profile no: 61
Map 1:10 000: 2926BD13 Gladstone
Latitude & Longitude: S29° 22.823' E26° 51.067'
Surface stoniness: None
Altitude:1522
Terrain unit: 3
Slope %: 2.8
Slope shape: Straight- LL
Aspect: West
Micro relief: None
Parent material solum: Binary; local colluvium (dolerite); underlying rock, Mu
Geological group: Beaufort

Soil form: Arcadia
Soil family: 1120 Rustenburg
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: Slight
Vegetation/Land use: Abandoned field
Water table: None
Described by: M Hensley & PAL le Roux
Date described: 9/2006
Weathering of underlying material: Moderate (Chemical and Physical)
Alteration of underlying material: Calcified
Evaluation for IRWH: Good

Horizon	Depth (mm)	Description:	Diagnostic horizon
A1	-300	Moist; undisturbed; **dry colour:** 10YR(3/1); **moist colour:** 2,5YR(2/0);clay; weak, medium subangular structure; slightly firm; few normal macropores and cracks; few clay cutans; 3 sec water absorption; many roots; diffuse, smooth boundary	Vertic
A2	-600	Moist; undisturbed; **dry colour:** 5YR(3/2); **moist colour:** 5YR(2,5/1); clay; strong, coarse angular blocky; firm; few normal macropores and cracks; few slickensides; many clay cutans; 1 sec water absorption;	Vertic
C1	-800	Moist; undisturbed; **dry colour** 10YR(5/1); **moist colour:** 2,5YR(2/0) (5/2); clay; medium, distinct, brown geogenic mottling and also few grey reduced Fe oxide mottles; 3 sec water absorption, many roots; gradual, smooth boundary	Unspecified material
C2	-1200	Moist; **dry colour:** 10YR(6/3); **moist colour:** 10YR(5/4); clay; common, medium, distinct, brown geogenic mottling and also few grey reduced Fe oxide mottles; slight free lime; many clay cutans; many slickensides; 3 sec water absorption; many roots	Unspecified material

Comment: Pi of A1 = 18.7 A2 = 19.5 C1 = 27.7

Hor. Sample no. 61	Exchangeable cations & CEC ($cmol_c\ kg^{-1}$)							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
300	26.00	0.70	3.20	0.20	30.10	24.70	45.74	121.86	7.5	6.3	0	1	13	19	2	9	54
600	7.00	0.80	1.60	0.20	9.60	25.50	39.84	37.65	7.8	6.4	0	1	13	18	2	3	64
800	28.00	0.70	8.60	3.20	40.50	15.20	23.38	266.45	8.2	6.8	3	2	5	17	1	8	65
1200	22.00	0.80	8.00	2.00	32.80	11.70	17.46	280.34	8.2	7.0	3	2	8	13	3	12	67

Profile no: 57	**Soil form:** Arcadia
Map 1:10000: 2926BD12 Gladstone	**Soil family:** 1120 Rustenburg
Latitude & Longitude: S29° 22.674 E26° 50.714	**Surface rockiness:** None
Surface stoniness: None	**Occurrence of flooding:** None
Altitude:1512	**Wind erosion:** None
Terrain unit: Transition (3L and 4)	**Water erosion:** Slight
Slope % : 2.4	**Vegetation/Land use:** Abandoned field
Slope shape: Concave -CL (slight)	**Water table:** None
Aspect: West	**Described by:** M Hensley
Micro relief: None	**Date described:** 9/2006
Parent material solum: Binary; underlying rock MU; local colluvium DR	**Weathering of underlying material:** Moderate (Chemical and Physical)
Geological group: Beaufort	**Alteration of underlying material.** Calcified
	Evaluation for IRWH: Good

Horizon	Depth (mm)	Description:	Diagnostic horizon
A	-250	Moist; **dry colour:** 5YR(4/1); **moist colour:** 5YR(3/2);clay; moderate, coarse, subangular blocky structure; moist firm; few normal macropores and cracks; few slickensides; few cutans; 3 sec water absorption; many roots; gradual, smooth boundary	Vertic
A2	-800	Moist; **dry colour:** 7,5YR(3/0); **moist colour:** 7,5YR(2/0); clay; moderate, ; firm coarse angular blocky; firm; few normal macropores and cracks; few slickensides; many cutans; 3 sec water absorption; many roots; gradual, smooth boundary	Vertic
C	-1200	Moist; **dry colour:** 10YR(7/2); **moist colour:** 10YR(6/3); clay; moderate coarse subangular blocky; firm; free lime; common, medium, faint, grey reduced Fe oxide mottles, and brown geogenic mottles; many cutans; many slickensides; 3 sec water absorption; few roots	Unspecified material

Comments: Pi of A=17,8 B1=22,2 C=36,0

Hor. Sample no. 57	Exchangeable cations & CEC ($cmol_c$ kg^{-1})							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
250	17.00	0.60	5.50	0.30	23.40	17.60	40.93	132.95	7.2	6.1	1	1	12	25	9	9	43
800	35.00	0.80	10.50	1.60	47.90	14.00	25.93	342.14	7.3	6.3	0	1	9	20	2	11	54
1200	20.00	0.80	5.70	0.40	26.90	25.30	34.66	106.32	8.0	6.9	1	1	3	14	3	5	73

Profile no: 76
Map 1:10 000: 2926BD13 Gladstone
Latitude & Longitude: S29° 22.774' E26° 51.567'
Surface stoniness: None
Altitude:1527
Terrain unit: 3
Slope % : 1.8
Slope shape: Straight - LL
Aspect: East
Micro relief: None
Parent material solum: Binary, underlying rock, mudstone (grey); local colluvium dolerite
Geological group: Beaufort

Soil form: Swartland
Soil family: 1122 Amandel (wet phase)
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation/Land use: Abandoned field
Water table: None
Described by: M Hensley
Date described: 9/2006
Weathering of underlying material: Moderate (Chemical and Physical)
Alteration of underlying material: Calcified
Evaluation for IRWH: Moderate

Horizon	Depth (mm)	Description.	Diagnostic horizons
A	-200	Moist; **dry colour:** 7,5YR(4/2); **moist colour:** 5YR(3/3); fine sandy clay loam; weak, coarse, subangular blocky; friable; few normal macropores and cracks; 1 sec water absorption; many roots; clear, smooth boundary	Orthic
B1	-600	Moist; **dry colour:** 7,5YR(3/2); **moist colour:** 5YR(3/2); clay; strong, coarse, angular blocky; firm; few normal macropores and cracks; common clay cutans; 3 sec water absorption; roots common; gradual, tonguing transition	Pedocutanic
B2/C	-800	Moist; **dry colour:** 7,5YR(5/0); **moist colour:** 7,5YR(4/0); clay; moderate, coarse, angular blocky; firm; few, normal macropores and cracks; common, clay cutans; few slickensides; 3 sec water absorption; gradual, smooth transition	Pedocutanic
C	-1110	Moderate free lime; faintly mottled grey and light olive, very pale and clearly hydromorphic saprolite	Saprolite

Comments: So starts at 800, 800-950 is MB0, then MB1, and MB3 at 1110. good rooting depth at 850mm. Pi of B2/C = 27,1

Hor. Sample no. 76	Exchangeable cations & CEC ($cmol_c\ kg^{-1}$)							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
200	2.00	1.10	9.40	1.20	13.70	11.60	34.12	118.10	7.2	6.4	2	3	29	20	4	6	34
600	14.00	0.90	4.50	0.20	19.60	21.40	32.92	91.59	7.4	7.0	1	2	9	18	1	2	65
800	18.00	0.70	8.60	0.80	28.10	13.80	22.26	203.62	8.1	7.0	2	2	8	16	2	12	62

Profile no: 201
Map 1: 10 000: 2926BA15 Feloana
Latitude & Longitude: S29° 08.131' E26° 44.939'
Surface stoniness: None
Altitude:1447
Terrain unit: 4L
Slope %: 2,0
Slope shape: Straight - LL
Aspect: N
Micro relief: None
Parent material solum: Binary; underlying rock mudstone; local colluvium dolorite
Geological group: Beaufort

Soil form: Arcadia
Soil family: 1200 Rustenburg
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation/Land use: Abandoned field/Disturbed land
Water table: None
Described by: PAL le Roux & M Hensley
Date described: 10/2006
Weathering of underlying material: Weak physical & chemical
Alteration of underlying material: Calcified
Evaluation for IRWH: good

Horizon	Depth (mm)	Description:	Diagnostic horizon
A1	-200	Dry, undisturbed; **dry colour:** 10YR(6/1); **moist colour:** 2,5YR(2/0); clay; strong, medium, angular blocky; very hard; many roots; gradual, smooth boundary	Vertic
A2	-700	Dry, undisturbed; **dry colour:** 10YR(3/1); **moist colour:** 2,5YR(2/0); clay; strong, coarse, angular blocky; very hard; many slickensides; many clay (pressure) cutans; very few, gravel, angular fragments; very few lime concretions; few roots; gradual, smooth boundary	Vertic
So	-800	Dry, undisturbed; few, distinct, olive mottles; few roots;	Saprolite

Comment.700-800mm is MB1-MB2; MB3 at 800, grey mudstone. Pi of A1=20.9and A2=34.9

Hor. Sample no. 201	Exchangeable cations & CEC ($cmol_c\ kg^{-1}$)							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
200	30.00	0.90	6.60	0.20	37.70	22.00	48.89	171.36	7.8	6.5	1	2	19	18	3	10	45
700	30.00	0.80	8.60	2.00	41.40	20.70	33.93	200.00	8.2	6.9	1	1	11	14	7	4	61

Profile no: 3
Map 1: 10 000: 2926BA15 Feloana
Latitude & Longitude: S29° 06.539' E26° 44.002'
Surface stoniness: None
Altitude:1410
Terrain unit: 3L Transition 3 to 4 on the 3rd erosion surface of landtype DC 17
Slope %: 1.9
Slope shape: CC (slight)
Aspect: E
Micro relief: None
Parent material solum: Single, sandstone (micaceous)
Geological group: Beaufort

Soil form: Swartland
Soil family: 1122 Amandel (wet phase)
Surface rockiness: None
Occurrence of flooding: None
Wind erosion: None
Water erosion: None
Vegetation/Land use: Open Grassveld
Water table: None
Described by: PAL le Roux & M Hensley
Date described: 10/2006
Weathering of underlying material: Weak chemical & physical
Alteration of underlying material: Ferruginised
Evaluation for IRWH: Moderate

Horizon	Depth (mm)	Description.	Diagnostic horizon
A	-230	Dry, undisturbed; **dry colour:** 7,5YR(5/4); **moist colour:** 7,5YR(4/4);Fine sandy loam; weak, medium, subangular blocky; slightly hard; very few, fine, gravel; many roots; clear, wavy boundary	Orthic
B	-550	Dry, undisturbed; **dry colour:** 7,5YR(6/6); **moist colour:** 7,5YR(4/6); clay; strong, coarse, angular blocky; very hard; common clay cutans; many roots; gradual tonguing boundary	Pedocutanic
C	-850	Undisturbed; common, coarse, prominent, oxidized Fe oxide, olive mottles and common, coarse, prominent, grey, reduced Fe oxide, mottles; weathered micaceous sandstone rated as MB 2-3	Saprolite

Comments: C horizon has tongues of pedocutanic into it, with signs of wetness; estimate effective rooting depth = 750mm.

Hor. Sample no. 3	Exchangeable cations & CEC ($cmol_c\ kg^{-1}$)							Base sat.	pH		Sand (%)				Silt (%)		Clay
	Ca	K	Mg	Na	S	CEC soil	CEC clay	(%)	H_2O	KCl	co	me	fi	v. fi	co	fi	(%)
230	3.00	0.30	1.60	0.30	5.20	5.20	52.00	100.00	6.0	5.0	3	8	46	25	10	1	10
550	10.00	0.60	3.70	0.30	14.60	12.90	32.25	113.18	6.1	4.7	1	2	20	17	3	15	40

Profile no: 54
Map 1: 10 000: 2926BA15 Feloana
Latitude & Longitude: S29° 06.386' E26° 43.190'
Surface stoniness: None
Altitude: 1398
Terrain unit: 5
Slope %: < 1
Slope shape: Straight - LL
Aspect: Absent
Micro relief: None
Parent material solum: Single - Alluvium
Geological group: Beaufort

Soil form: Tukulu
Soil family: 1120
Surface rockiness: None
Occurrence of flooding: Occasional
Wind erosion: None
Water erosion: None
Vegetation/Land use: Abandoned field
Water table: None
Described by: PAL le Roux & M Hensley
Date described: 06/10
Weathering of underlying material:
Alteration of underlying material: Calcified
Evaluation for IRWH: Good

Horizon	**Depth (mm)**	**Description.**	**Diagnostic horizon**
A	-300	Dry, undisturbed; **dry colour:** 2,5Y7/6; **moist colour:** 2,5Y4/6; fine sandy clay loam; weak, medium, subangular blocky; dry-hard; gradual smooth boundary	Orthic
B1	-550	Dry, undisturbed; **dry colour:** 10YR7/8; **moist colour:** 10YR4/6; fine sandy clay loam; moderate, medium, angular blocky; hard; common clay cutans; gradual smooth boundary	Neocutanic
B2	-1200	Dry undisturbed; **dry colour:** 10YR5/8; **moist colour:** 10YR4/6;clay; moderate, coarse, angular blocky; hard; common, clay cutans; very, few, medium, lime concretions; many coarse , prominent, grey, reduced Fe oxide mottles; few, fine, distinct, olive, oxidized Fe oxides mottles	Unspecified material with signs of wetness

Comments. B1 has CaCO in the matrix and few concretions; B2 hasCaCO3 concretions and none in the matrix

Hor. Sample no. 54	**Exchangeable cations & CEC ($cmol_c$ kg^{-1})**							**Base sat.**	**pH**		**Sand (%)**				**Silt (%)**		**Clay**
	Ca	**K**	**Mg**	**Na**	**S**	**CEC soil**	**CEC clay**	**(%)**	**H_2O**	**KCl**	**co**	**me**	**fi**	**v. fi**	**co**	**fi**	**(%)**
300	5.00	0.60	7.80	0.30	13.70	15.20	50.67	90.13	7.3	6.0	0	3	31	24	5	5	30
550	3.00	1.00	15.40	1.50	20.90	10.50	33.87	199.05	8.8	7.2	1	3	29	25	6	9	31
1200	3.00	0.60	17.20	5.40	26.20	24.20	50.42	108.26	8.9	7.6	1	2	17	18	2	11	48

Appendix 4 : Brief profile descriptions – Feloane

Location: Feloane

Described by: J. Gutter & M. Hensley; quality control PAL le Roux

Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL 4 = VL 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV 5 = VV 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC 6 =VC 9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
1	1	5a	6,588	43,861	A	0	200	ot	500	Oa	MB 4	U	ot is red brown
					B	200	450	vp					
					C	450	500	on					
2	1	5a	6,517	43,915	A	0	200	ot	600	Oa/Sw	MB 4	U	
					B	200	450	ne/vp					
					C	450	-600	on					
3	2	9b	6,539	44,002	A	0	300	ot	700	Sw	MB 3	M	600-700 is MB 2 with wetness 700-1200 MB 3 - 4 Gladstone series
					B	300	600	vp					
					C	600	700	so					
4	5	7b	6,572	44,065	A	0	250	ot	250	Ka		U	Depth limiting factor is water table (WT) - even in dry years evidently
					G	250	900	gh					
5	5	9a	6,608	44,115	A	0	400	ot	400	Ka		U	Depth limiting factor is the WT
					G	400	900	gh					
6	5	1a	6,647	44,182	A	0	200	ot	900	Du	MB 0	G	
						200	900	al					

Location: Feloane **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual 2 = clear 3 = abrupt	G = Good M = moderate U = Unsuitable	1 = LL 4 = VL 7 = CL 2 = LV 5 = VV 8 = CV 3 = LC 6 =VC 9 = CC	a = slight b = moderate c = defined	Mechanical resistance to root development

Terrain			Co-ordinates										
			29 Deg.	26 Deg.		Depth (mm)							
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
7	4	1a	6,759	44,186	A	0	150	ot	900	Bo	MB 1	G	Profile very dry
					B	150	500	vp					
					C	500	900	vw					
8	4	1b	6,733	44,105	A	0	500	ot	900	Tu	MB 2	G	
					B	500	800	ne					
					C	800	900	on					
9	4	7b	6,694	44,036	A	0	300	ot	900	Tu	MB 3	G	
					B	300	600	ne					
					C	600	900	on					
10	3	1b	6,648	43,969	A	0	300	ot	900	Sw	MB 4	M	
					B	300	600	vp					
					C	600	700	uw					
11	1	3a	6,715	43,886	A	0	200	ot	700	Sw	MB 3	M	Incipient signs of wetness slickensides is uw
					B	200	400	vp					
					C	400	750	uw					
12	3	3b	6,710	43,708	A	0	400	ot	400	Es		U	
					B	400	550	E					
					C	550	700	pr					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual 2 = clear 3 = abrupt	G = Good M = moderate U = Unsuitable	1 = LL 4 = VL 7 = CL 2 = LV 5 = VV 8 = CV 3 = LC 6 =VC 9 = CC	a = slight b = moderate c = defined	Mechanical resistance to root development

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
13	4	9b	6,705	43,595	A	0	300	ot	300	Es		U	
					B	300	400	E					
					C	400	800	pt					
14	4	1b	6,698	43,423	A	0	200	ot	600	Sw	MB 4	U	
					B	200	500	vp					
					C	500	600	so					
15	3	7b	6,617	43,571	A	0	300	ot	900	Tu	MB 1	G	C is weathered sandstone with clay rich tongues
					B	300	600	ne					
					C	600	900	on					
16	3	4b	6,607	43,480	A	0	350	ot	700	Gs	MB 3	U	
					B	350	700	le					
17	3	4b	6,542	43,373	A	0	200	ot	700	Sw	MB 4	M	C is weathered olive mudstone
					B	200	700	vp					
					C	700		so					
18	3	7b	6,406	43,438	A	0	350	ot	450	Gs	MB 4	U	
					B	350	450	lc					
19	5	1a	6,368	43,320	A	0	300	ot	300	Km	MB 3	U	Many motles in A and B. Hydromorphic
					B	300	350	gs					
					C	350	900	vp					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL, 4 = VL, 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV, 5 = VV, 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC, 6 =VC, 9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
Profile no.	TMU	Slope shape	29 Deg. Min. S	26 Deg. Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
20	3	1b	6,494	43,675	A	0	300	ot	900	Sw	MB 3	G	
					B	300	800	pr					
					C	800	900	c					
21	3	4a	6,341	43,759	A	0	250	ot	500	Sw	Mb 4	U	
					B	250	500	vp					
					C	500	600	so					
22	3	1a	6,324	43,655	A	0	200	ot	600	Sw	MB 4	U	Signs of wetness in so
					B	200	500	vp					
					C	500	600	so					
23	4	1a	6,244	43,563	A	0	150	ot	900	Sw	MB 2	G	
					B	150	600	vp					
					C	600	900	so					
24	5	1a	6,205	43,461	A	0	100	ot	950	Se	MB 1	G	
					B	100	500	vp					
					C	500	950	ud					
25	5	1a	6,149	43,373								U	Eroded area; no testpit made
26	3	5b	6,351	43,931	A	0	200	ot	200	Ms	MB 3	U	

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL, 4 = VL, 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV, 5 = VV, 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC, 6 =VC, 9 = CC	c = defined	

Terrain			Co-ordinates										
			29 Deg.	26 Deg.		Depth (mm)							
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
27	3	1b	6,201	43,803	A	0	200	ot	600	Sw	MB 4	U	
					B	200	500	vp					
					C	500	600	so					C is grey mudstone
28	5	1a	6,096	43,755	A	0	200	ot	200	Ka	MB 4	U	Many mottles in lower B.
					B	200	900	gh					Uneven surface close to river
					C		900+	uw					subject to flooding
29	3	5b	6,254	43,993	A	0	200	ot	200	Ms	MB 3	U	
30	3	1b	6,147	43,933	A	0	350	ot	800	Sw	MB 2	M	
					B	350	800	vp					vp is highly ferruginised
					C		800+	uw					
31	4	1a	6,060	43,900	A	0	250	ot	250	Ms	MB 4	U	
32	4	1a	6,125	44,074	A	0	300	ot	300	Ms	MB 4	U	
33	1 \ 3	1a	6,444	43,975	A	0	350	ot	350	Ms	MB 3	U	
34	3	1a	6,428	44,068	A	0	250	ot	250	Ms	MB 4	U	
35	5	1a	6,411	44,160								U	Eroded area; no testpit made

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL 4 = VL 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV 5 = VV 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC 6 =VC 9 = CC	c = defined	

Terrain			Co-ordinates										
			29 Deg.	26 Deg.		Depth (mm)							
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
36	5	1a	6,054	44,120								U	Eroded area; no testpit made
37	4	4a	6,674	43,316	A	0	200	ot	900	Sw	MB 1	G	
					B	200	800	vp					
					C	800	900	uw					
38	3	1b	6,685	43,227	A	0	700	ve	900	Ar	MB 3	G	
					B	700	900	un					
39	5	1a	6,478	43,259	A	0	300	ot	300	Kd		U	Part of sloop
					B	300	700	gs					
					C	600	900	gh					
40	4	1a	6,421	43,098	A	0	280	ot	900	Mu	MB 0	G	
					B	280	900	nc					
					C	900+		on					
41	3	3a	6,880	43,461	A	0	150	ve	900	Ar	MB3	G	
					B	150	700	ve					
					C	700	900	so					
42	3	5a	6,834	43,575	A	0	200	ot	900	Ss	MB 3	G	Rock outcrops nearby
					B	200	900	pr					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates										
			29 Deg.	26 Deg.		Depth (mm)							
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
43	3	5a	6,768	43,498	A	0	100	ot	400	Gs	MB 4	U	
					B	100	400	le					
44	3	4a	6.729	43,456	A	0	150	ot	600	Sw	MB 4	U	
					B	150	600	vp					Marked signs of wetness in so
					C	600+		so					
45	3	7a	6,657	43,461	A	0	300	ot	300	We	MB 4	U	
					B	300	500	sp					
						500	900	so					
46	3	9a	6,901	43,338	A	0	200	Me	900	Bo	MB2	G	
					B	200	600	vp					
					C	600	900	vw					
47	3	1b	6,804	43,307	A	0	200	ot	900	Sw	MB 3	G	
					B	200	600	vp					
					C	600	900	so					
48	3	3a	6,675	43,399	A	0	200	ot	900	Sw	MB 3	G	
					B	200	550	vp					
					C	550	900	uw					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual 2 = clear 3 = abrupt	G = Good M = moderate U = Unsuitable	1 = LL 4 = VL 7 = CL 2 = LV 5 = VV 8 = CV 3 = LC 6 =VC 9 = CC	a = slight b = moderate c = defined	Mechanical resistance to root development

Terrain			Co-ordinates			Depth (mm)							
Profile no.	TMU	Slope shape	29 Deg. Min. S	26 Deg. Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
49	3	1b	6,560	43,151	A	0	150	ml	900	Bo	MB 3	G	
					B	150	600	vp					
					C	600	900	so					
50	4 \ 5	9a	6,569	43,256	A	0	600	ve	900	Ar	MB 2	G	
					C	600	900	so					
51	4	1a	6,556	43,312	A	0	300	ot	900	Sw	MB 2	G	
					B	300	800	vp					
					C	800	900	uw					
52	5	1a	6,486	43,112	A / C	0	900	al	900	Du	MB 0	G	
53	5	1a	6,437	43,152	A	0	300	ot	900	Tu	MB 0	G	
					B	300	500	ne					
					C	500	900	on					
54	5	1a	6,386	43,190	A	0	200	ot	900	Oa	MB 2	G	Signs of stratification
					B	200	700	ne					
					C	700	900	un					
55	5	1a	6,338	43,253	A	0	400	ot	1000	Se	MB 0	G	Expect wetness 1000-1500
					B	400	900	vp					
					C	900	1000	ud					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual 2 = clear 3 = abrupt	G = Good M = moderate U = Unsuitable	1 = LL 4 = VL 7 = CL 2 = LV 5 = VV 8 = CV 3 = LC 6 =VC 9 = CC	a = slight b = moderate c = defined	Mechanical resistance to root development

Terrain			Co-ordinates										
			29 Deg.	26 Deg.		Depth (mm)							
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
57	5	1a	6,290	43,309	A	0	400	ot	1000	Se	MB 0	G	Expect wetness 1000-1500
					B	400	700	vp					
					C	700	1000	ud					
58	5	LL	6,271	43,287								G	Expect same as 57; penetrometer observations - test pit was not dug
59	5	LL	6,314	43,154									Eroded area; no testpit made
60	5	1a	6,350	43,131	A	0	300	ot	900	Du	MB 0	G	
					B	300	900	al					
61	5	1a	6,385	43,100	A	0	300	ot	900	Se	MB 3	G	Expect wetness 900-1500
					B	300	600	vp					
					C	600	900	ud					
62	5	1a	6,427	43,290	A	0	400	ve	900	Rg	MB 4	G	
					B	400	900	gh					
63	5	7a	6,297	43,366	A	0	350	ot	350	Es	MB 3	U	
					B	350	450	gs					
					C	450	900	pr					

Location: Feloane **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
Profile no.	TMU	Slope shape	29 Deg. Min. S	26 Deg. Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
64	5	1a	6,262	43,412	A	0	150	ot	900	Se	MB 3	G	Expect wetness 900-1500
					B	150	600	vp					
					C	600	900	ud					
65	4	1a	6,301	43,473	A	0	150	ot	900	Se	MB 1	G	Expect wetness 900-1500
					B	150	600	vp					
					C	600	900	ud					
66	4	1a	6,345	43,532	A	0	150	ot	900	Sw	MB 2	G	
					B	150	600	vp					
					C	600	900	ud					
67	3	7a	6,384	43,613	A	0	400	ot	400	Km		U	
					B	400	550	E					
					C	550	900	pr					
68	3	1a	6,413	43,689	A	0	300	ot	700+	Sw	MB 3	M	
					B	300	700	vp					
69	3	2a	6,437	43,757	A	0	200	ot	700	Sw	MB 3	M	
					B	200	600	vp					
					C	600	700	so					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
70	3	2a	6,466	43,809	A	0	200	ot	700	Sw	MB 4	M	
					B	200	600	vp					
					C	600	700	so					
71	5	1a	6,198	43,581	A	0	200	ot	200	Ms	MB 4	U	
					B	200+		R					
72	4	7a	6,912	44,533	A	0	180	ot	700	Sw	MB 3	M	C is weathered sandstone
					B	180	600	vp					
					C	600	700	so					
73	4	4a	6,808	44,501	A	0	150	ot	900	Sw	MB 3	G	
					B	150	900	vp					
					C	900	910	uw					
74	4	4b	6,760	44,421	A	0	200	ot	500	Sw	MB 4	U	
					B	200	450	vp					
					C	450	500	so					C is sandstone
75	4	4b	6,726	44,558	A	0	400	ve		Ar		M	Very shallow hole, expected at least 700mm
76	4	1a	6,830	44,596	A	0	400	ve	400	Re		U	Water table at 480mm
					B	400	800	gh					

Location: **Feloane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:
1 = gradual
2 = clear
3 = abrupt

Suitability for IRWH
G = Good
M = moderate
U = Unsuitable

Slope shape		
1 = LL	4 = VL	7 = CL
2 = LV	5 = VV	8 = CV
3 = LC	6 =VC	9 = CC

Slope intensity
a = slight
b = moderate
c = defined

MB 0-4
Mechanical resistance to root development

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
77	4	1b	6,903	44,612	A	0	400	ve	900	Re	MB 2	M	Calcareous
					B	400	900	gh					

Appendix 5: Feloane penetrometer observation data

Feloane penetrometer observations			
Penetr. Obs. No.	Coordinates	Effective depth (mm)	Suit. IRWH
248	S29 06.511 E26 44.080	800	M
249	S29 06.278 E26 43.890	500	U
250	S29 06.235 E26 43.859	600	U
251	S29 06.401 E26 43.769	800	M
252	S29 06.462 E26 43.759	800	M
253	S29 06.517 E26 43.740	500	U
254	S29 06.572 E26 43.731	<300	U
255	S29 06.636 E26 43.717	<300	U
256	S29 06.562 E26 43.658	<300	U
257	S29 06.602 E26 43.629	900	G
258	S29 06.435 E26 43.674	900	G
259	S29 06.359 E26 43.615	500	U
260	S29 06.374 E26 43.484	500	U
261	S29 06.400 E26 43.546	900	G
262	S29 06.445 E26 43.617	800	M
263	S29 06.375 E26 43.443	900	G
264	S29 06.441 E26 43.410	400	U
265	S29 06.440 E26 43.374	700	M
266	S29 06.733 E26 43.456	600	U
267	S29 06.780 E26 43.512	300	U
268	S29 06.818 E26 43.559	300	U
269	S29 06.897 E26 43.522	800	M
270	S29 06.885 E26 43.281	900	G
271	S29 06.799 E26 43.289	900	G

Appendix 6: Brief profile descriptions Potsane

Location: **Potsane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
201	4	1a	8,131	44,939	A	0	200	ve	900	Ar	MB 3	G	
					B	200	700	ve					At 800 is MB 1-2; grey mudstone
					C	700	800	so					
202	4	1a	8,236	44,976	A	0	200	ve	900	Ar	MB 3	G	
					B	200	700	ve					
					C	700	800	so					
203	3	4a	8,365	45,006	A	0	100	ml	900	Bo	MB 3	G	
					B	100	700	vp					
					C	700	900	so					
204	3	4a	8,410	45,017	A	0	100	ml	900	Bo	MB 3	G	
					B	100	700	vp					
					C	700	900	so					
205	3	1b	8,377	45,129	A	0	700	ve	1000	Ar	MB 3	G	
					B	700	1000	so					
206	3	1b	8,303	45,101	A	0	700	ve	1000	Ar	MB 2	G	
					B	700	1000	so					
207	4	1a	8,218	45,077	A	0	300	ot	300	Ms	MB 4	U	

Location: **Potsane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL, 4 = VL, 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV, 5 = VV, 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC, 6 =VC, 9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
208	4	1a	8,165	45,059	A	0	700	ve	900	Ar	MB 2	G	
					B	700	900	so					
209	3	4a	8,370	44,816	A	0	700	ve	900	Ar	MB 3	G	
					B	700	900	so					
210	3	1a	8,326	44,790	A	0	300	ml	900	Bo	MB 3	G	
					B	300	800	vp					
					C	800	900	uw					
211	3	1a	8,207	44,727	A	0	300	ml	900	Bo	MB 3	G	
					B	300	800	vp					
					C	800	900	uw					
212	3	1a	8,115	44,666	A	0	100	ml	800	Bo	MB 3	G	
					B	100	700	vp					
					C	700	800	so					
213	4	7a	7,926	43,957	A	0	250	ot	1000	Se	MB 2	G	
					B	250	900	vp					
					C	900	1000	uw					
214	3	4a	8,055	43,921	A	0	100	ml	900	Bo	MB 3	G	
					B	100	700	vp					
					C	700	900	so					

Location: **Potsane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
215	3	1a	8,172	43,885	A	0	100	ml	900	Bo	MB 3	G	
					B	100	700	vp					
					C	700	900	so					
216	3	1a	8,245	43,855	A	0	100	ml	900	Bo	MB 3	G	
					B	100	700	vp					
					C	700	900	so					
217	3	1b	8,330	43,834	A	0	200	ml	900	Bo	MB 3	G	
					B	200	650	vp					
					C	650	900	so					
218	3	5a	8,351	43,654	A	0	400	ml	900	Bo	MB 3	G	
					B	400	800	vp					
					C	800	900	on					
219	3	1b	8,269	43,664	A	0	150	ml	900	Bo	MB 3	G	
					B	150	700	vp					
					C	700	900	so					
220	3	1a	8,202	43,673	A	0	150	ml	900	Bo	MB 3	G	
					B	150	700	vp					
					C	700	900	so					

Location: **Potsane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape	Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL, 4 = VL, 7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV, 5 = VV, 8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC, 6 =VC, 9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
221	3	4a	8,113	43,667	A	0	500	ve	900	Ar	MB 3	U	Unsuitable because of eroded surface
					B	500	900	on					
222	4	7a	7,982	43,773	A	0	600	ve	900	Ar	MB 2	G	
					B	600	900	so					
223	4	7a	7,964	43,563	A	0	100	ml	900	Bo	MB 3	G	
					B	100	600	vp					
					C	600	900	ud					
224	3	1a	8,117	43,494	A	0	300	ml	900	Bo	MB 2	G	
					B	300	700	vp					
					C	700	900	ud					
225	3	1a	8,241	43,474	A	0	200	ot	500	Gs	MB 4	U	
					B	200	500	lc					
226	3	4b	7,875	43,339	A	0	750	ve	1000	Ar	MB 1	G	
					B	750	1000	unspec.					
227	4	7a	7,839	43,438	A	0	300	ot	300	Ms	MB 3	U	
228	3	4b	7,629	44,031	A	0	300	ot	300	Ms	MB 4	U	
					B	300+		R					

Location: Potsane **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
229	3	1b	7,769	43,995	A	0	200	ot	500	Gs	MB 4	U	
					B	200	500	lc					
230	3	4a	7,630	44,031	A	0	200	ot	900	Sw	MB 3	G	
					B	200	700	vp					
					C	700	900	ud					
231	3	1b	7,604	43,860	A	0	550	ve	900	Ar	MB 3	G	
					B	550	900	unspec.					
232	3	3a	7,681	43,805	A	0	100	ml	900	Bo	MB 3	G	
					B	100	600	vp					
					C	600	900	on					
233	4	7a	7,736	43,753	A	0	100	ot	600	Sw	MB 4	U	
					B	100	500	vp					
					C	500	800	so					
234	4	1b	7,593	43,583	A	0	300	ot	300	Ms	MB 4	U	
					B	300+		R					
235	3	4a	7,548	43,657	A	0	200	ot	700	Sw	MB 4	M	
					B	200	600	vp					
					C	600	700	so					

Location: **Potsane** **Described by:** J. Gutter & M. Hensley; quality control PAL le Roux Date: 6-11/06

Horizon transition:	Suitability for IRWH	Slope shape			Slope intensity	MB 0-4
1 = gradual	G = Good	1 = LL	4 = VL	7 = CL	a = slight	Mechanical resistance to root development
2 = clear	M = moderate	2 = LV	5 = VV	8 = CV	b = moderate	
3 = abrupt	U = Unsuitable	3 = LC	6 =VC	9 = CC	c = defined	

Terrain			Co-ordinates			Depth (mm)							
			29 Deg.	26 Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments
236	3	4a	7,490	43,350	A	0	300	ml	500	My	MB 4	U	
					B	300	500	lc					
237	3	7a	7,315	43,633	A	0	100	ot	900	Sw	MB 3	G	
					B	100	700	vp					
					C	700	900	ud					
238	3	7a	7,380	43,453	A	0	100	ot	900	Sw	MB 3	G	
					B	100	700	vp					
					C	700	900	uw					
239	3\4	4b	7,416	43,339	A	0	200	ot	200	Ms	MB 4	U	
					B	200+		R					

Appendix 7: Potsane penetrometer observations

Potsane penetrometer observations			
Penetr. Obs. No.		Effective depth (mm)	Suit. IRWH
301	S29 07.012 E29 43.515	900	G
302	S29 07.048 E29 43.503	900	G
303	S29 07.058 E29 43.492	700	M
304	S29 06.996 E29 43.432	700	M
305	S29 06.973 E29 43.509	300	U
306	S29 07.012 E29 43.553	500	U
307	S29 06.981 E29 43.600	600	U
308	S29 06.918 E29 43.706	450	U
309	S29 07.535 E29 43.985	650	U
310	S29 07.429 E29 43.929	550	U
311	S29 07.458 E29 44.071	Dolerite outcrop	U
312	S29 07.393 E29 44.123	450	U
313	S29 07.342 E29 44.187	450	U
314	S29 07.282 E29 44.228	Dolerite outcrop	U
440	S29 08.013 E26 44.843	700	M
441	S29 07.953 E26 44.826	400	U
442	S29 07.886 E26 44.815	600	U
443	S29 07.825 E26 44.799	700	M
444	S29 07.766 E26 44.784	800	M
445	S29 07.665 E26 44.756	800	M
446	S29 07.656 E26 44.658	500	U
447	S29 07.723 E26 44.661	600	U
448	S29 07.809 E26 44.677	500	U
449	S29 08.030 E26 43.470	800	M
450	S29 08.050 E26 43.396	800	M
451	S29 07.684 E26 43.916	500	U
452	S29 07.643 E26 43.760	600	U
453	S29 07.551 E26 43.793	400	U
454	S29 07.613 E26 43.082	200	U
455	S29 07.548 E26 43.098	400	U
456	S29 07.591 E26 43.266	600	U
457	S29 07.709 E26 43.390	600	U
458	S29 07.757 E26 43.364	300	U
459	S29 07.804 E26 43.443	600	U
460	S29 07.761 E26 43.478	800	M
461	S29 07.801 E26 43.562	Dolerite dyke	
462	S29 07.633 E26 43.662	800	M
463	S29 07.581 E26 43.688	700	M
464	S29 07.535 E26 43.712	600	U
465	S29 07.366 E26 43.687	800	M
466	S29 07.410 E26 43.623	700	M
467	S29 07.443 E26 43.574	600	U
468	S29 07.427 E26 43.505	500	U
469	S29 07.390 E26 43.408	600	U
470	S29 07.295 E26 43.377	900	G

Potsane penetrometer observations			
Penetr. Obs. No.		Effective depth (mm)	Suit. IRWH
471	S29 07.246 E26 43.346	700	M
472	S29 07.273 E26 43.288	600	U
473	S29 07.336 E26 43.276	500	U
474	S29 07.244 E26 43.433	700	M
475	S29 07.214 E26 43.494	500	U
476	S29 07.237 E26 43.554	600	U
477	S29 07.268 E26 43.607	500	U
478	S29 07.310 E26 43.687	600	U
479	S29 07.315 E26 43.540	900	G
480	S29 07.317 E26 43.430	900	G
481	S29 07.260 E26 42.970	300	U
482	S29 07.263 E26 42.901	900	G
483	S29 07.260 E26 42.817	600	U
484	S29 07.253 E26 42.767	<300	U
485	S29 07.310 E26 42.899	700	M
486	S29 07.201 E26 42.925	600	U
487	S29 07.200 E26 42.981	900	G
488	S29 07.111 E26 43.024	500	U
489	S29 07.107 E26 42.952	600	U
490	S29 06.945 E26 42.802	400	U
491	S29 06.955 E26 42.877	400	U
492	S29 06.869 E26 42.935	400	U
493	S29 06.757 E26 43.118	<300	U
494	S29 08.061 E26 44.696	900	G
495	S29 08.118 E26 44.758	900	G
496	S29 08.182 E26 44.825	900	G
497	S29 08.251 E26 44.893	900	G
498	S29 07.566 E26 44.352	400	U
499	S29 07.578 E26 44.414	600	U
500	S29 07.592 E26 44.482	700	M
501	S29 07.476 E26 44.479	600	U
502	S29 07.352 E26 44.482	700	M
504	S29 07.489 E26 44.735	400	U
505	S29 07.213 E26 44.829	600	U
506	S29 07.155 E26 44.865	800	M
507	S29 07.108 E26 44.828	900	G
508	S29 07.189 E26 44.947	800	M
509	S29 07.329 E26 45.127	800	M
510	S29 07.366 E26 45.088	400	U
511	S29 07.402 E26 45.156	700	M
512	S29 07.453 E26 45.178	500	U
513	S29 07.519 E26 45.222	700	M
514	S29 07.578 E26 45.207	400	U
515	S29 07.977 E26 45.805	600	U
516	S29 08.030 E26 45.877	400	U
517	S29 08.149 E26 45.852	800	M
518	S29 07.924 E26 44.971	500	U

Appendix 8 Short profile description form

Location: **Described by:** Date:

Horizon transition:
1 = gradual
2 = clear
3 = abrupt

Suitability for IRWH
G = Good
M = moderate
U = Unsuitable

Slope shape		
1 = LL	4 = VL	7 = CL
2 = LV	5 = VV	8 = CV
3 = LC	6 =VC	9 = CC

Slope intensity
a = slight
b = moderate
c = defined

MB 0-4
Mechanical resistance to root development

Terrain			Co-ordinates			Depth (mm)							
			Deg.	Deg.									
Profile no.	TMU	Slope shape	Min. S	Min. E	Master horizons	from	to	Diagnostic horizon	Effective rooting depth (mm)	Soil form	MB (0-4)	Suit. IRWH	Comments

APPENDIX 9 SURVEY PROCEDURES USED AT GLADSTONE AND FELOANE /POTSANE

9.1 Survey procedure used at Gladstone

The procedure followed is described below in a step by step format.

Step 1: The boundaries of the soilscape were transferred from 1:50000 to 1:10000 ortho-photo maps. All further field and laboratory work for the survey were conducted on the 1:10 000 maps.

Step 2: Strategic locations for toposequence lines were selected and drawn on the maps, and proposed sites for test pits (TP's) along these lines were marked. The co-ordinates of each site were determined by reference to the grid marks on the map edges. This was office work.

Step 3: Mr. J.J. Botha, researcher of the ARC-ISCW team at Glen, provided information about a suitable person at Gladstone (Mr Molatodi) to act as an agent to arrange labour and serve as local supervisor of the field work. Gladstone was visited for the first time on 7 March 2006. The proposed work was explained and wages agreed upon. The digging of test pits at selected locations was commenced on 8 March.

The sites selected for test holes were located by GPS and pegged out in the field with a steel fencing dropper at the top of which a strip of white material containing the TP number was tied. Mr. Jan Gutter an undergraduate BSc. Agric. student assisted with this task on two days per week. Mr. Molatodi deployed his TP diggers daily to proceed with their task. As their remuneration was based on the depth that had been dug (1,2m where possible), and number of TP's completed, they performed diligently. The supervisor was responsible for recording the TP's dug by each labourer. Payments were made at approximately weekly intervals to the workers. They generally varied in number up to a maximum of 10 at different times during the survey.

Step 4: Soil profiles were described using a form specifically developed for this survey. The form facilitates the task by eliminating the writing of descriptive words, and further by keeping the field worker aware of the characteristics that need to be described.

Step 5: Observations with the penetrometer were started on 15 March with one team of two labourers. Later, when TP digging had been completed, other teams were deployed for this task. As with the TP's, sites for strategic toposequence lines were selected and marked on the maps. Each team of two workers was provided with a rope 100 m long. Two marked droppers with flags on, were pegged in the field by GPS, 100 m apart, to describe the start of each line. The workers were instructed to use the two pegs as their direction finder, by siting back along them when making their observations. These were made at 100 m intervals by hammering in the penetrometer until it offered stern resistance. Each line was specified by means of a letter and a number e.g. A1, A2, etc., or B1, B2 etc., or C1, C2, etc. It was planned that a particular team of two workers would be responsible for all lines designated by a particular letter. Each team was given a notebook in which to record the number of the observation and the penetrometer reading depth. The completed "tear out" notebook pages on which results were recorded were to be given to the supervisor at the end of each day. This procedure worked reasonable well but there were shortcomings. It may be possible to overcome some of these.

9.2 Survey procedure used at Feloane/Potsane

Step 1 and step 2 of the Gladstone procedure were repeated for the Feloane/Potsane survey. Some alterations were made to Steps 3, 4 and 5 to reduce costs and improve efficiency.

With regard to step 3, acting on the advice of Mr J J Botha (ARC-ISCW Glen), instead of appointing a supervisor for the hole diggers, the local IRWH (Matangwane) leaders were asked if they could recruit labourers for us. It was explained that they would have no supervisory duties, and that recognition of their assistance would be in the form of a contribution of R100 to their Matangwane cooperative activities at the start of the survey, plus another R100 at the conclusion. The Matangwane leaders at both Feloane and Potsane are ladies. They both agreed. The served well throughout the survey. The need to keep a record of the test pits dug by each labourer was dealt with by giving each labourer a set of discs with a specific number allocated to him printed on the disc. The instructions were that each digger was to leave a disc of his in each test pit that he had dug. The plan was to collect the discs when the profiles were described, and payment made accordingly. The two improvements described here resulted in a considerable reduction in expenses.

Step 4 was improved in the following way. It was decided during this project that in order to qualify for the "good" and "moderate" ratings for IRWH a soil profile needed to have at least 900 mm and 700 mm, respectively, of rooting depth containing no problem horizons. At Gladstone the soil pits were dug to a depth of 1200 mm wherever possible. Although for classification purposes a soil profile needs to be exposed where possible to a depth of 1500 mm, the most important features occur within the top 900 mm. Probably because water is of such dominating importance for crop production in a semi-arid area, research results so far indicate that what is of cardinal importance for IRWH is a soil's capacity to store plant available water. Strongly hydromorphic horizons within about 700 mm from the surface (e.g. Estcourt and Klapmuts forms) are considered as disqualifications as they will probably impair root development during periods of heavy rain, and therefore not provide "plant available" water. Research is, however, still needed in this connection since there are large areas of soils like Westleigh, Avalon, Pinedene, Bloemdal and Bainsvlei forms in semi-arid areas with some degree of wetness which may be beneficial. Only relatively small areas of the latter soils occur in land type Dc17.

Because of these considerations and the danger of grazing animals falling into deep test holes, it was decided that 900 mm deep test pits were adequate for our objectives. Considerable time would also be saved in the task of describing the profiles. This procedure was therefore adopted for the survey of Feloane/Potsane.

To facilitate the process of describing the soil profiles an even more abbreviated form was developed (Appendix 8 in the final report). Only the essential information for evaluating and classifying the soil is called for.

Step 5 was also adapted. The adaptation is based on our reliance on the validity and value of predictive mapping. Penetrometer observations on a grid were abandoned. Our research assistant Mr Gutter assisted by two labourers made observations at key localities only. This procedure was only acceptable because Mr Gutter has already had a reasonable amount of soil survey experience.