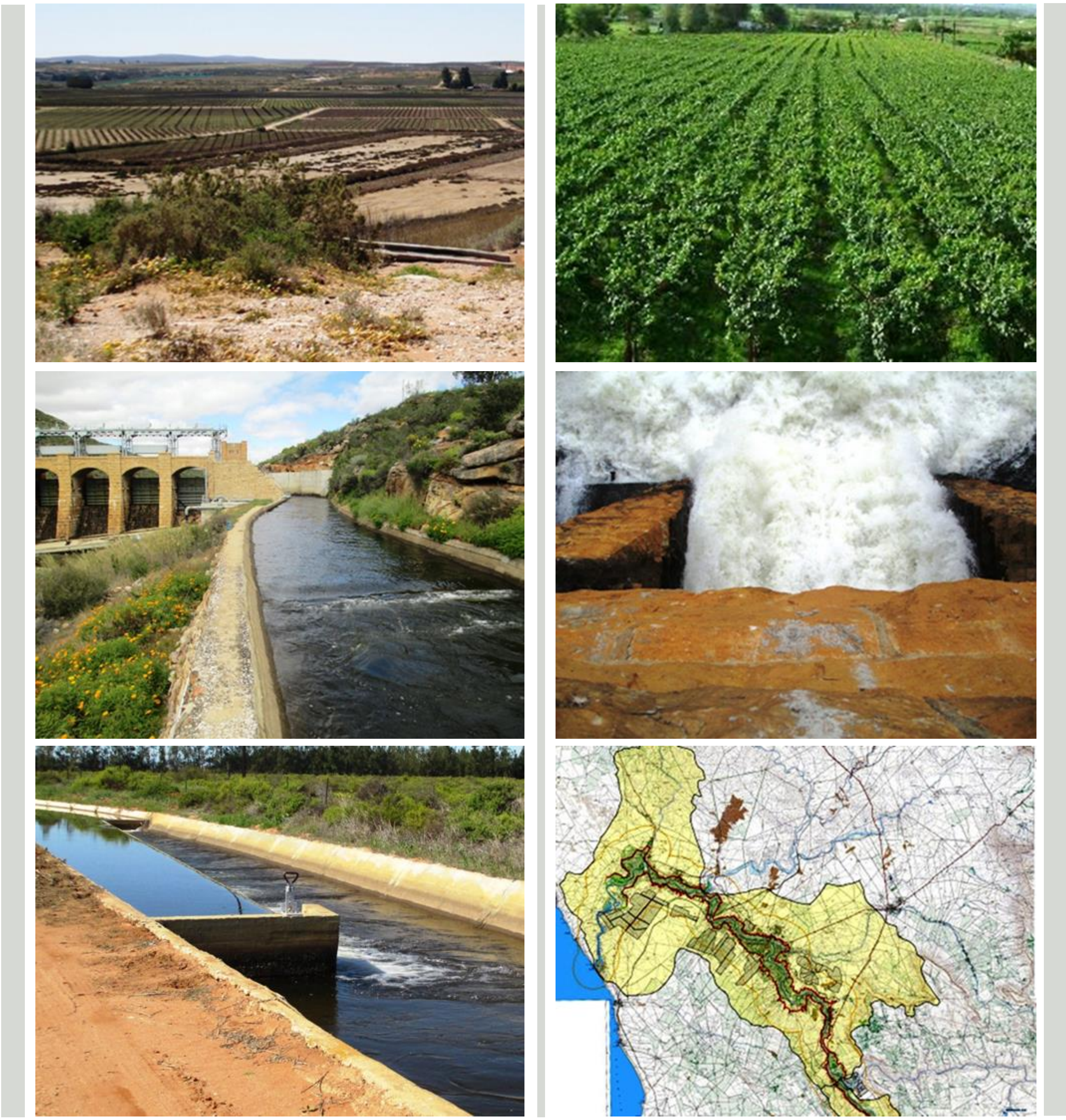
DWS Report No. P WMA 09/E10/00/0417/9

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam (WP0485)

Soil Survey Report



February 2019

DEPARTMENT OF WATER AND SANITATION

Directorate: Options Analysis

Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam

APPROVAL

Title	:	Soil Survey Report
Consultants	:	Aurecon South Africa (Pty) Ltd
Report status	:	Final
Date	:	February 2019

STUDY TEAM

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Document control record

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1977/003711/07

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Document control						aurecon
Report title		Soil Survey Report				
Document ID		P WMA 09/E10/00/0417/9	**Project number**		113834	
File path		\\Aurecon.Info\Shares\ZACPT\Projects\Projects\113834 Bridging Study Clanwilliam Dam\03 Prj Del\13 Reports\18 Soil Testing\Clanwilliam Soil Survey Report (Final)_Revised.Docx				
Client		Department of Water and Sanitation	**Client contact**		Mr M Mugumo	
Rev	**Date**	**Revision details/status**	**Prepared by**	**Author**	**Verifier**	**Approver**
0	2018/11/20	Draft	Vinpro	H Schloms F. Ellis B.H.A. Schloms		E van der Berg
1	2019/02/11	Final	Vinpro	H Schloms F. Ellis B.H.A. Schloms		E van der Berg
Current Revision		**1**				

Approval	
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water & sanitation
Department:
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Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam

SOIL SURVEY REPORT

February 2019

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This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa. 2019. *Soil Survey Report*. Prepared by Vinpro for Aurecon South Africa (Pty) Ltd as part of the Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam.

Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam

Reports produced as part of this project are indicated below.

Bold type indicates this report.

Report Index	Report Number	Report Title
1		Inception Report
2	P WMA 09/E10/00/0417/2	Capacity Building & Training Year 1
3	P WMA 09/E10/00/0417/3	Capacity Building & Training Year 2
4	P WMA 09/E10/00/0417/4	Water Requirements Assessment
5	P WMA 09/E10/00/0417/5	Distribution of Additional Available Water
6		Existing Infrastructure and Current Agricultural Development Sub-Report
7	P WMA 09/E10/00/0417/6	Existing Conveyance Infrastructure and Irrigated Land
8		Suitable Agricultural Areas and Land Ownership Report
9		Evaluation of Development Options Sub-Report
10	P WMA 09/E10/00/0417/10	Suitable Areas for Agricultural Development
11		Right Bank Canal Design Sub-Report
12		Conceptual Design Sub-Report
13		Environmental Screening Sub-Report
14		Jan Dissels and Ebenhaeser Schemes Design Sub-Report
15	P WMA 09/E10/00/0417/13	Feasibility Design
16	P WMA 09/E10/00/0417/7	Topographical Surveys
17	P WMA 09/E10/00/0417/8	Geotechnical Investigations
18	**P WMA 09/E10/00/0417/9**	**Soil Survey**
19		Financial Viability of Irrigation Farming Sub-Report
20	P WMA 09/E10/00/0417/11	Agricultural Production and Farm Development
21		Right Bank Canal Cost Analysis Sub-Report
22		Socio-Economic Impact Analysis Sub-Report
23	P WMA 09/E10/00/0417/12	Socio-Economic Impact Analysis
24	P WMA 09/E10/00/0417/14	Record of Implementation Decisions Report
25	P WMA 09/E10/00/0417/1	Main Report
26	P WMA 09/E10/00/0417/15	Historically Disadvantaged Farmers Report

Concise Description of the Content of Study Reports

Report Index	Report Number	Report Title and Description of Content
1		Inception The report forms part of the contract and stipulates the scope of work for the study, the contract amount and the contract period. It contains a detailed description of tasks and methodology, a study programme, human resource schedule, budget and deliverables. The Capacity Building and Training Plan has been included.
2	P WMA 09/E10/00/0417/2	Capacity Building & Training Year 1 Describes the range of capacity building and training activities planned for the study, and the activities undertaken during the first year of the study, including field-based training, training workshop 1 and mentorship of DWS interns through secondment.
3	P WMA 09/E10/00/0417/3	Capacity Building & Training Year 2 Describes the range of capacity building and training activities planned for the study, and the activities undertaken during the second year of the study, including field-based training, training workshop 2 and mentorship of DWS interns through secondment.
4	P WMA 09/E10/00/0417/4	Water Requirements Assessment Provides an analysis of the existing water use and current water allocations in the study area, and addresses ecological water requirements, water use for irrigated agriculture and projections for future use, current domestic and industrial water use and projections for future use, water use for hydropower and water losses in the water supply system.
5	P WMA 09/E10/00/0417/5	Distribution of Additional Available Water Confirms the volume of additional water available for development, after water has been reserved for the current water uses, as well as making recommendations on how the additional yield should be distributed among water use sectors and water users.
6		Existing Infrastructure and Current Agricultural Development Sub-Report Provides an overview of the extent and general condition of the current bulk water storage and conveyance infrastructure. This report also provides an overview of the locality and extent of the existing agricultural areas determined by reviewing Geographic Information System (GIS) data obtained from various sources.
7	P WMA 09/E10/00/0417/6	Existing Conveyance Infrastructure and Irrigated Land An update of the Sub-Report, providing a refinement of the current agricultural water requirements following evaluation of the current crop types, an assessment of the desirability of diverting releases for downstream irrigators via the Clanwilliam Canal and Jan Dissels River, to meet the summer ecological flows in the lower Jan Dissels River, and presents an Implementation Action Plan with costs.

Report Index	Report Number	Report Title and Description of Content
8		Suitable Agricultural Areas and Land Ownership Sub-Report Description of the collection of information and the preparation undertaken for the analysis of options, which includes a summary of existing irrigated areas and water use, cadastral information, land ownership, environmental sensitivity, soils suitability, water quality considerations and constraints, and the initiation of the process to identify additional areas suitable for irrigation.
9		Evaluation of Development Options Sub-Report Describes the salient features, costs and impacts of identified potential irrigation development options for new irrigation development in the lower Olifants River. This provides the background and an introduction to the discussions at the Options Screening Workshop held in December 2018.
10	P WMA 09/E10/00/0417/10	Suitable Areas for Agricultural Development Describes the supporting information, process followed and the salient features, costs and impacts of identified potential irrigation development options for new irrigation development in the lower Olifants River. Recommends the preferred options to be evaluated at feasibility level.
11		Right Bank Canal Feasibility Design Sub-Report Describes the Design Criteria Memorandum, based on best practice in engineering and complying with recognised codes and standards. Description of route alignments and salient features of the new Right Bank canal. Feasibility-level design of bulk infrastructure, including evaluation of capacities, hydraulic conditions, canal design, surface flow considerations, canal structures, power supply and access roads. Operational considerations and recommendations.
12		Conceptual Design Sub-Report Describes the scheme layouts at a conceptual level and infrastructure components to be designed, alternatives to consider or sub-options, and affected land and infrastructure, as well as the updated recommended schemes for new irrigation development.
13		Environmental screening Sub-Report Describes and illustrates the opportunities and constraints, and potential ecological risks/impacts and recommendations for the short-listed bulk infrastructure development options at reconnaissance level. Describes relevant legislation that applies to the proposed irrigation developments.
14		Jan Dissels and Ebenhaeser Schemes Feasibility Design Sub-Report Describes the Design Criteria Memorandum, based on best practice in engineering and complying with recognised codes and standards. Description of route alignments and salient features of the Jan Dissels and Ebenhaeser schemes. Feasibility-level design of bulk infrastructure, including evaluation of capacities, hydraulic conditions, intake structures, balancing dams and reservoirs, rising mains and gravity pipelines and trunk mains where relevant, power supply and access roads. Operational considerations and recommendations.

Report Index	Report Number	Report Title and Description of Content
15	P WMA 09/E10/00/0417/13	Feasibility Design Description of the approach to and design of selected bulk infrastructure at feasibility level, with supporting plans and implementation recommendations.
16	P WMA 09/E10/00/0417/7	Topographical Surveys Describes the contour surveys for the proposed identified bulk infrastructure conveyance routes and development areas, the surveying approach, inputs and accuracy, as well as providing the survey information.
17	P WMA 09/E10/00/0417/8	Geotechnical Investigations Presents the findings of geotechnical investigations of the various identified sites, as well as the approach followed, field investigations and testing, laboratory testing, interpretation of findings and geotechnical recommendations.
18	P WMA 09/E10/00/0417/9	Soil Survey Describes the soil types, soil suitability and amelioration measures of the additional area covering about 10 300 ha of land lying between 60 to 100 m above river level, between the upper inundation of the raised Clanwilliam Dam and Klawer.
19		Financial Viability of Irrigation Farming Sub-Report Describes the findings of an evaluation of the financial viability of pre-identified crop-mixes, within study sub-regions, and advises on the desirability of specific crops to be grown in these sub-regions. It includes an evaluation of the financial viability of existing irrigation farming or expanding irrigation farming, as well as the identification of factors that may be obstructive for new entrants from historically disadvantaged communities.
20	P WMA 09/E10/00/0417/11	Agricultural Production and Farm Development This report will focus on policy, institutional arrangements, available legal and administrative mechanisms as well as the proposed classes of water users and the needs of each. This would include identifying opportunities for emerging farmers, including grant and other types of Government and private support, and a recommendation on the various options and opportunities that exist to ensure that land reform and water allocation reform will take place through the project implementation.
21		Right Bank Canal Cost Analysis Sub-Report Provides an economic modelling approach to quantify the risk of the failure of the existing main canal and the determination of the economic viability of the construction of the new right bank canal to reduce the risk of water supply failure.
22		Socio-Economic Impact Analysis Sub-Report Describes the socio-economic impact analysis undertaken for the implementation of the new irrigation development schemes, for both the construction and operational phases. This includes a description of the social and economic contributions, the return on capital investment, as well as the findings of a fiscal impact analysis.

Report Index	Report Number	Report Title and Description of Content
23	P WMA 09/E10/00/0417/12	Socio-Economic Impact Analysis Synthesis of agricultural economic and socio-economic analyses undertaken, providing an integrated description of agricultural production and farm development and socio-economic impact analysis, as well as the analysis of the right bank canal costs and benefits.
24	P WMA 09/E10/00/0417/14	Record of Implementation Decisions Describes the scope of the project, the specific configuration of the schemes to be implemented, the required implementation timelines, required institutional arrangements and the required environmental and other approval requirements and mitigation measures, to ensure that the project is ready for implementation.
25	P WMA 09/E10/00/0417/1	Main Report Provides a synthesis of approaches, results and findings from the supporting study tasks and interpretation thereof, culminating in the study recommendations. Provides information in support of the project funding motivation to be provided to National Treasury.
26	P WMA 09/E10/00/0417/15	Historically Disadvantaged Farmers Report Describes the activities undertaken by an independent consultant to evaluate existing HDI Farmers policies and legislative context, identify, map and analyse prospective HDI farmers and potential land for new irrigation, as well as propose a mechanism for the identification and screening of HDI farmers.

Executive Summary

This report deals with the soil types, soil suitability and amelioration measures of the additional area covering about 10 300 ha of land lying between 60 to 100 m above river level between Clanwilliam Dam to Klawer. This 60 – 100 m zone was identified and added to the existing survey area that was completed during 2012 which covered the area up to 60 m above river level. The objectives, scope of work and terms of reference for this survey were briefly as follows:

- The soil suitability for irrigated crop production needs to be extended from the existing extent of mapping undertaken as part of the Clanwilliam Dam Raising Feasibility Study to a height of 100 m above either river, dam or canal level, as indicated on maps supplied
- The methodology to be followed to update the maps should be the same as the methodology used in the *Soils, Water Requirements and Crops Report* produced for the Clanwilliam Dam Raising Feasibility Study
- The objective of the study is to provide recommendations on the bulk conveyance infrastructure (new development / upgrading / rehabilitation) required for the equitable distribution of the existing and additional water for new irrigation areas to establish HDI farmers
- Carry out pit profiling and log the profile information using a GPS
- Append additional soil map units within the proposed study area to the soil map shapefile
- Provide all GIS data in a geodatabase with a report and maps.

The 2012 soil map legend was used for the 2018 survey. As this survey is also a reconnaissance soil survey, the legend stayed the same except for any new soil-terrain units that were identified. This was done in an effort to make sure that the new areas would join up smoothly with the existing (2012) boundaries and that information on soil suitability and other soil-related interpretations be the same for both reports.

The same methodology as was used and explained in the 2012 report was also used to map the soils for the 2018 areas.

Firstly, the 2012 soil boundaries were plotted on the latest Google Earth background with 5 m contour lines also visible. Two separate and independent visits were made to the survey area. The first visit was to familiarize themselves with the existing (2012) soil-terrain units (Messrs F Ellis and B Schloms have been involved in that survey) and, with limited field work, to prepare

a first draft of soil-terrain units of the new areas using the 2012 legend. This first draft map was thereafter taken to the field on a second round to prepare the final map. On the second round the following procedure was used:

Based on soil properties and variation in soil types and terrain form, uniform soil-terrain units were delineated during the field excursion on the draft map that covered the 2018 survey area. During the field excursion soil observations were made at all available soil exposures such as road cuts and drainage trenches, and a hand auger was used for additional observations. It was not necessary to use a mechanical digger to make extra soil pits for observation purposes. In a few cases none of the existing map units could accommodate a particular delineated area. In those cases, new map units were created and defined in terms of terrain type and dominant soils.

It was decided to retain the relatively simple two-level legend that consisted of an upper level of soil groups and a second level of soil sub-groups used in the 2012 report. Twelve soil groups were defined on the basis of two or more of the following properties: general soil type, soil colour, texture of the topsoil, soil depth, drainage, terrain position. An identification letter symbol (A to L) was given for each soil group. The legend covers the soils from Keerom to the coast used for the 2012 survey. The soil groups mapped and defined for the 2018 survey included 33 of the 2012 soil groups but another seven subgroups under the soil complexes upper level were identified and described.

A combined soil map legend for the new survey area was defined and used for the soil maps.

Hereafter the soil suitability for irrigated crops was determined for the same crops mentioned in the 2012 report. Soil limitations were identified as for the 2012 report. An additional non-soil limitation (namely slope) was added. Slope influences the cultivation of land and is therefore regulated by the “Conservation of Agricultural Resources (Act, 43 of 1983) Regulations”. Total areas (ha) of the three classes that occur within the 60 – 100 m above river level 2018 mapping area (totalling 10332 ha) were determined as 4951 ha (0 – 12 % class), 2850 ha (12 – 20%) and 2531 ha (>20 % class). The >20 % slopes therefore covers about 25 % of the total survey area. Further details about slopes are given in electronic map form.

Five classes were used to rate the potential and recommendation of soil sub-groups for irrigated crop production (see **Table E1 below**). Due to the negative effect, indirect and direct, of free lime on growth and production, soils with calcareous horizons were rated one unit lower than non-calcareous soils with similar properties. Although it was difficult to accommodate salinity in these evaluations, soil sub-groups with a very high salinity were downgraded compared to similar non-saline soils.

Table E1 **Classes used to evaluate the potential and recommendation of soil sub-groups for annual and perennial crops before and after amelioration of subsoil limitations**

Soil potential	Recommendation for irrigated crop production	Percent of maximum potential
Low (L)	Not recommended (NR)	≤ 40%
Medium-Low (ML)	Marginally recommended (MR)	> 40 - ≤ 50%
Medium (M)	Conditionally recommended (CR)	> 50 - ≤ 60%
Medium-High (MH)	Recommended (RE)	> 60 - ≤ 80
High (H)	Highly recommended (HR)	>80%

The information given in **Table E1** above was applied to each soil sub-group identified to derive at a "potential of soil units for irrigated annual and perennial crop production". Thereafter a table summarizing the surface areas of the five potential suitability and recommended classes was compiled (**Table E2**).

Table E2 **Surface area of five potential suitability classes for the production of tuberous and non-tuberous crops and perennial crops before and after amelioration of subsoil limitations in four main areas in the Olifants River Basin from Clanwilliam Dam to Klawer between 60 – 100 m above river level.**

Potential class and recommendation	Annual tuberous crops (ha) 1)	Annual non-tuberous crops (ha) 2)	Perennial crops 3)	
			Before amelioration (ha)	After amelioration (ha)
Clanwilliam Dam to Klawer (between 60 – 100m)				
≤ 40 % (NR)	8457	7132	9259	5729
> 40 - ≤ 50 % (MR)	802	1010	973	2280
> 50 - ≤ 60 % (CR)	100	1693	20	1107
> 60 - ≤ 80 % (RE)	973	497	80	1217
> 80 % (HR)	0	0	0	0
Total area (ha) Clanwilliam dam to Klawer	10332			

1) This includes crops such as potatoes, onions, sweet potatoes, and carrot; usually without hardpan amelioration.
2) This includes crops such as tomatoes, pumpkin, and bean; usually after hardpan amelioration.
3) This refers mainly to dry, wine and table grapes and citrus.

From this table it is clear that most of the soil classes identified falls within the *Not Recommended* category

Lastly, amelioration measures recommended per soil sub-group, is given.

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Appendix C

Structure of Soil Code and Explanation of Symbols

Tables

1 Introduction

1.1 Background

The objective of the Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam is to provide recommendations on the bulk conveyance infrastructure required for the equitable distribution of the existing and additional water from the raised Clanwilliam Dam.

1.2 2012 Soil Survey

All soil surveys that have been conducted up to the year 2012 throughout the Olifants River Basin were mentioned in the 2012 report (Clanwilliam Dam Raising: Utilisation of Additional Water; Soil types, soil suitability and amelioration by Lambrechts, Schloms and Ellis, hereafter refer to 2012 soil report). The 2012 report and map were used to extend the survey area from the present 60 m to 100 m above river level. Both the 2012 survey information and the new areas to be surveyed (roughly from Clanwilliam dam to Klawer) were supplied by Aurecon in electronic format to be used.

For the 2012 soil survey the Terms of Reference (TOR) were as follows:

"In combination with the WODRIS soils data, data from other studies and expert knowledge, a soils map will be compiled for the Olifants River Basin from Keerom, south of Citrusdal, to the coast. The map will specifically focus on areas already identified for establishing *resource poor farmers, the inundation area of the dam, and the Olifants River south of the Clanwilliam Dam. Areas of unknown soils will however also be indicated. The lateral extent of the area covered will on average be about 60 m above the levels of the river or existing canals or an agreed horizontal distance away. An expert system approach will be used to evaluate the different soils in terms of likely physical and chemical limitations, amelioration measures and suitability for a variety of climatically adapted crops"*.

1.3 2018 Soil Survey

For the 2018 soil survey the Objective, Scope of Work and Terms of Reference (TOR) decided upon were given as follows:

1.3.1 Objective

The soil suitability for irrigated crop production needs to be extended from the existing extent of mapping undertaken as part of the Clanwilliam Dam Raising Feasibility Study to a height of 100m above either river, dam or canal level, as indicated in the accompanying (low resolution) maps, as follows:

- 100m above a raised Clanwilliam Dam full supply level, to just upstream of the dam's full supply level in the Olifants River
- 100m above the Clanwilliam Canal
- 100m above the Olifants and Jan Dissels rivers, in the river reach between the Clanwilliam Dam and Bulshoek Weir
- 100m above the Bulshoek Weir water level
- 100m above the Bulshoek Canal, up to the vicinity of Klawer.

1.3.2 Scope of Work

The methodology to be followed to update the maps should be the same as the methodology used in the Soils, Water Requirements and Crops Report produced for the Clanwilliam Dam Raising Feasibility Study.

Aurecon will provide higher-resolution maps (with 5m contours) of the study area indicating the area of existing soil mapping and the areas to be extended. Existing soil maps can also be provided in digital format.

Undertake the necessary field investigations. Land owners are also expected to be a valuable source of information.

Expand the existing soil complex map. Evaluate the soil suitability for irrigated crop production and update the suitability maps for the irrigated crop production of annual (tuberous and non-tuberous) and perennial (after amelioration) crops for the Olifants River Basin as indicated in the accompanying maps, to a height of 100m above either river, dam or canal level.

Digitisation and updating of the mapping can either be done by Aurecon or it can be offered as a service. Time should be allowed for liaison and refinement of the maps.

1.3.3 Terms of Reference (2018 Survey)

Project no: WP11077 – Post Feasibility Bridging Study for the Proposed Bulk Conveyance Infrastructure from the Raised Clanwilliam Dam for a period of 24 months. The objective of the study is to provide recommendations on the bulk conveyance infrastructure (new development / upgrading / rehabilitation) required for the equitable distribution of the existing and additional water for new irrigation areas to establish HDI farmers.

The Sub-consultancy Services involves extension of the soil survey that was undertaken in the 'Soils, Water Requirements and Crops Report' produced for the Clanwilliam Dam Raising Feasibility Study, and will include the following:

- Creation of a Digital Elevation Model (DEM) of the area to assess the terrain in detail.
- Slope analysis of the terrain using the DEM to determine which areas fall in the unsuitable land class, and identify which areas will be surveyed.
- Organise access to farms where required.
- Carry out pit profiling and log the profile information using a GPS.
- Append additional soil map units within the proposed study area to the soil map shapefile.
- Provide all GIS data in a geodatabase with a report and maps.

2 Soil Map Legend and Soil Map for the 2018 Study Area

The 2012 soil map legend was used for this (2018) survey. As this survey is also a reconnaissance soil survey, the legend stayed the same except for any new soil-terrain units that were identified. This was done in an effort to make sure that the new areas would join up smoothly with the existing (2012) boundaries and that information on soil suitability and other soil-related interpretations be the same for both reports.

The same methodology as was used and explained in the 2012 report was also used to map the soils for the 2018 areas. This methodology is explained below:

Firstly, the 2012 soil boundaries were plotted on the latest Google Earth background with 5 m contour lines also visible. Two separate and independent visits were made to the survey area. The first visit was to familiarize ourselves with the existing (2012) soil-terrain units (two of us namely Ellis and B Schloms have been involved in that survey) and, with limited field work, to prepare a first draft of soil-terrain units of the new areas using the 2012 legend. This first draft map was thereafter taken to the field on a second round to prepare the final map. On the second round we used the following procedure:

Based on soil properties and variation in soil types and terrain form, uniform soil-terrain units were delineated during the field excursion on the draft map that covered the 2018 survey area. During the f field excursion soil observations were made (see Annexure A **Table 2.1** for additional profiles described in more detail) at all available soil exposures such as road cuts and drainage trenches, and a hand auger was used for additional observations. It was not necessary to use a mechanical digger to make extra soil pits for observation purposes. In a few cases none of the existing map units could accommodate a particular delineated area. In those cases, new map units were created and defined in terms of terrain type and dominant soils.

It was decided to retain the relatively simple two-level legend that consisted of an upper level of soil groups and a second level of soil sub-groups used in the 2012 report. Twelve soil groups were defined on the basis of two or more of the following properties: general soil type, soil colour, texture of the topsoil, soil depth, drainage, terrain position (see **Table 2.1**). An identification letter symbol (A to L) was given for each soil group. The legend in **Table 2.1** covers the soils from Keerom to the coast used for the 2012 survey. The soil groups mapped and defined for the 2018 survey included 33 of the 2012 soil groups but another seven subgroups under the soil complexes upper level were identified and described in **Table 2.2**.

Except for soil group F, all the other soil groups were subdivided into two or more soil sub-groups based on selected soil properties. The primary aim in the selection of properties for each group was that the different soil sub-groups in a particular group require different soil amelioration and/or management practices and differ in terms of suitability for crop production. The following two soil groups can be used as examples:

- **Grey, moderately deep to deep, poorly drained duplex soil group**: Two soil sub-groups were defined on the basis of depth to a restrictive subsoil clay layer and presence of coarse fragments (stones) in the bleached upper subsoil.
- **Alluvial soils on floodplains and lower river terrace soil group**: Four soil sub-groups were defined. On the basis of clay content there are two sub-groups each with < 6 % and > 6 % clay. The sandy subdivision was subdivided on the presence or absence of coarse fragments, while the more clayey subdivision was separated on the basis of wetness and presence of free lime.

Table 2.1 Combined soil map legend for the Olifants River Basin from Keerom to the coast used for the 2012 soil survey

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
Well drained red apedal soils	A 1	Very deep (>100 cm), well drained red apedal soils locally on non-calcareous dorbank; <5% clay in topsoil; medium sand dominant; heuweltjies absent or very rare.
	A 2	Similar to A 1 with occasional heuweltjies.
	A 3	Moderately deep to deep (60->100 cm), well drained red apedal soils on non-calcareous dorbank; <5% clay in topsoil; medium sand dominant; common heuweltjies.
	A 4	Similar to A 3 except for localised areas of unstable dunes.
	A 5	Similar to A3 plus very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.
	A 6	Association of moderately deep (50-65 cm) red apedal soils on non-calcareous dorbank and yellow-brown apedal soils with or without signs of wetness in the deep subsoil; ≤5 % clay in topsoil; medium and coarse dominant; common heuweltjies.

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
	A 7	Deep (>100 cm) red and yellow-brown apedal soils and locally non-calcareous dorbank at 65-100 cm; ≤5 % clay in topsoil; fine and medium sand dominant; common heuweltjies.
	A 8	Moderately deep (>60 cm) to deep (>100 cm), stony, red (locally yellow-brown) apedal loamy soils; ferricrete locally present; 5 – 10 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
Moderately to well drained, deep, yellow to grey sandy soils	B 1	Well drained, moderately deep (>60 cm) to deep (>100 cm), non-stony, yellow-brown and locally red apedal sandy soils; <5 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
	B 2	Moderately well to well drained, deep (100 cm), non-stony, yellow-brown apedal soils without or with signs of wetness in the deep subsoil and deep bleached sands; <5 % clay in topsoil; coarse and medium sand dominant; no heuweltjies.
	B 3	Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent.
	B 4	Moderately well to well drained, deep (100 cm), non-stony, yellow-brown apedal soils without signs of wetness in the deep subsoil and deep bleached sands; <5 % clay in topsoil; coarse and medium sand dominant; no heuweltjies.
Grey to yellow, predominantly moderately to well drained sandy soils (on higher lying terraces)	C 1	Predominantly deep (>100 cm), non-stony, poorly drained sandy soils; <5% clay in topsoil; medium and coarse sand dominant; no heuweltjies.
	C 2	Predominantly deep (>100 cm), well drained sandy soils; with or without stones; <6% clay in topsoil; medium and coarse sand dominant; no heuweltjies.
	C 3	Deep (120 cm), moderately drained grey coloured sandy soils; non-stony; <5% clay in topsoil; coarse sand dominant; no heuweltjies.
Well drained loamy red and/or yellow soils (on higher lying river terraces and pediments)	D 1	Moderately deep (>60 cm) to deep (generally >100 cm), stony to gravelly red apedal soils; 10-15% clay in topsoil; medium sand dominant; occasional heuweltjies.
	D 2	Deep (>100 cm), non-stony, weakly structured yellow soils; 6-10% clay in topsoil; medium sand dominant; common to abundant calcareous heuweltjies.
	D 3	Predominantly deep (>100 cm), stony, yellow-brown neocutanic and neocarbonate saline soils with and without signs of wetness; luvic; 5-15 % clay in topsoil; fine to medium sand dominant; locally common heuweltjies.
	D 4	Shallow (<45 cm) to moderately deep (50-70 cm), non-stony red neocutanic saline soils on dorbank; 3-8 % clay in topsoil; medium and coarse sand dominant; abundant heuweltjies.
	D 5	Moderately deep (60-80 cm) red neocutanic and red apedal soils on dorbank; usually calcareous and saline; rare to common heuweltjies.
	D 6	Similar to D 5 plus very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.

Soil groups	**Soil sub-groups**	
	Map symbol	**Description of sub-groups**
Moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank (on high lying terraces)	E 1	Complex of yellow-brown loamy soils without (>100 cm) or with underlying dorbank (60-80 cm; saline; calcareous); 5-15 % clay in topsoil; fine and medium sand dominant; plus F 1 soils; abundant heuweltjies.
	E 2	Complex of medium deep (60-80 cm) yellow-brown loamy soils with a neocarbonate subsoil on a hardpan carbonate horizon; 5-15 % clay in topsoil; fine to medium sand dominant; abundant heuweltjies.
	E 3	Predominantly very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually saline and calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; plus duplex soils; abundant heuweltjies.
Shallow soils on dorbank	F 1	Very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.
Grey, moderately deep to deep, poorly drained duplex soils	G 1	Moderately deep to deep (60-90 cm), non-stony, poorly drained duplex soils with dense, wet clayey subsoil; <5% clay in topsoil; coarse and medium sand dominant; usually no heuweltjies.
	G 2	Moderately shallow to deep (40-90 cm), stony, poorly drained duplex soils with dense, wet or dry clayey subsoil; <6% clay in topsoil; coarse and medium sand dominant.
Shallow, moderately drained, non-saline and saline duplex soils	H 1	Moderately deep to shallow (<50 cm), moderately drained, duplex soils on structured clay from Bokkeveld formation shales, usually non-saline and non-alkaline; occasionally gravelly; 5-15% clay in topsoil; fine to coarse sand dominant.
	H 2	Shallow (30-45 cm), non-gravelly loamy soils, without or with an E horizon, usually moderately drained, on structured subsoil clay, usually saline with an alkaline pH; 5-10 % clay in topsoil; medium and coarse sand dominant.
Shallow lithosolic soils	I 1	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant.
	I 2	Shallow (<40 cm), gravelly lithosolic soils on Bokkeveld formation shales; 10-20% clay in topsoil; fine sand dominant; no heuweljies, free lime or dorbank.
	I 3	Shallow (<40 cm), mostly saline lithosolic soils on Bokkeveld formation shales; highly dissected landscape due to erosion; 10-20% clay in topsoil; fine sand dominant; few heuweltjies, free lime or dorbank.
	I 4	Shallow (<40 cm), gravelly lithosolic soils on Nama formation rocks.
	I 5	Very shallow (<20 cm) gravelly lithosolic soils on Nama formation rocks.

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
Alluvial soils on floodplains and lower river terraces	J 1	Deep (>100 cm), non-calcareous and non-saline, grey, non-stony, well drained stratified sandy alluvial soils; <6% clay in topsoil; medium to coarse sand dominant.
	J 2	Deep (>100 cm), non-calcareous and locally saline, grey to dark coloured, non-stony, usually poorly drained stratified sandy alluvial and pale coloured soils; <6% clay in topsoil; medium and coarse sand dominant.
	J 3	Deep (>100 cm), non-calcareous and commonly saline, grey, non-stony, stratified alluvium commonly with signs of wetness; locally soils with neocutanic or plinthic subsoil horizons; >6% clay in topsoil; fine and medium sand dominant.
	J 4	Moderately deep (>60cm), calcareous and saline, weakly structured alluvial soils; >6% clay in topsoil; fine and medium sand dominant.
Physically unstable dunes	K 1	Unstable dunes with deep yellow sandy soils.
	K 2	Unstable dunes with deep red or yellow sandy soils with rare red soils on non-calcareous dorbank.
	K 3	Unstable grey coastal dune sands.
Land classes	L 1	Rivers, streams and recent floodplains.
	L 2	Saline vlei soils.
	L 3	Highly dissected land.
	L 4	Steep mountain slopes with shallow, stony lithosolic soils; predominantly sandstone and quartzite rocks.
	L 5	Steep mountains, predominantly sandstone and quartzite rocks.
	L 6	Steep hills and slopes, predominantly of shale or slate rocks.
Soil complexes	I 1+B 1	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Well drained, moderately deep (>60 cm) to deep (>100 cm), non-stony, yellow-brown and locally red apedal sandy soils; <5 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
	I 1+B 3	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent.
	I 1+I 2	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Shallow (<40 cm), gravelly lithosolic soils on Bokkeveld formation shales; 10-20% clay in topsoil; fine sand dominant; no heuweljies, free lime or dorbank
	B 3+I 1	Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent plus Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant.

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
	H 1+G 2	Moderately deep to shallow (<50 cm), moderately drained, duplex soils on structured clay from Bokkeveld formation shales, usually non-saline and non-alkaline; occasionally gravelly; 5-15% clay in topsoil; fine to coarse sand dominant. plus Moderately shallow to deep (40-90 cm), stony, poorly drained duplex soils with dense, wet or dry clayey subsoil; <6% clay in topsoil; coarse and medium sand dominant.
	J 2+ J 1	Deep (>100 cm), non-calcareous and locally saline, grey to dark coloured, non-stony, usually poorly drained stratified sandy alluvial and pale coloured soils; <6% clay in topsoil; medium and coarse sand dominant. plus Deep (>100 cm), non-calcareous and non-saline, grey, non-stony, well drained stratified sandy alluvial soils; <6% clay in topsoil; medium to coarse sand dominant
	C 1+J 1	Predominantly deep (>100 cm), non-stony, poorly drained sandy soils; <5% clay in topsoil; medium and coarse sand dominant; no heuweltjies plus Deep (>100 cm), non-calcareous and non-saline, grey, non-stony, well drained stratified sandy alluvial soils; <6% clay in topsoil; medium to coarse sand dominant

Each soil sub-group is characterised by a letter-number (e.g. A 1) symbol. The letter symbol represents the soil group symbol and the number suffix is sequential from one (1) up to eight (8) within each soil group. The number suffix has no intrinsic meaning. It only serves as an identifier for different soil sub-groups belonging to the same soil group but differ in one or more important soil properties. For the 2012 soil map the final boundaries between soil sub-groups on the 1 : 50 000 topographic maps were digitised by Ninham Shand Consulting, Cape Town, and each sub-group was characterised by its relevant map symbol.

Table 2.2, that covers the total survey area from Clanwilliam Dam to Klawer up to 100 m was based on that of **Table 2.1**. Map symbols that were absent are also listed here.

Table 2.2 Combined soil map legend for the Clanwilliam to Klawer survey area used for the 2018 soil survey (covers all areas up to 100 m above river level)

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
Well drained red apedal soils	A 1	Not present in 2018 survey area
	A 2	Not present in 2018 survey area
	A 3	Not present in 2018 survey area
	A 4	Not present in 2018 survey area
	A 5	Not present in 2018 survey area
	A 6	Not present in 2018 survey area
	A 7	Not present in 2018 survey area
	A 8	Moderately deep (>60 cm) to deep (>100 cm), stony, red (locally yellow-brown) apedal loamy soils; ferricrete locally present; 5 – 10 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
Moderately to well drained, deep, yellow to grey sandy soils	B 1	Well drained, moderately deep (>60 cm) to deep (>100 cm), non-stony, yellow-brown and locally red apedal sandy soils; <5 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
	B 2	. Not present in 2018 survey area
	B 3	Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent.
	B 4	Moderately well to well drained, deep (100 cm), non-stony, yellow-brown apedal soils without signs of wetness in the deep subsoil and deep bleached sands; <5 % clay in topsoil; coarse and medium sand dominant; no heuweltjies.
Grey to yellow, predominantly moderately to well drained sandy soils (on higher lying terraces)	C 1	Predominantly deep (>100 cm), non-stony, poorly drained sandy soils; <5% clay in topsoil; medium and coarse sand dominant; no heuweltjies
	C 2	Not present in 2018 survey area
	C 3	Not present in 2018 survey area
Well drained loamy red and/or yellow soils (on higher lying river terraces and pediments)	D 1	Moderately deep (>60 cm) to deep (generally >100 cm), stony to gravelly red apedal soils; 10-15% clay in topsoil; medium sand dominant; occasional heuweltjies.
	D 2	Deep (>100 cm), non-stony, weakly structured yellow soils; 6-10% clay in topsoil; medium sand dominant; common to abundant calcareous heuweltjies.
	D 3	Predominantly deep (>100 cm), stony, yellow-brown neocutanic and neocarbonate saline soils with and without signs of wetness; luvic; 5-15 % clay in topsoil; fine to medium sand dominant; locally common heuweltjies.
	D 4	Not present in 2018 survey area
	D 5	Not present in 2018 survey area
	D 6	Not present in 2018 survey area

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
Moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank (on high lying terraces)	E 1	Complex of yellow-brown loamy soils without (>100 cm) or with underlying dorbank (60-80 cm; saline; calcareous); 5-15 % clay in topsoil; fine and medium sand dominant; plus F 1 soils; abundant heuweltjies.
	E 2	Complex of medium deep (60-80 cm) yellow-brown loamy soils with a neocarbonate subsoil on a hardpan carbonate horizon; 5-15 % clay in topsoil; fine to medium sand dominant; abundant heuweltjies.
	E 3	Predominantly very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually saline and calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; plus duplex soils; abundant heuweltjies.
Shallow soils on dorbank	F 1	Very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.
Grey, moderately deep to deep, poorly drained duplex soils	G 1	Moderately deep to deep (60-90 cm), non-stony, poorly drained duplex soils with dense, wet clayey subsoil; <5% clay in topsoil; coarse and medium sand dominant; usually no heuweltjies.
	G 2	. Not present in 2018 survey area
Shallow, moderately drained, non-saline and saline duplex soils	H 1	Moderately deep to shallow (<50 cm), moderately drained, duplex soils on structured clay from Bokkeveld formation shales, usually non-saline and non-alkaline; occasionally gravelly; 5-15% clay in topsoil; fine to coarse sand dominant.
	H 2	Shallow (30-45 cm), non-gravelly loamy soils, without or with an E horizon, usually moderately drained, on structured subsoil clay, usually saline with an alkaline pH; 5-10 % clay in topsoil; medium and coarse sand dominant.
Shallow lithosolic soils	I 1	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant.
	I 2	Shallow (<40 cm), gravelly lithosolic soils on Bokkeveld formation shales; 10-20% clay in topsoil; fine sand dominant; no heuweljies, free lime or dorbank.
	I 3	Shallow (<40 cm), mostly saline lithosolic soils on Bokkeveld formation shales; highly dissected landscape due to erosion; 10-20% clay in topsoil; fine sand dominant; few heuweltjies, free lime or dorbank.
	I 4	Not present in 2018 survey area
	I 5	Very shallow (<20 cm) gravelly lithosolic soils on Nama formation rocks.
Alluvial soils on floodplains and lower river terraces	J 1	Deep (>100 cm), non-calcareous and non-saline, grey, non-stony, well drained stratified sandy alluvial soils; <6% clay in topsoil; medium to coarse sand dominant.
	J 2	Deep (>100 cm), non-calcareous and locally saline, grey to dark coloured, non-stony, usually poorly drained stratified sandy alluvial and pale coloured soils; <6% clay in topsoil; medium and coarse sand dominant.
	J 3	Deep (>100 cm), non-calcareous and commonly saline, grey, non-stony, stratified alluvium commonly with signs of wetness; locally soils with neocutanic or plinthic subsoil horizons; >6% clay in topsoil; fine and medium sand dominant.
	J 4	Not present in 2018 survey area

Soil groups	Soil sub-groups	
	Map symbol	Description of sub-groups
Physically unstable dunes	K 1	Unstable dunes with deep yellow sandy soils.
	K 2	Not present in 2018 survey area
	K 3	Not present in 2018 survey area
Land classes	L 1	Rivers, streams and recent floodplains.
	L 2	Not present in 2018 survey area
	L 3	Highly dissected land.
	L 4	Steep mountain slopes with shallow, stony lithosolic soils; predominantly sandstone and quartzite rocks.
	L 5	Steep mountains, predominantly sandstone and quartzite rocks.
	L 6	Steep hills and slopes, predominantly of shale or slate rocks.
Soil complexes	I 1+B 1	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Well drained, moderately deep (>60 cm) to deep (>100 cm), non-stony, yellow-brown and locally red apedal sandy soils; <5 % clay in topsoil; coarse and medium sand dominant; heuweltjies absent or rare.
	I 1+B 3	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent.
	I 1+I 2	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus Shallow (<40 cm), gravelly lithosolic soils on Bokkeveld formation shales; 10-20% clay in topsoil; fine sand dominant; no heuweljies, free lime or dorbank
	B 3+I 1	Moderately well drained, deep (>100 cm), non-stony, bleached and yellow apedal soils, usually with signs of wetness in the subsoil; <5 % clay in topsoil; medium and coarse sand dominant; heuweltjies absent plus Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant.
	H 1+G 2	Not present in 2018 survey area
	J 2+ J 1	Not present in 2018 survey area
	C 1+J 1	Not present in 2018 survey area
	C 1+G 1	Predominantly deep (>100 cm), non-stony, poorly drained sandy soils; <5% clay in topsoil; medium and coarse sand dominant; no heuweltjies plus moderately deep to deep (60-90 cm), non-stony, poorly drained duplex soils with dense, wet clayey subsoil; <5% clay in topsoil; coarse and medium sand dominant
	E 2+F 1	Predominantly medium deep (60-80 cm) yellow-brown loamy soils with a neocarbonate subsoil on a hardpan carbonate horizon; 5-15 % clay in topsoil; fine to medium sand dominant; abundant heuweltjies plus very shallow to shallow (20-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.
	K 1+F 1	Predominantly unstable dunes with deep yellow sandy soils plus very shallow to shallow (10-40 cm) soils on hard to very hard dorbank, usually calcareous; 5-10 % clay in topsoil; fine and medium sand dominant; saline and alkaline; abundant heuweltjies.

Soil groups	Soil sub-groups	
	Map symbol	**Description of sub-groups**
	I 3+L 3	Predominantly shallow (<40 cm), mostly saline lithosolic soils on Bokkeveld formation shales; 10-20% clay in topsoil; fine sand dominant; few heuweltjies, free lime or dorbank within a highly dissected landscape due to erosion
	I 3+E 2	Predominantly shallow (<40 cm), mostly saline lithosolic soils on Bokkeveld formation shales; highly dissected landscape due to erosion; 10-20% clay in topsoil; fine sand dominant; few heuweltjies, free lime or dorbank plus medium deep (60-80 cm) yellow-brown loamy soils with a neocarbonate subsoil on a hardpan carbonate horizon; 5-15 % clay in topsoil; fine to medium sand dominant; abundant heuweltjies.
	I 1+L 5	Predominantly shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay in topsoil; coarse and medium sand dominant plus inclusions of steep mountains, predominantly sandstone and quartzite rocks.
	I 3+I 4	Predominantly shallow (<40 cm), mostly saline lithosolic soils on Bokkeveld formation shales; highly dissected landscape due to erosion; 10-20% clay in topsoil; fine sand dominant; few heuweltjies, free lime or dorbank plus shallow (<40 cm), gravelly lithosolic soils on steep slopes, predominantly of shale or slate rocks.

In addition to the description of the different soil sub-groups, the dominant (occupies more than 60% of the map unit) and subdominant soil forms and families were determined.

Based on recognizable, as well as inferred properties, the soils were classified according to Soil Classification Working Group (1991) into soil forms and soil families. Soil forms are defined in terms of the type and vertical sequence of diagnostic horizons or materials. For communication, soil forms are given locality names, e.g. Hutton or Garies. These names are abbreviated to two-letter symbols, e.g. Gr for Garies form. Soil forms are subdivided into soil families using properties that are not used in the definition of the defined diagnostic horizon(s) or material(s) characteristic for the particular soil. Soil families are identified by a four-digit number that is combined with the soil form name or abbreviation; e.g. Gr 1000 is family number 1000 of the Garies form. Refer to Soil Classification Working Group (1991) for definitions of diagnostic horizons and materials and family criteria.

The principles underlying the concept of a diagnostic horizon and the definitions of the diagnostic horizons that are characteristic of the different soil forms in the Olifants River Basin as well as the family criteria are defined in Soil Classification Working Group (1991).

All the dominant and subdominant soil forms and families that were identified in the 2012 and 2018 soil map legends (**Table 2.1 and Table 2.2)** for the Olifants River Basin 2012 and the 2018 surveys are listed in **Table 2.3.** In many map units "heuweltjies", a micro-relief feature associated with termite activity are present. In **Table 2.3** the estimated percentage of the land surface covered by "heuweltjies" is listed for those map units with heuweltjies. Refer to Soil Classification Working Group (1991) for the diagnostic horizon sequences of the different soil forms and the family criteria used to define soil families.

Table 2.3 Dominant and subdominant soil forms, families and heuweltjies in the soil sub-groups defined for the Olifants River Basin 2012 soil map and the 2018 survey area

Soil groups	Sub-group map symbol	Dominant soil form/family [1)]	Subdominant soil form/family
Well drained red apedal soils	A 1	Gr 1000 Hu 3100	
	A 2	Gr 1000 Hu 3100	Heuw (10%)
	A 3	Gr 1000	Heuw (20%)
	A 4	Gr 1000 Dunes	Heuw (15%)
	A 5	Kn 1000 Gr 1000	Heuw (30)
	A 6	Gr 1000 Cv 3100	Pn 3100 Heuw (15%)
	A 7	Gr 1000 Hu 3100	Cv 3100 Heuw (15%)
	A 8	Hu 3100 Oa 2120 Cv 3100	Ct 1100 Fw 1120 Pn 3100
Moderately to well drained, deep, yellow to grey sandy soils	B 1	Pn 3100 Cv 3100 Hu 3100	Ct 1100 Fw 1120 Oa 2120
	B 2	Cv 3100 Pn 3100 Fw 1210	
	B 3	Fw 1120 Lo 2000 Ct 1100	Cv 3100 Kd 2000 Vf 2120
	B 4	Cv 3100 Fw 1210	
Grey to yellow, predominantly moderately to well drained sandy soils (on higher lying terraces)	C 1	Lo 1000 Lo 2000 Fw 1120 Fw 1220	Fw 1110 Fw 1210 Kd 2000
	C 2	Cv 3100 Oa 2110 Lo 2000	Ct 1100 Fw 1120 Vf 2110
	C 3	Fw 1120 Fw 1110 Lo 1000	Ct 1100 Kd 1000 Fw 1220
Well drained loamy red and/or yellow soils (on	D 1	Hu 3100 Oa 1220 Oa 1210 Tu 1210	Gc 3100 Oa 2220 Gs 1111 Heuw (10%)

Soil groups	Sub-group map symbol	Dominant soil form/family [1)]	Subdominant soil form/family
higher lying river terraces and pediments)	D 2	Oa 2120 Cv 3200	Gr 2000 Ou 2120 Heuw (25%)
	D 3	Oa 2120 Tr 2120 Mu 2120	Du 1120 Du 1220
	D 4	Ou 1210	Heuw (25%)
	D 5	Ou 1/2210 Gr 1000	Heuw (10%)
	D 6	Ou 1210 Ou 2220 Kn 1000	Heuw (30%)
Moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank (on high lying terraces)	E 1	Ou 2110 Ou 2120 Oa 2120 Kn 1000	Heuw (20%)
	E 2	Pr 2110	Vf 2120 Heuw (30%)
	E 3	Kn 1000	Vf 2120 Es 1100 Ss 2100 Heuw (30%)
Shallow soils on dorbank	F 1	Kn 1000	Ou 1210 Ou 2210 Heuw (35%)
Grey, moderately deep to deep, poorly drained duplex soils	G 1	Kd 1000 Kd 2000 Lo 1000	Pn 3100 Lo 2000 Ka 1000
	G 2	Kd 1000 Kd 2000 Es 1100 Es 2100	Pn 3100 Lo 1000 Ka 1000
Shallow, moderately drained, non-saline and saline duplex soils	H 1	Km 1120 Km 2120 Ss 2100 Es 1100 Es 2100	Sw 2121 Ss 1100 Kd 2000
	H 2	Kd 2000 Ss 2100 Es 1100 Km 2120	
Shallow lithosolic soils	I 1	Cf 1200 Gs 2211	Ms 1100 Ms 2100 Cv 3200

Soil groups	Sub-group map symbol	Dominant soil form/family [1)]	Subdominant soil form/family
		Cv 3100 (Rock)	
	I 2	Ms 2100 Gs 2121 Oa 1210	Sw 2111 Km 1120 Km 1110
	I 3	Rock Ms 2100 Gs 2122 Oa 1210	Cg 1000 Kn 1000 Sw 2111 Km 1120 Km 1110
	I 4	Gs 2211 Ms 2100 Rock	
	I 5	Rock Gs 2211	
Alluvial soils on floodplains and lower river terraces	J 1	Du 1210 Du 1110	Oa 1110 Fw 1110 Cv 3100
	J 2	Du 1210 Lo 1000 Lo 2000	Tu 1120 Fw 2110
	J 3	Du 1110 Du 1210	Tu 2110 We 1000
	J 4	Pr 2120 Du 1220	
Physically unstable dunes	K 1	Dunes Cv 3100	
	K 2	Dunes Hu 3100 Cv 3100	Gr 1000
	K 3	Dunes	
Land classes	L 1		
	L 2		
	L 3		
	L 4	Rock Ms 2100	
	L 5	Rock	
	L 6	Rock	Gs 2211
Soil Complexes: Soil groups and soil sub-groups listed under Soil Complexes in Table 2.1 and Table 2.2are combinations of more than one group or sub-group listed in this table. An example is I 3 + I 4. The first mentioned symbol (e.g. I 3) represents at least 60 % surface area of that specific unit			

[1] Occupies more than 60% of the soil group or sub-group

3 Soil Suitability for Irrigated Crop Production

3.1 General

Different crops have root systems with characteristic lateral and vertical growth habits and have specific requirements in terms of aeration and density. A minimum usable soil depth is therefore required for unrestricted root development and water and nutrient uptake to ensure a healthy, productive plant.

According to Sys *et al*. (1993) the soil requirements of a few perennial crops are the following:

Citrus: maximum rooting depth 1.0 – 1.2 m; well drained and well aerated; light textured soils preferred.

Avocado: deep, medium to coarse textured soils are preferred; heavy soils with waterlogging not suitable; well drained with water table deeper than 2.0 m.

Mango: moderately deep (> 0.5 m) to deep; well drained; water table > 2.3 m; optimum texture sandy loam to loam.

The optimum soil properties (especially depth and texture) of other perennial crops such as grapes and table grapes are largely depending on the requirements of the specific rootstock that is used.

Although annual vegetable crops are usually considered as shallow rooted, most of the annual vegetables crops will grow better with a higher production on deep soils compared to shallow soils.

The soils in the Olifants River Basin study area, however, have a variety of naturally occurring soil properties that might restrict the ability of plant roots to develop and absorb water and nutrients. The more important limiting properties will briefly be discussed in the following paragraphs.

3.2 Physical and morphological soil limitations

3.2.1 Low clay content

Most of the soils in the Olifants River Basin that have developed from Table Mountain Sandstone (TMS) rocks or TMS derived weathering products (e.g. soil sub-groups B 3, C 1, I 1, J 1 and J 2 in the 2018 survey area) have very low clay in the top- and upper subsoil. The silt and fine sand content is also very low. Due to the low rainfall and high summer temperatures in the study area the natural organic carbon content is generally extremely low. In the 2018 survey area the TMS derived sandy soils are yellow to pale coloured with very little iron oxide.

These sandy, low carbon soils have a low water holding capacity. This is probably the most limiting factor in irrigated crop production through large sections of the study area.

One of the measures used by potato producers to limit the limitations associated with very sandy soils is to cover the soil surface with a layer more clayey material, at least 200 mm thick, and mix the “clay” with the underlying sand to a depth of 400 mm.

A new tendency is to cover perennial crops (such as citrus, stone fruit and table grapes) under permanent netting to prevent wind damage, sunburn and also limit evaporation.

3.2.2 Cemented hardpans

Hardpan carbonate horizons and dorbank are common diagnostic materials in many soils in the study area (e.g. soil sub-groups E 2, E 3 and F 1). Calcium carbonate is the primary cementing agent in hardpan carbonate horizons and silica in dorbank. These pans vary in hardness from moderately to extremely hard, with the latter type the most common. The pans are mostly massive to weakly platy, with rare vertical cracks or weakness planes. These pans are a severe limitation for root penetration and are slowly permeable to water.

It is a common practice to break these pans during deep soil cultivation with a tine-implement (commonly referred to as a ripper; rip ploughing) or by other mechanical means (e.g. bulldozer blade). Loose hardpan material is open and porous and generally a good medium for root development. In soils with moderately shallow hardpans, large quantities of medium large to very large fragments of the disrupted hardpan material might be brought to the surface of the soil. These fragments might affect planting of crops and restrict traffic.

3.2.3 Surface crusting and hard-setting

Surface crusting and hard-setting is a physical phenomenon that is largely determined by the exchange properties (concentration of and ratio between extractable and soluble base cations) of the soil material. It is further aggravated by the low organic carbon, high fine sand plus silt, and low sesquioxide content of the soils. Most of the soil types associated with heuweltjies are generally bleached in the dry state, which is an indication of low iron content, and have relatively high fine sand plus silt content; e.g. soil sub-groups D 2, D 6, E 3 and F 1.

Topsoil with such properties is physically unstable and disperses on wetting, sets hard with subsequent drying and forms a thin (≤ 10 mm) surface crust with a low water infiltration rate. The dispersive nature is generally enhanced by sodium (and magnesium) ions and is especially severe when irrigated with low salt containing water.

Management practices such as organic mulching, regular surface application of gypsum (2 – 3 t/ha/annum), or cover crops, are essential to lower the risk of surface crusting.

3.2.4 Dense and/or strongly structured subsoil clay layers

A moderately to strongly developed blocky or prismatic subsoil structure, with or without signs of wetness, is usually associated with a fairly high clay content, somewhat swelling clays and/or high percentage of exchangeable sodium and/or magnesium ions (e.g. soil sub-groups G 1 and H 2).

Structured, clayey subsoil is usually dense with a low macro-porosity. With an increase in the degree of structural development, size and angularity of the structural units (peds), the greater the negative effect is on root and water penetration.

This limitation can be improved through mechanical loosening of the subsoil clay layer and application of gypsum in cases where the clays are physically stable (low exchangeable sodium and magnesium saturation). When the clay is physically unstable very little can be done to improve the internal soil drainage and effective rooting depth.

3.2.5 Wetness

The average annual rainfall throughout the study area decreases from about 225 mm at Clanwilliam, to as low as 120 mm at Koekenaap in the north. Except for the cooler area near the coast the average maximum temperature during the summer months is generally high throughout the basin.

Under the low rainfall conditions from Clanwilliam to the coast combined with the high summer temperature it is reasonable to assume that the soils should not show any signs of periodic wetness.

Even in the drier section of the basin years with abnormally high rainfall, however, are not abnormal. Although the highest average monthly rainfall at Klawer Co-operative Wine Cellar is only 38 mm, the maximum monthly rainfall can be as high as 90 mm. Depending on the infiltration rate of the topsoil, these abnormally high rainfall incidences might lead to free water accumulation in some soil profiles.

Wetness results in a decrease in oxygen and an increase in carbon dioxide concentration in the soil system. This affects active root respiration and leads to reduction and lateral leaching of iron oxides. Iron loss might affect the physical stability of the soil material especially under conditions of high exchangeable sodium and/or magnesium saturation (e.g. in the duplex soils).

Soils with signs of wetness should therefore be artificially drained for optimum irrigated land use. Duplex soils with an impermeable subsoil clay layer should be ridged for deep rooted perennial crops and even for winter plantings of annual crops.

3.2.6 Weathering rock

Underlying weathering rock occurs in all the soils of the shallow lithosolic soil group. Weathering rock is always denser and more impervious to air, water and plant roots than overlying horizons but the degree of weathering and original structure of the rock has a large effect on how limiting the material might be.

Shallow lithosolic soils associated with TBS (soil sub-group I 1) are commonly used for citrus, and lately even for mango production. Although the effective depth of these soils is limited by the moderately hard to very hard underlying TBS rock, these soils are in many instances preferred by the producers to deeper soils after the rock has been shattered and loosened by deep ripping. Negative properties of ripped TBS soils are the high concentration of coarse rock fragments, very rapid hydraulic conductivity and low water holding capacity. With judicious irrigation practices, however, these limitations can largely be managed.

Shallow lithosolic soils that have developed from Bokkeveld (soil sub-groups I 2 and I 3) and Nama (soil sub-group I 5) formation rocks in the drier middle and northern sections of the basin are very seldom used for perennial crop production. The only exception is between Clanwilliam Dam and Bulshoek Weir where these soils are used for grapes. These lithosolic soils usually contain considerable quantities of soluble salts (especially sodium and magnesium) as well as varying concentrations of coarse fragments.

3.2.7 Wind erosion

Although wind erosion is strictly not a physical or morphological soil limitation, it is a serious limitation associated with sandy soils (see **section 3.1 Low clay content**) and requires special management practice such as mixing it with clay, the establishment of windbreaks, surface mulching and even horticulturally non-ideal row directions. The use of permanent netting cover as previously mentioned in section **3.2.1** will also alleviate this problem.

3.2.8 Slopes

Although steep slopes are strictly not a physical or morphological soil limitation, it plays an important role in deciding whether land can be utilized for irrigation purposes or not. Slope influences the cultivation of land and is therefore regulated by the "Conservation of Agricultural Resources (Act, 43 of 1983) Regulations". (see Annexure B) for an extract of the Act). For the 2012 survey slopes were not taken into consideration. With the increase of the original 60 m to 100 m above river level for the 2018 survey some steep slopes occur within the demarcated areas, especially in the mountainous regions. The decision was made to determine the three slope classes mentioned in the Act. They are:

- Areas where slope should not be a problem for cultivation (0 – 12 per cent slope),
- areas where special permission would be needed (12 – 20%) and
- areas that cannot be considered due to the very steep nature (>20%).
- Total areas (ha) of the three classes that occur within the 60 – 100 m above river level 2018 mapping area (totalling 10332 ha) were determined as 4951 ha (0 – 12 % class), 2850 ha (12 – 20%) and 2531 ha (>20 % class). The >20 % slopes therefore covers about 25 % of the total survey area. Further details about slopes are given in electronic map form.

3.3 Chemical soil limitations

3.3.1 Acidity

During the WODRIS a large number of soil samples (372) were analysed for pH (measured in 1M KCl; soil-solution ratio 1 : 25; pH_{KCl}). Based on average topsoil pH_{KCl} values on a soil form basis showed that except for the Fernwood and Pinedene form soils, all the soils had a pH_{KCl} above 6.0. Acidity is therefore no limitation in soils of the northern section of the Olifants River Basin from Klawer to the coast.

During the DWAF (2004) study producers/farmers from Keerom Dam to Bulshoek Weir were requested to submit any soil analyses that were done for soil preparation purposes. A total of 278 analytical data sets were received. Nearly 60 % of these samples had a pH_{KCl} lower than the optimum 5.5 for crop production. The general tendency, however, was an increase in pH from the south to the north. This would imply that acidity could be a relatively serious limitation for establishing perennial crops on "new" soils and liming during soil preparation will be essential.

No additional soil samples were analysed during the 2018 survey as the information gathered during 2012 were extensive and sufficient.

3.3.2 Free carbonates and alkalinity

Due to the low rainfall in the study area from Bulshoek Weir to the coast the soils are generally moderately to poorly leached with a high base saturation and pH_{KCl} values of > 6.0. In non-sandy soils the base content may be so high that free carbonates [$CaCO_3$ or $CaMg(CO_3)_2$], and even gypsum ($CaSO_4.2H_2O$) precipitate as free salts. These soils tend to be saline with pH_{KCl} values in the region of 8.0.

As a result of the high pH values, the solubility of nutrients such as phosphorus, zinc, iron, copper and manganese, is very low and has a low availability to plants. The less crystalline and more powdery the carbonates, the more severely the solubility is affected.

The presence of free carbonates (and gypsum when present), however, improves the physical stability of soil material. Calcareous soils are therefore more friable and porous than similar non-calcareous soils.

3.3.3 Salt affected soils (salinity)

As was pointed out in the preceding paragraphs, many soils in the drier parts of the study areas tend to be saline. Although the general salt profile of these soils is an increased soluble salt content with depth, the spatial salt profile may vary significantly between soil sub-groups and even between soil families within a particular soil complex (Provincial Government Western Cape, 2003).

Although rainfall is the overall determining factor that affects the salt content of soils, it is further influenced by texture, position in the landscape (upper, middle or lower slope position), slope type (convex, concave, or straight), slope percentage and presence of termites.

Soils on lower, concave, nearly level slope positions tend to be more saline than soils on upper, convex slope positions with a fairly steep gradient. In addition, soils on or near "heuweltjies" are usually extremely saline.

Although certain crops may tolerate a certain amount of free salts in the soil system, most crops, especially deciduous fruit, grapes and citrus, are sensitive to saline soil conditions. The effect of salinity on plants is twofold. Firstly, too high a concentration of free salts in soil (so-called *saline soils*) increases the osmotic pressure of the soil solution that affects the total tension at which plants must absorb water. The plant available water is therefore decreased. Secondly, sodium and chlorine ions can be toxic to plants.

3.4 Effective rooting depth

Effective rooting depth is defined as that depth of soil from which plants absorb most of their water and nutrients. This is a highly variable factor that depends on the plant type, method of irrigation, as well as various soil properties. The most important physical and morphological soil properties that influence rooting depth in the Olifants River Basin are subsoil wetness, cemented hardpans, dense and structured subsoil clays and weathering rock.

For optimum growth and production, most perennial plants (inter alia grapes, table grapes, Stone fruit, citrus and mangos) require a minimum effective rooting depth of more than 600 mm. With an increase in rooting depth the root environment becomes more suitable and the buffer capacity of the soil against drought increases.

In the evaluation of rooting depth in different soil types, one should distinguish between annual and perennial crops. For annual crop production, producers very seldom apply any deep soil amelioration measures such as deep soil tillage to break up limiting hardpans. For perennial crops such as wine and table grapes, citrus and mangos deep soil tillage to break up the subsoil limiting layers is a standard practice. The effective rooting depth therefore is increased.

3.5 Qualify limiting soil properties, soil potential and recommendation for crop production

The inherent features of the soils identified in the 2018 study area from Clanwilliam Dam to Klawer can be used for general interpretations concerning those soil properties that might affect rooting depth, inhibit plant growth, and influence management practices.

At present it is impossible to quantify the negative effect of limiting soil properties on crop growth and production. Based on experience, however, these properties can be used to formulate broad guidelines to qualify the degree to which any particular soil property might act as a limitation. Five qualitative classes, *viz*. **None**, **Low**, **Moderate, Severe** and **Variable** were used to qualify the intensity of physical and chemical limitations in the various soil sub-groups. In many soil sub-groups the soil families are comparable in terms of limitations. In other soil sub-groups, however, the soil families differ in terms of their respective limitations. In the latter case the soil families that have the most severe limitations were used to qualify the degree of the respective limitations. Due to the variation in a particular property that might be encountered within a particular soil sub-group, the limitation degree was in certain instances qualified as ranges, e.g. **None - Low**; **Low - Moderate**; **None - Severe**; etc.

In **Annexure A: Table 2.2** six physical and two chemical limitations are qualified for all the soil sub-groups (except land classes) as defined in the map legend (refer to **Table 2.1** above).

The approach used in the Western Cape to evaluate soil potential for perennial crops such as deciduous fruit, vines and citrus, is the so-called expert system approach. This approach requires a sound scientific and practical knowledge of soil as a natural resource, crop specific requirements and tolerances, and soil-crop-climate interactions. In addition, a sound knowledge and understanding of soil amelioration measures and soil related management practices are essential to place any soil type in the correct soil potential category.

Three soil specialists with a sound knowledge of irrigation farming in the Olifants River Basin evaluated the potential, primarily physical, of individual soil sub-groups with reference to irrigated crop production of annual and perennial crops, before and after amelioration of subsoil limitations. The average ratings were determined for each soil complex based on the ratings of the three soil specialists. The final potential ratings by soil subgroup are listed in **Table 3.3**.

The soil limitations that were used in the expert system approach to determine soil potential were:

- Physical limitations:
  - low clay content in top- and upper subsoil horizons; and
  - effective depth limiting properties or materials such as wetness, dense clay horizon, weathering rock, hardpan carbonate horizon and dorbank.
- Chemical limitations:
  - alkalinity; and
  - salinity in upper and lower B horizons or hardpan.
- Wind erosion hazard on exposure.

Heuweltjies (termite mounds) are listed as an additional limitation. Soils on or next to heuweltjies are generally saline, calcareous, with a soft or hardpan carbonate subsoil horizon. The more heuweltjies (expressed as a percentage of surface area) that occur in a soil sub-group the greater the salinity, alkalinity and effective depth limitation.

Five classes were used to rate the potential and recommendation of soil sub-groups for irrigated crop production (see **Table 3.1**). Due to the negative effect, indirect and direct, of free lime on growth and production, soils with calcareous horizons were rated one unit lower than non-calcareous soils with similar properties. Although it was difficult to accommodate salinity in these evaluations, soil sub-groups with a very high salinity were downgraded compared to similar non-saline soils (**Table 3.2**).

Table 3.1 Classes used to evaluate the potential and recommendation of soil sub-groups for annual and perennial crops before and after amelioration of subsoil limitations

Soil potential	Recommendation for irrigated crop production	Percent of maximum potential
Low (L)	Not recommended (NR)	≤ 40%
Medium-Low (ML)	Marginally recommended (MR)	> 40 - ≤ 50%
Medium (M)	Conditionally recommended (CR)	> 50 - ≤ 60%
Medium-High (MH)	Recommended (RE)	> 60 - ≤ 80
High (H)	Highly recommended (HR)	>80%

Table 3.2 Potential of soil units and complexes for irrigated annual and perennial crop production before and after amelioration of soil limitations (amelioration measures indicated by an upper script) in the area of Clanwilliam to Klawer[1]

Soil sub-group	Soil potential[2] and Recommendation			
	Annual crops		Perennial crops[5]	
	Tuberous[3]	Non- tuberous[4]	Before amelioration	After amelioration
A 8	50 (MR)	70 (RE)	70 (RE)	80[6] (RE)
B 1	65 (RE)	60 (CR)	50 (MR)	60[6] (CR)
B 3	65 (RE)	60 (CR)	50 (MR)	60[8] (CR)
B 4	50 (MR)	40 (NR)	40 (NR)	45[8] (MR)
B 3 + I 1	50 (MR)	40 (NR)	35 (NR)	55[8] (CR)
C 1	50 (MR)	50 (MR)	20 (NR)	40[8] (NR)
C 1 + G 1	50 (MR)	50 (MR)	20 (NR)	40[8] (NR)
D 1	50 (MR)	70 (RE)	60 (CR)	70[7,8] (RE)
D 2	60 (CR)	70 (RE)	60 (CR)	80[6] (RE)
D 3	50 (MR)	60 (CR)	50 (MR)	50[6] (MR)
E 2 + F 1	40 (NR)	60 (CR))	50 (MR)	65[6] (RE)
F 1	20 (NR)	60 (CR)	20 (NR)	65[6] (RE)
G 1	45 (MR)	50 (MR)	25 (NR)	45[8] (MR)
H 1	20 (NR)	40 (NR)	20 (NR)	35[8,9] (NR)
H 2	20 (NR)	40 (NR)	20 (NR)	35[8,9] (NR)
I 1	20 (NR)	40 (NR)	30 (NR)	50[9] (MR)
I 2	20 (NR)	40 (NR)	30 (NR)	40[9] (NR)
I 3	10 (NR)	10 (NR)	10 (NR)	10[9] (NR)
1 5	10 (NR)	10 (NR)	10 (NR)	10[9] (NR)

Soil sub-group	Soil potential[2] and Recommendation			
	Annual crops		Perennial crops[5]	
	Tuberous[3]	Non- tuberous[4]	Before amelioration	After amelioration
I 1 + B 3	40 (NR)	50 (MR)	40 (NR)	50[8,9] (MR)
I 1 + L 5	0 (NR)	0 (NR)	0 (NR)	0 (NR)
I 3 + E 2	20 (NR)	40 (NR)	20 (NR)	35[8,9] (NR)
I 3 + L 3	0 (NR)	0 (NR)	10 (NR)	30[9] (NR)
I 3 + I 4	10 (NR)	20 (NR)	10 (NR)	20[9](NR)
J 1	70 (RE)	70 (RE)	50 (MR)	60[9] (CR)
J 2	50 (MR)	50 (MR)	30 (NR)	50[8,9] (MR)
J 3	60 (CR)	60 (CR)	65 (RE)	75[8,9] (RE)
K 1	40 (NR)	30 (NR)	30 (NR)	30 (NR)
K 1 + F 1	40 (NR)	30 (NR)	30 (NR)	30 (NR)
L 1	0 (NR)	0 (NR)	0 (NR)	0 (NR)
L 3	0 (NR)	0 (NR)	0 (NR)	0 (NR)
L 4	0 (NR)	0 (NR)	10 (NR)	30[9] (NR)
L 5	0 (NR)	0 (NR)	0 (NR)	0 (NR)
L 6	0 (NR)	0 (NR)	0 (NR)	0 (NR)

Percentage of maximum potential	Recommendation for irrigated crop production
≤ 40%	Not recommended (NR)
>40 - ≤50%	Marginally recommended (MR)
>50 - ≤60%	Conditionally recommended (CR)
>60 - ≤80%	Recommended (RE)
> 80%	Highly recommended (HR)

1 - Covers all areas up to 100 m above river level
2 - This includes crops such as potatoes, onions, sweet potatoes, and carrots (usually without amelioration of subsoil limitations, e.g. dorbank).
3 - This includes crops such as tomatoes, pumpkin, and beans (usually after amelioration of subsoil limitations, e.g. dorbank).
4 - This refers mainly to dry, wine and table grapes and citrus.
5 - Loosening of dorbank.
6 - Loosening of laterite (hard plinthite).
7 - Drainage.
8 - Deep, mechanical soil tillage.
9 - Mixing of depositional layers.

The lateral extent of the area that will be used for the utilisation of the additional water from the enlarged Clanwilliam Dam will probably be on average about 100 m above the level of the river or existing canals or an agreed horizontal distance (probably 2.5 km) away.

These lateral limits were digitised and also shown on one of the electronic maps included for the survey area. The surface area of the five potential suitability and recommendation classes (≤ 40 % NR; > 40 - ≤ 50 % MR; > 50 - ≤ 60 % CR; > 60 - ≤ 80 % RE; > 80 % HR) for the production of tuberous and non-tuberous crops and perennial crops before and after amelioration of subsoil limitations for each soil sub-group in the 2018 survey area is shown in **Table 3.3**.

This information is summarised in **Table 3.3**.

Table 3.3 Surface area of five potential suitability classes for the production of tuberous and non-tuberous crops and perennial crops before and after amelioration of subsoil limitations in four main areas in the Olifants River Basin from Clanwilliam Dam to Klawer between 60 – 100 m above river level.

Potential class and recommendation	Annual tuberous crops (ha) [1]	Annual non-tuberous crops (ha) [2]	Perennial crops [3]	
			Before amelioration (ha)	After amelioration (ha)
Clanwilliam Dam to Klawer (between 60 – 100m				
≤ 40 % (NR)	8457	7132	9259	5729
> 40 - ≤ 50 % (MR)	802	1010	973	2280
> 50 - ≤ 60 % (CR)	100	1693	20	1107
> 60 - ≤ 80 % (RE)	973	497	80	1217
> 80 % (HR)	0	0	0	0
Total area (ha) Clanwilliam dam to Klawer	10332	10332	10332	10332

1 This includes crops such as potatoes, onions, sweet potatoes, and carrot; usually without hardpan amelioration.

2 This includes crops such as tomatoes, pumpkin, and bean; usually after hardpan amelioration.

3 This refers mainly to dry, wine and table grapes and citrus.

4 Amelioration of Physical and Morphological Soil Limitations

Measures required to improve the physical and morphological limitations are briefly discussed in the following paragraphs.

4.1 Deep tillage of soils

In **Table 3.3** the ideal depth and type of deep soil tillage are specified on a soil sub-group basis. Four depth categories, *viz*. ***shallow*** (± 400 mm), ***moderately deep*** (± 600 mm), ***deep*** (± 900 mm), and ***very deep*** (± 1 200 mm) were used. Although very deep were seldom specified in **Table 3.3**, it is most probably the more ideal depth for soils with moderately deep to deep hardpans. The deeper the depth of loosening the better internal drainage would be. The necessity for a specific type and depth of deep cultivation was also specified in terms of ***not necessary***, ***recommended*** and ***essential***.

Only two types of deep soil cultivation were used in **Table 3.3**, *viz:*

- ***Rip plough*** **(*Afr.: Skeurploeg*)**: It consists of one or more vertical tines with a small "share" at the bottom. Although the tine width can vary from the front to the back, it has a relatively narrow (≈50 mm) front view. Ripper ploughs are mainly used on shallow soils with weathering rock, dorbank or hardpan carbonate horizon as limiting layer. It causes a shattering of the hard layer without mixing of the individual layers. Such implements are not suitable for the mixing of ameliorants (especially lime), although gypsum, by letting it flow behind the tine, is sometimes put into the subsoil.
- ***Shift plough*** **(*Afr.: Skuifdolploeg*):** A shift plough differs from a normal delve in terms of the size and shape of the mould board. The mould board is modified in different ways. The upper point can be made shorter so that the mould board has an equal width from the top to the bottom. The concavity can also be decreased. Presently most mould boards are nearly flat. The angle, from bottom to top, of the mould board plate can be decreased, as well as the angle to the rear. In addition, the angle to a horizontal plane of the share can be changed from the normal 45° to more than 75°. The width of the plate that remains in the middle of the

mould board can vary but is determined mainly by the plough construction. The smaller, more vertical and narrower the mould board, and the greater the cavity in the plate, the less subsoil will be brought to the soil surface and the different layers will be moved sideways. By cutting the mould board at the top in such a way that it has a downward angle away from the plough, large volumes of topsoil will flow over the plate during tillage and flow down behind the mould board and are then mixed with the subsoil. Such variations are made on soils with high subsoil densities. It can also be used to place ameliorants at different depths into the soil, with a certain degree of mixing of the top- and subsoil.

4.2 Drainage of soils

Although wetness is not a serious natural limitation in most of the soil sub-groups in the Olifants River Basin, especially in the northern section from Klawer to the coast, drainage should, for many reasons, be considered as an essential practice for sustainable development in the potentially irrigable soils.

When natural or man induced (e.g. over-irrigation for the removal of soluble salts and boron) wetness of irrigated lands is the primary reason for draining soils, it is essential that all possible causal factors are removed or improved. These include leaking earth dams, clogged natural drainage canals, dense soil layers (plough pans due to cultivation) with low infiltration rates, as well as injudicious over-irrigation.

Depending on the cause of water-logging, different approaches as to the best method for drainage, should be followed. In practice, two main drainage types are distinguished:

- **Cut-off or intercept drainage** is used where free water moves laterally in porous, sandy or gravelly layers overlying dense subsoil (e.g. soil groups G and H), from a higher to a lower lying down-slope position. The cut-off drain is more or less perpendicular to the flow direction of the free water.
- **Subsoil drains** are used on nearly level high lying terraces or concave, low lying landscape positions where true water tables might occur (e.g. soil sub-groups C 1, J 2 and J 3).

Except for soil groups G and G (duplex soils), shallow, perched water tables are relatively rare in the Olifants River Basin. The development of man induced perched water tables, however, is not uncommon when large areas are developed for irrigation, especially when the irrigation management is not at a high level.

The main reason why subsoil drainage is essential for sustainable irrigated agriculture in the northern section of the basin is soil salinity. Although the salinity of the soil sub-groups varies considerably from non-saline to saline, soil sub-groups that include heuweltjies, and soil types with soft or hardpan carbonate horizons, dorbank and neocarbonate B horizons, are generally moderate to severely saline.

The only mechanism for desalinisation of soils is through leaching with controlled over-irrigation. The degree of over-irrigation and the resultant leaching fraction (this is the difference between the irrigation water requirement and the amount of water actually applied) will depend on the salinity level of the soil, as well as the salt tolerance of the crop.

Drainage is essential to remove the salt containing leaching water. If this water is not removed, severely saline conditions could develop on lower slope positions, depression areas, as well as on the up-slope side of orchard/vineyard roads.

Although the degree of over-irrigation, and therefore amount of leaching water, will differ between soils, an average of 20 % over-irrigation will be required during the first two to three years to remove most of the soluble salts; this would probably result in a 10% leaching fraction. After two to three years a much smaller degree of over-irrigation should be required.

4.3 Ridging or cambered beds

The aim of ridging is to increase the rooting depth of shallow, well-drained (e.g. Glenrosa form, and poorly drained shallow and medium deep duplex (e.g. Estcourt, Klapmuts and Kroonstad form) soils.

For citrus, wine grapes, table grapes and stone fruit production, ridging is at times considered as an alternative amelioration measure if deep tillage presents problems such as:

- the high cost of deep tillage to uniformly ameliorate the limitation;
- ploughing up or exposure of subsoil clay; or
- internal drainage of the subsoil is too slow.

The construction of ridges might appear to be a simple operation, but it is important that the correct position, slope direction, ridge height and row width are selected. Ridges should never be parallel on the contour. During building of ridges it is important that the soil on the ridges is not compacted.

4.4 Recommended soil amelioration measures on a soil sub-group basis.

In **Table 4.1** the recommended physical and amelioration measures are listed on soil sub-group basis.

Table 4.1 Recommended physical and chemical amelioration measures for soil sub-groups (excluding unstable dunes and land classes) in the Olifants River Basin, Clanwilliam to Klawer

Soil sub-group	Drainage	Ridging	Deep soil cultivation		Gypsum
			Shift plough	Rip plough	
A 8			Recom DE		
B 1			Recom DE		
B 3	Recom		Recom DE		
B 4			Recom DE		
B 3 + I 1	Recom			Recom DE	
C 1 + G 1	Recom		Recom DE		
D 1			Essen DE		
D 2	Recom		Essen DE	Recom VD	Recom
D 3	Recom		Essen DE	Recom VD	Essen
E 2 + F 1	Recom			Essen DE-VD	Essen
F 1	Recom			Essen DE-VD	Essen
G 1	Essen		Recom MD	Recom DE	
H 1	Recom	Essen		Essen DE	Recom
H 2	Recom	Essen		Essen DE	Recom
I 1				Essen DE	
I 2	Recom			Essen DE	Recom
I 3	Recom			Essen DE	Essen
1 5	Recom			Essen DE	Essen
I 1 + B 3	Recom			Recom DE	
I 1 + L 5					
I 3 + E 2	Recom			Essen DE	Essen
I 3 + L 3					
I 3 + I 4					
J 1			Essen DE		
J 2	Essen		Essen DE		
J 3	Recom		Essen DE		
K 1			Essen DE		
K 1 + F 1				Essen DE	Essen
L 1					
L 3					
L 4					
L 5					
L6					

Notes:

i) The following classes were used to qualify the necessity for a particular amelioration measure:

Necessity	Symbol
Not necessary	(No symbol)
Recommended	Recom
Essential	Essen

ii) The following depth classes were used with the recommendations for shift ploughing or ripping.

Depth class		Symbol
Description	**Depth (mm)**	
Shallow	± 400	SH
Moderately deep	± 600	MD
Deep	± 900	DE
Very deep	± 1 200	VD

iii) Depending on the chemical analysis of the soil, part of recommended gypsum is applied during deep soil cultivation, while the rest is applied during the initial desalinisation leaching phase.

iv) Drainage is recommended to remove a) free water from moderately to poorly drained soils, and b) to remove saline leaching water from the soil system especially during the desalinisation phase of land development.

v) The following soil sub-group units (I 1+ L 3, I3+L3, I3+I4, L1, L2, L3, L4, L5, L6) have been omitted due to several severe constraints (e.g. very steep slopes and rock outcrops) that prevents any cultivation.

5 References

Soil Classification Working Group. 1991. Soil Classification: A Taxonomic System for South Africa. Mem Natural Agric. Resources for S.A. No. 15.

Sys, C; Van Ranst, E; Debaveye, J & Beernaert, F. 1993. Land Evaluation, Part III, Crop Requirements. Agricultural Publications No 7. University of Ghent, Belgium.

Appendices

APPENDIX A: COORDINATES AND DESCRIPTION OF SOIL PROFILES

Profile			Depth	Form &	Subsoil limitations/properties				Topsoil			Wet-	Changes	Transi-	Suitability	Suitability
number			codes	Family	Upper	Middle	Lower	Coarse	Coarse	Sand	Clay	ness		tional	rating	rating
	lat	lon						fragments*	fragments	grade	class	class		form	perennials	annuals
1	-31.78162	18.59669	1	Kn 1000	db3					me	1				4	2
2	-31.780271	18.59563	1	Kn 1000	db3					me	1				4	2
3	-31.782093	18.59731	1	Cv 2100						me/fi	1				5.5	6
4	-31.78814	18.59917	1 8	Ga 1000	db2/3					me/fi	1				4.5	4.5
5	-31.78279	18.60740	1	Kn 1000	db3					me	1				4	2
6	-31.79198	18.59248	2	Ga 1000	db3					me	1				4.5	4
7	-31.77886	18.58764	1 3	Ga 1000	db3					me	1/2				4.5	4
8			2 7	Gs 21/211	lo+3f+3g+2k	Ro				co	1/2				4.5	4.5
9			3 9	Fw 1210	gs(ye)	gs(gr)				co	1				4	4
10	-32.34013	18.92423	1/2	Ms 1100	R0			2g+4k		me	1				2	3
11	-32.31161	18.91164	2/3	Gs 2211	so			2g + 2k		fi	3/4				4	4.5
12	-32.20195	18.86966	3	Gs 2211	so			2g		me/co	1/2				5.5	5.5
13	-32.04912	18.75795	2 6	Kd 1/200	gc					me/co		6			4	4.5

APPENDIX B: CONSERVATION OF AGRICULTURAL RESOURCES ACT, 1983 (ACT 43 OF 1983)

REGULATIONS

[Amended by GN R 2687 of 1985-12-06 and GN R 280 of 2001-03-30.]

The Deputy Minister of Agriculture, acting on behalf of the Minister of Agriculture, has under section 29 of the Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983), made the regulations in the Schedule.

Page 3

Cultivation of land with a slope

3.(1) Except on authority of a written permission by the executive officer, no land user shall cultivate any land if it -

(a) has a slope of more than 20 per cent; or

(b) has a slope of more than 12 per cent, is situated in an area specified in column 1 of Table 1, consists mainly of soil of a soil form and soil series respectively specified in columns 2 and 3 of the said Table opposite the area concerned and, if applicable, has such physical properties as may be specified in column 4 of the said Table opposite the soil series concerned.

(2) The prohibition contained in subregulation (1) (a) shall not apply in respect of land which is under cultivation on the date of commencement of these regulations, provided it is already protected effectively in terms of regulation 4 against excessive soil loss due to erosion through the action of water.

(3) The provisions of regulations 2 (2), (3) and (4) shall apply mutatis mutandis with regard to an application for a permission referred to in subregulation (1).

APPENDIX C: STRUCTURE OF SOIL CODE AND EXPLANATION OF SYMBOLS

1 Structure of soil code

The code consists of two series of letter-number symbols, separated by a horizontal line, arranged in the following order:

Position to horizontal line	For description refer to section
Above the line	
Depth of horizons and/or materials	2.1
Soil form	2.2
Soil family	2.3
Subsoil limitations or properties	2.4
Below the line	
Texture of topsoil horizon	3.1
Additional qualifiers	3.2

In a Microsoft Word or Excel table the letter-number symbols can be written in a single line with the "above the line" letter-number symbols followed by the "below the line" letter-number symbols.

In uncultivated soils the term topsoil horizon refers to the natural A horizon, while for cultivated soils it refers to the upper 150 - 300 mm of the soil profile affected by tillage.

2 Classes and symbols for properties above the line

2.1 Horizon and/or effective depths

The depths of all the diagnostic as well as non-diagnostic horizons and/or materials encountered in a profile are coded with a number symbol in front of the soil form symbol. Depth classes and symbols used are:

Depth class (mm)	Symbol	Depth class (mm)	Symbol
0 .- 150	1	750 - 950	7
150 - 250	2	950 - 1 150	8
250 - 350	3	1 150 - 1 350	9
350 - 450	4	1 350 - 1 550	0
450 - 550	5	>1 550	no symbol
550 - 750	6		

Depth symbols for diagnostic horizons or materials specified in a particular soil form are arranged from shallow (topsoil transition) to deep (deepest subsoil transition) before the form symbol (e.g. 3 5 Es 1100, where 3 refers to the A/E transition and 5 to the E/B transition). Depth symbols for subsoil limitations or properties (arranged from shallow to deep) appear between the depth symbols for diagnostic horizon transitions and the form symbol (e.g. 3 5 3 Es 1100; the second 3 indicates the depth of a subsoil limitation or property.)

2.2 Soil Form

Soil forms and abbreviations used in the soil code are explained by the Soil Classification Working Group (1991). For example Tu is the abbreviation for a Tukulu form soil.

2.3 Soil family

Soil families are identified by a locality name or coded by means of a four-digit symbol (Soil Classification Working Group, 1991). For example 1110 is the four-digit symbol for the Hefnaar soil family of the Augrabies soil form. In the code the four-digit symbol is used directly after the soil form abbreviation symbol; e.g. Ag 1110.

2.4 Subsoil limitations and properties

The depth of soil utilized by plant roots is determined by a variety of soil materials and factors. For example, in the Valsrivier soil form the maximum effective root depth is determined by the pedocutanic B.

In those forms where the limiting horizon is part of the defined sequence of horizons that is diagnostic of the soil form, the symbol for the limiting material or horizon do not have to be coded. It is, however, recommended that symbols for all diagnostic horizons are included in the code. If the limiting horizon or material is not included in the sequence of diagnostic horizons, the symbol for the specific horizon or material must be specified after the family number in the code. The depth symbol for such horizons is written between the depth symbol for diagnostic horizons and the soil form symbol.

The more important materials that may affect root penetration and water infiltration to a greater or lesser extent are one or more of the following:

- **Moderate to strongly structured, unconsolidated material without signs of wetness**

  vp - Blocky clay: a non-gleyed soil material with a non-uniform non-red colour and a moderate or stronger structure when moist. It largely meets the requirements of a pedocutanic B horizon

  vr - Blocky clay: a non-gleyed soil material with a uniform red colour and a moderate or stronger structure when moist. It largely meets the requirements of a red structured B horizon

- **Weaker than moderately structured, unconsolidated material without signs of wetness**

  nc - Calcareous unconsolidated material with signs of soil development, e.g. aggregation, clay illuviation and/or disappearance of original stratification. It largely meets the requirements of a neocarbonate B horizon. Red as well as non-red variants occur.

  re - Red, non-calcareous soil material with a structure weaker than moderate blocky or prismatic. It largely meets the requirements of a red apedal B horizon.

  sk - Calcareous material which largely meets the requirements of a soft carbonate horizon.

  ye - Brown or yellow-brown, non-calcareous soil material with a structure weaker than moderate blocky or prismatic. It largely meets the requirements of a yellow-brown apedal B horizon.

Note: The colour of certain of these horizons/materials (e.g. **nc**) might be important for land use interpretation and soil suitability evaluation. In such cases the dominant colour should be coded by using the following colour abbreviation symbols: **dkgr** = dark grey; **gr =** grey; **grye** = grayish yellow; **re =** red; **ye =** yellow and **yere** = yellowish red.

For example the combined symbol **nc/yere** (horizon/material symbol linked to the colour symbol with forward slash) refers to a yellowish red neocarbonate horizon/material.

- **Textural stratification in diagnostic and non-diagnostic unconsolidated material**

Depending on the mode of transport (water or wind) and deposition, some unconsolidated materials are texturally stratified. However, with time soil development may result in the disappearance of the stratification. However, in certain young soils stratification can still be detected. Since textural stratification is an important characteristic in land use, it has to be indicated in the code in the following way:

1 Description	2 Symbol
3 Textural stratification non-prominent or absent	
Predominantly loamy or porous silt	U6

3 Classes and symbols for properties below the line

3.1 Texture of topsoil and directly underlying E or apedal B1 horizon

The texture is coded in terms of the:

- sand grade for soils with less than 20% clay and
- clay content (percentage).

Classes and abbreviations for sand grade clay content are the following:

Sand grade	Symbol
fine	fi

Clay content	Symbol
15 – 20	4
20 – 35	5

Examples:

- A topsoil developed from parent material with 18 % clay and fine sand grade is coded by the symbol **fi 4**.
- In cases where the clay content is on or near the boundary between two classes, e.g. 23 %, it should be coded as **fi 4/5**.

3.2 Additional qualifiers

- **Tge** Other (general) topsoil related features

  Tge-nca - Non-calcareous A horizon: Having a non-calcareous topsoil horizon (associated with soils where the subsoil is calcareous by definition e.g. neocarbonate, soft carbonate or within certain families, e.g. pedocutanic B)

  Tge-cal - Calcareous A horizon: Having a calcareous upper or whole part of the topsoil that is calcareous lying on a subsoil that is non-calcareous. Calcareous nature due to natural factors such as dust blown in. It is optional to use this symbol also for a soil having a calcareous topsoil in soils where the subsoil is also calcareous by definition e.g. neocarbonate, soft carbonate or within families, e.g. pedocutanic B.

4 Examples of a fully coded description

Although the sequential position of the symbols for certain components used in the soil code is fixed, the sequence of non-diagnostic subsoil limitations and their respective depth symbols can be coded in more than one way. The detail that soil surveyors want to include in the code may also differ. For this reason a few examples will discussed as guidelines for individuals that is not familiar with the code.

Example:

Dystrophic, luvic Hutton form soil with an A/B transition at 300 mm, extremely hard ferricrete (hard plinthite) at 850 mm and stoneline at 500 mm. The topsoil contains 15 % coarse gravel and 35 % stones, 15 – 20 % clay, and has a coarse sand grade. The clay content of the B is constant with depth. The code for this soil may be written in one of the following ways

Field code 1 <u>3 7 5 Hu1200 re hp2 sl</u>
2g+4k co4

Field code 2 <u>3 5 7 Hu1200 sl hp2</u>
2g+4k co4

Word/Excel format 1 3 7 5 Hu1200 re hp2 sl
followed in same line by a double forward slash and then
2g+4k co4

Word/Excel format 2 3 7 5 Hu1200 hp2 sl
followed in same line by a double forward slash and then
2g+4k co4

Note: Field code 1 and Word/Excel format 1 is the preferred way of coding.

It is recommended that when the code is captured in a Word or Excel format table, the separate items of the code should each constitute a separate column. The following can be used as an example of a Word format table:

Profile number	Depth codes	Soil form and family	Subsoil limitations/properties				Topsoil			Wetness class	Changed properties or condition
			Upper subsoil	Middle subsoil	Lower subsoil	Coarse frag-ments	Coarse frag-ments	Sand grade	Clay class		
1	2 4 6 2	Tu 2110	ne/ye	gs+4g	vp	3f+2g	2f	co	3	3	md 7
2	3 6 8 3	Es 1100	pr	sw		6f	4f	fi	2/3	6	dr

The subsoil limitations/properties are sequentially linked to the depth codes from right to left. For example:

Profile 1

Depth codes	2 ↓	4 ↓	6 ↓	2 ↓
Subsoil limitations/properties	ne/ye	gs+4g	vp	3f + 2g
Upper and lower depth of subsoil limitation/property	20 - 40 cm	40 - 60 cm	60 cm and deeper	20 – 40 cm

Profile 2

Depth codes	3 ↓	6 ↓	8 ↓	3 ↓
Subsoil limitations/properties		pr	sw	6f
Upper and lower depth of subsoil limitation/property	30 - 60 cm	60 - 85 cm	85 cm and deeper	30 – 60 cm

The first 3 in the depth code refer to the boundary between the orthic A and the E horizon.

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