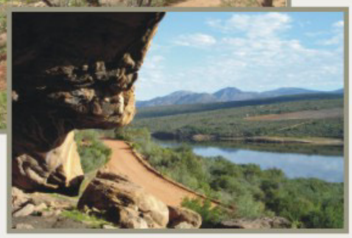
DWAF Report No. P WMA 17/E10/00/1109

DEPARTMENT OF
WATER AFFAIRS
AND FORESTRY

Feasibility Study for the Raising of Clanwilliam Dam

Soils, Water Requirements and Crops



Final

February 2009

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CONSULTING SERVICES

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY
DIRECTORATE OPTIONS ANALYSIS

FEASIBILITY STUDY FOR THE RAISING OF THE CLANWILLIAM DAM

SOILS, WATER REQUIREMENTS AND CROPS

Final

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Department of Water Affairs and Forestry
Directorate Options Analysis

FEASIBILITY STUDY FOR THE RAISING OF THE CLANWILLIAM DAM

APPROVAL

Title	:	Soils, Water Requirements and Crops
DWAF Report No.	:	P WMA 17/E10/00/1109
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EXECUTIVE SUMMARY

Soil Survey

The terms of reference for the study *inter alia* required a compilation of a soils map for the Olifants River Basin from Keerom, south of Citrusdal, to the coast. The lateral extent of the area covered will on average be about 60 m above the level of the river or existing canals or an agreed horizontal distance away. The soils map is based on:

i) the extensive reconnaissance soil survey of the Citrusdal valley from the Clanwilliam Dam south as far as Keerom (Lambrechts, *et al*., 1989);
i) the extensive, more detailed *Western Cape Olifants/Doring River Irrigation Study* (WODRIS; Provincial Government Western Cape, 2003),
iii) data from other soil studies; and
iv) expert knowledge.

To integrate the WODRIS and Citrusdal soil survey information and to fill in the unmapped section north of Clanwilliam Dam to Bulshoek Weir and the Trawal-Klawer area to the west of the Olifants River, a two-day field excursion was undertaken. Soil observations were made at all available soil exposures. A hand auger was used for additional observations. Landowners in the unmapped area were interviewed regarding the soil types on their property. Subsequent to the field excursion the boundaries of uniform soil-terrain units in the unmapped section as well as the boundaries on the 1 : 50 000 scale soil map of the Citrusdal survey were checked and modified where necessary. The soil-terrain polygons of the WODRIS soils map was left unchanged. The next step was to develop a new soil map legend. A simple two-level legend consisting of an upper level of soil groups and a second level of soil complexes was compiled. 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 and/or terrain position. An identification letter symbol (A to L) was given for each soil group. Soil groups were subdivided into soil complexes based on selected soil properties. The final soil complex boundaries on 1 : 50 000 topographic maps were digitised by Ninham Shand Consulting, Cape Town. In addition to the description of the different soil complexes, the dominant (occupies more than 60% of the map unit) and subdominant soil forms and families were determined. The percentage of the land surface covered by "heuweltjies", a micro-relief feature associated with termite activity, was also estimated.

There is a pronounced difference in the dominant soil complexes between the southern and northern sections of the basin. The dominant soils in the southern section are: moderately to well drained, deep, yellow to grey sandy soils (complex B 3); grey, moderately deep to deep, poorly drained duplex soils (complex G 1); shallow lithosolic soils (complex I 1; alluvial soils on floodplains and lower river terraces (complex J 2); and land classes (complex L 1). In the northern section the dominant soils were: well drained red apedal soils (complexes A 1, A 3, A 5 and A 7; well drained loamy red and/or yellow soils on higher lying river terraces and pediments (complexes D 5 and D 6); moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank on high lying terraces (complex E 1); shallow soils on dorbank (complex F 1); alluvial soils on floodplains and lower river terraces (complex J 3); physically unstable dunes (complex K 2); and land classes (complex L 3).

Soil Suitability for irrigated crop production

Soils in the Olifants River Basin have a variety of naturally occurring soil properties that restrict the ability of plant roots to develop and absorb water and nutrients. These include physical and morphological (e.g. low clay content; cemented hardpans; surface crusting and hard-setting; dense and/or strongly structured subsoil clay layers; wetness; weathering rock and wind erosion) as well as chemical (e.g. acidity; free carbonates and alkalinity; and salinity) limitations.

Based on experience, the degree to which any particular soil property might act as a limitation was qualified as none, low, moderate, severe and variable in the various soil complexes. In soil complexes where soil families differ in terms of their respective limitations, soil families that have the most severe limitations were used to qualify the degree of the respective limitations. The real effect of a limitation, however, is not necessarily of the same intensity for all the limitations

An expert system approach was used to evaluate the potential of the different soil complexes for the production of annual and perennial crops. Five classes were used, *viz*.

low	=	not recommended
medium-low	=	marginally recommended
medium	=	conditionally recommended
medium-high	=	recommended
high	=	recommended

Calcareous and saline soils were rated one unit lower than non-calcareous and non-saline soils with similar properties. Three soil specialists with a sound knowledge of irrigation farming in the Olifants River Basin evaluated the potential, primarily physical, of soil complexes for irrigated crop production of annual and perennial crops, before and after amelioration of subsoil limitations.

Based on these evaluations about 2 000 ha are recommended for perennial crops (e.g. citrus and wine grapes) in the southern section of the basin from Keerom to Bulshoek Weir. Another 19 000 ha are marginally and conditionally recommended, provided that subsoil limitations are properly ameliorated. About 8 600 ha of this class have a potential rating that is near the upper limit of the conditionally recommended class. The main limitations in this class are wetness and shallow underlying weathering rock combined with low clay content. These limitations are relatively easy to ameliorate and with judicious irrigation practices, approximately 10 000 ha can be used for economic viable production of citrus and wine grapes. Within the lateral extent of the survey, approximately 10 000 ha is available in the Keerom to Bulshoek section for any combination of irrigated annual (tuberous and non-tuberous) and perennial (citrus, wine grapes, mangos) production.

The soils in the surveyed area from Bulshoek to the coast differ greatly from those in the southern section in terms of the dominant limitation(s). Deep, well-drained red sandy soils (soil complexes A 1 and A 2) can be highly recommended for irrigated tuberous and non-tuberous crops without any subsoil amelioration measures. However, these soils are only conditionally recommended for perennial crops due to the very sandy nature and risk of sandblasting. The very shallow soils on dorbank of the F 1 soil complex are totally unsuitable for the production of tuberous crops even after loosening of the hardpan. Non-tuberous crops are conditionally recommended while perennial crops are recommended on these soils after amelioration of subsoil limitation. In this section there is approximately 105 000 ha that can be recommended for the production of perennial crops after amelioration of subsoil limitations, in particular hardpans, and provision is made for leaching and drainage to remove soluble salts from saline environments. Most of the areas recommended for perennial crops can also be used for irrigated non-tuberous annual crop production. In addition to these areas, certain soil complexes that are not recommended for perennial crops due the very sandy nature of the soils can be recommended for irrigated tuberous crops.

Amelioration of physical and morphological soil limitations

Deep soil tillage is used to ameliorate depth limiting dense or hard horizons (e.g. cemented hardpans, dense clay layers, weathering rock and wetness), to mix horizons of varying and different texture, and to eliminate unfavourable chemical conditions (e.g. acidity, salinity) by means of deep placement of ameliorants. The necessity and ideal depth for a specific type of tillage was specified for each soil complex. The cost of deep soil tillage depends on the type of propulsion, the implement type, tillage depth, and site and land features. The cost as supplied by one contractor range from as low as R 4 000/ha ha, to as high as R 32 000/ha, depending on soil type and tillage depth. The average cost of deep soil tillage supplied by farmers/producers during two Commercial Farmers Workshops, ranged from R 4 250/ha to R 7 000/ha in the Keerom to Bulshoek Weir section and R 10 000/ha to R 19 000/ha in the Bulshoek Weir to the coast section.

Wetness is not a serious natural limitation in the northern section of Olifants River Basin. In the southern section drainage is an essential on soils that are subject to natural or man-induced wetness. Soil complexes with heuweltjies, and soils with soft or hardpan carbonate horizons, dorbank and neocarbonate B horizons, are moderately to severely saline with a soluble salt load as high as 15 - 90 t/ha to a depth of 900 mm. Some crops can tolerate a certain concentration of free salts in the soil system but table grapes and citrus are very sensitive to salinity. Saline soils can be desalinised by leaching under controlled over-irrigation. Drainage is essential to remove the salt containing leaching water. Although it is not possible to specify specific drain spacings for different soil complexes, it may range from very narrow at 30 m to 35 m on very wet and/or saline soils, to as wide as 75 m to 100 m on sloping lands. Depending on depth and pipe size, the drainage cost might range from as low as R 8 000 too as high as R 30 000 per ha.

If the saline drainage water is dumped into the natural streams and rivers it will result in eutrophication and salinisation of the lower reaches of the rivers. Water users downstream along the Olifants River might complain if this river is used as a drainage ditch.

Most of the producers/farmers at the Commercial Farmers Workshops considered drainage as a non-essential measure, while 10 entries considered drainage as an essential or locally required amelioration measure on soil complexes with either wet or saline/calcareous soils. The estimated leaching requirement (based on soluble salt load and inherent drainage conditions) and recommended deep soil tillage practice and cost were specified for ten dominant soil complexes in the northern and southern sections of the Olifants River Basin.

Chemical soil composition

During the WODRIS, a total of 372 samples were analysed for pH measured in water (pHWater) and resistance (in ohms). Of these, 174 were analysed in detail. Topsoil samples were analysed for trace elements (Cu, Zn, Mn, B). The results were used for various cation ratio, soluble sodium and lime and gypsum requirement calculations. The soluble sodium content and ameliorant requirement were also determined for each profile to a depth of 900 mm.

For the southern section from Keerom to Bulshoek Weir, ODRS (Department of Water Affairs and Forestry, 1998) data as well 278 analitical data sets received from 8 farmers/producers were used. Previous land use as well as soil type was seldom indicated.

In the northern section, extractable magnesium (Mg) and potassium (K) had no direct influence on pH, while calcium (Ca) and sodium (Na) significantly influenced pHKCl. In the southern section all the cations had a significant influence on pHKCl. Calcareous soils may attain a maximum pHKCl of approximately 8.5, while sodium rich soils have pH values higher than 8.5.

In the northern section average topsoil pHKCl ranged from lower than 6.0 for the Fernwood and Pinedene soils forms to as high as 7.7 for the Gamoep soil form with a hardpan carbonate horizon. Soil forms with a neocarbonate B, soft or hardpan carbonate horizon or dorbank, and duplex soils had very high extractable Mg and Na values. Horizons containing free lime had very high pHKCl values, with exceptionally high average extractable Ca and Na, and to a lesser extent Mg and K.

On average the pKKCl of soil samples from Keerom to Bulshoek Weir increase from the south to the north. Soils north of Clanwilliam Dam with exceptionally high Ca values (> 20 cmolc/kg) are associated with heuweltjies and contain free lime.

High pHKCl and Ca values could have a serious effect on the solubility and plant availability of phosphorus (P) and trace elements. Crops sensitive to deficient levels of trace elements, especially Fe, could be seriously affected.

The relationship between water-soluble cations and anions, saturated soil paste resistance and ECe was highly significant. Regression models should prove valuable to estimate the potential soluble salt load released during the initial phases of leaching dry land areas that are developed as new irrigated lands. Because of the ease and low cost of soil paste resistance measurements, large numbers of samples can be handled to characterise the soluble salt load from new lands.

In the Keerom to Bulshoek Weir section the soluble salt content in the soils increases from the south to the north. This increase is associated with a decrease in rainfall from south to north as well as a greater contribution of shale, compared to sandstone, weathering products as parent material.

The level of Cu and Zn in the WODRIS samples was generally lower than the sufficiency norms. Except for very sandy soils the concentration level of Mn was always sufficient. Soils with calcareous subsoil horizons had an average topsoil B concentration slightly higher than the sufficient norm while in soils without subsoil free lime it was in the low range. In dorbank without lime the average boron concentration was 8.1 mg/kg, but increased to 13.6 mg/kg in dorbank with lime and 19.9 mg/kg in soft or hardpan carbonate horizons. Based on the one set of trace element analyses in the Keerom to Bulshoek Weir section Cu, Zn and B concentrations were below the sufficiency norm. Mn in topsoil samples was near the minimum norm, but deficient in the subsoil.

Chemical ameliorants

In the WODRIS the average topsoil P value by soil form ranged from as low as 2.0 - 3.0 mg/kg (Vilafontes and Pinedene form soils) to as high as 51.4 mg/kg (Oudtshoorn form soils). In the Keerom to Bulshoek Weir section the average phosphorous in topsoils was 54.2 ± 5.6 mg/kg and decreased to 39.0 ± 3.8 mg/kg and 18.9 ± 4.5 mg/kg, respectively in the upper and lower subsoil. The WODRIS P levels are significantly lower than the Keerom to Bulshoek Weir levels due to the fact that the WODRIS samples were from uncultivated or annually cropped soils, while the latter samples were mostly from lands/camps that have been used for perennial crops and might have received considerable quantities of P fertilizer. The plant availability of the high P in calcareous soils is questionable.

To increase the P level to 30 mg/kg to a depth of 600 mm in the Bulshoek Weir to the coast section, the P requirement of soil forms without any free lime ranged from 125 kg/ha to 225 kg/ha, while in the Keerom to Bulshoek Weir section it was 110 and 230 kg/ha.

From the WODRIS results only highly leached, yellow-brown or bleached, sandy soils have relatively low levels of extractable K, while all the other soils had high to very high levels of K. The K requirement is therefore low. In the Keerom to Bulshoek Weir section the average K requirement based on K saturation percentage ranged from 6 kgK/ha to as high as 163 kgK/ha to a depth of 900 mm. The equivalent values based on K concentration were 196 kgK/ha to 386 kgK/ha. Based on saturation percentage no potassium is required for all the sample groups north of Clanwilliam.

The ideal pHKCl for vines and deciduous fruit is approximately 5.5. Citrus and other subtropical plants are adapted to slightly lower pH values, while lucerne and medics prefer a pHKCl of closer to 6.0, and potatoes a pHKCl < 5.0. Due to the low average annual rainfall in the study area north of Clanwilliam, acid soils (pHKCl ≤ 5.5) are rare. Only soil complexes A 1, A 3, A 7, B 2, B 4, D 5 and H 2 would require lime to improve the soil pH. The total lime requirement of these soils for an amelioration depth of 900 mm ranged from 12 t/ha to as much as 30 t/ha. In the Keerom to Bulshoek Weir section the average calcitic lime requirement ranged from 7.8 t/ha/900 mm depth to 13.1 t/ha/900 mm depth and dolomitic lime requirement from zero to 2.9 t/ha/900 mm depth. In the northern part of this section the total lime requirement is very low.

The ideal ratio between base cations is 75 % Ca2+: 15 % Mg2+: 5 % K+: <5% Na+. Any significant deviation from this ratio (high Mg and Na) affects nutrient availability, plant growth and physical stability of the soil material. Application of gypsum combined excess salt leaching is used to ameliorate such soils. In the WODRIS the gypsum requirement to a depth of 900 mm for the duplex, Knersvlakte and Oudtshoorn soils was 28, 26 and 23 t/ha/900 mm, respectively. The average for the Garies soils was approximately 14 t/ha/900 mm, while the requirement for all the other soils was < 10 t/ha/900 mm.

In the southern part of Keerom to Bulshoek Weir section the gypsum requirement was < 3.5 t/ha/900 mm. In the northern part the average requirement was nearly 40 t/ha/900 mm with a maximum of 47 t/ha/900 mm. These high values are comparable to certain values in the WODRIS.

Leaching requirement

For sustainable crop production under irrigation the saline soils in the Olifants River Basin require leaching to decrease to soluble salt content. For field crops an electrical conductivity of the drainage water (ECdw) of 800 mS/m is generally considered as the upper limit of salt tolerance. For irrigation water with conductivities of 100, 200 and 300 mS/m (Eciw), the respective leaching requirements will be 13 %, 25 % and 38 %. The quality of the irrigation water used along the Olifants River Basin is extremely good, with conductivity as low as 25 mS/m. This implies a leaching requirement of ≤ 3 %. If an ECdw of 800 mS/m is used as the upper limit of salt tolerance, the average soluble salt content should be lowered to approximately 100 me/l. A more acceptable and sustainable ECdw of 400 S/m would imply that the salt content is lowered to 50 me/l.

Soils with a fairly low salinity could be leached in one irrigation season or year. It is, however, impractical for the more saline soils; five years is probably a more realistic time period. The ratio of the total volume of water required to dilute the salts in a soil to a concentration of 100 me/l or 50 me/l over five irrigation seasons could be used as an index of the "leaching requirement". Assuming an annual irrigation water requirement of 10 000 m^3, and a dilution water volume of 5 000 m^3 and 10 000 m^3 for a 100 me/l and 50 me/l salt concentration respectively, the leaching requirement would be 10 % and 20 %, respectively.

Irrigation water requirement

The net average annual irrigation water requirement for deciduous fruit, citrus and grapes based on eight crop factor suites for seven weather stations from Keerom to the coast were calculated for the ODRS (Department of Water Affairs and Forestry, 1998). Most of the crop factor suites gave fairly similar water requirements, with deciduous fruit in the lower and citrus in the higher range. Short cycle irrigation scheduling significantly increased the annual requirement. The net average irrigation requirement (excluding leaching requirement) increased from 850 – 1000 mm in the Keerom to Bulshoek Weir section to 1 000 - 1 200 mm in the Bulshoek Weir to the coast section. Peak monthly net irrigation water requirement increased from 200 mm/month in the upper to a maximum of 225 mm/month in the lower Olifants River Basin. A leaching component of 10% to 20% was recommended for saline soils in the drier areas. Under the harsh and variable climatic conditions along the middle and lower reaches of the Olifants River Basin long-term average values should not be used. It was recommended that for design purposes average + standard deviation A-pan values should be used for those months with peak irrigation requirement.

Net water requirement calculated from class A-pan evaporation values and crop conversion factors only represents water lost through evapotranspiration. The gross "on-land" water requirement can be significantly greater as a function of the type of irrigation system, irrigation scheduling and the leaching fraction (up to 10% - 20%). Based on the information submitted by farmers/producers the gross water application at Citrusdal for citrus was 8 000 and 10 000 m^3/ha/a for drip and micro irrigation, respectively, while the net requirement for wine grapes was 7 500 and 8 500 m^3/ha/a at Lutzville and Vredendal, respectively.

For the WODRIS, the irrigation water requirement was based on the Irrigation Sub-model of the Water Balance Model (WBM), as modified by the Department of Water Affairs and Forestry (DWAF, 1998). Average monthly rainfall for two fairly homogeneous climates zones (FHCZ) was used to estimate effective annual rainfall (mm/a) according to the method recommended by the Soil Conservation Services (SCS) in the USA and used in the "ETCrop" computer programme. For vegetables and grapes, effective rain > 20 and > 10 mm/month, respectively was taken into consideration. The net irrigation requirement (NIR) is the monthly depth of irrigation water required, adjusted for effective rainfall. The annual NIR calculated for wine grapes and vegetables in cooler northern FHCZ 1 was 805 mm/a and 1 001 mm/a, respectively. In the warmer FHCZ 2 the values for wine grapes, table grapes and vegetables were 857 m/a, 1 037 mm/a and 1 051 mm/a, respectively. An average leaching fraction of 10 % was used. Standard irrigation application efficiency factors (drip 95 %, micro-jet 80 %, sprinkler 75 %, centre pivot 85 % and flood 65 %) were used to convert crop water use to irrigation water requirement. These efficiency factors were decreased by 5 % for emerging farmers.

Assuming a crop split of 75 % wine grapes + 25 % vegetables in FHCZ 1, the gross irrigation requirement was estimated as 11 753 m^3/ha/a. For FHCZ 2, the corresponding volume for a crop split of 37.5 % wine grapes + 37.5 % table grapes + 25 % vegetables was 13 265 m^3/ha/a. The peak water demand in January for these crop splits was 1 877 m^3/ha and 2 170 m^3/ha for FHCZ 1 and 2, respectively.

To verify the results of the two previous studies the SAPWAT computer program (Van Heerden and Crosby, 2002) was used in the present study. Four stations with reliable climate data were used; *viz*. Lutzville NIWW (141 mm mean annual rainfall), Klawer Wine Cellar (211 mm), HLS Augsburg (215 mm) and Citrusdal NIVV (401 mm). This program was used to calculate the total irrigation water requirement for a variety of crops and different irrigation systems. According to the results, citrus, a non-deciduous plant, has a significantly higher total irrigation requirement (Lutzville drip = 1 366 mm/a; Citrusdal drip = 1 138 mm/a) than wine grapes (Lutzville drip = 908 mm/a; Citrusdal drip = 813 mm/a). Citrus under micro irrigation requires approximately 15 % more water than under drip. The average seasonal irrigation water requirement of vegetables ranged from 615 mm for potatoes planted in February to 877 mm for table tomatoes planted in September. Compared to Citrusdal, the average seasonal water requirement for vegetables is approximately 10 %, 18 % and 6 % higher at Lutzville, Klawer and Augsburg, respectively. In the drier section north of Bulshoek Weir with less leached, commonly saline and/or calcareous soils the total irrigation requirement should be increased by a 10 % leaching fraction.

The crop water requirement for citrus obtained during the Agricultural Workshops was approximately 300 – 400 mm lower than the SAPWAT estimates. For wine grapes the difference was 130 mm lower, for vegetables 100 - 200 mm lower. The water requirement for potatoes under centre pivot was approximately the same.

Crop adaptability

Climate- and soil suitability are the most critical factors that will determine the potential expansion of sustainable, economic viable irrigation in the Olifants River Basin. Due to the advanced farming technology and management skills that exist in the intensely developed sections of the basin, most of the inherent soil limitations do not pose any serious constraints on irrigation development.

Climate information was used to conduct an extensive search for potential crops according to the Ehlers screening system (Ehlers, JH, undated) that grouped useful plants according to their temperature requirements. This screening process was based primarily on temperature.

According to comments received from workshop attendants climatically adapted crops currently grown in the study area include the following:

- Maize (especially sweet corn) is widely planted from Keerom to the coast.
- Most vegetable crops (e.g. onions, potatoes, tomatoes, sweet potatoes, watermelons, cantaloupes and butternuts) are climatically well adapted and extensively planted. Planting date is determined by climate. Cabbage, cauliflower, chillies, lettuce, pumpkin, squash and green beans are planted on a small scale for the open market.
- Bitter Seville, citron, lemons, clementine, navel, valencia, satsuma and mandarin are mainly planted in the Clanwilliam-Citrusdal region.
- Grapes are adapted to the climatic conditions along the Olifants River and have a variety of marketing possibilities (e.g. wine, table grapes, raisins, preserving, and "gasohol". Specific climate sub-zones in the Olifants River Basin have specific advantages in terms of grape production.

Other climatically adapted crops that can be recommended are the following:

- Vegetables crops such as garlic, beetroot, rhubarb and eggplant.
- Subtropical fruit such as avocado, mango, papaya, persimmon, granadilla, figs and guavas.
- Nuts such as macadamias, almonds and pecan.

Agricultural workshops

To increase the reliability of qualitative soil suitability evaluations based on soil survey and chemical information, as well as the effect of climate, two round-table agricultural workshops were held at Spruitdrif Cellar, Vredendal, and Citrus Juices Offices, Citrusdal, on 16 August and 17 August 2005 respectively. Various farmers/producers in the study area, technical advisors and experts in the citrus, grape and vegetable industries were invited to these round-table discussions with the consultants for the raising of the Clanwilliam Dam. Unfortunately the number of invited farmers/producers that attended the workshops, especially at Citrusdal, was far below the number that indicated that they would participate.

Each of the compiler groups had to choose at least three soils types that are typical/dominant of their respective farms. The participants completed a questionnaire that covered the following aspects pertaining to the soils in the study areas:

- Type, depth and cost of mechanical soil tillage.
- Preferred irrigation system for different crops and cost.
- Irrigation water requirement for different crops and irrigation systems.
- The need for other soil amelioration measures (e.g. drainage, salt leaching, wind control etc).
- Type and amount of chemical ameliorants used at soil preparation.
- Suitability of soils and production levels for different crops.
- Planting date and length of growing season for different annual crops.

The questionnaire results were summarised on a soil type basis for the Keerom to Bulshoek Weir and Bulshoek Weir to the coast sections of the study area, and were compared with the results of the soil and crop water requirement study. In most cases the two data sets compared well and confirmed the qualitative soil suitability evaluations based on soil survey and chemical information. However, there were certain anomalies regarding deep soil tillage cost and the necessity for drainage.

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APPENDICES

GLOSSARY AND ABBREVIATIONS

°C	Degrees Celsius
a	Annum
A-pan	Class A evaporation pan
B	Boron
Ca	Calcium
$CaCO_3$	Calsium carbonate
$CaMg(CO_3)_2$	Calcium-magnesium carbonate; dolomite
$CaSO_4.2H_2O$	Gypsum
CEC	Cation exchange capacity
Cl	Chloride
CLI	Conveyance loss
$cmol_c/kg$	Ion concentration expressed in centimol charge per kilogram
Cu	Copper
D_{dw}	Depth of drainage water
D_{iw}	Depth of irrigation water
EC_{dw}	Electrical conductivity of drainage water
ECe	Electrical conductivity of saturated soil extracts
EC_{iw}	Electrical conductivity of irrigation water
ESP	Exchangeable sodium percentage
ETo	Reference evapotranspiration
F	F-ratio
FAO	Food and Agricultural Organisation
Fe	Iron
FHCZ	Fairly homogenous climate zones
ha	Hectare
HCl	Hydrochloric acid
IR	Infiltration rate
IRC	Irrigation application efficiency (100 % efficiency = 1.0)
ISCW	Institute for Soil, Climate and Water
K	Potassium
Kc	Crop factors
KCl	Potassium chloride
kg/ha/150 mm	Kilogram per hectare per 150 mm soil depth
kg/ha/300 mm	Kilogram per hectare per 300 mm soil depth
kg/m^3	Kilogram per cubic metre
kPa	Kilopascal
LER	Leaching requirement
Lin	Linear model
Log	Logarithm
LR	Leaching requirement
M	Marginally adapted
m	metre
$m^3/ha/a$	Cubic metre per ha per annum
me/l	Milli-equivalents per liter
mg/kg	Milligram per kilogram
Mg	Magnesium
mm	Millimetre
mm/a	Millimetre per annum
mm/m	Millimetre per metre
mm/month	Millimetre per month
$mmol_c/l$	Ion concentration expressed in millimol charge per liter
Mn	Manganese
mS/m	Millisiemens per metre
Mult	Multiplicative model
N	Normal
Na	Sodium
NH_4-Ac	Ammonium acetate
NIR	Net irrigation requirement
NS	Non-significant

O	optimally adapted
ODRS	Olifants/Doring River Basin Study
P	Phosphorus
pH_{H2O}	pH measured in water
pH_{KCl}	pH measured in potassium chloride solution
PR	precipitation rate
PVC	Polyvinyl chloride
R	Rand
R/ha	Rand per hectare
REF	Effective annual rainfall
S	Sub-optimally adapted
SABS	South African Buro of Standards
SAR	Sodium adsorption ratio
SCS	Soil Conservation Services of the USA
SO_4^{2-}	Sulphate
Std dev	Standard deviation
T	T-value
t/ha	Ton per hectare
t/ha/150 mm	Ton per hectare per 150 mm depth
TMS	Table Mountain Sandstone
U	Undifferentiated
USA	United States of America
USDA	United States Department of Agriculture
VINPRO	Vine Producers Consultation Services
WODRIS	Western Cape Olifans/Doring River Irrigation Study
Zn	Zinc

1. SOIL SURVEY AND SOIL SUITABILITY

1.1 Introduction

Various soil surveys have been conducted throughout the Olifants River Basin.

Rudman *et al* (1978) was responsible for a very extensive reconnaissance soil survey along the Olifants River. This survey covered an area from Bulshoek Weir northwards as far as Lutzville/Papendorp, and from the coast to the escarpment east of Vanrhynsdorp. A detailed soil survey of the Lutzville Experimental Farm was done Feyt (1982) and Saayman (1975) did a soil study of De Neus, Trawal.

A reconnaissance soil survey of the Citrusdal valley from the Clanwilliam Dam south as far as Keerom was conducted by Lambrechts *et al* (1989). The Citrusdal valley soil survey was instructed by the Citrusdal Irrigation Board. The purpose was the compilation of a soils map at reconnaissance level of approximately 56 000 ha of land to determine the location and amount of land suitable for economic production of citrus. The soils were grouped into 14 single and 8 complex map units, and four land classes (see **Appendix A: Table 1.1**).

The available soils information for the Olifants River Basin was collated for the *Olifants/Doring River Basin Study* (ODRS; Department of Water Affairs and Forestry, 1998). Although the existing soil survey maps and reports contained a lot of useful information, the mapping legends that were used for individual surveys differed considerably. For the ODRS the soil information had to be transformed in such a way that the soils in the different localities could be compared horizontally. Except for the Citrusdal survey (Lambrechts *et al*, 1989), all the other surveys made use of the 1977 system of soil classification for South Africa (MacVicar *et al.*, 1977). The first step therefore was to reclassify the soils according to the new soil classification system for SA (Soil Classification Working Group, 1991) into soil forms and families. The individual map legends with the reclassified soil forms and families were used for evaluation and no attempt was made to develop a single map legend for the whole study area. One of the main outcomes of the ODRS was the proposal of two development scenarios in the Olifants River Basin. These scenarios refer to the Coastal Region and Aties Karoo (including the Klawer area) development scenarios.

The ODRS was followed by the *Western Cape Olifants/Doring River Irrigation Study* (WODRIS; Provincial Government Western Cape, 2003). This study included a more detailed soils investigation to determine the dominant soil types and general distribution pattern in three development scenarios, *viz*. the Coastal Region, Aties Karoo (including the Klawer area) and Melkboom. The primary physical and chemical limitations, crop suitability and amelioration measures of the dominant soils had to be determined. Because no serious deviations were found in the reconnaissance soil map and reclassified soil forms and families in the Rudman *et al* (1978) map legend as reported in the ODRS (DWAF, 1998), as well as irrigation potential ratings, it was decided to use the Rudman *et al* (1978) soils map as a basis for the WODRIS field soil survey.

Ortho- and aerial photos were studied to determine localities with characteristic photo images representing typical soil-terrain combinations. These images were used in combination with the Rudman *et al* (1978) soils map for a final selection of land units that could be used as primary target sites for a more detailed investigation of the soils in the WODRIS. The selected land units were at a higher elevation than the present irrigation canals, and were mostly natural "veld" or old strip cropped wheat lands in these areas. In a few of the selected land units relatively small areas occurred that are at present used for irrigated vegetable, pasture, vine and even citrus production.

A total of 217 soil pits were dug along twenty-three traverses in the selected land units for a more detailed study of the soils. The soils profiles were described and classified according to Soil Classification Working Group (1991). A soil map was compiled by the delineation of fairly uniform photo-images in those sections of the WODRIS area covered by the soil traverses. Based on these images and distribution of soil types along the traverses, 16 soil associations or map units were initially identified.

The survey area was subsequently extended to include the area east of longitude 18°30' and south of latitude 31°30' as far as the Atlantic Coast on 1 : 50 000 topo-cadastral sheet 3118 CA Papendorp. No additional soil pits were made in this extended area. Soil observations were based on road cuts and by soil auger. The description of the soil map units by Rudman *et al.* (1978) in the extended area was combined with road cut and auger soil observations to group the soils according to the initial 16 soils associations defined for the WODRIS. In many instances, however, the soils in the extended area (e.g. the coastal dunes and wet "vlei" soils at Ebenaeser) did not qualify for any of the defined associations. Ten additional soil associations were therefore defined to effectively accommodate these soils.

The initial 16 soil and additional ten association names were combined for the whole of the study area to compile a general soil association legend for the WODRIS irrigation scenarios (see **Appendix A: Table 1.2**).

For both the Citrusdal valley reconnaissance survey (Lambrechts *et al*., 1989) and the WODRIS study the suitability of the maps units was evaluated for crop production. For the Citrusdal study citrus was used as primary crop, while tuberous and non-tuberous annual as well as perennial crops (mainly grapes) were used in the WODRIS.

1.2 Soil classification and map

In Section 3.2.8 Irrigation: a. Current Irrigation and Irrigation Potential of the Inception Report for the Feasibility Study for the Raising of the Clanwilliam Dam in the Western Cape the terms of reference pertaining to the soil study were summarised as follow:

"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.

Soil suitability maps will be compiled. The average cost for chemical and physical amelioration measures will be determined on a soil type basis."

According to the terms of reference and budget constraints no time was allowed for additional field work in the unmapped sections of the study area for the compilation of a soils map for the Olifants River Basin from Keerom, south of Citrusdal, to the coast. The unmapped section of the study is essentially north of Clanwilliam Dam to Bulshoek Weir and the Trawal-Klawer area to the west of the Olifants River.

The Rudman *et al* (1978) study covered the northern part of the Trawal-Klawer area. In an attempt to obtain more soils information in the unmapped section various institutions (e.g. Department of Agriculture Western Cape, Elsenburg) and private soil consultants working in that area were contacted about soils studies undertaken in that section. Two reports were obtained from the Department of Agriculture Western Cape, Elsenburg, which contained soils information of the farm Augsburg Clanwilliam (Feyt, 1997) and part of the Clanwilliam commonage (Van Niekerk, 2001). Two detailed farm soil survey reports were obtained from the University of Stellenbosch (Lambrechts and Schloms, 2003; Schloms *et al*, 2004). In addition, *ad hoc* soil survey data was obtained from ACI cc, a private consultancy group in Somerset West, of certain sections of the farm Radyn to the north of Clanwilliam.

A serious constraint in the compilation of a soil map for the whole study area was that the WODRIS, Citrusdal and all the other soil surveys mentioned in the previous paragraph made use of its own descriptive map legend.

To integrate the WODRIS and Citrusdal soil survey information and to fill in the unmapped section of the Olifants River Basin, a two-day field excursion was undertaken during March 2005. The main focus area was north of the turnoff from the N7 national road to Algeria to as far north as Klawer. 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. On both sides of the Olifants River east-west traverses were generally followed to obtain as much soils information as possible on the lateral soil changes from the lower river terraces to the upper boundary at approximately 60 m above the levels of the river or existing canals. A number of landowners in the unmapped area were also interviewed regarding the soil types on their property.

Based on the properties of soils, variation in soil types and terrain form, uniform soil-terrain units were delineated during the field excursion on 1 : 50 000 topographic maps that covered the unmapped area. Both the WODRIS and Citrusdal map legends were used to select the map unit symbol that best represented the soil types in a delineated area. In a few cases none of the existing map units could be accommodated in a particular delineated area. In those cases new map units were created and defined in terms of terrain type and dominant soils.

Subsequent to the field excursion the boundaries of uniform soil-terrain units in the originally unmapped section as well as the boundaries on the 1 : 50 000 soil map of the Citrusdal survey were checked and modified where it was considered essential to produce a better soil map. The delineation of uniform soil-terrain units of the WODRIS soils map was left unchanged.

The next step was to develop a new soil map legend that included the WODRIS and Citrusdal soil units as well as the new units created during the field excursion. Initially a number of different legend models were tried. It was finally decided that a relatively simple two-level legend that consisted of an upper level of soil groups and a second level of soil complexes could accommodate all the previously defined soil map units. 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 1.1**). An identification letter symbol (A to L) was given for each soil group.

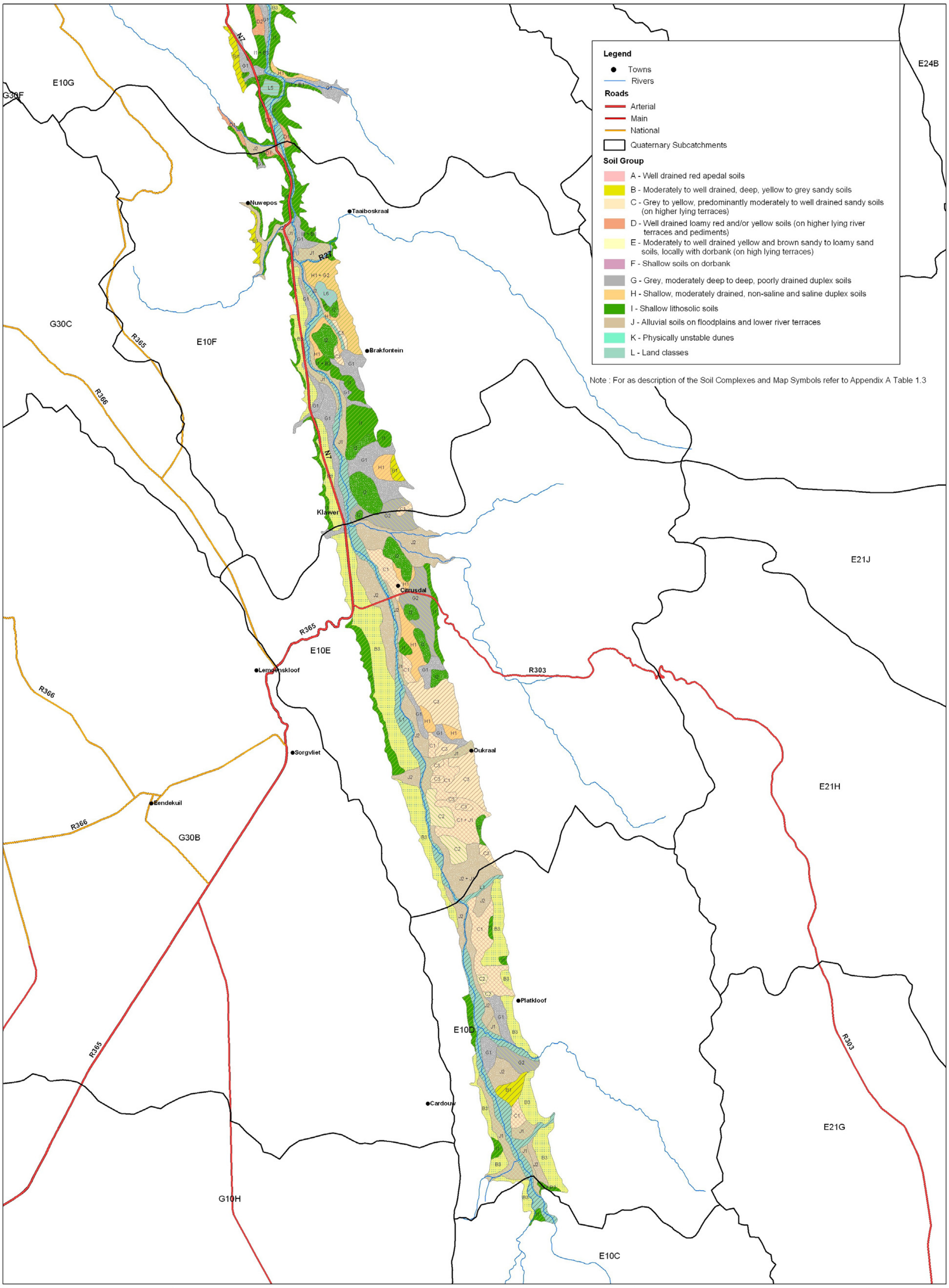
Table 1.1 Description and symbols of the twelve soil groups defined for the soils map of the Olifants River Basin

Soil Groups	
Description	**Symbol**
Well drained red apedal soils	A
Moderately to well drained, deep, yellow to grey sandy soils	B
Grey to yellow, predominantly moderately to well drained sandy soils (on higher lying terraces)	C
Well drained loamy red and/or yellow soils (on higher lying river terraces and pediments)	D
Moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank (on high lying terraces)	E
Shallow soils on dorbank	F
Grey, moderately deep to deep, poorly drained duplex soils	G
Shallow, moderately drained, non-saline and saline duplex soils	H
Shallow lithosolic soils	I
Alluvial soils on floodplains and lower river terraces	J
Physically unstable dunes	K
Land classes	L

Except for soil group F, all the other soil groups were subdivided into two or more soil complexes based on selected soil properties. The primary aim in the selection of properties for each group was that the different soil complexes 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 complexes 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 complexes were defined. On the basis of clay content there are two complexes 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.

Each soil complex 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 complexes belonging to the same soil group but differs in one or more important soil properties. The final soil map legend is set out in **Appendix A: Table 1.3**. The final boundaries between soil complexes on the 1 : 50 000 topographic maps were digitised by Ninham Shand, Cape Town, and each complex was characterised by its relevant map symbol (see **Figure 1.1**).



Western Cape Olifants / Doring River Irrigation Study

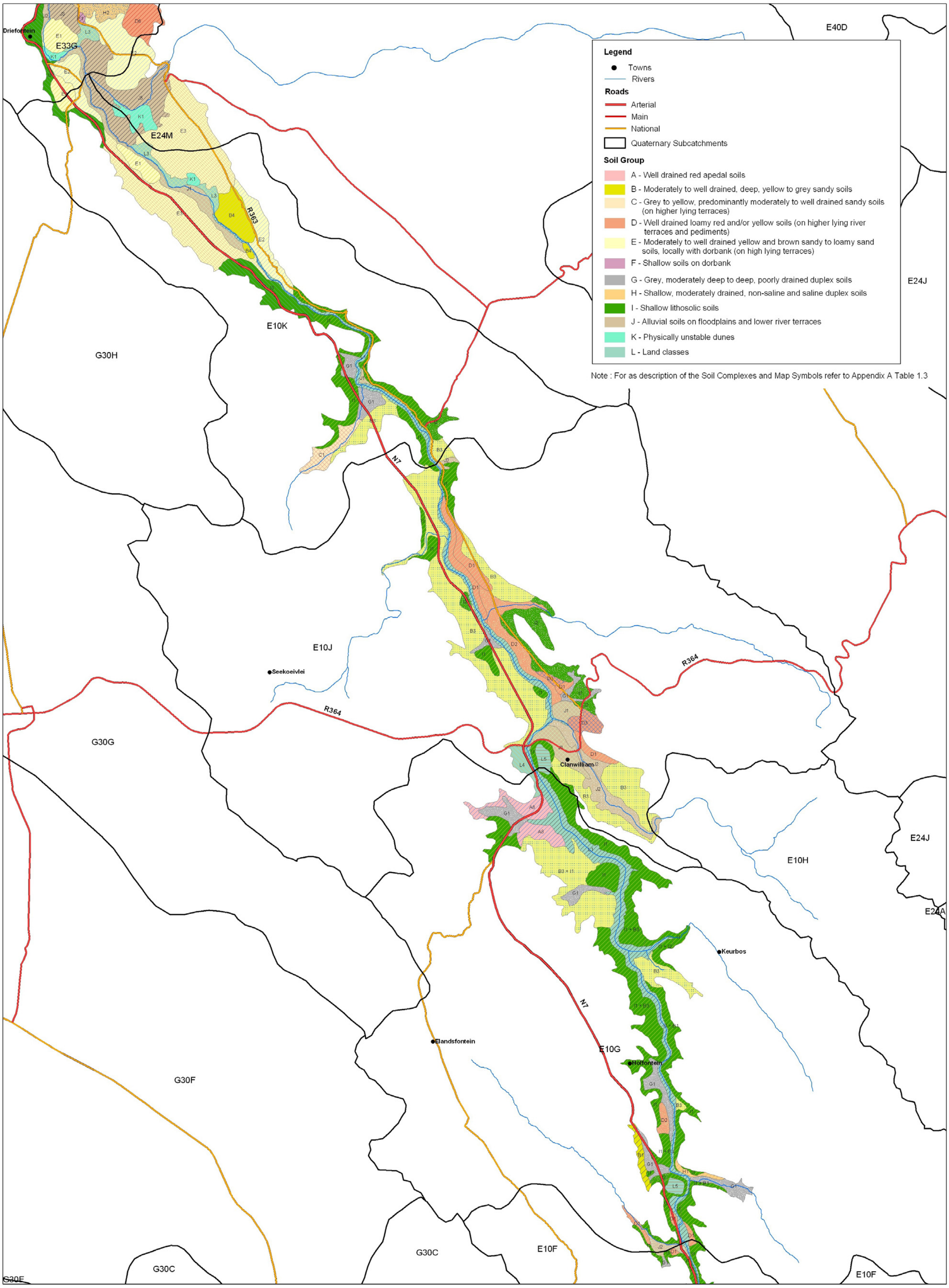
Soil Complex Map of the Olifants River Basin from Keerom to the coast

Scale : 3 1.5 0 3 Kilometers 1 : 85 000

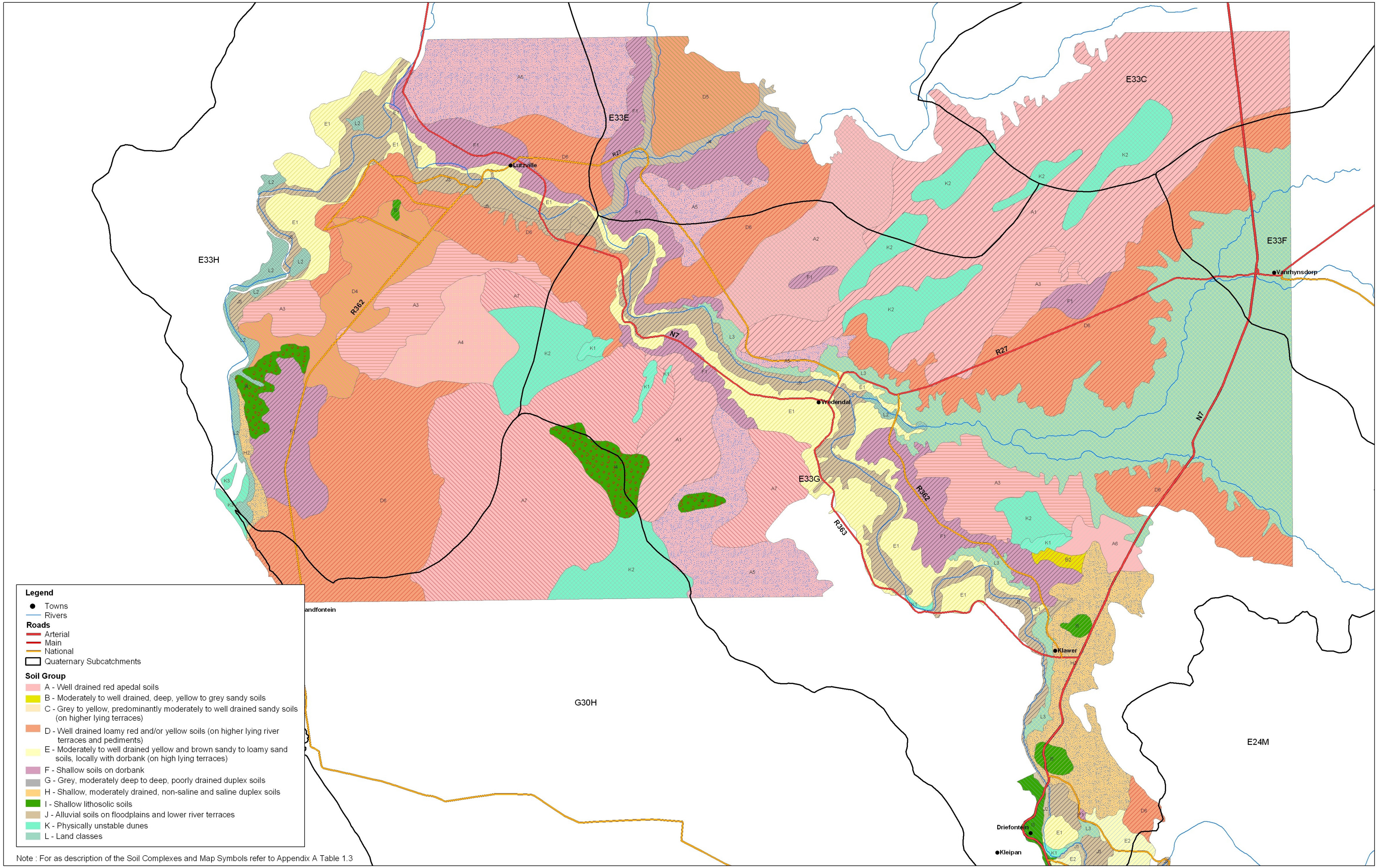
Path : i:/hydro/400415/arcview/projects/fig11_1.mxd

SHEET 1 OF 3

Figure 1.1



Western Cape Olifants / Doring River Irrigation Study *Soil Complex Map of the Olifants River Basin from Keerom to the coast*	Scale : 3 1.5 0 3 Kilometers 1 : 85 000	N	SHEET 2 OF 3
	Path: i:/hydro/400415/arcview/projects/fig11_2.mxd		**Figure 1.1**



Western Cape Olifants / Doring River Irrigation Study

Soil Complex Map of the Olifants River Basin from Keerom to the coast

Scale: 3 1.5 0 3 Kilometers

1 : 85 000

N

Path: i:/hydro/400415/arcview/projects/fig11_3.mxd

SHEET 3 OF 3

Figure 1.1

In addition to the description of the different soil complexes, the dominant (occupies more than 60% of the map unit) and subdominant soil forms and families were determined. For the southern section of the basin the soil forms and families typical of a specific soil complex were essentially extracted from the Citrusdal soil survey with minor changes (Lambrechts *et al.*, 1989). For the WODRIS section of the basin the soil forms and families were extrapolated from the soils information along the 23 survey traverses (WODRIS). The soil forms and families in new map units that were created to accommodate soil-terrain units in the unmapped section that did not qualify for one of the WODRIS or Citrusdal map units were based on field observations during the two-day field excursion and *ad hoc* soil classification and mapping reports on a farm level.

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 **Appendix B** for brief 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 final soil map legend (**Appendix A: Table 1.3**) for the Olifants River Basin are listed in **Appendix A: Table 1.4.** In many map units "heuweltjies", a micro-relief feature associated with termite activity are present. In **Appendix A: Table 1.4** the estimated percentage of the land surface covered by "heuweltjies" is listed for those map units with heuweltjies. In **Appendix A: Table 1.5** the diagnostic horizon sequences of the different soil forms are listed alphabetically according to the form abbreviation symbol together with the family criteria of identified soil families.

The digitised soil complex map (**Figure 1.1**) was used to determine the surface area (in hectare) of all soil complex polygons. These values were determined on a soil complex basis for the different quaternary subcatchments in the Olifants River Basin (see **Appendix A: Table 1.6**). Because of the differences in parent material, terrain character and climate between the southern and northern sections of the basin, the basin was broadly subdivided into two sections, *viz*. Keerom to Bulshoek Weir and from Bulshoek Weir to the coast.

The total area surveyed in the southern section is approximately 30 000 ha, while the northern section covers 140 000 ha. One of the reasons for this large difference is the relative narrow width of the basin in the south compared to the north. Another reason is that in the south the lateral extent of the survey was restricted to 60 m above the level of the river or existing canals, while the northern section was surveyed during the WODRIS beyond this lateral limit.

From **Appendix A: Table 1.6** it is evident that in both sections there is a pronounced difference in the dominant soil complexes between quaternary subcathments. In the Keerom to Bulshoek Weir section the dominant soil complex(s) in the quaternary subcatchments (E10C to E10J) from south to north vary in the following way: subcatchment E10C = soil complex L 1; E10D = B 3; E10E = B 3 and J 2; E10F = G 1; E10G = I 1 and L 1; E10J = B 3. In the Bulshoek Weir to the coast section the variation is the following: E10K = E 3; E24M = E 3; E33C = A 1; E33E = A 1, A 5, D 5 and F 1; E33F = D 6 and L 3; E33G = A 1 and D 6; E33H = A 5and D 5; G30H = A 7.

In **Table 1.2** the information in **Appendix A: Table 1.6** is summarised for the two sections and for the total study area. The dominant soils in the southern section are: moderately to well drained, deep, yellow to grey sandy soils (complex B 3); grey, moderately deep to deep, poorly drained duplex soils (complex G 1); shallow lithosolic soils (complex I 1; alluvial soils on floodplains and lower river terraces (complex J 2); and land classes (complex L 1). In the northern section the dominant soils are: well drained red apedal soils (complexes A 1, A 3, A 5 and A 7; well drained loamy red and/or yellow soils on higher lying river terraces and pediments (complexes D 5 and D 6); moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank on high lying terraces (complex E 1); shallow soils on dorbank (complex F 1); alluvial soils on floodplains and lower river terraces (complex J 3); physically unstable dunes (complex K 2); and land classes (complex L 3).

Although there are these differences in soil the composition of the different quaternary subcatchments might appear to be abnormally high, this is acceptable when the differences in parent material, climate and terrain from Keerom to the coast is taken into consideration. Compared to other catchments, e.g. the Breede River Valley, these differences are not abnormal for the Western Cape with its very long (millions of years) history of soil development and complex nature of the soil forming factors.

Table 1.2 Area (ha) of the different soil complexes in the Olifants River Basin from Keerom to Bulshoek Weir (Section 1), Bulshoek to the coast (Section 2) and the total survey area

Soil group	Soil complex	Section 1	Section 2	Total
Well drained red apedal soils	A 1	130.4	17 478.7	17 609.1
	A 2		3 877.8	3 877.8
	A 3		5 728.4	5 728.4
	A 4		2 030.9	2 030.9
	A 5		9 358.1	9 358.1
	A 6		641.9	641.9
	A 7		11 639.4	11 639.4
	A 8	412.7		412.7
Moderately to well drained, deep, yellow to grey sandy soils	B 1	327.3		327.3
	B 2	0.0	158.2	158.2
	B 3	6 109.6	298.8	6 408.3
	B 4	0.0	334.0	334.0
Grey to yellow, predominantly moderately to well drained sandy soils (on higher lying terraces)	C 1	925.8	216.4	1 142.2
	C 2	313.3		313.3
	C 3	911.2		911.2
Well drained loamy red and/or yellow soils (on higher lying river terraces and pediments)	D 1	590.1		590.1
	D 2	475.5		475.5
	D 3	173.7		173.7
	D 4		3 019.1	3 019.1
	D 5		11 722.2	11 722.2
	D 6		14 823.9	14 823.9
Moderately to well drained yellow and brown sandy to loamy sand soils, locally with dorbank (on high lying terraces)	E 1		7 214.8	7 214.8
	E 2		1 294.0	1 294.0
	E 3		2 526.7	2 526.7
Shallow soils on dorbank	F 1		9 089.6	9 089.6
Grey, moderately deep to deep, poorly drained duplex soils	G 1	2 291.4	209.9	2 501.3
	G 2	762.2		762.2
Shallow, moderately drained, non-saline and saline duplex soils	H 1	566.2		566.2
	H 2		3 680.7	3 680.7
Shallow lithosolic soils	I 1	3 367.5	798.9	4 166.5
	I 2	1 450.4	106.2	1 556.6
	I 3		1 376.3	1 376.3
	I 4		2 839.7	2 839.7
	I 5		371.8	371.8
Alluvial soils on floodplains and lower river terraces	J 1	1 285.1	368.9	1 654.0
	J 2	2 555.5	51.5	2 607.0
	J 3		6 862.0	6 862.0
	J 4		8.7	8.7
Physically unstable dunes	K 1		659.0	659.0
	K 2		7 148.3	7 148.3
	K 3		109.8	109.8
Land classes	L 1	3 376.8	294.3	3 671.1
	L 2		1 048.9	1 048.9
	L 3		15 206.1	15 206.1
	L 4	127.3		127.3
	L 5	143.8		143.8
	L 6	74.4		74.4
Combined complexes	B 3 + I 1	852.8		852.8
	C 1 + J 1	307.6		307.6
	H 1 + G 2	364.5		364.5
	I 1 + B 1	307.4		307.4
	I 1 + B 3	925.3		925.3
	I 1 + I 2	69.9		69.9
	J 2 + J 1	460.8		460.8
Total		**29 658.7**	**142 593.6**	**17 2252.2**

1.3 Soil suitability for irrigated crop production

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 largely depend on the requirements of the specific rootstock that is used.

Although annual vegetable crops are usually considered as shallow rooted, most of the commonly produced vegetables 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.

1.3.1 Physical and morphological soil limitations

a) 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 complexes B 1, B 3, C 1, C 2, C 3, I 1, J 1 and J 2 in the southern section of the basin) as well as from aealion sands (e.g. soil complexes A 1, A 2, A 3, A 4, B 2 and B 4 in the northern section of the basin) 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 northern section the soil colour of these sandy soils is predominantly red to reddish brown due to a fairly high iron oxide content, while the TMS derived sandy soils in the southern section is yellow to pale coloured with very little iron oxide.

The water holding capacity of soil is primarily determined by the clay content. The capacity per unit clay, however, is positively affected by an increase in organic material, silt and fine sand content and sesquioxides (mainly iron oxides). It is therefore evident that the sandy soils in the Olifants River Basin have a low water holding capacity.

It is generally accepted that a clay content of approximately 10 % is the limit below which the water holding capacity might become a limiting factor in crop production. Since the sandy soils have ≤ 5 % clay, combined with a very low organic carbon and silt plus fine sand content, water holding capacity might be one of the most limiting factors in irrigated crop production through large sections of the study area.

During dry periods with very high temperatures and windy conditions (typical summer conditions in the study area) a high level of irrigation management is required to maintain the plant available water at an optimum level. It is also difficult to maintain plant nutrients (especially nitrogen) at an optimum level of sufficiency. Dry sandy topsoils are very susceptible to wind erosion and can cause serious damage to seedlings and young fruit trees and vines.

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.

b) Cemented hardpans

Hardpan carbonate horizons and dorbank are common diagnostic materials in many soils in the study area (e.g. soil complexes A 3, A 5, A 6, D 4, D 5, 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.

Depending on the hardness and depth of the hardpan below the soil surface 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.

c) Surface crusting and hard-setting

Although surface crusting and hard-setting can be considered as physical/morphological phenomena, it is largely determined by the exchange properties (concentration of and ratio between extractable and soluble base cations) of the soil material. It is further negatively influenced 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 a low iron content, and have a relatively high fine sand plus silt content; e.g. soil complexes A 5, D 2, D 4, D 6, E 3 and F 1.

Topsoil with such properties is physically unstable. It 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.

d) 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 percentages of exchangeable sodium and/or magnesium ions (e.g. soil complexes G 1, G 2, H 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.

e) Wetness

The average annual rainfall throughout the study area decreases from about 350 mm/a in the south at Citrusdal, 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. However, in the southern section of the basin with a higher rainfall soils with signs of periodic wetness could develop. The signs of wetness (grey colours with low chromas, sometimes with blue or green tints, with or without sesquioxide mottling) are the result of the presence of free water at some depth in the profile.

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 topsoils, these abnormally high rainfall incidences might lead to free water accumulation in some soil profiles.

Due to the very open and porous nature of the soils associated with TBS weathering products and aeolian sands, excess soil water flows freely to concave lower slope positions where the water accumulate above a less permeable layer (e.g. clay, hardpan or even weathering rock) to form a perched water table (e.g. soil complexes G 1, G 2, H 1 and H 2). In deep sands a freatic water table might develop (e.g. soil complexes B 3, B 4, C 1 and J 2). In soils with a perched water table a grey, pale coloured E horizon can develop while a freatic, usually fluctuating, water table might lead to the formation of unspecified material with signs of wetness or soft plinthite in the deep subsoil (e.g. Pinedene, Tukulu and Longlands soil forms) or bleaching of the deep subsoil (e.g. Fernwood soil form).

The presence of free water leads to a decrease in oxygen and an increase in carbon dioxide concentration in the soil system. This affects active root respiration, and lead 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).

Depending on the depth and duration of the hydromorphic conditions, soils with signs of wetness should therefore be artificially drained for optimum land-use, especially for irrigated agriculture. Duplex soils with an impermeable subsoil clay layer that cannot be drained should be ridged for deep rooted perennial crops and even for winter plantings of annual crops.

f) Weathering rock

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

In the southern section of the basin shallow lithosolic soils associated with TBS (soil complex **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. Possible reasons why these soils are preferred is the lower frost hazard due to a higher lying terrain position and better drainage compared to lower lying soils. 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 complexes **I** 2 and **I** 3) and Nama (soil complexes **I** 4 and **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.

In addition to the limited effective depth, lithosolic soils that have developed from clayey sedimentary and metamorphic Bokkeveld and Nama formation rocks usually contain considerable quantities of soluble salts (especially sodium and magnesium) in drier areas, as well as varying concentrations of coarse fragments.

g) 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 1.3.1: 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.

1.3.2 Chemical soil limitations

a) Acidity

During the WODRIS a large number of soils were sampled. All the soil samples collected (372) were analysed for pH measured in a soil-water paste (abbreviation pH_{H2O}). pH was also measured in 1M KCl (soil-solution ratio of 1 : 25; pH_{KCl}) on 174 samples that were selected for detail chemical analyses. Based on the pH_{H2O} values only 38 (approximately 10 %) of the samples could be considered as acid (pH_{H2O} < 6.0) (Provincial Government Western Cape, 2003). 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. Only 11 of the 116 subsoil samples had a pH_{KCl} below 6.0. Acidity is therefore no limitation in soils of the northern section of the Olifants River Basin from Klawer to the coast.

In the ODRS (Department of Water Affairs and Forestry, 1998) it was reported that in the higher rainfall southern section of the basin sandy soils are always acid to extremely acid. These findings were based on a very limited number of soil samples. To confirm these results producers/farmers from Keerom 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 was an increase in pH from the south to the north. Although previous land use was not always indicated, soils that were never used for citrus plantings apparently had the lowest pH. 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. This will increase the establishment cost of citrus orchards on new soils compared to the cost of replanting on old citrus soils.

b) 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.

c) 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 complexes 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.

Three types of salt affected soils are found in the study area:

- **Saline soils**: These are soils with a high soluble salt content, but relatively low exchangeable sodium saturation. Saline soils generally tend to be physically fairly stable and non-dispersible in freshwater.
- **Sodic soils:** These are soils with a low soluble salt content, but a high exchangeable sodium and/or magnesium saturation and pH. Sodic soils are physically unstable and highly dispersible in fresh (non-saline) water. They therefore set hard on drying, and are fairly dense and impervious in the moist state.
- **Saline-sodic soils:** These are soils with a high soluble salt content and relatively high exchangeable sodium saturation. Saline-sodic soils generally tend to be physically fairly stable and non-dispersible in freshwater.

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.

1.3.3 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, citrus, 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.

1.3.4 Qualify limiting soil properties and soil potential for crop production

The inherent features of the soils identified in the study area from Keerom to the coast 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 complexes. In **Appendix A:**

Table 1.7 six physical and two chemical limitations are qualified for all the soil complexes (except complexes defined as land classes), as defined in the map legend (see **Appendix A: Table 1.3**). Although the soil families in many soil complexes are comparable in terms of limitations, in certain soil complexes 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 complex, the limitation degree was in certain instances qualified as ranges, e.g. **None - Low**; **Low - Moderate**; **None - Severe**; etc.

It should, however, be emphasised that the real effect of a limitation is not necessarily of the same intensity for all the limitations. For example:

- A low clay content could have a severe influence on growth and production under poorly managed irrigation and fertilizer programs. With a suitable irrigation system, correct irrigation scheduling and fertilization, the negative effect of a low clay content could, under normal conditions, be managed in such a way that growth and production are not affected. Because soil texture (clay content) cannot be changed, irrigated crop production on sandy soils requires highly sophisticated irrigation and fertilizer management programs on a continuous basis.
- The actual limitation of subsoil hardpans, as well as clay layers and weathering rock, depends on the hardness and/or density, lateral continuity and depth below the soil surface. Because soil amelioration prior to establishing perennial crops (e.g. grapes, citrus) generally involves the mechanical loosening of the limiting material, the negative effect of the effective depth limiting material on growth and production will decrease. The relative decrease depends on the success of loosening. For instance discontinuous hardpans, not extremely hard, and at a depth of between 450 mm to 600 mm are generally most successfully loosened. Once hardpans and weathering rock have been loosened the material will remain loose and porous. Although the hardpan clods and rock will largely remain non-utilisable by roots, the interstitial material will be porous and friable. In the case of clay layers, the type of clay, chemical composition and degree of wetness will determine the long-term success of loosening.
- Soils subject to periodic hydromorphic conditions must be drained to decrease the negative effect of wetness on crop growth and production. The efficiency of any drainage system to remove free soil water decreases over time. The rate of decrease, however, depends on other physical and chemical soil properties, as well as chemical soil amendments (e.g. gypsum) that might have been added to the soil. In addition to lower efficiency levels over time, drainage systems require regular (annual) maintenance and cleaning.

Various parametric models to estimate or calculate the potential of soils for crop production have been described over the last 30 to 40 years in international publications. These parametric methods, however, have a very limited applicability. It can only be used for soil potential evaluation in localities with environmental conditions (soil, climate, terrain) similar to those for which the model was developed.

Researchers and technical advisors in the grape and fruit industry have on many occasions attempted to apply these parametric methods for local conditions. A certain degree of success was achieved in quantifying crop production potential of soil types that are comparable to those soils used in the original parametric model development. Most of the soils in the Western Cape, however, differ significantly from the soils used in model development, and very poor production potential values were obtained. For this reason parametric models are not used in the Western Cape for soil potential evaluations.

Due to the limitations associated with the above approach, the most practical way to evaluate soil potential in the Western Cape 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, by individual experts. 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.

The advantage of the expert system approach compared to a parametric approach can be explained by comparing soil complex A 3 (dominant soil family is Gr 1000) and G 1 (dominant soil families are Kd 1000 and Kd 2000) (see **Appendix A: Table 1.3)**. Both soil types have ≤ 5% clay in the top- and upper subsoil. The upper subsoil in A 3 is a red apedal B overlying dorbank, while in G 1 it is an E horizon overlying a gleyed clay. In both soils the water holding capacity is low and the infiltration rate is rapid due to the low clay content. In A 1 excess soil water in the A and B horizons will drain away freely, while in G 1 it will accumulate in the E horizon and lead to hydromorphic conditions. A 3 therefore has a higher potential for deep-rooted perennial crops than G 1. In an expert system it is relatively easy to come to these conclusions compared to a rigid parametric approach.

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 complex the greater the salinity, alkalinity and effective depth limitation becomes.

Five classes were used to rate the potential of soil complexes (see **Table 1.3**). 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 complexes with soils with a very high salinity were downgraded compared to similar non-saline soils.

Three soil specialists with a sound knowledge of irrigation farming in the Olifants River Basin evaluated the potential, primarily physical, of individual soil complexes 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 three ratings of the soil specialists. The final potential ratings by soil complex are listed in **Appendix A: Table 1.8**.

Table 1.3 Classes used to evaluate the potential of soil types for annual and perennial crops before and after amelioration of subsoil limitations

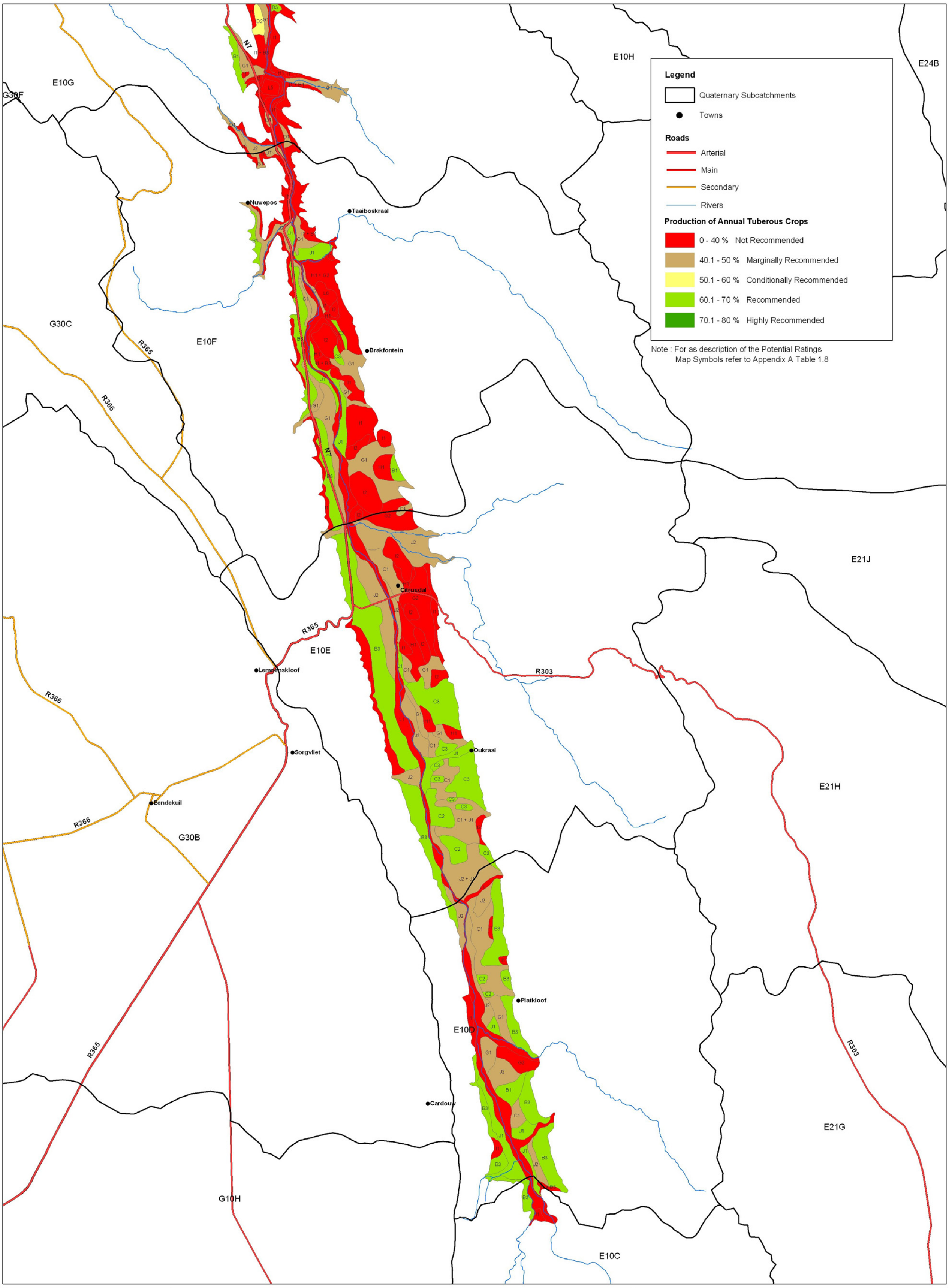
Potential	Recommendation for irrigated crop production	Percentage of maximum potential
Low	Not recommended	≤ 40%
Medium-low	Marginally recommended	> 40 - ≤ 50%
Medium	Conditionally recommended	> 50 - ≤ 60%
Medium-high	Recommended	> 60 - ≤ 80
High	Highly recommended	>80%

The potential ratings by soil complex in **Appendix A: Table 1.8** were combined with the surface area of the soil complexes in the southern (from Keerom to Bulshoek Weir) and northern (from Bulshoek Weir to the coast) sections of the basin to determine the total surface area (in hectare) of five potential suitability classes (≤ 40 %; > 40 - ≤ 50 %; > 50 - ≤ 60 %; > 60 - ≤ 80 %;> 80 %) for annual tuberous and non-tuberous crops and perennial crops, before and after amelioration of soil limitations (see **Table 1.4**). In **Figures 1.2**, **1.3** and **1.4** the spatial distribution of the different potential classes for these crop types are presented.

Table 1.4 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 the Olifants River Basin

Southern section of basin (Keerom to Bulshoek Weir)				
Potential class	Annual tuberous crops (ha) 1)	Annual non-tuberous crops (ha) 2)	Perennial crops 3)	
			Before amelioration (ha)	After amelioration (ha)
≤ 40 %	11536	10774	18077	8099
> 40 - ≤ 50 %	7718	7303	9660	11063
> 50 - ≤ 60 %	476	7463	1196	8575
> 60 - ≤ 80 %	9930	4118	726	1922
> 80 %	0	0	0	0
Total area (ha)	29 659			
Northern section of basin (Bulshoek Weir to the coast)				
Potential class	Annual tuberous crops (ha)	Annual non-tuberous crops (ha)	Perennial crops	
			Before amelioration (ha)	After amelioration (ha)
≤ 40 %	83054	33457	86701	32540
> 40 - ≤ 50 %	812	5194	17418	1552
> 50 - ≤ 60 %	24264	21089	29118	2699
> 60 - ≤ 80 %	34464	82854	9356	105802
> 80 %	0	0	0	0
Total area (ha)	142 594			

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.



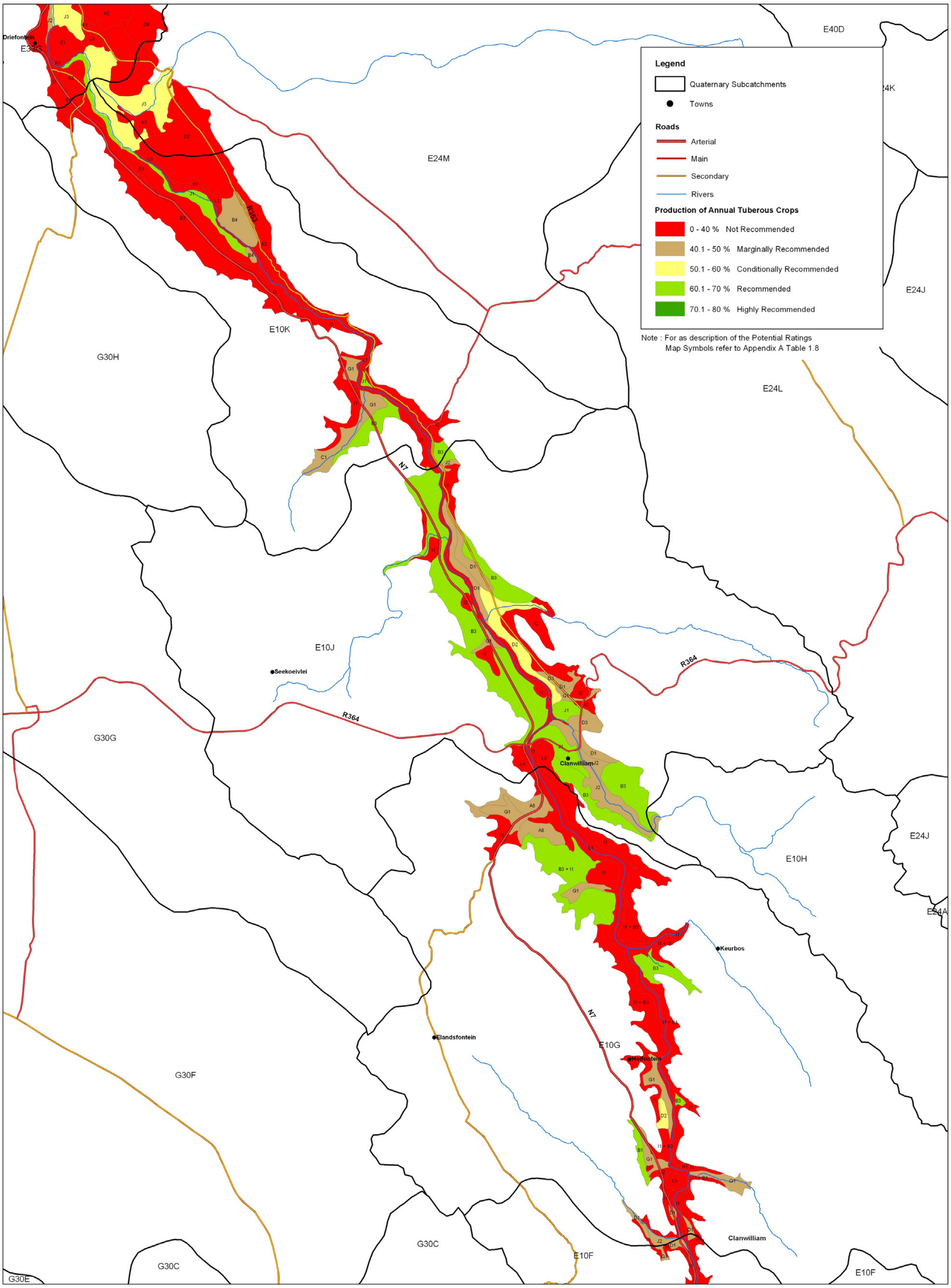
Western Cape Olifants / Doring River Irrigation Study

Potential Rating of Soil Map Units
for the Production of Annual Tuberous Crops

Scale : 5 2.5 0 5 Kilometers
1 : 75 000
N
Path: i:/hydro/400415/arcview/projects/fig12_1.mxd

SHEET 1 OF 3

Figure 1.2



Western Cape Olifants / Doring River Irrigation Study

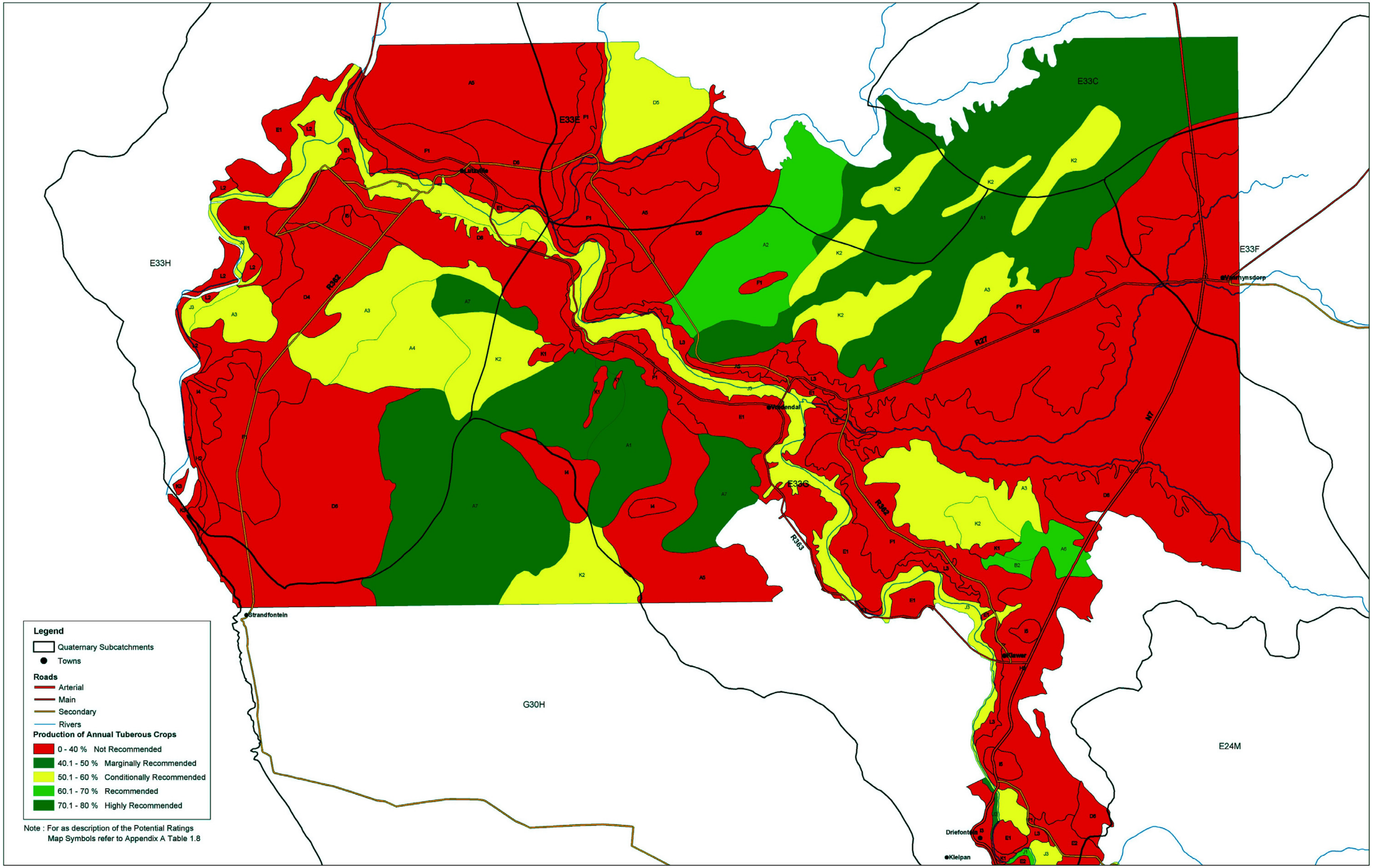
Potential Rating of Soil Map Units
for the Production of Annual Tuberous Crops

Scale : 1 : 75 000 (5 2.5 0 5 Kilometers)

Path: i:/hydro/400415/arcview/projects/fig12_2.mxd

SHEET 2 OF 3

Figure 1.2



Western Cape Olifants / Doring River Irrigation Study

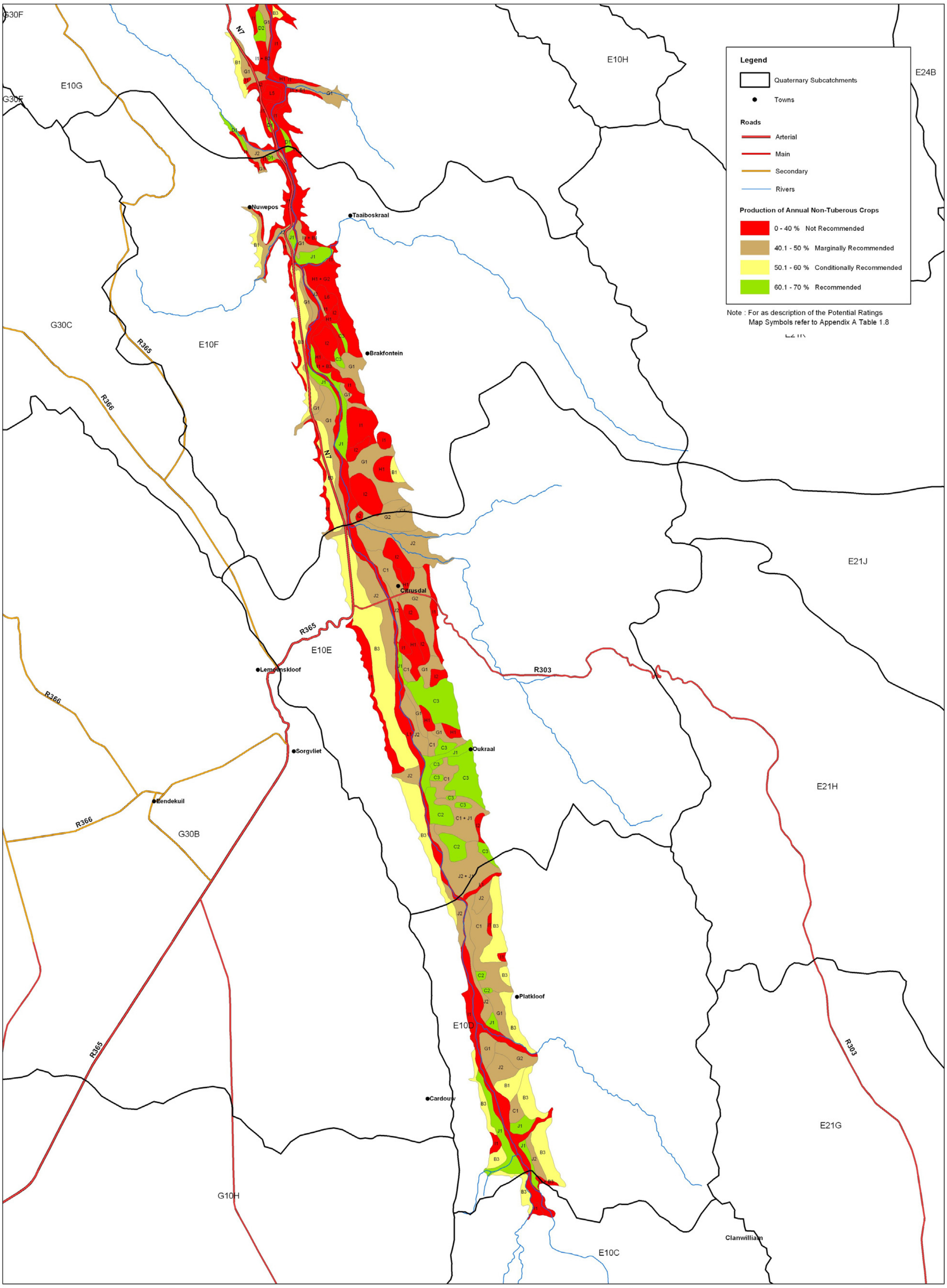
Potential Rating of Soil Map Units for the Production of Annual Tuberous Crops

Scale : 3 1.5 0 3 Kilometers
1 : 85 000

Path: i:/hydro/400415/arcview/projects/fig12_3.mxd

SHEET 3 OF 3

Figure 1.2

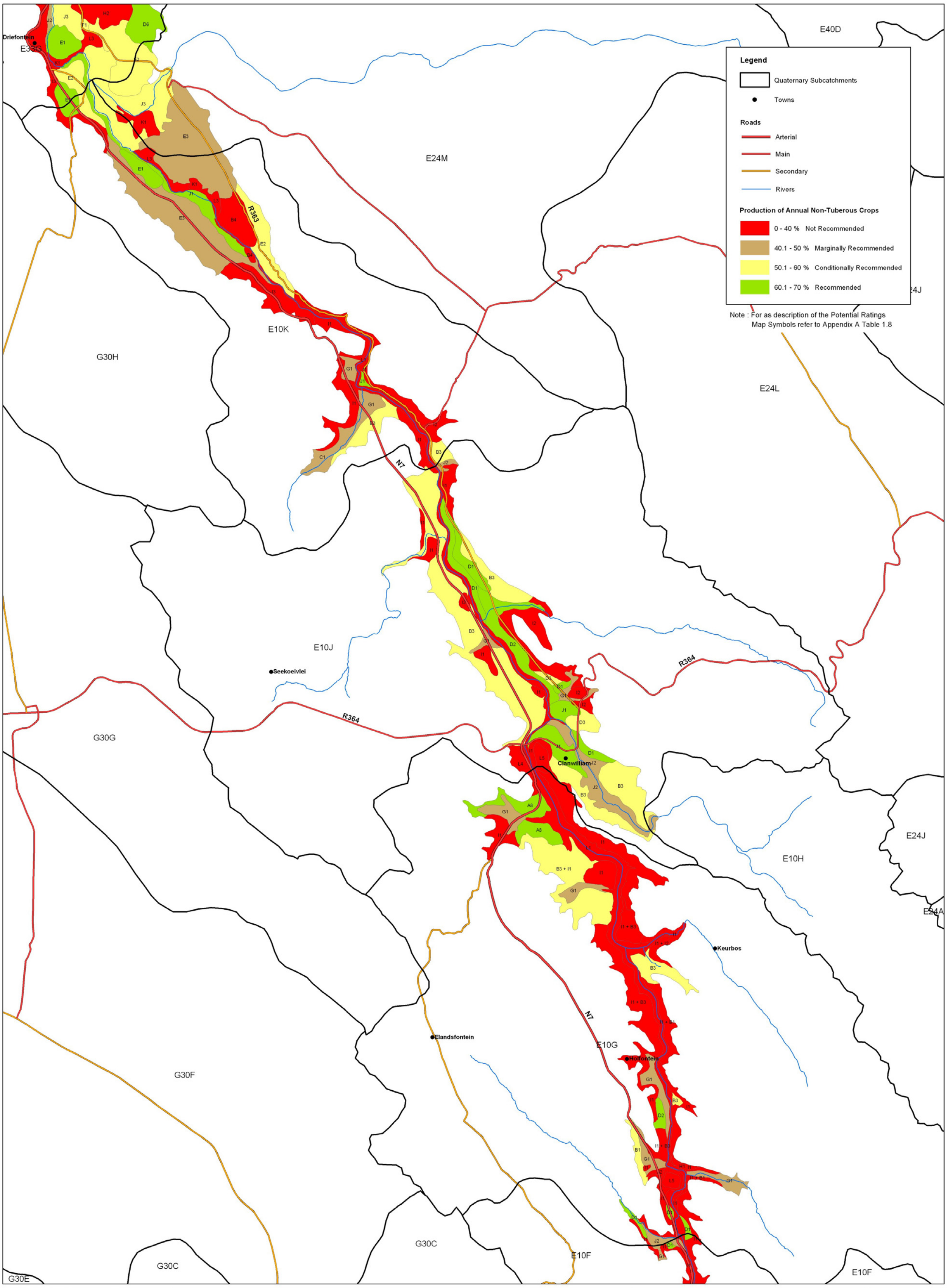


Western Cape Olifants / Doring River Irrigation Study

Potential Rating of Soil Map Units
for the Production of Annual Non-Tuberous Crops

Scale : 3 1.5 0 3 Kilometers
1 : 85 000
Path: i:/hydro/400415/arcview/projects/fig13_1.mxd
SHEET 1 OF 3

Figure 1.3



Western Cape Olifants / Doring River Irrigation Study

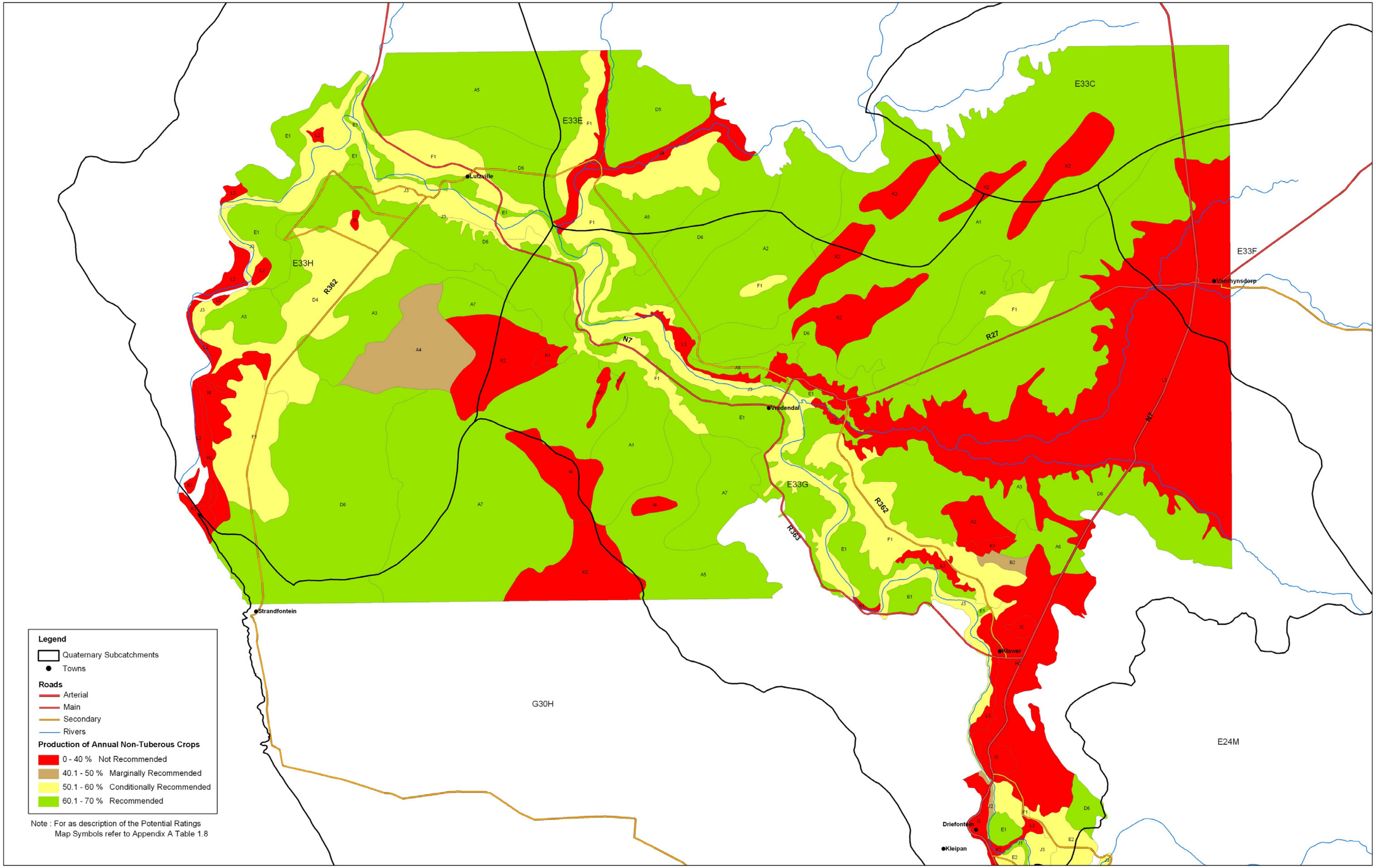
Potential Rating of Soil Map Units for the Production of Annual Non-Tuberous Crops

Scale : 3 1.5 0 3 Kilometers 1 : 85 000

Path: i:/hydro/400415/arcview/projects/fig13_2.mxd

SHEET 2 OF 3

Figure 1.3



Western Cape Olifants / Doring River Irrigation Study

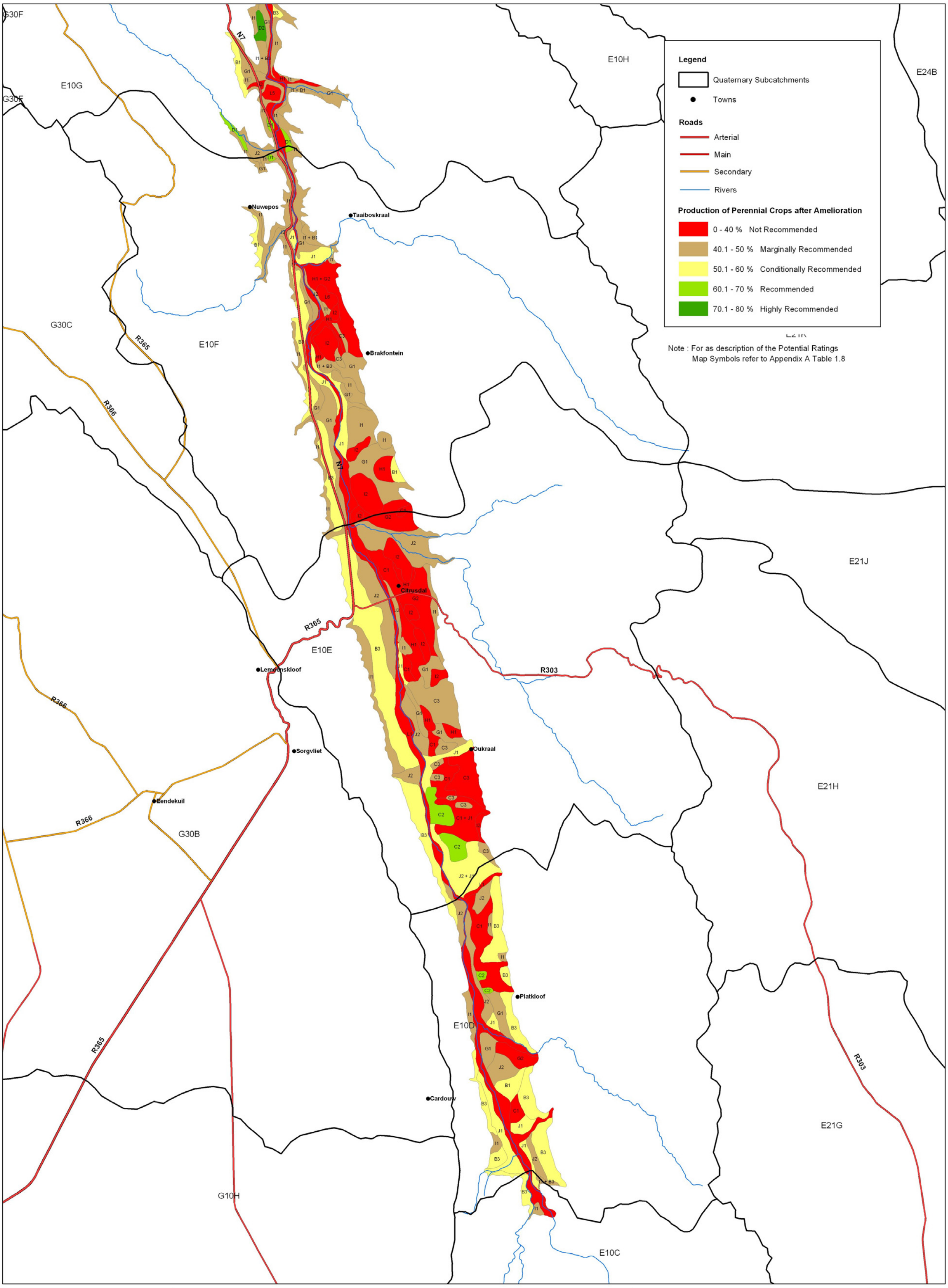
Potential Rating of Soil Map Units for the Production of Annual Non-Tuberous Crops

Scale : 3 1.5 0 3 Kilometers
1 : 85 000

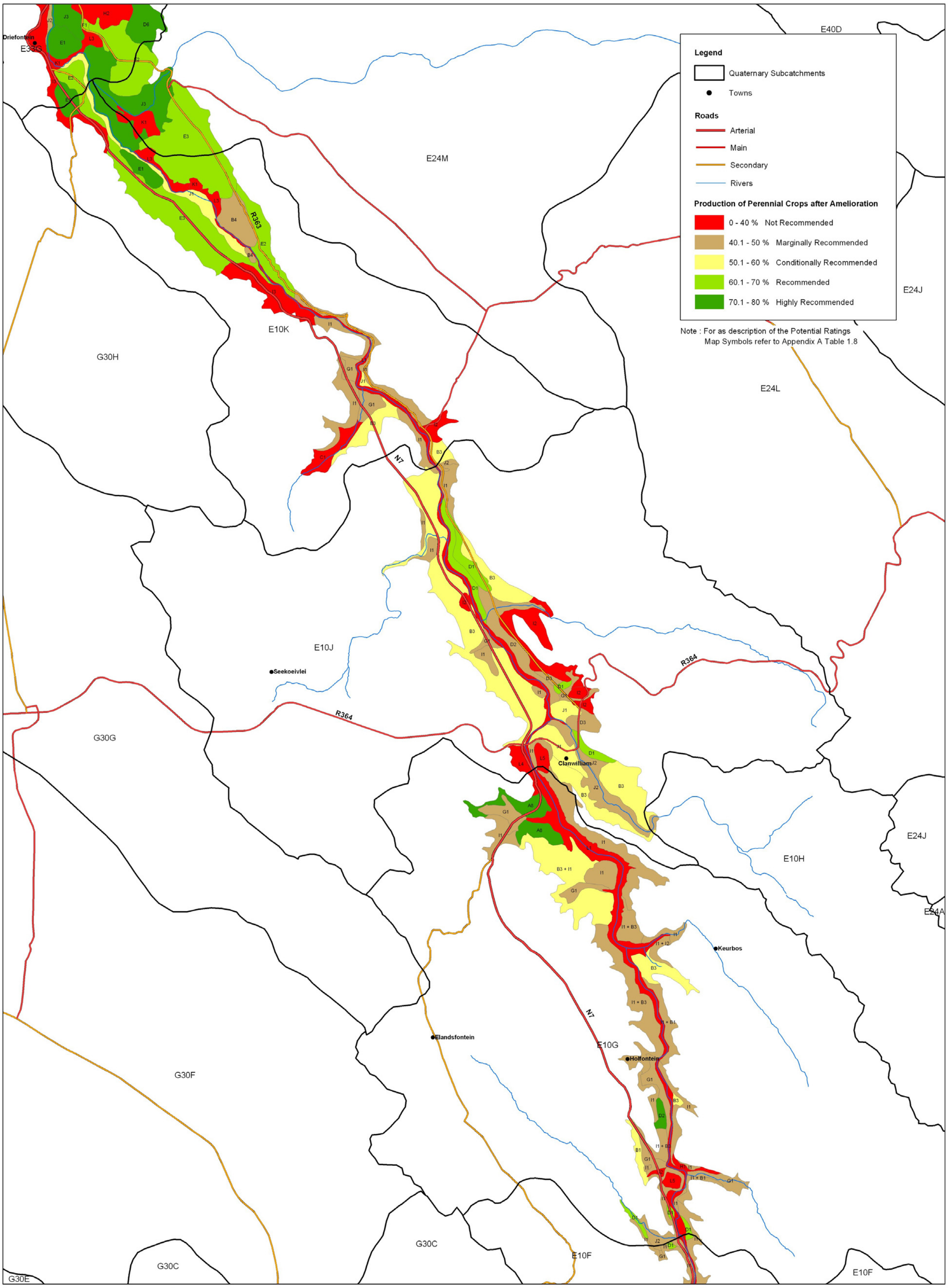
Path: i:/hydro/400415/arcview/projects/fig13_3.mxd

SHEET 3 OF 3

Figure 1.3



	Western Cape Olifants / Doring River Irrigation Study	Scale : 3 1.5 0 3 Kilometers 1 : 85 000 N	SHEET 1 OF 3
	Potential Rating of Soil Map Units for the Production of Perennial Crops after Amelioration of Soil Limitation	Path: i:/hydro/400415/arcview/projects/fig14_1.mxd	**Figure 1.4**



Western Cape Olifants / Doring River Irrigation Study

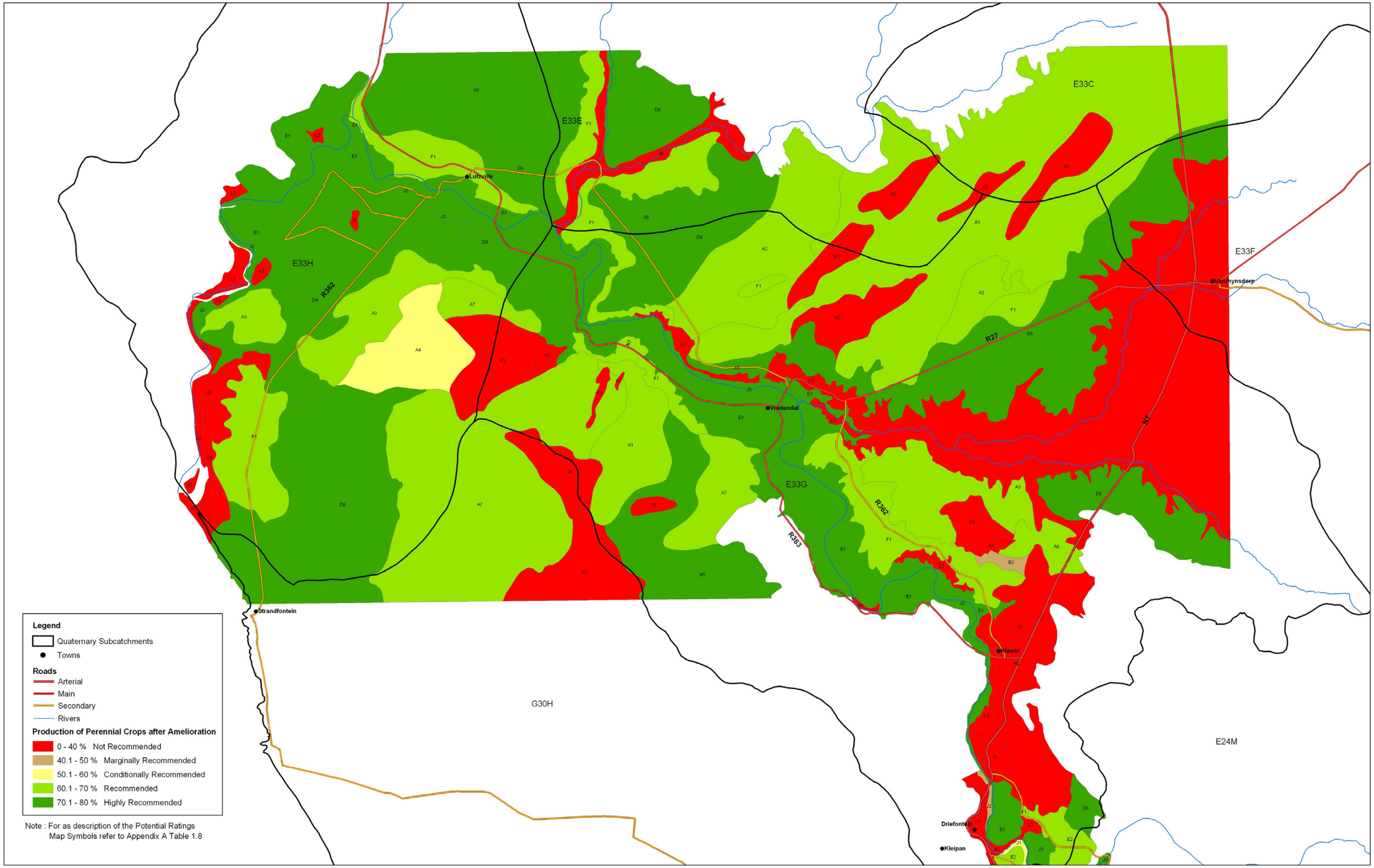
Potential Rating of Soil Map Units for the Production of Perennial Crops after Amelioration of Soil Limitation

Scale : 1 : 85 000 (3 1.5 0 3 Kilometers)

Path: i:/hydro/400415/arcview/projects/fig14_2.mxd

SHEET 2 OF 3

Figure 1.4



Western Cape Olifants / Doring River Irrigation Study

Potential Rating of Soil Map Units for the Production of Perennial Crops after Amelioration of Soil Limitation

Scale : 3 1.5 0 3 Kilometers

1 : 85 000

N

Path: i:/hydro/400415/arcview/projects/fig14_3.mxd

SHEET 3 OF 3

Figure 1.4

According to **Table 1.4** about 2 000 ha are recommended for perennial crops such as citrus and wine grapes in the southern section of the basin from Keerom to Bulshoek Weir. Another 19 000 ha are marginally and conditionally recommended provided that subsoil limitations are properly ameliorated. About 8 600 ha of this class has a potential rating that is near the upper limit of the conditionally recommended class. The main limitations in this class are wetness and shallow underlying weathering rock combined with a low clay content. These limitations are relatively easy to ameliorate and with judicious irrigation practices to maintain plant available soil water at an optimum level, approximately 10 000 ha can be used for economic viable production of citrus and wine grapes in this section of the basin. Approximately the same area can be used for either tuberous or non-tuberous annual crops.

Within the lateral extent of the survey to about 60 m above the level of the river approximately 10 000 ha is available in the Keerom to Bulshoek section of the Olifants River Basin for any combination or irrigated annual (tuberous and non-tuberous) and perennial (citrus, wine grapes, mangos) production.

The soils in the surveyed area from Bulshoek to the coast differ greatly from those in the southern section in terms of the dominant limitation(s). From **Appendix A: Table 1.8** it is evident that deep, well drained red sandy soils (soil complexes A 1 and A 2) can be highly recommended for irrigated tuberous and non-tuberous crops without any subsoil amelioration measures. However, these soils are only conditionally recommended for perennial crops due to the very sandy nature and risk of sandblasting. The very shallow soils on dorbank of the F 1 soil complex are totally unsuitable for the production of tuberous crops even after loosening of the hardpan. This is due to the negative effect of the large volume of coarse hardpan fragments on tuber development and quality. Non-tuberous crops are conditionally recommended while perennial crops are recommended on these soils after amelioration of subsoil limitation.

The implication of the different potential ratings of soil complexes in the Bulshoek Weir to the coast section for annual and perennial crops as outlined in **Appendix A: Table 1.8** is that, depending on the dominant soil type in a particular section of the study area that might be considered for future irrigation development, certain crop types might be excluded from a possible crop program. For instance, soil complexes dominated by Knersvlakte form soils (e.g. soil complexes E 3 and F 1) would never be recommended for large-scale commercial vegetable (tuberous crops) production.

In the surveyed area from Bulshoek Weir to the coast there is approximately 105 000 ha that is in the recommended potential class for the production of perennial crops after amelioration of subsoil limitations, in particular hardpans, and provision is made for leaching and drainage to remove soluble salts from saline environments (see **Table 1.4**). Most of the areas recommended for perennial crops can also be used for irrigated non-tuberous annual crop production. In addition to these areas, certain soil complexes that are not recommended for perennial crops due the very sandy nature of the soils can be recommended for irrigated tuberous crops (see **Figures 1.2**, **1.3** and **1.4**).

1.4 Amelioration of physical and morphological soil limitations

The performance of a crop on a particular soil is dependent on the following factors:

- Presence of limiting factors in the soil.
- Success with which limitations can be ameliorated.
- Permanency of improvement.
- Manipulation of land or orchard practices to ensure that, after improvement, the limitation does not redevelop.
- Sensitivity or adaptability of the specific crop to the limitation.

Soil properties that could be considered as limitations in the study areas were discussed in the preceding paragraphs. Most of these properties are inherent soil features that developed under specific combinations of environmental conditions, *inter alia* past and present climate; parent material (lithology); topography (elevation, terrain position, slope); organisms and time. Some features, however, may be the result of, or could be intensified by wrong soil cultivation practices.

Measures required to improve the physical and morphological limitations are generally relatively straightforward. In certain case, however, it is more difficult because the limitations might be a complex of two or more limitations that operate interdependently.

In the following section, some principles will be discussed about the more important measures that can be taken to improve these limitations.

1.4.1 Deep tillage of soils

The above ground performance of all plants is directly related to the lateral and vertical distribution of primary roots, and the degree of branching and fineness of the secondary roots. The aim of deep soil tillage is to:

- ameliorate the depth limiting nature of horizons or materials (e.g. cemented hardpans, dense clay layers, weathering rock and wetness);
- mix horizons of varying and different texture; and
- eliminate unfavourable chemical conditions (e.g. acidity, salinity) by means of deep placement of ameliorants (e.g. lime or gypsum combined with leaching and drainage).

Amelioration of subsoil limitations by deep soil tillage before establishing new orchards and vineyards is an extremely important practice. The main reasons are:

- Many soils in the study area naturally have a limited rooting depth due to especially shallow subsoil hardpan or clay layers or weathering rock.
- Because of the great cost associated with the establishment of orchards and vineyards, and the tendency for higher plant densities and therefore smaller soil volumes available for plant root development, all measures must be taken to ensure that the maximum potential soil

depth is made available to the plants. The solution lies in creating a greater rooting depth during soil preparation, especially to create a better "quality" available soil volume. "Quality" refers to a properly and uniformly loose soil with a uniform distribution of ameliorants.

Although no quantitative standards or norms are available, a number of criteria can be used to evaluate the necessity for deep soil tillage:

- **Crop selection**: One of the most comprehensive publications dealing with soil depth requirements of different crops is that by Sys *et al*. (1993). According to this publication the potential rooting depth of perennial crops is generally greater than 1.0 m, while for annual crops, e.g. onions and potatoes, it is between 500 – 600 mm. Optimum production is obtained when the effective rooting depth is greater than the potential rooting depth of the crop.

  Although the potential rooting depth of most plants are greater than 500 mm (annual) or 1.0 m (perennial), the minimum soil depth requirement of especially perennial crops could be considerably less provided that the plant has access to sufficient nutrients and water in the root zone. This implies a high level of irrigation and fertilizer management. In the case of perennial crops, e.g. citrus and vines, the rootstock that is used also plays a very important role. In **Table 1.5** minimum soil depth guidelines for different vine rootstocks are given. This implies that the production of grapes, grafted onto Salt Creek rootstock, on a shallow soil could be comparable to grapes, grafted onto Richter 99, on a deep soil.

  Table 1.5 Depth adaptation of different rootstocks for grapes

Depth adaptation	Depth (mm)	Rootstock
Very shallow	± 300	Salt Creek
Shallow	± 450	101-14
Medium deep	± 600	Richter 110
Deep	± 900	Richter 99 Ruggeri

  Although crop type determines the depth of tillage, other factors such as the amelioration of dense subsoil layers to improve internal soil drainage could be the decisive factor that will determine the final depth of deep tillage for wetness sensitive crops or rootstocks.

- **Soil type**: The type and depth of any subsoil limitation will determine what measures are essential to create the best "quality" root medium on each soil type and how to maintain it.
- **Implement**: Although different implements and power sources are used by growers and contractors, the specific action of the implement on different soils is seldom considered at the initial stage. For every soil type it must be determined whether:
  - the soil should be loosened with a sideways movement of material (shift ploughing);
  - the different layers inverted (inverse ploughing);
  - different layers and ameliorants be mixed (mix ploughing); or
  - layers loosened without disturbance or mixing (ripping).

To ensure that deep tillage is effectively applied, it is essential that the following factors should be taken into account during deep soil tillage:

- The soil water content must be between the plasticity limit and wilting point to ensure optimal crumbling when the smallest tractive power is required.

- The cutting or slice width must not be optimal. If it is too wide, untilled ridges will be left in the subsoil and big clods may form. If it is too narrow the cost per unit area will be too high. As a general rule the distance between cuts should not be more than 66 % of the working depth, or further than 600 mm apart if the working depth is 800 mm or deeper.

- The use of one or two directions of tillage depends on the implement used, the mixing of soils layers required, as well as the mass of especially lime or gypsum to be mixed with the subsoil layers. The ideal angle between two tillage directions is approximately 60°.

- To create optimum internal soil drainage the deepest tillage direction should be as near as possible to perpendicular to the contour and more or less parallel with the row direction. This is particularly important where wetness is an inherent soil limitation.

- Shallow soil preparation with homogeneous mixing is preferable to deeper tillage with uneven mixing and formation of big clods.

In **Appendix A: Table 1.9** the ideal depth and type of deep soil tillage are specified on a soil complex 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 **Appendix A: Table 1.9**, 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 **Appendix A: Table 1.9**, *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 45º to more than 75º. 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.

Another deep soil tillage method that was commonly used in the past, but rarely at present due to excessive cost, is the so-called “bulldozer blade" method. It is especially suited for soils in the Klawer to the coast section of the basin with very hard, cemented subsoil pans at a depth just beyond the reach of a rip plough. The "bulldozer blade" method involves the removal of the fairly loose soil material (e.g. topsoil and red apedal sand in Garies form soils). The exposed underlying hardpan is then disrupted with the blade into very large fragments or blocks. These blocks are further broken into finer units by the bulldozer tracks. The loose material is subsequently spread over the loose hardpan material and the surface levelled. (Note: One of the soil methods specified during the Commercial Farmers Workshop held at Vredendal on 16 August 2005, by one of compilers of the soils questionnaire is similar to the "bulldozer blade" method except that a rip plough is used to break the hardpan).

The cost of the different kinds of deep soil tillage depends on the type of propulsion used, the implement type, tillage depth, and site and land features. In **Table 1.6** the cost as supplied by one contractor is given. From this table it is clear that depending on soil type and depth of tillage the cost range from as low as R 4 000 per ha to as high as R 32 000.

Table 1.6 Caterpillar D8R or D9 as propulsion (Information supplied by Mr J Nolte of Nolte & Son, Soil Moving CC, Welbedacht; Prices October 2005)

Soil type	Type of mounting	Tillage practice		Number of culti-vations	Slice width (mm)	Tillage depth (mm)	Action [1] cost dry (R/ha)	Total [2] wet cost (R/ha)
		Practice number	Action(s)					
Clayey	3-point	1	Rip	1	900	1 200	4 800	
	3-point		Shift	1	550	1 100	6 600	15 390
Clayey	3-point	2	Rip	1	1 200	1 200	3 800	
	3-point		Shift	1	750	1 100	5 500	12 555
Sandy	3-point	3	Shift	1	550	1 100	5 000	6 750
Shallow soils	Draw bar	4	Double shift plough	Full surface		600	3 600	4 860
Shallow soils	3-point	5	Rip	1	900	1 200	4 800	
			Ridging:					
			<400 mm				1 700	8 775
			>500 mm				2 500	9 855
Shallow hardpan	3-point	6	Rip	3	900	1 200	18 200	24 570
Shallow clay	3-point	7	2 Tines	1			2 400	3 240
	3-point	8	3 Tines	1			1 600	2 160
Sand		9	Excavator	Full surface		900	9 700	13 095
Loam		10	Excavator	Full surface		1 200	14 000	18 900
		11	Excavator	Full surface		≥1 300	24 000	32 400
		12	Rip	1	900	1 200	4 800	
			Excavator	Rows only			5 000	13 230

1) Dry means without fuel.
2) Wet means with fuel.

Other comments:

- A Caterpillar D6 is approximately 25 % cheaper than a D8R or D9 but tillage depth is at least 200 mm shallower.
- The transport and permit cost must be added to the total wet cost (R 2 500 to R 3 000 for a D8 and R 3 500 to R 4 000 for a D9).
- In soil complexes with heuweltjies, the heuweltjies are ripped in two directions and the area in between ripped once followed by shift ploughing.

1.4.2 Drainage of soils

Although wetness is not a serious natural limitation in most of the soil complexes 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. A detailed soil survey generally can be used to determine the cause of water-logging and deductions can be made to identify the best drainage system for individual cases.

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. The drain must have a gradient that is steep enough so that water accumulating in the drain is removed quickly from the landscape. The drain, over its full length, must be placed at least 300 mm deep in the dense, underlying layer. It is essential that the lowest drain level is continuous with a uniform slope gradient. It is further advisable to start a cut-off drain as an open furrow to get an idea of the amount of water (stream flow) to be removed. With the stream flow known, the minimum drainpipe size required to remove the water can be determined.
- **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 complexes C 1, C 3, J 2 and J 3). The height of the water table is controlled by the water level in neighbouring rivers or depressions. Because the lateral movement of the free water is generally very slow, cut-off drains cannot be used. In such cases use is made of a network of drains that, to a greater or lesser extent, are connected to each other.

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 complexes varies considerably from non-saline to saline, soil complexes that include heuweltjies, and soil types with soft or hardpan carbonate horizons, dorbank and neocarbonate B horizons, are generally moderate to severely saline. The soluble salt content in the latter soils varies from about 5 t/ha to 30 t/ha for a 300 mm thick layer. This implies that the total salt load in the saline soils can be as high as 15 - 90 t/ha to a depth of 900 mm (Provincial Government Western Cape, 2003).

Although certain crops can tolerate a certain concentration of free salts in the soil system, most crops, especially table grapes and citrus, are sensitive to saline soil conditions. The effect of salinity on plants is twofold:

- Free salts increase the osmotic pressure of the soil solution and affect the total tension at which plants absorb water.
- Sodium and chlorine ions have a direct toxic effect on plants.

It is therefore essential to desalinate saline soils.

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.

The actual cost of drainage depends on a number of variables that include:

- depth of drainage trench;
- size of drainage pipes; and
- spacing between drainage lines.

In **Table 1.7** the effects of the first two variables are summarised. It is evident that the cost in Rand per 100 m drainage installed, varies from as low as approximately R 6 300 to as high as R 10 300 (these prices are based on information supplied by A J G Joubert, Drainage Consultant, Franschhoek; prices as at March 2001). The actual cost on a hectare basis will therefore be a function of the drain spacing. Although it is not possible to specify specific drain spacings for different soil complexes in the Olifants River Basin, spacing may range from very narrow at 30 m to 35 m, to as wide as 75 m to 100 m on sloping lands. Depending on depth and pipe size, the cost of drainage might therefore range from as low as R 8 000 to as high as R 30 000 per ha.

An extremely important aspect pertaining to drainage is the question around the saline drainage water. At present, irrigation farmers throughout South Africa use the natural streams and rivers as dumping sites for their drainage water. This, however, have resulted in eutrophication and salinisation of the lower reaches of many of our rivers; the Breede River is probably the best example in the Western Cape.

Table 1.7 Cost of drainage at two installation depths and for three pipe diameters (Information supplied by Mr A J G Joubert, Drainage Consultant, Franschhoek; Prices as at October 2005)

Depth[1)]	Excavation and refill wet cost[2)]	Plastic[3)]	One manhole per 100m pipe length	Installation	Pipe[4)] diameter	Pipe[5)] cost	Gravel	Total cost
(m)	(R/100m)	(R/100m)	(R/100m)	(R/100m)	(mm)	(R/100m)	(R/100m)	(R/100m)
1.3 - 1.7	2 600	25	1 950	1 100	75	1 700	1 510	8 885
					110	2 700	1 800	10 175
					160	5 460	2 250	13 385
2.0 - 2.5	3 600	25	2 800	1 600	75	1 700	1 510	11 235
					110	2 700	1 800	12 525
					160	5 460	2 250	15 735

1) A depth of 2.0 - 2.5 m is generally recommended for alluvial soils.
A depth of 1.2 - 1.5 m is commonly used for soils on sloping terrain.
2) Wet cost refers to the cost including fuel.
3) No Bidum is used.
4) The pipe diameter is a function of annual rainfall, size of land to be drained, and position in the landscape.
5) Only rigid 3 m PVC pipes (SABS grade) with a double row of holes are used.

Because of the potentially large salt load in the drainage water from many of the soil complexes in the northern section of the study area, water users downstream along the Olifants River might complain if this river is used as a drainage ditch.

For sustainable long-term irrigation farming it is therefore proposed that most of the salts that are generated through new irrigation developments should in some way or another be collected and stored in "salt" dams. The saline water in these dams should only be released into the Olifants River during the winter months when the river is in flood. Such costs have not been incorporated here.

Questions:

The majority of producers who attended the Commercial Farmers Workshops held at Vredendal on 16 August 2005 and Citrusdal on 17 August 2005, however, considered drainage for salt removal as unnecessary. According to the producers the negative effect of soluble salts on growth and production can be managed and manipulated by judicious drip irrigation.

This, however, leads to the following questions:

- *Is there any proof that drip irrigation does not lead to lateral down-slope movement and accumulation of soluble salts; thus increased salinisation in sections of blocks and orchards, and natural drainage depressions?*
- *Is the narrow "desalinated" strips parallel to the drip lines sufficient for optimum growth and production under severe climatic conditions; e.g. excessively warm, dry and windy periods?*
- *What is the effect of full surface wetting by micro- and sprinkle irrigation on salt distribution and salinisation of lower slope landscape positions?*

1.4.3 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 and wine grape 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.

Although ridging allows producers to utilize soils which otherwise could not be used economically for irrigated fruit and grape vine production, it creates various problems in orchard management.

Certain producers are inclined to use ridging as an amelioration measure instead of deep soil tillage and/or drainage. Generally the decisive reason is the relatively low cost of ridging compared to the high cost of ridging/drainage. Ridging, however, should be discouraged as an amelioration measure on soils that can be more successfully ameliorated by deep tillage, with or without drainage.

1.4.4 Recommended input values for deep soil tillage and drainage

During the Commercial Farmers Workshops held at Vredendal on 16 August 2005 and Citrusdal on 17 August 2005, the producers/farmers that attended the meeting were asked to complete a questionnaire (see **Section 5** of this report). One of the questions was the cost of soil tillage prior to planting of perennial crops. The average cost and standard deviation of different deep soil tillage practices by soil group for the southern (Keerom to Bulshoek Weir) and northern (Bulshoek Weir to the coast) sections of the Olifants River Basin is listed in **Table 1.8**. Due to a number of apparently unrealistic (either too low or too high) tillage cost values by certain compilers of the questionnaire, it was decided not to use the average tillage cost, but to adapt it slightly to be more in line with the values in **Table 1.6** as a more realistic input value for soil tillage cost estimate purposes.

Table 1.8 Cost of deep soil tillage in the Olifants River Basin based on inputs from Commercial Farmers Workshops

Soil group [1)]	Tillage practice	Number of entries	Soil tillage cost (R/ha)	
			Average cost	Standard deviation
Keerom to Bulshoek Weir				
B	Mix plough	3	R 7 000	R 2 645
	Rip	4	R 4 250	R 645
C	Mix plough	3	R 7 000	R 2 645
	Rip	2	R 4 750	R 353
I	Rip	3	R 7 166	R 2 565
J	Mix plough + Ridge	1	R 5 000	
	Mix plough	1	R 6 000	
	Rip	2	R 4 250	R 353
Bulshoek Weir to the coast				
A	Push away surface + Rip	3	R 16 333	R 2 309
	Rip	5	R 19 000	R 2 236
E	Mix plough	3	R 15 166	R 2 466
	Push away surface + Rip	1	R 20 000	
	Rip	2	R 13 000	R 1 414
H	Mix plough	1	R 14 000	
	Mix plough + trenching	1	R 10 000	
	Mix plough	4	R 11 875	R 2 174
	Rip	2	R 13 000	R 1 414
	Trenching	1	R 12 000	

[1)] See **Table 1.1** for definition of soil groups.

Most of the producers/farmers at the Commercial Farmers Workshops considered drainage as a non-essential physical amelioration measure on soils from the following soil groups: A 1, A 3, B 2, B 3, C 2, E 1, E 2, H 2, I 1, I 2, J 1 and J 3. Nine entries were from the Keerom to Bulshoek Weir section of the basin and 12 from Bulshoek Weir to the coast. Although most of these soil groups mostly consist of well drained soils, certain soil groups (e.g. A 3, B 3, and J 3) have one or more soil families that are subject to periodic wetness or saline and/or calcareous.

Ten entries throughout the basin considered drainage as an essential or locally required amelioration measure on a variety of soil complexes. Most of these soil complexes either have wet or saline/calcareous soils. This implies that drainage is required to remove either excess soil water or soluble salts leached from the profile.

Based on the estimated leaching requirement as a function of soluble salt load, four drainage densities and cost classes were defined (see **Table 1.9**). The drainage cost for each drainage density was calculated based on the information in **Table 1.7** (see **Table 1.10)**.

Table 1.9 Drainage density and cost based on four leaching requirements

Parameter	Drainage density			
	None	Low	Medium	High
Leaching requirement (%)	<3	≥3-<15	≥15-<25	≥25
Drainage cost per hectare	R 0	R 6 500	R 13 500	R 25 000

Table 1.10 Estimated cost of three drainage densities based on a 25 ha block

Parameter	Drainage density		
	Low	Medium	High
Distance between laterals (m)	250	100	50
Total length of laterals (m)	1 000	2 500	5 000
Diameter of laterals (mm)	75	75	75
Length of main drain (m)	500	500	500
Diameter of main drain (mm)	75	110	110
Total cost 25 ha	R 168 525	R 343 500	R 628 875
Cost per hectare	R 6 741	R 13 740	R 25 155

Based on the degree of wetness of the dominant soils in soil complexes with wet soils, a similar approach was followed to estimate the drainage cost (R/ha).

In **Table 1.11** the recommended cost for deep soil tillage and drainage are listed for the dominant soil complexes (excluding land classes) in the southern (Keerom to Bulshoek Weir) and northern (Bulshoek Weir to the coast) sections of the Olifants River Basin.

Table 1.11 Estimated cost of deep soil tillage and drainage for the dominant soil complexes in the southern (Keerom to Bulshoek Weir) and northern (Bulshoek Weir to the coast) sections of the Olifants River Basin (see Table 1.6 for tillage practice numbers)

Dominant soil complex [1)]		Recommended tillage practice [2)]	Tillage cost (R/ha)	Drainage cost (R/ha)
Symbol	Area (ha)			
Keerom to Bulshoek Weir				
B 3	6 110	3	R 6 750	R 6 500
C 1	926	3	R 6 750	R 10 000
C 3	911	3	R 6 750	R 10 00
D 1	590	2	R 12 555	R 0
G 1	2 291	5	R 8 775	R 8 000
G 2	762	5	R 8 775	R 8 000
I 1	3 368	6	R 16 380	R 0
I 2	1 450	5	R 8 775	R 0
J 1	1 285	4	R 4 860	R 0
J 2	2 556	4	R 4 860	R 10 000
Bulshoek Weir to the coast				
A 1	17 479	3	R 6 750	R 0
A 3	5 728	3	R 6 750	R 0
A 5	9 358	Combination 3+6	R 15 000	R 6 500
A 7	11 639	3	R 6 750	R 0
D 5	11 722	Combination 3+6	R 15 000	R 6 500
D 6	14 824	Combination 3+6	R 15 000	R 13 500
E 1	7 215	Combination 3+6	R 15 000	R 6 500
F 1	9 090	6	R 24 570	R 6 500
J 3	6 862	4	R 4 860	R 6 500
K 2	7 148	4	R 4 860	R 0

1) See **Table 1.1** for definition of soil complexes.
2) See **Table 1.6** for explanation of tillage practice numbers.

2. CHEMICAL AND PHYSICAL SOIL COMPOSITION

2.1 Introduction

During the *Olifants/Doring River Basin Study* (ODRS; Department of Water Affairs and Forestry, 1998) the chemical and physical characterisation of the soils and chemical ameliorants required to eliminate chemical limitations were based on existing analytical data. Various data sets were available, e.g. Rudman *et al*. (1978), Feyt (1982), Saayman (1975) and Lambrechts and Schloms (1995). The detail, however, varied significantly between data sets and there were also certain differences in the methods used to determine a particular parameter. The data were carefully studied and all potentially unreliable data were excluded. The approach that was followed to select sample sites or profiles for sampling also differed between the data sets. In the case of Rudman *et al*. (1978) profiles were selected on a random, non-spatial basis merely to characterise different soil-terrain combinations. In the case of data sets that related to fertilizer recommendations for soil/land development (e.g. Lambrechts & Schloms, 1996), the samples represent composite samples from similar profiles grouped as map units.

The random chemical data sets were therefore of such a nature that it could not be used for detail statistical comparison of different soil-land units. The composite samples, however, were suitable for quantitative spatial evaluations. The following components of the selected data were used for summary statistics analyses: pH; resistance of soil paste (ohms); Emerson & Bakker (1973) gypsum requirement based on extractable exchangeable cations; soluble sodium chloride based on extractable and exchangeable sodium. The data were also subjected to regression analyses to determine the effect of texture on pH, resistance of saturated soil paste, gypsum requirement and soluble sodium chloride content of the soils.

During the WODRIS study a total of 217 soil profiles along 23 traverses were described and classified according to the soil classification used in South Africa (Soil Classification Working Group, 1991). To develop a more comprehensive chemical profile of the different soils, 148 of the 217 soil profiles described, were selected for sampling. Most profiles were sampled on a diagnostic horizon or material basis. In a limited number of profiles only specifically selected subsoil horizons were sampled. A total of 372 samples were collected. All the samples were analysed for pH measured in water (pH_{Water}) and resistance (in ohms) measured in a saturated soil paste with a standard USDA soil cup with a cell constant of 0.25.

A total of 174 samples were selected for more detailed chemical analyses that included the following: coarse fragments (volume %); pH measured in 1.0 M KCl (soil-solution ratio of 1:2.5 (pH_{KCl}); saturated soil paste resistance (ohms); extractable phosphorus (Bray II method for samples with pH $\leq$ 7; Olsen method when pH > 7); extractable acidity at pH7; and NH_4-Ac extractable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+). Soil samples with a soil paste resistance of less than 500 ohms (89 of the 174 selected samples), were additionally analysed for: water saturation percentage; electrical conductivity (ECe; mS/m) of saturated extract; water soluble cations (Ca^{2+}, Mg^{2+}, Na^+, K^+); and water soluble anions (Cl^-, SO_4^{2-}). All the topsoil samples were additionally analysed for: 0.1 N HCl extractable trace elements (Cu, Zn and Mn); and warm water extractable B. Warm water extractable boron was also determined on all crushed subsoil hardpan samples. Thirty-one samples (31) were selected for physical analysis that included: soil particle analyses (coarse, medium and fine sand; silt; clay; expressed in mass %); soil texture; water retention at -10 kPa and -100 kPa (expressed in mass %); and easily available water holding capacity (in mm/m soil depth).

The individual analyses were used to calculate the following parameters: NH_4-Ac extractable cations were corrected to exchangeable cations by subtracting water soluble cations; sum of exchangeable cations; extractable cation percentage; ratio between exchangeable divalent cations and pH7 extractable acidity (so-called R-value); Ca:Mg ratio; soluble sodium content at a soil bulk density of 1 500 kg/m^3; sodium adsorption ratio (SAR); lime requirement for a R-value of 10; gypsum requirement using the Emerson & Bakker (1973) regression model (Lambrechts & Saayman, 1994); single and double super phosphate requirement for optimum of 30 mg P/kg soil.

The soluble sodium content (kg/ha/150 mm layer thickness), lime and gypsum (t/ha/150 mm layer thickness), and super phosphate (kg/ha/150 mm layer thickness) requirements were corrected for sample layer thickness and coarse fragment content. A standard lower depth of 900 mm was used to determine the thickness of the deepest subsoil layer. The sum of the layer soluble sodium content and ameliorant requirements was then summated for each profile.

The number of soil analyses combined with the calculated chemical parameters was sufficient to compile a reasonably reliable chemical profile of the soils that were covered during the WODRIS study.

The soil chemical information from the ODRS, however, was insufficient to construct a chemical profile of the soils in the southern section of the Olifants River Basin from Keerom to Bulshoek Weir (Department of Water Affairs and Forestry, 1998). The terms of reference of the present study did not allow for any additional fieldwork, soil sampling and analyses. For that reason producers/farmers from Keerom to Bulshoek Weir were requested to submit any soils analyses that were done for soil preparation purposes. A total of 278 sets of analytical data were received. Unfortunately previous land use as well as soil type was seldom indicated on the analytical data sheets for the individual data sets. The complete data set is given in **Appendix A: Table 2.1**. The origin, type and number of analytical data sets received from producers/farmers are summarised in **Table 2.1**.

Table 2.1 Origin, type and number of analytical data sets received from producers/farmers in the Keerom to Bulshoek section of the Olifants River Basin

Sample group	Farm name	Nearest town	Type of sample	Number of data set or profiles	Number of samples
1	Brakfontein	Citrusdal	Composite	23	53
2	Brakfontein	Citrusdal	Profile	7	17
3	Maanskloof	Citrusdal	Composite	20	57
4	Cape Mango's	Clanwilliam	Profile	5	10
5	De Vlei	Clanwilliam	Profile	6	17
6	Radyn	Clanwilliam	Profile	48	96
7	Radyn	Clanwilliam	Composite	6	12
8	Radyn	Clanwilliam	Profile	8	16
Total number of samples					278

2.2 Discussion of chemical analytical data

2.2.1 Soil pH and extractable base cations

In the WODRIS study the soil analytical data were subjected to a correlation analysis to determine the potential influence of extractable base ions on pH_{KCl} (see **Table 2.2**). Extractable magnesium (Mg) and potassium (K) apparently had no direct influence on pH, while calcium (Ca; 1%) and sodium (Na; 5%) significantly influenced pH_{KCl}. A similar correlation analysis was done on the data from the Keerom to Bulshoek section (see **Table 2.2**). All the cations had a significant (1 %) influence on pH_{KCl}.

Table 2.2 Regression analysis of pHKCl by and extractable base cations

Variables		Parameter	Estimate	T-value and F-ratio	Probability Level	Correlation coefficient
Dependent	Independent					
Bulshoek Weir to the coast (WODRIS)						
pH_{KCL}	Extractable Ca	Intercept	1.7962	116.8380T	0.0000	
		Slope	0.0634	7.8315T	0.0000	
		Model^{Mult}		61.3317F	0.0000	0.5127$^{1\%}$
	Extractable Mg	NS				
	Extractable Na	Intercept	6.5108	69.8081	0.0000	
		Slope	0.0298	2.4138	0.0168	
		Model ^{Lin}		5.8262	0.0000	0.1810$^{5\%}$
	Extractable K	NS				
Keerom to Bulshoek Weir						
pH_{KCL}	Extractable Ca	Intercept	1.6394	180.1470	0.0000	
		Slope	0.1370	19.8032	0.0000	
		Model^{Mult}		392.1675	0.0000	0.7661$^{1\%}$
	Extractable Mg	Intercept	1.7550	116.0640	0.0000	
		Slope	01496	12.5594	0.0000	
		Model^{Mult}		157.7376	0.0000	0.6031$^{1\%}$
	Extractable Na	Intercept	1.8053	56.5000	0.0000	
		Slope	0.0780	6.0571	0.0000	
		Model^{Mult}		36.6883	0.0000	0.3431$^{1\%}$
	Extractable K	Intercept	1.9975	81.0128	0.0000	
		Slope	0.1805	16.3936	0.0000	
		Model^{Mult}		268.7509	0.0000	0.7024$^{1\%}$

Explanation of superscripts:

^{Mult}	Multiplicative model	$Y = aX^b$ *(Note: Intercept = Log a)*
^{Lin}	Linear model	$Y = a + bX$
^{T}	T-value	
^{F}	F-ratio	
NS	Non-significant	
$^{1\%}$	Significant at 1% level	
$^{5\%}$	Significant at 5% level	

The significant multiplicative relationship between Ca and pH_{KCl} in both sections implies that an equivalent increase in extractable Ca has a smaller effect on pH in the higher than the lower concentration ranges. According to the model calcium saturated system (soils with free lime) may attain a maximum pH_{KCl} of approximately 8.5.

Although Mg had no significant effect on pH_{KCl} in the WODRIS, in the area below Bulshoek Weir it had a significant effect, similar to that Ca, in the Keerom to Bulshoek Weir section.

The linear relationship between extractable Na and pH_{KCl} found in the WODRIS implies a continuous increase in pH as the Na concentration increases. In the Keerom to Bulshoek Weir section the relationship was similar to that of Ca. This would imply that sodic soils might have pH values greater than the 8.5 maximum associated with calcium saturated systems.

In the WODRIS the extractable base ions and pH_{KCl} were subjected to an analysis of variance by soil form (only topsoil data) and by diagnostic horizon or material.

According to the *WODRIS Soils and Irrigation Potential Report* (Provincial Government Western Cape, 2003) the average topsoil pH_{KCl} by soil form ranged from slightly lower than 6.0 for the Fernwood and Pinedene soils forms to as high as 7.7 for the Gamoep soil form with a hardpan carbonate subsoil horizon. pH_{KCl} as well as extractable Mg and K in topsoils differed significantly between soil forms, while Ca and Na are non-significant. The reason why Ca and Na were non-significant could be due to the very large standard error relative to average values. The average pH_{KCl} of topsoils was largely determined by the nature of the underlying subsoil. Garies with a red apedal B horizon on dorbank (usually without lime) had a lower pH_{KCl} than topsoils overlying subsoils that contain lime, e.g. neocarbonate B or soft or hardpan carbonate horizons. Although the difference in average topsoil extractable Ca by soil form was non-significant, higher Ca values were normally associated with neocarbonate B or soft and hardpan carbonate horizons.

The average topsoil extractable Mg by soil form was also strongly related to the nature of the underlying subsoil. Except for the Garies form, all the soil forms with a neocarbonate B, soft or hardpan carbonate horizon or dorbank, had very high average Mg values. This was also true for duplex soils with either a structured clay or gleyed loam/clay subsoil. Topsoil extractable Na had a similar tendency as topsoil extractable Mg.

The average pH_{KCL} and extractable Ca, Mg, Na and K differed significantly between the different subsoils.

Subsoils associated with duplex soils (e.g. E horizon, gleyed loam/clay, structured B) generally had the lowest average pH_{KCl} values. The average extractable Ca was moderate in comparison to the other horizons, while Mg, and to a lesser extent Na, was very high in comparison to the Mg in non-calcareous subsoils.

Non-calcareous B horizons (e.g. red apedal, neocutanic) had intermediate average pH_{KCl} values, and generally low average extractable Ca, Mg, Na and K values.

All the horizons containing free lime (e.g. neocarbonate B, soft and hardpan carbonate horizon, dorbank with lime) had very high average pH_{KCl} values, with exceptionally high average extractable Ca and Na, and to a lesser extent Mg and K.

Dorbank without lime had a fairly low average pH_{KCl} and extractable Ca value, but average extractable Mg, Na and K were very high.

It was impossible to analyse the analytical data received from producers in the Keerom to Bulshoek Weir section of the study area in the same manner as the WODRIS data. The reason was the unspecified nature of the samples in terms of soil form or family and diagnostic horizon. Although in a few cases composite soil samples were characterised with a map symbol that reflected the dominant soil form(s) of an area sampled, the detail was not sufficient for a detail analysis of variance by diagnostic horizon. For this reason only the average, standard deviation, minimum and maximum pH_{KCl} and extractable base cations were determined for each of the eight sample groups. Depending on how the soils were sampled, these values were determined in each group at two or three depths (see **Table 2.3**).

Soil sample groups 1, 2 and 3 are north of Citrusdal, group 4 is south of Clanwilliam Dam, group 5 is near Clanwilliam town and 6, 7 and 8 is north of Clanwilliam.

From **Table 2.3** it is evident that sample groups 1, 3 and 4 have the lowest average pH_{KCL} values. The highest average in these groups over the two or three sample depths is 4.6. Although the maximum pH_{KCL} could be as high as 6.5, the low standard deviation values indicate that most of the samples have an acidic pH. Average extractable Ca, Mg and Na are also very low in the upper sample depth (1). At sample depths 2 and 3 the average Ca, Mg and Na values are also low, although the standard deviation and maximum values are considerably higher than for the upper sample depth. The low pH_{KCL} and extractable cations are due to the slightly higher rainfall and predominantly sandy nature of the soils that most probably developed from Table Mountain Sandstone derived soil material. The higher maximum values in the second and third sample depths could be due to more clayey samples with a shale origin.

Table 2.3 Average, standard deviation, minimum and maximum pHKCl and extractable cations for each of the eight soil sample groups from Keerom to Bulshoek Weir

Sample depth	Number of samples	Statistical parameter	pH (KCl)	Extractable cations ($cmol_c$/kg)			
				Ca	Mg	Na	K
Sample group 1: Brakfontein, Citrusdal; composite samples							
1	23	Average (Std dev)	4.6 (0.8)	0.82 (0.50)	0.29 (0.21)	0.06 (0.03)	0.10 (0.06)
		Minimum - Maximum	3.5 – 5.8	0.30 - 2.31	0.10 - 1.01	0.03 - 0.13	0.04 – 0.32
2	23	Average (Std dev)	4.3 (0.9)	0.94 (1.43)	0.41 (0.49)	0.14 (0.28)	0.07 (0.05)
		Minimum - Maximum	3.4 - 6.5	0.20 - 7.16	0.06 - 2.02	0.03 - 1.4	0.02 – 0.19
3	7	Average (Std dev)	4.2 (1.0)	0.64 (0.46)	1.43 (1.96)	0.47 (0.68)	0.07 (0.05)
		Minimum - Maximum	3.2 - 5.6	0.25 - 1.53	0.11 - 5.68	0.04 - 1.86	0.02 – 0.17
Sample group 2: Brakfontein, Citrusdal; profile samples							
1	7	Average (Std dev)	5.1 (0.8)	1.56 (1.08)	0.70 (0.7)	0.17 (0.24)	0.15 (0.11)
		Minimum - Maximum	3.9 - 6.0	0.27 - 3.27	0.09 - 1.77	0.01 - 0.61	0.03 - 0.35
2	7	Average (Std dev)	4.8 (1.3)	2.85 (5.42)	1.74 (2.82)	0.64 (0.91)	0.10 (0.08)
		Minimum - Maximum	3.8 - 6.9	0.17 - 15.09	0.06 - 7.90	0.01 - 2.41	0.04 - 0.26
3	2	Average (Std dev)	4.5 (0.6)	0.90 (1.09)	1.68 (2.31)	2.19 (3.09)	0.04 (0.01)
		Minimum - Maximum	4.0 - 4.9	0.13 - 1.67	0.04 - 3.31	0 - 4.37	0.03 - 0.04

Table 2.3 (continued)

Sample depth	Number of samples	Statistical parameter	pH (KCl)	Extractable cations (cmolc/kg)			
				Ca	Mg	Na	K
Sample group 3: Maanskloof, Citrusdal; composite samples							
1	20	Average (Std dev)	4.6 (0.6)	0.73 (1.14)	0.32 (0.16)	0.08 (0.06)	0.09 (0.05)
		Minimum - Maximum	3.9 - 6.0	0.12 - 4.47	0.19 - 0.88	0.04 - 0.28	0.04 - 0.26
2	20	Average (Std dev)	4.2 (0.3)	0.36 (0.61)	0.28 (0.13)	0.08 (0.06)	0.06 (0.03)
		Minimum - Maximum	3.9 - 4.8	0.07 - 2.48	0.19 - 0.75	0.04 - 0.23	0.03 - 0.16
3	16	Average (Std dev)	4.0 (0.1)	0.20 (0.23)	0.26 (0.09)	0.07 (0.04)	0.05 (0.03)
		Minimum - Maximum	3.8 - 4.3	0.05 - 0.81	0.19 - 0.52	0.04 - 0.17	0.03 - 0.15
Sample group 4: Cape Mangos, Clanwilliam; profile samples							
1	5	Average (Std dev)	4.2 (0.8)	0.76 (1.02)	0.26 (0.31)	0.06 (0.06)	0.11 (0.09)
		Minimum - Maximum	3.5 - 5.5	0.11 - 2.55	0.05 - 0.8	0.02 - 0.16	0.03 - 0.27
2	5	Average (Std dev)	4.4 (1.4)	2.43 (4.88)	1.34 (2.55)	0.39 (0.72)	0.17 (0.21)
		Minimum - Maximum	3.2 - 6.7	0.06 - 11.15	0.02 - 5.88	0.01 - 1.67	0.03 - 0.53
Sample group 5: Die Vlei, Clanwilliam; profile samples							
1	6	Average (Std dev)	5.7 (0.8)	2.87 (1.6)	0.51 (0.09)	0.12 (0.04)	0.22 (0.05)
		Minimum - Maximum	4.4 - 6.5	0.98 - 4.95	0.34 - 0.61	0.06 - 0.16	0.16 - 0.27
2	6	Average (Std dev)	4.2 (0.6)	1.15 (0.67)	0.22 (0.08)	0.09 (0.07)	0.09 (0.02)
		Minimum - Maximum	3.6 - 5.1	0.27 - 2.01	0.12 - 0.34	0.03 - 0.19	0.07 - 0.13
3	5	Average (Std dev)	4.0 (0.4)	0.54 (0.43)	0.13 (0.07)	0.09 (0.07)	0.05 (0.02)
		Minimum - Maximum	3.6 - 4.5	0.10 - 1.16	0.03 - 0.21	0.01 - 0.16	0.02 - 0.08
Sample group 6: Radyn, Clanwilliam; profile samples							
1	48	Average (Std dev)	6.3 (0.8)	3.51 (3.89)	0.85 (0.59)	0.17 (0.12)	0.34 (0.19)
		Minimum - Maximum	4.3 - 7.8	0.57 - 22.34	0.21 - 2.87	0.03 - 0.56	0.12 - 0.91
2	48	Average (Std dev)	6.3 (0.9)	3.9 (4.75)	1.15 (1.06)	0.32 (0.29)	0.34 (0.23)
		Minimum - Maximum	4.2 - 7.9	0.29 - 23.05	0.23 - 4.71	0.06 - 1.23	0.13 - 1.07
Sample group 7: Radyn, Clanwilliam; composite samples							
1	6	Average (Std dev)	5.8 (1.1)	2.05 (1.0)	0.70 (0.33)	0.10 (0.02)	0.38 (0.14)
		Minimum - Maximum	3.9 - 6.9	0.62 - 3.28	0.3 - 1.15	0.06 - 0.12	0.24 - 0.64
2	6	Average (Std dev)	5.9 (0.9)	4.48 (7.68)	0.74 (0.65)	0.14 (0.05)	0.20 (0.07)
		Minimum - Maximum	4.9 - 7.4	0.97 - 20.15	0.4 - 2.07	0.09 - 0.21	0.08 - 0.3
Sample group 8: Radyn, Clanwilliam; profile samples							
1	8	Average (Std dev)	6.4 (0.6)	1.99 (1.0)	0.61 (0.20)	0.12 (0.16)	0.31 (0.07)
		Minimum - Maximum	5.5 - 7.3	0.73 - 3.67	0.41 - 0.99	0.01 - 0.49	0.23 - 0.41
2	8	Average (Std dev)	5.5 (1.0)	1.44 (0.71)	0.76 (1.01)	0.35 (0.69)	0.2 (0.07)
		Minimum - Maximum	3.9 - 6.4	0.88 - 2.89	0.29 - 3.25	0.03 - 2.04	0.14 - 0.36

Sample group 2 is from the same farm as group 1. The higher pH_{KCL} and extractable cations in group 2 could be due to the inclusion of samples from lands that have been limed in the past or it might be the result of a higher clay content (see **Appendix A: Table 2.1**).

The average topsoil pH_{KCL}, Ca and Mg of sample group 5 is higher than that of the groups between Citrusdal and Clanwilliam, but decreases with depth to similar values. The higher Ca and Mg in the topsoil are most probably due to liming.

Sample groups 6, 7 and 8 from the farm Radyn, between Clanwilliam and Bulshoek Weir, have on average the highest pH_{KCL}, Ca and Mg throughout the profile of all the sample groups. The range in pH_{KCL} and Ca values is generally high. Based on the exceptionally high Ca values of more that

20 $cmol_c$/kg in certain samples of groups 6 and 7, the soils probably contain free lime and might be associated with heuweltjies. These high pH soils with free lime are therefore similar to many soils in the WODRIS area.

It should be emphasised that the presence of free lime and associated high pH might influence land use, crop selection and fertilization. High pH_{KCl} and Ca values could have a serious effect on the solubility and plant availability of especially phosphorus (P) and trace elements such as copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe). Special attention should be given to P-fertilization. Crops sensitive to deficient levels of trace elements, especially Fe, could be seriously affected. Soil forms such as Addo, Coega, Knersvlakte, Prieska and Trawal in the WODRIS area generally contain extremely high concentrations of extractable Mg and Na in both top- and subsoils. Under dry land conditions these soils are generally saline and should be fairly stable to dispersion. Irrigation and salt leaching from the upper soil layers might decrease the salt concentration without affecting the ratio between extractable Mg+Na and Ca. The combined effect of the high Mg+Na could lead to a decrease in the physical stability of the soil material, especially when high quality (non-saline) irrigation water is used. This could lead to severe dispersion and crusting of topsoils, with a decrease in infiltration rate and permeability.

2.2.2 Water soluble and extractable base cations and soil paste resistance

During the WODRIS study 89 samples with a soil paste resistance of ≤ 500 ohms were analysed for water soluble cations and anions. Water content at saturation as a mass percentage and the electrical conductivity (expressed as mS/m) was determined. The soluble Ca, Mg, K and Na content (in mmolc/l extract) were used to calculate the sodium adsorption ratio SAR), and by subtraction, to correct the extractable base ions to exchangeable base ions (expressed in cmolc/kg soil).

Because standard soil analyses for agricultural purposes generally only determine the extractable base ion content of soils, regression models were developed between extractable and water-soluble base ions. The relationship between extractable and water soluble base ions was very strong, especially for monovalent Na ions. Although all the linear relationships are significant at the 1% level, the larger multiplicative correlation coefficients are indicative that, with an increase in the concentration of any particular extractable base ion, the relative solubility of the non-exchangeable fraction decreases. This difference is especially evident for K. This might imply that in addition to the effect of solubility, soluble K may also be affected by other physico-chemical reactions such as adsorption and exchange reactions. The following correlation models could be used to estimate the water-soluble base ion content of soils based on standard NH4-Ac extractable base ion analyses:

Soluble Ca = $-2.9984 \times \text{Extractable Ca}^{0.8607}$
Soluble Mg = $-2.5177 \times \text{Extractable Mg}^{1.0824}$
Soluble K = $-3.0467 \times \text{Extractable K}^{0.9402}$
Soluble Na = $-0.8766 \times \text{Extractable Na}^{0.9803}$
(*Note*: The intercept in a multiplicative model $Y = a X^b$ is Log a)

Based on the intercept of the linear relationships that increases from 0.0349 for Ca, 0.0577 for K, 0.1694 for Mg, to 0.4164 for Na, the relative solubility of Ca and K was very low (≤ 6 %). Mg had a solubility of approximately 17 %, while Na had a solubility of 42 %. The difference in relative solubility between Ca, Mg and Na might imply that the concentration of, and ratio between base ions, in drainage water from newly developed saline lands under irrigation, might follow the following pattern (Provincial Government Western Cape, 2003):

- Depending on the initial soluble salt content of the soil, as well as the degree of over-irrigation, the salt content in the drainage water during the initial leaching phase, might vary from fairly low to very high. Sodium will be the dominant ion, with decreasing quantities of Mg and Ca.
- With time the total salt content of the drainage water will decrease, with Na becoming less dominant, and a relative increase in Mg.
- In the latter stages the total salt content will most probably be relatively low, with Mg the dominant ion, followed by Ca and small concentrations of Na.

Although soil paste resistance (measured in a standard soil cup) is used by most institutions as an indicator of soil salinity, some institutions prefer to use saturated extract conductivity (in mS/m). The relationship between these two parameters was highly significant in the WODRIS and was used to estimate the electrical conductivity of saturated soil extracts (ECe) from soil paste resistance values.

The relationship between water soluble cations and anions, saturated soil paste resistance and ECe was also calculated. All the relationships were highly significant. The regression coefficients for Na, Cl, as well as for the sum of cations and for anions are particularly large. These regression models were used to estimate the soluble cation and anion concentration in cmolc/kg soil, and the ion mass in kg/ha/300 mm depth (soil bulk density 1 500 kg/m3), for soil paste resistance values from 500 ohms to as low as 25 ohms. Although the estimated cation concentration is approximately double the anion concentration at high resistance values, the total cation and anion concentration is approximately the same at low resistance values. Expressed in mass per volume of soil (surface area x depth), the total salt concentration increases exponentially with a decrease in resistance. The estimated salt mass is approximately 1 300 kg/ha/300 mm depth in soils with a resistance of 500 ohms, while at a resistance of 50 ohms it might be as high as 19 000 kg/ha/300 mm depth. In extremely saline soils, the total soluble salt load to a depth of 1.0 m might therefore be as high as 100 t/ha (Provincial Government Western Cape, 2003).

The multiplicative models should prove valuable to estimate the potential soluble salt load released during the initial phases of leaching dry land areas that are developed as new irrigated lands. Because of the ease and low cost of soil paste resistance measurements, large numbers of samples can be handled to characterise the soluble salt load from new lands.

Because soluble salts in soil have a direct and indirect effect on practices such as irrigation, drainage, fertilization and crop suitability, soil paste resistance values were used for an analysis of variance by diagnostic horizon/material by soil form to determine the difference between soil forms and localities in the WODRIS area. The results are summarised in **Table 2.4**.

Table 2.4 Average soil paste resistance of diagnostic horizons in the WODRIS area (Provincial Government Western Cape, 2003)

Diagnostic horizon	Soil paste resistance		Salinity class
	Average	Standard error	
	(ohms)		
Soft and hardpan carbonate horizon	59	8	Extremely saline
Dorbank with lime	65	9	
Saprolitic material	183	50	Very saline
Dorbank without lime	215	28	
Gleyed loam or clay subsoils	268	47	
Neocarbonate B	372	88	Moderately saline
Structured cutanic horizons	550	378	
Neocutanic B	906	369	Marginal
Orthic A	2 728	246	Non-saline
Red and Yellow-brown apedal B	3 613	437	
E horizon	5 786	1 535	

From the **Table 2.4** the following tendencies are evident:

- Red and yellow-brown apedal B and E horizons had the highest average resistance of 3 613 and 5 786 ohms, respectively. Orthic A horizons with an average resistance of 2 728 ohms formed a group between this group of highly leached (high resistance) diagnostic horizons and all the other diagnostic subsoil horizons or materials.
- Neocarbonate B and structured cutanic horizons were moderately saline, while neocutanic B horizons were marginally saline.
- Neocarbonate B horizons in soil forms with a soft or hardpan carbonate subsoil horizon varied from very saline in the Addo form (average resistance 131 ohms), to moderately saline in the Prieska form (average resistance 435 ohms). In the Trawal form with a dorbank subsoil, the average resistance was 1 165 ohms (non-saline). In certain Trawal form soils, however, the neocabonate B horizons could be saline.
- Dorbank horizons without lime were less saline than dorbank with lime. In the Garies, Knersvlakte and Trawal soil forms the average resistance in the non-calcareous variant was 256, 185 and 339 ohms, respectively, while in the calcareous variant the average value decreased to 81, 113 and 43 ohms, respectively. Along all the traverses the average resistance of the non-calcareous dorbank horizons was significantly higher than those of the calcareous variants.
- Soft and hardpan carbonate horizons were the most saline horizon type in the WODRIS area with average resistance values of < 100 ohms.
- Structured cutanic horizons in duplex soils were moderately to very saline with an average resistance value of 173 ohms.
- Gleyed loam or clay subsoil in duplex soils was moderately saline with an average resistance value of 232 ohms and standard error of 65 ohms. In Pinedene form soils these horizons were slightly less saline with an average resistance value of 339 ohms.

- Soil paste resistance of saprolitic (weathering shale) samples varied from very to moderately saline (90 and 200 ohms). Due to the low rainfall in the study area it should be expected that most saprolitic materials have a significant content of soluble salts.

The soil analyses received from farmers/producers in the Keerom to Bulshoek Weir section of the study area were unspecified in terms of soil form or diagnostic horizon sampled. An approach similar to that used for the WODRIS area could therefore not be followed. To develop a picture of the salinity hazard in the Keerom to Bulshoek section of study area the average, standard deviation, minimum and maximum resistance was determined for each group of samples by depth (see **Table 2.5)**.

Table 2.5 Average, standard deviation, minimum and maximum soil paste resistance (ohms) for six soil sample groups from Keerom to Bulshoek Weir

Sample group	Sample depth	Number of samples	Statistical parameter	Resistance (ohms)
1: Brakfontein, Citrusdal; composite samples	1	23	Average (Std dev)	7383 (3067)
			Minimum - Maximum	1662 - 14085
	2	23	Average (Std dev)	5697 (3736)
			Minimum - Maximum	116 - 13889
	3	7	Average (Std dev)	4063 (4155)
			Minimum - Maximum	450 - 11494
2: Brakfontein, Citrusdal; profile samples	1	7	Average (Std dev)	5696 (6415)
			Minimum - Maximum	820 - 18099
	2	7	Average (Std dev)	6468 (8166)
			Minimum - Maximum	653 - 22727
	3	2	Average (Std dev)	12865 (18068)
			Minimum - Maximum	89 - 25641
3: Maanskloof, Citrusdal; composite samples	1	20	Average (Std dev)	6005 (1778)
			Minimum - Maximum	3100 - 9300
	2	20	Average (Std dev)	8245 (2870)
			Minimum - Maximum	4100 - 15300
	3	16	Average (Std dev)	9213 (4180)
			Minimum - Maximum	3600 - 18000
4: Cape Mangos, Clanwilliam; profile samples	1	5	Average (Std dev)	7710 (5562)
			Minimum - Maximum	1290 - 14640
	2	5	Average (Std dev)	7332 (7673)
			Minimum - Maximum	50 - 19140
5: Die Vlei, Clanwilliam; profile samples	1	6	Average (Std dev)	923 (714)
			Minimum - Maximum	410 - 2200
	2	6	Average (Std dev)	1300 (1130)
			Minimum - Maximum	490 - 3400
	3	5	Average (Std dev)	1406 (801)
			Minimum - Maximum	630 - 2680
6: Radyn, Clanwilliam; profile samples	1	48	Average (Std dev)	1019 (815)
			Minimum - Maximum	130 - 3500
	2	48	Average (Std dev)	822 (659)
			Minimum - Maximum	170 - 2750

From **Table 2.5** it is evident that the average resistance of soil sample groups 1, 2, 3 and 4 over all depths is higher than 4 000 ohms, and generally with a high standard deviation. These high average values are an indication of low salt content. The high standard deviation in the subsoil of sample groups 1 and 2 is confirmed by minimum resistance values of lower than 120 ohms. These low values are an indication of a fairly high soluble salt content. Samples with low resistance values are apparently associated with wet or more clayey subsoil.

The minimum resistance in sample group 3 is greater than 3 000 ohms. According to the soil map symbols for sample group 3 the soils are generally moderately to well drained sands on mid and upper slope terrain positions. These soils are therefore well leached as confirmed by the high resistance values.

Although soil group 4 is apparently well leached, the minimum subsoil resistance is 50 ohms. The extractable Ca and Mg in that sample is very high and the soil is most probably contain free lime. The only explanation for this anomaly is that the sample represents the subsoil of a calcareous heuweltjie.

The average resistance of sample groups 5 increases from about 900 ohms in the topsoil to 1 300 and 1 400 in the second and third depth layers. The minimum resistance in all the samples is 410 ohms that is moderately saline. On average the soils of the sample group could be considered as non-saline.

In sample group 6 the average resistance decreases from about 1 000 ohms in the topsoil to 800 in the subsoil. The minimum resistance in both top- and subsoil is less than 200 ohms that is very saline.

From these results it is apparent that the soluble salt content in the soils increases from the south (sample groups 1, 2 and 3) to the north (sample group 6). This increase is associated with a decrease in rainfall from south to north as well as a greater contribution of shale, compared to sandstone, weathering products as parent material. Shale normally contains more bases than sandstone and could give rise to saline soils in areas with a low rainfall.

It is also apparent that certain soils between Clanwilliam and Bulshoek Weir are comparable to soils in the WODRIS area with calcareous subsoils in terms of soluble salt content.

2.2.3 Trace element content of topsoil horizons

Potentially plant available trace elements copper, zinc, manganese and boron were determined in a limited number of topsoil samples in the WODRIS study. A one-way analysis of variance by soil form showed that only copper (Cu) and manganese (Mn) differ significantly between soil forms, while zinc (Zn) and boron (B) were not significantly different between soil forms.

The sufficiency level of the various trace elements in the different soils was evaluated according to the sufficiency norms of Kotzé (2001). It was clear that:

- Except for one sample from a Coega form soil with a sufficient copper concentration of 2.48 mg/kg, all the other soils had a copper concentration far below the minimum sufficiency level.

- The maximum average zinc concentration was 1.25 mg/kg. This value is far lower than the minimum sufficiency level of 10 mg/kg.

- Except for the Clovelly, Pinedene, Fernwood, Oakleaf and duplex soils, with manganese levels of less than the 10 mg Mn/kg soil minimum sufficiency level, all the other soil forms had manganese concentration levels far above the maximum norm of 20 mg/kg.

- Soil forms with calcareous subsoil horizons generally had an average topsoil boron concentration slightly higher than the sufficient range of 0.2 - 0.5 mg/kg. Soils without free lime in the subsoil, however, had average topsoil boron concentrations in the low range.

To compare the trace element concentration between different soils, the concentration of individual trace elements in soil forms was rated from one, the lowest concentration, to 13, the highest concentration. An average rating was then calculated for individual soil forms. The rating for copper, manganese, and to a lesser extent zinc and boron, was fairly consistent for individual soil forms. The general tendency was that soil forms without calcareous subsoil horizons tend to group in the low average rating classes, while soils with calcareous subsoils group in the higher average rating classes. Although this implies that the extractable metal trace element concentration (Cu, Zn, Mn) is higher in the latter soils, the higher topsoil pH might limit the availability of these elements to plants; metal trace elements become less soluble with an increase in pHKCl above approximately 6.0. The availability of boron, however, increased with an increase in pH. This would imply that boron should be sufficient in these soils, and might even reach concentration levels that might be toxic to sensitive plants.

Only one set of trace element analyses was received from farmers/producers in the Keerom to Bulshoek Weir section of the study area. In **Table 2.6** the average, standard deviation, minimum and maximum copper (Cu), zinc (Zn), manganese (Mn) and boron (B) concentration at three sampling depths are given. According to the sufficiency norms of Kotzé (2001) the average and maximum Cu and especially Zn concentrations in the three sampling depths are below the minimum level. The average Mn in the topsoil samples is near the minimum norm (8.5 mg/kg vs. 10 mg/kg). In the subsoil samples the average Mn is far below the minimum norm. At all three depths the maximum Mn concentration, however, is more than the sufficient norm. The average B concentration at all three depths is just below the low norm of< 0.2 mg/kg. The maximum B concentration in the upper two sample layers is sufficient. The minimum B concentration, however, is far below the low norm.

Table 2.6 Average, standard deviation, minimum and maximum trace element concentration in sample group 3 (Maanskloof) in the Keerom to Bulshoek Weir section

Sample depth	Statistical parameter	Cu	Zn	Mn	B
		(mg/kg)			
0-300 mm	Average	0.90	0.64	8.52	0.16
	Standard deviation	0.24	0.62	7.34	0.07
	Minimum	0.40	0.10	1.00	0.10
	Maximum	1.40	2.30	31.00	0.33
300-600 mm	Average	0.80	0.60	3.50	0.16
	Standard deviation	0.30	0.69	4.38	0.07
	Minimum	0.50	0.10	1.00	0.10
	Maximum	1.80	2.90	18.00	0.34
600-900 mm	Average	0.70	0.43	2.25	0.15
	Standard deviation	0.28	0.32	2.84	0.05
	Minimum	0.20	0.10	1.00	0.10
	Maximum	1.20	1.50	12.00	0.24

From the WODRIS as well as Keerom to Bulshoek Weir trace element analyses it is clear that trace element deficiencies could be expected in many soils in the Olifants River Basin. In acid soils deficiencies could be ameliorated by soil application of trace element compounds before planting of perennial crops. On soils with a pH_{KCl} of > 5.5 the deficiencies can only be corrected with foliar sprays.

During the WODRIS boron was initially only determined in selected topsoil samples. Because of the potentially toxic boron levels in subsoil hardpan materials (personal communication - M du Preez) boron was determined in a number of subsoil hardpan samples. The average boron in hardpans by soil form ranges from as low as 1.0 mg/kg to as high as 28.4 mg/kg. The different hardpan types differed significantly at the 1% level. In dorbank without lime the average boron concentration was 8.1 mg/kg. The average boron increased to 13.6 mg/kg in dorbank with lime to 19.9 mg/kg in soft or hardpan carbonate horizons (Provincial Government Western Cape, 2003).

Although most of the hardpan samples had boron levels far higher than the 1.0 mg/kg toxic level, high boron levels is not considered as a limiting factor in the WODRIS area. M du Preez (personal communication), however, specifically referred to a new table grape development in the Melkboom area, where vine growth was severely affected by toxic boron levels in soils with calcareous hardpans. Only after intensive over-irrigation and leaching of soluble salts, including boron, did growth improve to an acceptable level. For any new irrigation development in areas with calcareous subsoils/hardpans the potentially toxic boron levels should be taken into consideration. Drainage water during the first number of years from such developments should therefore never be considered as an alternative source of irrigation water due to the toxic effect of the boron on commercial crops.

2.3 CHEMICAL AMELIORANTS

2.3.1 Extractable phosphorous and phosphate fertilizer requirement

During the WODRIS, 176 samples were analysed for extractable phosphorus. The Bray II method was used for samples with a pHKCl of ≤ 7.0, while the Olsen method was used for samples with a pHKCl of > 7.0. A one-way analysis of variance showed that the P-concentration in topsoil samples differed significantly (1 % level) between soil forms, with a significant difference by soil form for upper subsoils, lime pans and dorbank samples.

Topsoil P is significantly (1% level) related with a negative correlation coefficient to soluble salt load of the material. The higher the resistance, the lower the soluble salt load and the lower the extractable P concentration. This would imply that well-drained soils with a sandy red or yellow-brown apedal B horizon had low extractable P levels. Soils with a lower degree of leaching due to a higher clay content, lower slope position or associated with termite activity, will have a lower soil paste resistance and therefore higher extractable P levels. P in all horizons was significantly (1% level) correlated with pHKCl. The positive correlation coefficient indicated that P levels increased with an increase in pHKCl. This confirms the negative topsoil P by resistance correlation coefficient. As resistance decreased, the salt load and base saturation increased, free lime may even be present, and P levels increased (Provincial Government Western Cape, 2003).

A similar relationship was determined for the analytical date received from farmers/producers in the Keerom to Bulshoek section of the basin, as well as historic data used in the ODRS. The relationship was:

Phosphorous (mg/kg) = $-1.8918 \times pH_{KCl}^{3.0445}$ and
Phosphorous (mg/kg) = $7.2902 \times Ohms^{-0.5568}$
(*Note*: The intercept in a multiplicative model $Y = a X^b$ is Log a)

Extractable P increases in non-structured upper subsoils in the following manner:

E horizon (4.6 ± 1.7) < Red and Yellow-brown apedal B (5.9 ± 2.6) < Neocutanic B (13.8 ± 3.9) < Neocarbonate B (18.4 ± 7.2).

As the average P increased, soil paste resistance decreased and pH_{KCl} increased in a similar manner. A similar tendency of increasing average P values was determined for dorbank without lime 5.4 ± 2.1) < dorbank with lime (8.6 ± 4.9) < soft and hardpan carbonate horizon (20.0 ± 6.1).

The average topsoil P value by soil form ranged from as low as 2.0 - 3.0 mg/kg (Vilafontes and Pinedene form soils) to as high as 51.4 mg/kg (Oudtshoorn form soils). Generally, low average topsoil P values were associated with non-calcareous upper subsoils (e.g. Clovelly, Fernwood and Garies soil forms) and high average P values with calcareous subsoils (e.g. Prieska and Trawal soil forms).

In the Keerom to Bulshoek Weir section the average phosphorous in topsoils decreased from 54.2 ± 5.6 mg/kg to 39.0 ± 3.8 mg/kg and 18.9 ± 4.5 mg/kg, respectively in the upper and lower subsoil.

The reason why the WODRIS phosphorous levels are significantly lower than the Keerom to Bulshoek Weir levels is most probably due to the fact that all the WODRIS samples were from uncultivated or annually cropped soils, while many of the latter samples were from lands/camps that have been used for perennial crop and might have received considerable quantities of P fertilizer.

Although the WODRIS calcareous subsoils and topsoils associated with these calcareous horizons, generally contained fairly high concentrations of extractable P, the plant availability of the phosphate is questionable. Application of water soluble phosphate fertilizer to calcareous soils, generally leads to the formation of a series of products that become more basic and less soluble in water. Phosphates in calcareous soils high in calcium therefore have a low solubility and plant availability.

During soil preparation of new lands for vine or fruit production, producers are generally advised to ameliorate the P level in the soil to an optimum level of approximately 25 - 30 mg/kg. Although technical advisers may differ regarding the depth of amelioration, it is generally between 600 mm and 800 mm.

To compare the phosphate requirement of the soils in the WODRIS area, total P and single phosphate requirements were calculated to a soil depth of 600 mm. In soils where a hardpan horizon occurred within 600 mm from the soil surface, only 33% of the required phosphate for this particular material was used. The reason for a decreased P requirement was the hardness of the pans that break into large blocks and the low efficiency of mixing. The P requirement by soil form differed significantly (1% level). Soil forms with a calcareous horizon directly below the topsoil, or soils with a calcareous subsoil dorbank, had a zero (negative value) or relatively low average phosphorus and single super phosphate requirement to a soil depth of 600 mm. Most of the soil forms without any free lime within 600 mm soil depth had a P requirement of between 125 kg/ha to 225 kg/ha. This is equivalent to 1 250 kg to 2 250 kg of single super phosphate per hectare to raise the P level to 30 mg/kg soil to a depth of 600 mm.

The total P requirement was estimated for the Keerom to Bulshoek Weir samples to a depth of 900 mm and average and standard deviation were calculated on soil sample group basis. According to **Table 2.7** soil sample groups 1 to 4 from the Citrusdal to Clanwilliam have a phosphorous requirement that range from 170 to 350 kg/ha. This is equivalent to about 110 and 230 kg/ha for a depth of 600 mm. This is similar to the values obtained for the WODRIS. The phosphorous requirement for soil sample groups 5 and 6 north of Clanwilliam was, however, significantly lower (less than 40 kg P per hectare).

2.3.2 Extractable potassium and potassium fertilizer requirement

Potassium (K) is a very important plant nutrient and fairly large quantities are required by plants, e.g. 3 kg K for 1 ton of grapes. To maintain a good nutrient balance in soil, a generally accepted norm for K nutrition is a K soil content of approximately 5.5 % (sandy texture) to 4.5 % (loamy texture) of the cation exchange capacity (CEC ≈ sum of extractable base ions).

In soils, however, that have:

- a saturated soil paste resistance of < 500 ohms;
- a pH_{KCl} > 6.0;
- extractable Ca > 5.0 $cmol_c$/kg soil; and
- a history of lime or gypsum application

the K saturation norm does not apply because of the unrealistic high sum of extractable/exchangeable base ions. For such soils an optimum K concentration is used instead of the 4.5 – 5.5 saturation norm. Conradie (1994) recommended a K concentration of 50 mg/kg for sand, 70 mg/kg for loam and 100 mg/kg for clay. This is equivalent to 0.13, 0.18 and 0.26 cmolc K/kg soil, respectively.

In the WODRIS only seven topsoil samples had an extractable K level that required K fertilisation to increase the K status to the required concentration level or to 4.5 – 5.5 % K saturation (Provincial Government Western Cape, 2003). From the WODRIS results it was evident that except for certain highly leached, yellow-brown or bleached, sandy soils (e.g. Clovelly, Fernwood, Pinedene and Vilafontes form), with relatively low levels of extractable K, all the other soils had high to very high levels of K. Even the red apedal B horizon of the Garies soil form had an average K status of 81(± 8) mg/kg soil.

Table 2.7 Average, standard deviation, minimum and maximum phosphoros requirement to a depth trace 900 mm in sample groups in the Keerom to Bulshoek Weir section of the Olifants Doring River Basin

Statistical parameter	Gypsum	Dolomitic lime 1)	Calcitic lime	Phosphorus	KCl 2)	KCl 3)
	(t/ha)			(kg/ha)		
Sample group 1: Brakfontein, Citrusdal; composite samples						
Average (Std dev)	1.6 (4.3)	0.6 (0.8)	9.2 (9.1)	292 (77)	326 (167)	107 (115)
Minimum – Maximum	0 - 17.8	0 - 2.3	0 - 27.2	72 - 369	0 - 576	0 - 432
Sample group 2: Brakfontein, Citrusdal; profile samples						
Average (Std dev)	3.4 (7.1)	0.7 (1.1)	13.1 (11.2)	275 (66)	280 (152)	163 (177)
Minimum – Maximum	0 - 19.1	0 - 2.7	0 - 27.3	198 - 374	0 - 464	0 - 521
Sample group 3: Brakfontein, Citrusdal; composite samples						
Average (Std dev)	0 (0)	0 (0)	9.6 (4.4)	170 (108)	386 (136)	46 (57)
Minimum – Maximum	0 - 0	0 - 0	3.3 - 19.9	12 - 387	112 - 606	0 - 255
Sample group 4: Mangos, Clanwilliam; profile samples						
Average (Std dev)	3.2 (4.5)	0.9 (1.1)	9.5 (8.4)	351 (41)	308 (250)	6 (12)
Minimum – Maximum	0 - 9.8	0 - 2.5	0 - 21.5	286 - 397	0 - 571	0 - 28
Sample group 5: Die Vlei, Clanwilliam; profile samples						
Average (Std dev)	0.6 (1.4)	2.9 (1.5)	7.8 (7.7)	13 (20)	196 (68)	97 (119)
Minimum – Maximum	0 - 3.5	1.2 - 5.6	0 - 18.3	0 - 45	85 - 290	0 - 317
Sample group 6: Radyn, Clanwilliam; profile samples						
Average (Std dev)	3.1 (5.1)	2.1 (7.2)	0.4 (1.4)	33 (70)	0 (2)	0 (0)
Minimum – Maximum	0 - 24.5	0 - 38.1	0 - 6.8	0 - 282	0 - 14	0 - 0
Sample group 7: Radyn, Clanwilliam; composite samples						
Average (Std dev)		1.8 (4.4)	0.8 (1.8)		94 (109)	0 (0)
Minimum – Maximum		0 - 10.7	0 - 4.4		0 - 244	0 - 0
Sample group 8: Radyn, Clanwilliam; profile samples						
Average (Std dev)		0.1 (0.1)	0.4 (0.8)		1 (2)	0 (0)
Minimum – Maximum		0 - 0.3	0 - 2.1		0 - 7	0 - 0
Sample group 9: NIWW experimental farm, Lutzville; profile samples						
Average (Std dev)	6 (9.7)	0 (0)	0 (0)		0 (0)	0 (0)
Minimum – Maximum	0 – 23.6	0 – 0	0 - 0		0 - 0	0 - 0
Sample group 10: De Wet, Trawal; profile samples						
Average (Std dev)	2.2 (5)	0 (0)	0 (0)		0 (0)	0 (0)
Minimum – Maximum	0 – 17.2	0 – 0	0 - 0		0 - 0	0 - 0
Sample group 11: Rudman *et al*. 1978, Vredendal-Vanrhynsdorp; profile samples						
Average (Std dev)	39.7 (46.8)	0 (0)	0 (0)		97 (121)	0 (0)
Minimum – Maximum	0 – 137.4	0 – 0	0 - 0		0 - 269	0 - 0
Sample group 12: Brink farm samples, Vredendal-Vanrhynsdorp; profile samples						
Average (Std dev)	3.2 (5.5)	0 (0)	0 (0)		31 (51)	16 (40)
Minimum – Maximum	0 – 18.9	0 - 0	0 - 0		0 - 180	0 - 114

1) Dolomitic lime with 8.7% magnesium.
2) Optimum K concentration based on texture: sand 50 mg/kg; loam 70 mg/kg; clay 100 mg/kg.
3) Based on potassium saturation in soil with pH <6.0, resistance >500 ohms and extractable Ca <5.0 cmol/kg: sand 5.5% and loam 4.5% K saturation.

The K requirement for the farmer/producer analytical data from Keerom to Bulshoek Weir and historic data used in the ODRS was estimated using both the optimum concentration and saturation percentage guidelines (see **Appendix A: Table 2.2**). The average, standard deviation, minimum and maximum K requirement were calculated for each sample group (see **Table 2.7**).

The K requirement based on optimum K concentration was consistently higher than the requirement based on K saturation percentage. A possible reason for this difference is the sandy texture and low CEC of many soils in the study area. With a CEC of 1.5 $cmol_c$ /kg, a K saturation percentage of 5.5 % is 0.08 $cmol_c$ K/kg. This value is significantly lower than the optimum K concentration of 0.13 $cmol_c$ K/kg (Conradie, 1994).

The average K requirement based on K saturation percentage for sample groups 1 to 5 south of Clanwilliam range from 6 kgK/ha to as high as 163 kgK/ha to a depth of 900 mm. The equivalent values based on K concentration are 196 kgK/ha to 386 kgK/ha. Based on saturation percentage no potassium is required for all the sample groups north of Clanwilliam. This is comparable to the very low K requirement recorded in the WODRIS. Based on K concentration the K requirement range from zero to a maximum of 100 kgK/ha.

Based on these results the K levels in most of the soils north of Clanwilliam is sufficiently high only to require maintenance K application, or high enough that during the first number of years after planting no K fertilisation is required for crops such as wine grapes. Vegetables may, however, require some maintenance K. Under normal farming conditions potassium should therefore never be a serious nutrient limitation in irrigated crop production.

In the section south of Clanwilliam the natural K levels are low and would require amendment. Due to the very sandy and permeable nature of most soils in this area K cannot be used as a pre-plant soil ameliorant because most of the applied K will be leached from the root zone before it can be used be the newly established crop; e.g. citrus or grapes. A judicious program of K fertilization after planting should be followed to maintain the plant available K concentration in the soil at an optimum level.

2.3.3 Lime requirement

Different crop types have specific soil pH ranges where the crop has the best performance. For most crops, particularly vines and deciduous fruit, the ideal pH is approximately 5.5 measured in KCl. Citrus and other subtropical plants, however, are adapted to slightly lower pH values. Certain pasture crops, e.g. lucerne and medics, prefer a pH_{KCl} of closer to 6.0, while potatoes do best at $pH_{KCl} < 5.0$. When pH is lower than the crop specific ideal range, growth is inhibited by the presence of toxic elements, generally aluminium and manganese. At very low pH values, phosphate solubility is also very low.

Due to the low average annual rainfall in the study area north of Clanwilliam, acid soils ($pH_{KCl} \leq 5.5$) are rare. During the WODRIS less than 12 % of the samples that were analysed, had a $pH_{KCl} \leq 5.5$. Based on the average pH_{KCl} by soil form, the Pinedene form had the lowest average pH_{KCl} of 5.4($\pm$0.3), followed by Clovelly (5.7$\pm$0.3) and the duplex soils (6.9$\pm$0.3). The average pH_{KCl} for all the other soil forms was greater than 6.0. Based on these observations, it could be expected that only the following soil complexes would require lime to improve the soil pH: A 1, A 3, A 7, B 2, B 4, D 5 and H 2 (Provincial Government Western Cape, 2003).

The calculation of lime requirement is based on the relationship between R-value and pH_{KCl}, where R-value is the ratio between extractable Ca+Mg and acidity extracted with a pH 7 buffered solution. In soils with an inverse Ca:Mg-ratio, 1.25Ca is used instead of Ca+Mg. According to Eksteen (1969) an ideal pH_{KCl} of 5.5 is equivalent to R=10. The lime requirement (t/ha for a

300 mm thick soil layer) of acid WODRIS soil samples was generally less than 4 t/ha. In a few instances the requirement was very high; more than 10 t/ha/300 mm). The total lime requirement for an amelioration depth of 900 mm, can, however, be as much as 20 t to 30 t on a hectare basis (Provincial Government Western Cape, 2003).

The total lime requirement to a depth of 900 mm was calculated for the Keerom to Bulshoek Weir section of the study area based on analytical data from producers/farmers (see **Appendix A: Table 2.2**). Because of the low extractable magnesium concentration in many samples south of Clanwilliam the dolomite requirement was calculated for dolomite containing 8.7 % Mg according to the equation of Kotzé (2001). The calcitic lime is the difference between the total lime and dolomite requirements. Based on the lime (calcitic and dolomitic) requirement of individual profile or sample sets, the average, standard deviation, minimum and maximum lime requirement were calculated for the different sample groups (see **Table 2.7**).

From **Table 2.7** it is evident that for sample groups 1 to 5 that the average calcitic lime requirement is fairly high. It ranges from 7.8 t/ha/900 mm depth (sample group 5) to 13.1 t/ha/900 mm depth (sample group 2). The dolomitic lime requirement for these sample groups ranges from zero to 2.9 t/ha/900 mm depth.

Sample groups 6 to 8 north of Clanwilliam have a lower lime requirement compared to the groups to the south; the calcitic lime is < 1 t/ha/900 mm depth and dolomitic lime is < 2 t/ha/900 mm depth.

The pH of the soils in the other sample groups from the dry section north of Bulshoek Weir was high and a dolomitic and calcitic lime requirement of zero.

The difference in lime requirement between individual pits in the WODRIS and the large standard deviation in lime requirement in sample groups south of Clanwilliam imply that soils should intensely be sampled before establishing perennial crops under irrigation. Based on pH analyses the spatial extent of low pH soils can be identified and these areas can then be correctly limed. This will also ensure that lime is not applied in areas with pH values of more than 5.5 that could lead to nutritional problems.

2.3.4 Gypsum requirement

The concentration and ratio between exchangeable base cations vary considerably between soils and between horizons within a soil. The ideal ratio between base cations is 75 : 15 : 5 : <5 for Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} respectively. Any significant deviation from this ratio may have an effect on nutrient availability, plant growth and on the physical stability of the soil material. The nutritional aspects can be accommodated and managed within normal fertilizer programs. For instance, a low K concentration and ratio can be eliminated by judicious K fertilization.

The effect on the physical properties of an imbalance between Ca, Mg and Na, however, is more difficult to manage. Under relatively low levels of soluble salts in soils, a high Na, and to a lesser extent Mg, saturation normally leads to dispersion of soil clay particles. On drying this could lead to compaction, hard-setting and the formation of surface crusts. Under such conditions the soil is dense, has a low porosity, is poorly aerated and has a low infiltration rate. Generally, an exchangeable Na saturation percentage (ESP) of 15 % is considered as the upper limit of stability.

Many Southern African soils, for whatever reason, are unstable at ESP values as low as 5 - 7. In the past, Mg was considered as a favourable cation, comparable to Ca. Emerson and Bakker (1973), however, showed that as Na is removed from soil through leaching, Mg will replace Na as the dispersing ion.

Soils with a sufficiently high salt content to prevent dispersion under normal conditions could become sensitive when irrigated with good quality water (low EC value) and partial leaching of the free salts.

A low Ca:Mg-ratio may also have a significant effect on Ca uptake by crops that might affect product quality. Although this is not recognised as a limiting factor in wine grapes, it could significantly affect table grapes, citrus and deciduous fruit, to such an extent that quality and shelf life are so poor that the product is unsuitable for export.

A large percentage of the WODRIS soil types that were analysed and qualified as naturally dispersive soils, will become dispersive on leaching, or could affect product quality. The standard approach to ameliorate such soils is to lower the ESP by gypsum application and leaching of excess soluble salts (Richards, 1954). Emerson and Bakker (1974), however, recommended Mg- and Na replacement by Ca through gypsum application to an exchangeable Mg+Na saturation of approximately 33%.

Both approaches are based on exchangeable cation concentration. In South Africa, however, most laboratories only determine extractable base cations not corrected for the soluble components. The gypsum calculation model of Emerson and Bakker (1973) was adapted by Lambrechts and Saayman (1994) to use extractable base cations and not exchangeable ions. Due to the potential negative effect of Mg on product quality, it was decided to use a 20 % Mg+Na saturation and not the recommended 33 % saturation of Emerson and Bakker (1994). In the case of horizons with a lime requirement, the gypsum requirement is corrected for the equivalent Ca contribution from the lime.

In the WODRIS the average gypsum requirement in t/ha/150 mm soil depth, was determined by diagnostic horizon by soil form (Provincial Government Western Cape, 2003). The average gypsum requirement was fairly similar for the orthic A, E, red and yellow-brown apedal B and neocutanic B horizons; approximately 1.2 - 1.5 t/ha/150 mm soil depth. The average requirement of the orthic A by soil form ranged from zero in the Coega form, to as high as 3.6 t/ha/150 mm in the Addo form. The neocarbonate B horizon had on average the lowest subsoil gypsum requirement.

The hardpan horizons had the highest gypsum requirement. In dorbank without lime, the average requirement was the highest at 5.7 t/ha/150 mm. Between soil forms, however, there is a very large variation. In well-drained red and yellow-brown sandy soils, the dorbank had a very high gypsum requirement, while in those soil forms with free lime in the subsoil the requirement was zero, e.g. Addo. In hardpans with free lime the average gypsum requirement ranged from 2.2 to 2.7 t/ha/150 mm.

In structured cutanic horizons, and gleyed loam or clay subsoils the gypsum requirement was generally very high, with respective average values of 6.4 and 9.7 t/ha/150 mm.

The gypsum requirement of individual horizons was used to calculate the requirement to a depth of 900 mm for individual soil profiles. Although there was no statistical significant difference in the gypsum requirement to 900 mm between soil forms, the average requirement differed greatly between soils. Duplex, Knersvlakte and Oudtshoorn soils had the highest gypsum requirement; approximately 28, 26 and 23 t/ha/900 mm, respectively. The average for the Garies soils was approximately 14 t/ha/900 mm, while the requirement for all the other soils is less than 10 t/ha/900 mm.

The standard error in gypsum requirement for individual soil forms was very high. The variation within soil forms could be so high that it is essential that individual soil profiles should be analysed to determine the actual gypsum requirement for amelioration to a depth of 900 mm. This was especially important for those soil forms with a high requirement. The difference between a 10 *vs.* a 30 t/ha/900 mm gypsum requirement could have serious financial as well as ecological implications.

The gypsum requirement was determined for the farmer/producer analytical data from Keerom to Bulshoek Weir and historic data used in the ODRS in a similar way as for the WODRIS samples (see **Appendix A: Table 2.2**). The average, standard deviation, minimum and maximum gypsum requirement to a depth of 900 mm were determined for those sample groups where the analytical data included soil paste resistance that is used in the Lambrechts and Saayman (1994) model to determine gypsum requirement. From **Table 2.8** it is evident that the average gypsum requirement for sample groups 1 to 6 from Keerom to Clanwilliam is less than 3.5 t/ha/900 mm. Sample group 3 had a zero gypsum requirement. Most of the soils in these sample groups are sandy and have developed from low salt containing Table Mountain sandstone weathering products. The soils are mostly non-saline with low concentrations of extractable Na and Mg and should have a zero a very low gypsum requirement. The high standard deviation as well high maximum gypsum requirement (as high as 19 t/ha/900 mm) in sample groups 1, 2, 4 and 5, however, is an indication that saline soils with high concentrations of extractable Na and Mg do occur in the area between Keerom and Clanwilliam. These soils are most probably associated with more clayey shale weathering products.

The average gypsum requirement of sample groups 9 to 12 north of Bulshoek Weir to the coast is generally higher than for samples groups 1 to 6 to the south. Especially in sample group 11 the average gypsum requirement is nearly 40 t/ha/900 mm with a maximum of 47 t/ha/900 mm. These higher values are comparable to certain values for the WODRIS.

As input cost guideline the mean and standard error of the gypsum requirement (t/ha to a depth of 900 mm) was calculated on a soil form basis (see **Table 2.8**). These values should, however, be used with caution because of the very large standard errors.

2.3.5 Leaching requirement

Many soils in the Olifants River Basin are saline and require leaching to decrease to soluble salt content for sustainable crop production under irrigation. Leaching requirement is defined as the fraction of irrigation water that must be leached through the root zone to control soil salinity at any specific level. The leaching requirement is the ratio of the equivalent depth of drainage water (Ddw) to the depth of irrigation water (Diw). It is generally expressed as a percentage or fraction.

This ratio is equal to the inverse ratio of the corresponding electrical conductivity of the drainage (EC_{dw}) and irrigation water (EC_{iw}):

$$LR = D_{dw} \div D_{iw} = EC_{iw} \div EC_{dw}$$

Table 2.8 Gypsum requirement to a soil depth of 900 mm by dominant soil form in the WODRIS (2003)

Soil form	Gypsum requirement in ton per ha per 900 mm soil depth	
	Count	Average (Std Error)
Addo	2	8.0 (2.6)
Clovelly	3	6.1 (1.9)
Gamoep	2	5.1 (3.9)
Garies	10	13.6 (3.2)
Hutton	3	8.1 (1.1)
Knersvlakte	10	26.2 (6.3)
Oudtshoorn	9	23.3 (9.5)
Prieska	5	5.5 (3.7)
Trawal	4	8.1 (5.7)
Duplex	6	27.6 (4.3)
Heuweltjie	12	6.7 (2.3)

For field crops an EC_{dw} value of 800 mS/m is generally considered as the upper limit of salt tolerance. For irrigation water with conductivities of 100, 200 and 300 mS/m, the respective leaching requirements will be 13 %, 25 % and 38 %. The quality of the irrigation water used along the Olifants River Basin is extremely good, with conductivity as low as 25 mS/m. This implies a leaching requirement of ≤ 3 %.

The problem in the WODRIS area is the naturally high soluble salt content in many of the soils that are potentially suitable for irrigated crop production. These soils should therefore be leached to remove soluble salts to a specific soil salinity level. If an EC_{dw} of 800 mS/m is used as the upper limit of salt tolerance, it implies that the average soluble salt content should be lowered to approximately 100 me/l throughout the soil. A more acceptable and sustainable EC_{dw} of 400 S/m would imply that the salt content should be lowered to 50 me/l.

Based on the depth weighted mass of NaCl to a depth of 1 200 mm the volume of water required to dilute the NaCl to a concentration of 100 me/l and 50 me/l, was calculated for individual profiles during the WODRIS study.

Because the concentration of Na^+ and Cl^- in saturated soil water extracts could be as low as 50 % of the total potentially soluble NaCl, the volume of water required to dilute the soluble salt content to 100 me/l or 50 me/l could therefore be considerably larger than the volume based only on soluble NaCl. In addition, soluble Ca^{2+}, Mg^{2+}, K^+ and SO_4^{2-} ions are also present in the saturated water extract. The estimated volume of dilution water is therefore conservative.

The rate at which soluble salts could be leached from soil depends on various factors that may include type of salt, infiltration rate, sealing of the soil surface, hydraulic conductivity, evaporation and removal rate of drainage water. If a moderate to high infiltration and hydraulic conductivity rate is maintained over time (surface applied gypsum, organic mulching), the initial drainage water will be very salty. With continued leaching, the salt concentration will over time decrease exponentially to a concentration level that should be a function of the ratio between D_{dw} and D_{iw}.

It is possible to leach soil to the required salt concentration level in one irrigation season or year for soils with a fairly low salinity. It is, however, impractical for the more saline soils. Five years is most probably a more realistic time period. The ratio of the total volume of water required to dilute the salts in a soil to a concentration of 100 me/l or 50 me/l over five irrigation seasons could probably be used as an index of the "leaching requirement" of the different soils. Assuming an annual irrigation water requirement of 10 000 m^3, and a dilution water volume of 5 000 m^3 and 10 000 m^3 for a 100 me/l and 50 me/l salt concentration, respectively, the leaching requirement would be:

5 000 m^3 ÷ (10 000 m^3 x 5 years) x 100 = 10 %, and
10 000 m^3 ÷ (10 000 m^3 x 5 years) x 100 = 20 %.

After the initial five year leaching period, a standard leaching requirement based on the EC_{iw} and required EC_{dw} should be used.

In **Table 2.9** the estimated leaching requirement for a salt concentration of 100 and 50 me/l in the leaching water, as well as an average recommended leaching requirement, are given by dominant soil form in the Olifants River Basin.

Table 2.9 Estimated and recommended elaching requirement for two elaching water salt concentrations for the dominant soils in the Olifants River Basin (Provincial Government Western Cape, 2003)

Soil form	Salt concentration of leaching water		Recommended leaching requirement (%)
	100 me/l	50 me/l	
	Leaching requirement (%)		
Addo	12	25	20
Coega	20	39	30
Clovelly	1	1	0
Fernwood	0	0	0
Gamoep	10	20	15
Garies	2	4	< 5
Glenrosa	3	7	5
Hutton	0	1	0
Kroonstad	2	4	< 5
Klapmuts	3	6	5
Knersvlakte	10	19	15
Oakleaf	4	9	5
Oudtshoorn	13	26	20
Pinedene	1	1	1
Prieska	16	33	25
Sterkspruit	12	24	20
Trawal	12	25	20
Vilafontes	3	5	< 5
Duplex (general)	6	12	10
Heuweltjie	12	24	20

3. IRRIGATION WATER REQUIREMENT

3.1 Introduction

The water requirement of any particular crop for optimum/maximum growth and production is determined by those salient climatic conditions (*inter alia.* temperature, humidity, wind) that affect evaporation and transpiration; generally referred to as evapo-transpiration. Under any specific combination of climate, crop type, tree manipulation practice, etc., transpiration is a fairly constant component of total evapo-transpiration. Evaporation, however, is a variable component and depends on the water application method (e.g. drip, micro, sprinkler, centre pivot and flood irrigation), the depth of water applied per irrigation, and the soil surface area wetted during irrigation.

Long-term monthly average rainfall and A-pan evaporation data is generally used to calculate crop water requirement for design and planning of irrigation systems. On-land irrigation water requirement, however, is based on short-term (daily; weekly) measured rainfall and evaporation data.

The standard method used in South Africa to predict the water requirement of crops is based on evaporation from an open water surface; so called *class A-pan evaporation data*. These values, however, have to be converted to "actual" water requirement by a so called *crop conversion factor*. The crop factor is a variable value that changes with :

(i) growth stage of the plant,
(ii) type of plant/crop
(iii) irrigation system, and
(iv) irrigation scheduling.

In the deciduous fruit, citrus and grape industries a number of crop factor suites are recommended by researchers and used by technical advisors. The eight crop factors suites generally used to estimate the irrigation water requirement for these crops under different conditions are the following:

- table grapes on sandy soils, De Doorns, according to Saayman (1996);
- wine grapes on a 14-21 day irrigation cycle according to P Myburgh, RIOV, Nietvoorbij (personal communication);
- wine grapes on a 7 day irrigation cycle according to P Myburgh, RIOV, Nietvoorbij (personal communication);
- wine grapes on a 3-4 day irrigation cycle according to P Myburgh, RIOV, Nietvoorbij (personal communication);
- early season deciduous fruit according to Infruitec E.5 (1988);
- middle season deciduous fruit according to Infruitec E.5 (1988);
- citrus according to Infruitec E.5 (1988); and
- citrus according to Institute for Soil, Climate and Water (ISCW).

The crop factors for vegetables are according to the guidelines set out in *Estimated irrigation requirements of crops in SA* (1985).

A factor that has a significant effect on annual irrigation water requirement of crops is the nature, seasonal distribution and amount of rainfall. In the northern part of Olifants River Basin the average annual rainfall is fairly low (see **Appendix A: Table 3.1**) with a high monthly standard deviation. Under these conditions the contribution of rainfall to the actual long-term water requirement of irrigated crops is so small that it can be omitted from any calculation concerning irrigation water requirement. In the southern section of the basin the average annual rainfall is significantly higher with a relatively lower seasonal variability. In these areas rainfall contributes significantly to the annual water requirement of crops, and decreases the irrigation water requirement. According to the WODRIS study the average annual rainfall gradually increases from less than 200 mm per annum near the coast (e.g. Ebenhaeser and Lutzville) to a maximum of 400 mm south of Citrusdal.

The total measured amount of rain, however, cannot be considered as effective available water in soil for crop requirements. Although a large range of factors might decrease the effectiveness of rain, the main reasons are :

(i) evaporation from exposed soil or plant surfaces
(ii) runoff during heavy showers, and
(iii) percolating losses.

Various approaches are used to convert measured rain to effective rain. In cases where daily measurements are available, any rainfall incident of less than 10 mm precipitation is usually considered as zero effective. The field water capacity of the soil to a predetermined rooting depth is used to calculate the amount of rain required to saturate the soil to field capacity. Excess rain is also considered as not effective in the water balance calculation.

Other factors that influence the effectivity of rain include the following:

- In vegetated situations (pastures, maize, fruit trees, grape vines) a certain volume of rainwater is required to wet the above ground part of the growing crop. This amount can vary greatly between crop types and growing stage. The amount of water required to wet the crop/plant may also increase through evaporation during the rain incidence. The volume evaporated depends on wind intensity and humidity. Only rain in excess of that required for crop/plant wetting could be considered as effective.

- The spatial distribution of the rainwater in excess of the crop/plant wetting requirement could be affected by crop type and plant management practices. In the case of full cover pastures the excess water would most probably reach the soil surface in a spatially evenly distributed manner. In central leader pruned fruit orchards, however, it could be expected that the excess water would tend to flow along the outside surface of the tree canopy with very little water going vertically through the trees. This results in a low precipitation under the trees with significantly higher precipitation along the drip zone on both sides of tree rows. This uneven wetting will affect the effectiveness of that fraction of the rain that reaches the soil surface.

- Effectivity is further affected by water infiltration rate (IR) and precipitation rate (PR). As long as IR > PR, the water could be considered as essentially effective. Depending on slope and row direction, a certain proportion of the positive difference between PR-IR may accumulate as free water on the soil surface. At the end of the rain incidence, this free water may infiltrate into the soil. On moderately to fairly steep slopes (>5% slope) and in situations where row direction is not parallel to the contour, however, the free water will laterally flow out of the land or orchard. This could significantly affect the effectiveness of the rain.

- Although the soil infiltration rate is largely determined by inherent soil properties (e.g. soil texture, organic carbon content, exchangeable base cations), soil surface management practices could have a significant influence on the specific infiltration rate in certain soils. In vineyards for instance, soil surface management practices that include mulching or winter cover crops, increase infiltration (and permeability) rate compared to clean cultivation.

- Soils mechanically loosened for fruit and grape vine plantings, are initially very loose and open with high infiltration rates. Certain soils in the Olifants River Basin, however, are physically unstable and tend to re-compact and develop surface crusts subsequent to mechanical loosening. The initially high infiltration rate will therefore decrease over time and the effectiveness of applied water will also decrease due to more runoff.

- Another factor that may influence rain effectiveness is the rooting depth under specific plant-soil conditions and the water holding capacity of the soil within the rooting zone. In situations with a fairly shallow rooting depth, excess water could be lost through drainage. The deeper the effective rooting depth, the smaller the drainage loss, and therefore a higher effectivity of the rain.

- The relative rate of lateral water distribution compared to permeability in a particular soil may also affect rainfall effectivity. In highly permeable soils with a fairly slow lateral distribution rate, a spatially uneven application of water may result in severe drainage losses from zones with high application rates compared to zones with a low application rate. In soils with higher lateral distribution rates, less water will be lost through drainage.

3.2 Irrigation water requirement determined in the ODRS

In the ODRS 13 weather stations with A-pan evaporation data were used to estimate the irrigation water requirement for a variety of crops. Seven of these stations occur in the present defined study area for the raising of the Clanwilliam Dam from Keerom to the coast. The evaporation data included average daily, plus-minus the standard deviation, and total annual evaporation based on monthly averages (see **Appendix A: Table 3.2**). It is evident that the daily standard deviation A-pan evaporation is fairly high especially during summer at certain weather stations, e.g. Vredendal. There is also no distinct pattern in the total annual A-pan evaporation from Keerom to the coast. The cooler Lutzville station had a higher annual evaporation than Citrusdal PP and Augsburg that is much warmer. This could be due to a higher average wind-run of 166 km day^{-1} at Lutzville compared to 108 km day^{-1} at Augsburg.

In **Table 3.1** the crop factors that were used to estimate the irrigation requirement for deciduous fruit, citrus and grapes are listed.

Table 3.1 Crop factors suites for deciduous fruit, citrus and grapes

Month	Saayman [1]	Myburgh 14-21 days [2]	Myburgh 7 days [3]	Myburgh 3-4 days [4]	Fruit early [5]	Fruit middle [6]	Citrus Infruitec [7]	Citrus ISCW [8]
Jul	0.20	0.25	0.25	0.25	0.20	0.20	0.50	0.45
Aug	0.20	0.25	0.25	0.25	0.25	0.20	0.40	0.45
Sept	0.20	0.36	0.28	0.33	0.30	0.27	0.40	0.45
Oct	0.30	0.46	0.46	0.56	0.40	0.35	0.40	0.45
Nov	0.36	0.52	0.62	0.72	0.45	0.40	0.40	0.45
Dec	0.46	0.56	0.68	0.78	0.50	0.45	0.40	0.50
Jan	0.49	0.55	0.58	0.68	0.50	0.50	0.40	0.55
Feb	0.60	0.45	0.55	0.65	0.50	0.50	0.40	0.60
Mar	0.60	0.44	0.42	0.52	0.40	0.45	0.50	0.65
Apr	0.39	0.25	0.25	0.35	0.20	0.20	0.50	0.70
May	0.20	0.25	0.25	0.25	0.20	0.20	0.50	0.65
Jun	0.20	0.25	0.25	0.25	0.20	0.20	0.50	0.60

1. Irrigation water requirement for table grapes on sandy soils, De Doorns, according to Saayman (1996).
2. Irrigation water requirement for wine grapes on a 14-21 day irrigation cycle according to P. Myburgh, RIOV, Nietvoorbij (personal communication).
3. Irrigation water requirement for wine grapes on a 7 day irrigation cycle according to P. Myburgh, RIOV, Nietvoorbij (personal communication).
4. Irrigation water requirement for wine grapes on a 3-4 day irrigation cycle according to P. Myburgh, RIOV, Nietvoorbij (personal communication).
5. Early season deciduous fruit according to Infruitec E.5 (1988).
6. Middle season deciduous fruit according to Infruitec E.5 (1988).
7. Citrus according to Infruitec E.5 (1988).
8. Citrus according to Institute for Soil, Climate and Water (ISCW).

The net average annual irrigation water requirement for deciduous fruit, citrus and grapes based on these eight crop factor suites for the seven weather stations from Keerom to the coast that were calculated for the ODRS are listed in **Table 3.2**.

Table 3.2 Estimated net average annual irrigation water requirement (mm/a) for deciduous fruit, critrus and grapes basedon eight crop factor suits for seven weather stations in the Olifants River Basin from Keerom to the coast

Weather station	Average annual irrigation water requirement (mm) based on eight crop factor suites							
	Saayman	Myburgh 14-21 days	Myburgh 7 days	Myburgh 3-4 days	Fruit early	Fruit middle	Citrus Infruitec	Citrus ISCW
Augsburg	778	828	912	1091	749	719	765	1011
Citrusdal PP	618	644	722	870	579	558	593	800
Citrusdal NIVV	849	918	1002	1210	820	779	957	1261
Klawer	930	997	1087	1295	900	858	999	1291
Lutzville	891	968	1051	1242	868	828	981	1251
Vredendal 2	1033	1127	1212	1424	1009	967	1174	1477
Vredendal 3	995	1081	1172	1381	967	927	1101	1374

It is evident that the annual net irrigation water requirement differs greatly between weather stations and crop factor suites; by implication between crop-soils-irrigation method combinations. The data in **Table 3.2** were used for multiple range analyses to determine the differences in net irrigation water requirement between crop factor suites and weather stations (see **Table 3.3**).

Table 3.3 Multiple range analyses on annual net irrigation water requirement (mm/a)

a) Analysis by crop factor suite (13 ODRS weather stations)

Crop factor suite	**Average annual irrigation water** (mm)	Homogeneous groups
Fruit (middle season)	768	a - - -
Fruit (early season)	802	a - - -
Saayman (table grapes)	835	a b - -
Citrus (Infruitec)	855	a b - -
Myburgh (14-21 days)	890	a b - -
Myburgh (7 days)	977	- b c -
Citrus (ISCW)	1118	- - c d
Myburgh (3-4 days)	1168	- - - d

b) Analysis by weather station

Weather station	**Average annual irrigation water** (mm)	Homogeneous groups
Citrusdal PP	673	a - - - - -
Augsburg	857	- b c - - -
Citrusdal NIVV	974	- - c d - -
Lutzville	1011	- - - d - -
Klawer	1045	- - - d e -
Vredendal 3	1125	- - - d e -
Vredendal 2	1178	- - - -e f

From the multiple range analyses it were evident that most of the calculation methods gave fairly similar net annual irrigation water requirements, with deciduous fruit on the lower and citrus on the higher range of the scale respectively. Short cycle irrigation scheduling resulted in a significant increase in the annual requirement. The average irrigation requirement (excluding potential leaching requirement), however, differ significantly between stations. The net average irrigation requirement for the Keerom to the coast section of the Olifants River Basin were summarised in following order:

Upper Olifants River **850-1000 mm**	**<**	**Lower Olifants River** **1 000-1 200 mm**

In the ODRS it was recommended that in the drier areas with saline soils, an additional quantity of water should be applied as a leaching component to remove free salts from the rooting zone. Although it was difficult to predict the actual leaching component, it can be as high as 10% to 20%, especially during the initial phases of development. The winter season (months with a low water requirement) would be the best period for over-irrigation and leaching of saline soils.

It was further stressed that under the harsh and variable climatic conditions along the middle and lower reaches of the Olifants River Basin (north of Clanwilliam Dam), it is important not to concentrate only on long-term average values. It was recommended that for design purposes it is essential to use average + standard deviation A-pan values for those months with peak irrigation requirement (**Table 3.4**). The exceptionally high monthly peak requirements at Vredendal 2 and 3 were due to unrealistically high standard deviation values in A-pan evaporation and were disregarded in further calculations.

It was also evident that peak monthly irrigation requirements for citrus according to ISCW or based on a very short irrigation cycle (Myburgh; 3-4 days), are significantly higher compared to peak requirements according to the other methods of calculation. Peak requirements based on these two methods were also disregarded. Multiple range analysis for peak monthly net irrigation water requirement showed an increase from 200 mm/month in the upper to a maximum of 225 mm/month in the lower Olifants River Basin.

Table 3.4 Peak net monthly irrigation water requirement (mm/month) at seven weather stations in the Olifants River Basin from Keerom to the coast for eight crop factor suites

Weather station	Peak net monthly irrigation water requirement (mm/month) based on eight crop factor suites							
	Saayman	Myburgh 14-21 days	Myburgh 7 days	Myburgh 3-4 days	Fruit early	Fruit middle	Citrus Infruitec	Citrus ISCW
Augsburg	210	226	255	294	206	206	164	226
Citrusdal PP	176	194	204	240	176	176	141	194
Citrusdal NIVV	210	225	268	308	204	204	163	225
Klawer	238	248	299	343	226	226	181	248
Lutzville	208	227	276	316	203	203	162	223
Vredendal 2	405	455	480	562	413	413	331	455
Vredendal 3	353	259	252	306	276	265	294	382

In the ODRS it was emphasised that the net water requirement calculated from class A-pan evaporation values and crop conversion factors only represents the amount of water required to replenish the water lost through evaporation and transpiration. The gross water requirement, that is the "on land" amount of water applied to the soil surface, however, can be significantly greater than the net requirement. The actual increase from net to gross requirement, depends on the type irrigation system. It is generally assumed that the efficiency of flood irrigation is 60%, sprinkler 80%, and micro-systems 90-95%. Efficiency of applied irrigation water is also affected by irrigation scheduling. Although it was difficult to quantify the effect of poor scheduling, it can be significant on well-drained sands with a low water holding capacity. Another factor that should be taken into consideration is the additional amount of water required to leach free salts from the rooting zone in saline soils; e.g. in the northern section of the Olifants River Basin. This leaching requirement may add up to 10% to 20% to the net irrigation water requirement.

During the ODRS round table discussions with leading farmers, irrigation experts and other technical consultants on the quantity of irrigation water applied in the Olifants River Basin, is was apparent that very little quantitative data were available. Based on the information submitted the gross water application at Citrusdal for citrus was 8 000 and 10 000 m^3/ha/a for drip and micro irrigation, respectively, while the net requirement for wine grapes was 7 500 and 8 500 m^3/ha/a at Lutzville and Vredendal, respectively.

Based on the preceding information, net annual and peak monthly water requirements can be extrapolated for five broad areas in the Olifants/Doring River basin.

In the ODRS the net water requirements for a mix of deciduous fruit and/or citrus and/or grapes were extrapolated from the estimated water requirements at the different weather stations.

Assuming an irrigation efficiency factor of 90% (based on micro-systems), gross quantities at the edge of the field were calculated from the net values (**Table 3.5**). The gross quantities did not include potential water loss from storage dams due to evaporation and seepage, as well as losses along the distribution system (from the storage dam to the land).

Table 3.5 Recommended gross annual, gross annual plus 10% leaching, and peak monthly water requirements for two broad areas in the Olifants River Basins

Broad area	**Recommended gross water** (m^3/ha/a)		
	Annual volume (no leaching)	**Annual volume with leaching**	**Peak monthly volume**
Upper Olifants River	9 500		2 250
Lower Olifants River	11 000	12 000	2 500

3.3 Irrigation water requirement determined in the WODRIS

For the WODRIS an estimate was required of the theoretical water requirement of current agricultural activities in the study area (2004). It was agreed that the method of calculation, and associated assumptions, for irrigation water requirement would be based on the *Irrigation Sub-model of the Water Balance Model* (WBM) as modified by the Department of Water Affairs and Forestry (DWAF, 1998). This model incorporated the following parameters:

ETo = Reference evapo-transpiration
Kc = Crop factors
REF = Effective annual rainfall
LER = Leaching requirement
IRC = Irrigation application efficiency (100 % efficiency = 1.0)
CLI = Conveyance loss

The reference evapo-transpiration was derived from the Penman-Monteith method (mm/a) according to the procedure of Smith (1992). Monthly weather data for each of the two Fairly Homogenous Climate Zones (FHCZ) were identified in the WODRIS study. ETo values were taken from a representative nearby weather station within a FHCZ. The annual ETo for the FHCZ 1 (Coastal area) and FHCZ 2 (Klawer area) was 1 694 mm/a and 1 812 mm/a, respectively.

Crop factors used in conjunction with the Penman-Monteith reference evapo-transpiration were obtained from a crop factor database that was developed according to the standard FAO method (Allen and Smith, 1998) using inputs from a large number of South African practitioners. These crop factors were modified according to actual water use in the study area.

Average monthly rainfall for the two FHCZ was used to estimate effective annual rainfall (mm/a) according to the method recommended by the Soil Conservation Services (SCS) in the USA and used in the "ETCrop" computer programme. For vegetables, however, only where the effective rain exceeded 20 mm/month was it taken into consideration. For grapes only effective rainfall > 10 mm/month was taken into consideration.

The net irrigation requirement (NIR) is the monthly depth of irrigation water required, adjusted for effective rainfall. The annual NIR calculated for wine grapes and vegetables in FHCZ 1 was 805 mm/a and 1 001 mm/a, respectively. In the warmer FHCZ 2 the values for wine grapes, table grapes and vegetables were 857 m/a, 1 037 mm/a and 1 051 mm/a, respectively.

A leaching requirement was considered essential due to the low rainfall of the study area and to ensure that no long-term salt build-up in the irrigated soils will take place. An average leaching fraction of 10 % was used.

Standard irrigation application efficiency factors were used to convert crop water use to irrigation water requirement. These factors reflect the water losses through in-field application using different irrigation systems. For commercial growers these factors were: drip 95 %, micro-jet 80 %, sprinkler 75 %, centre pivot 85 % and flood 65 %. Except for flood, the efficiency factors were decreased by 5 % for emerging farmers.

Conveyance loss to edge of field was not taken into consideration in the calculation of irrigation water requirement.

Assuming a crop split of 75 % wine grapes + 25 % vegetables in FHCZ 1, the gross irrigation requirement, including a 10% leaching fraction, was estimated as 11 753 m^3/ha/a. For FHCZ 2 the corresponding volume for a crop split of 37.5 % wine grapes + 37.5 % table grapes + 25 % vegetables was 13 265 m^3/ha/a. The peak water demand in January for these crop splits was 1 877 m^3/ha and 2 170 m^3/ha for FHCZ 1 and 2, respectively.

3.4 Irrigation water requirement in the Olifants River Basin from Keerom to the coast according to SAPWAT

In the ODRS the irrigation water requirement in the Olifants River Basin from Keerom to the coast was determined for deciduous fruit, citrus and grapes according to the A-pan evaporation – crop factor model. In the WODRIS the requirement was determined for wine and table grapes and vegetables in general for the section of the basin from Klawer-Melkboom to the coast using the Penman-Monteith method to determine a reference evapo-transpiration.

In order to verify the recommended irrigation water requirements in the two previous studies the SAPWAT computer program (Van Heerden and Crosby, 2002) was used in the present Feasibility Study for the Raising of the Clanwilliam Dam. On the SAPWAT weather station database only four stations with reliable climate data that fall within the spatial limits of the soil study are listed (see **Table 3.6**).

Table 3.6 Weather stations in the SAPWAT computer program database that fallwithin the spatial limits of the soil study in the Olifants River Basin (Van Heerden and Crosby, 2002)

Station name	Latitude	Longitude	Elevation (mamsl)	Mean annual rainfall (mm)
Lutzville (NIWW)	-31°36’	18°26’	31	141
Klawer Wine Cellar	-31°47’	18°38’	68	211
HLS Augsburg	-32°10’	18°54’	156	215
Citrusdal (NIVV)	-32°34’	18°59’	198	401

Long-term climate data was used to estimate the crop water requirement of different crop according the SAPWAT computer program. The parameters that were selected in the SAPWAT program to estimate crop factors and water requirement are listed in **Table 3.7**. In **Table 3.8** the ET crop, effective rainfall and total irrigation water requirement is listed for the selected crops, irrigation systems and planting dates for annual crops.

Table 3.7 Parameters selected to estimate crop factors and water requirement for six crops according to the SAPWAT computer program (Van Heerden and Crosby, 2002)

Crop	Citrus	Citrus	Wine grapes	Onions	Potatoes	Tomatoes
Crop option [1)]	Average	Average	Medium			
Cover at full growth [2)]	90 %					
Account of rainfall [3)]	Yes					
Season normality [4)]	Normal (median season)					
Irrigation system	Micro	Drip	Drip	Centre pivot	Centre pivot	Drip
Frequency of wetting: Initial [5)] Rest of season [5)]	 7 days	 3 days	 3 days	 2 days 4 days	 2 days 4 days	 1 days 1 days
Wetted area [6)]	100 %	20 %	20 %	100 %	100 %	20 %
System efficiency [7)]	90 %	95 %	95 %	85 %	85 %	95 %
Water distribution uniformity [8)]	85 %					
Target yield [9)]	Normal					

1) The crop option choices for citrus are below average, average or above average production, while for wine grapes the choices are early/short, medium or late/long season. For onions the choices are spring or autumn planting dates, and for tomato processing or table,
2) A standard cover at full growth of 90 % was selected for all the crops.
3) Effective rainfall was included in the irrigation requirement calculations.
4) The choice is favourable, normal or severe season. A normal season was selected that represents the median.
5) For perennial crops the default irrigation frequency of seven days was selected, while for annual crops under centre pivot the initial frequency was two days and for the rest of the season four days, and for drip a continuous frequency of one day.
6) For micro and centre pivot a wetted area of 100 % was selected and for drip irrigation 20 %. A smaller wetted area will reduce the evaporation from the soil.
7) The SAPWAT default irrigation efficiency of the selected irrigation system was used.
8) A constant water distribution uniformity of 85 % was selected.
9) A normal yield was selected.

Based on **Table 3.8** citrus, a non-deciduous plant, has a significantly higher total irrigation requirement than wine grapes. Citrus under micro irrigation requires approximately 15 % more water than under drip irrigation.

The average seasonal irrigation water requirement of vegetables range from as low as 615 mm for potatoes planted in February to as high as 877 mm for table tomatoes planted in September.

Over all vegetables the average seasonal water requirement is approximately 10 %, 18 % and 6 % higher at Lutzville, Klawer and Augsburg, respectively, compared to Citrusdal. Although the actual percentages differ, the pattern between the weather stations is the same for citrus and wine grapes.

Table 3.8 Crop water requirement (ET), effective rainfall and total irrigation water requirement for six selected crops in the Olifants River Basin according to the SAPWAT computer program (Van Heerden and Crosby, 2002)

Note : No leading requirement is included in these estimates

Crop	Planting date annual crops	Irrigation system	Weather station	ET crop (mm/a)	Effective rain (mm/a)	Total irrigation requirement (mm/a)
Citrus		Drip	Lutzville	1 187	133	1 366
			Klawer	1 288	169	1 466
			Augsburg	1 111	224	1 225
			Citrusdal	1 081	278	1 138
		Micro	Lutzville	1 296	133	1 583
			Klawer	1 405	169	1 698
			Augsburg	1 209	224	1 410
			Citrusdal	1 181	278	1 328
Wine grapes		Drip	Lutzville	813	136	908
			Klawer	878	174	965
			Augsburg	789	229	865
			Citrusdal	777	281	813
Onions	August	Centre pivot	Lutzville	627	50	822
			Klawer	661	61	860
			Augsburg	603	73	761
			Citrusdal	557	183	619
Potatoes	February	Centre pivot	Lutzville	476	40	628
			Klawer	528	53	682
			Augsburg	431	49	549
			Citrusdal	455	34	599
Tomatoes – Processing	December	Drip	Lutzville	521	14	634
			Klawer	560	12	693
			Augsburg	546	16	660
			Citrusdal	549	51	643
Tomatoes – Table	December	Drip	Lutzville	640	35	774
			Klawer	702	32	841
			Augsburg	632	43	752
			Citrusdal	644	63	755
	September	Drip	Lutzville	730	35	876
			Klawer	700	38	934
			Augsburg	755	47	895
			Citrusdal	723	134	801

In the drier section of the Olifants River Basin north of Bulshoek Weir with less leached, commonly saline and/or calcareous soils the total irrigation requirement in **Table 3.8** should be increased by a leaching fraction of approximately 10 % to ensure that salt built up in the soils does not take place during irrigation.

If the crop water requirements obtained during the Agricultural Workshops from the farmers/producers are compared with the SAPWAT estimates the following tendencies are observed:

- According to the farmers the irrigation water requirement for citrus between Keerom and Clanwilliam is 700 mm/a and 1 000 mm/a, respectively for drip and micro irrigation. These volumes are approximately 300 – 400 mm lower than the volumes estimated by the SAPWAT computer model.

- According to the farmers the average irrigation water requirement for wine grapes is approximately 700 mm/a and 800 mm/a for the Keerom-Clanwilliam and Klawer-Lutzville sections of the basin. These volumes are approximately 130 mm less than the volumes estimated by the SAPWAT computer model.

- The average irrigation water requirement of 650 mm/season for potatoes under centre pivot received from the farmers is approximately the same as that of the SAPWAT computer model.

- The actual volume of water used by the farmers for other vegetables is generally less than the volume estimated by the SAPWAT computer model. The differences range from about 100 mm to 200 mm per season.

4. CROP ADAPTABILITY

4.1 Introduction

The present land use in the Olifants River Basin encompasses a range of scenarios in terms of crops, type of water supply, irrigation systems, and horizontal and vertical intensity of irrigated land use.

These scenarios range from:

- intensive citrus with "own" water in the Citrusdal valley south of the Bulshoek Weir; to
- intensive wine grapes, table grapes, vegetables, and other crops with irrigation board water north of Bulshoek Weir.

Climate- and soil suitability are the most critical and determining factors that will determine the potential expansion of sustainable, economic viable irrigation in the Olifants River Basin. To improve the reliability of qualitative climate and soil suitability evaluations, various farmers, technical advisors and experts in the fruit and grape industry were invited to a round-table discussion with consultants for the ODRS study. Special attention was given to soil and climate requirements of citrus cultivars and rootstocks and wine and table grapes. The general climate and soil suitability of five areas (Coastal zone, Knersvlakte, Aties Karoo, Trawal and Olifants River south of Clanwilliam Dam) were specified for these crops in terms of very suitable, suitable under certain conditions and not suitable. Other crops such as pawpaw, avocado, olives and mangos were also discussed but no specific recommendations were made in terms of soil and climate suitability.

During the WODRIS study two agricultural workshops were held during which crop adaptability was also discussed. Climate information was used to conduct an extensive search for potential crops according to the Ehlers screening system (Ehlers, JH, undated). This screening process was based primarily on temperature. Specific recommendations were made regarding potential crops grouped into the following categories: arable; vegetables; aromatic and herb crops; berry, fruit and nut crops; oil and fibre crops; and pastures.

During the present study two round-table agricultural workshops were held at Spruitdrif Cellar, Vredendal, and Citrus Juices Offices, Citrusdal, on 16 August and 17 August 2005, respectively. Various farmers/producers in the study area, technical advisors and experts in the citrus, grape and vegetable industries were invited to these round-table discussions with the consultants for the raising of the Clanwilliam Dam. One of the aims of these workshops was to make use of local experience in terms of crop suitability mainly in terms of climate.

4.2 Soil suitability

Due to the advanced farming technology and management skills that exist in the intensely developed sections of the basin most of the inherent soil limitations do not pose any serious constraints on irrigation development. Limitations such as limited effective rooting depth, wetness, subsoil density, high acidity, low nutrient status, etc. are effectively ameliorated by a variety of mechanical and chemical measures. Many soils that were considered not suitable for irrigation development, however, have already been ameliorated and in many cases carry highly productive orchards.

Initial irrigation development in the Olifants River Basin was on the fairly level low lying soils. In the northern section of the basin this was on fairly heavy and silty alluvial soils while in the southern section it was mainly dry or wet alluvial sands. Over the last few decades the tendency was to move away from the low lying soil to higher lying, non-alluvial soils. Especially from Trawal to the coast these higher lying soils differ significantly, both in terms of physical and chemical properties from those in the southern section of the basin. These soils are generally base saturated with neutral to alkaline pH values, and in most instances initially saline. Another common feature is dense subsoil hardpans cemented by lime and/or silica. These hardpans are generally very hard and a severe restriction to root penetration and water movement. Although it is very costly to mechanically ameliorate these hardpans, it is a very good rooting medium; especially for vine rootstocks, once they are broken and loose.

With the exception of the relatively impermeable, fine silty alluvial soils, removal of saline salts through leaching is comparatively easy and relatively quick. Properly designed subsoil drainage systems, however, are rarely found along the Olifants River Basin, with the result that the saline (salty) leaching water in many cases lead to salinisation of lower lying fields or lands, as well as the downstream waters of the Olifants River; to such an extent that the water quality at times is unsuitable for irrigation.

The neutral to alkaline soil pH values are the one soil property that cannot practically be changed to more acidic values. This is therefore a permanent soil restraint for crops or rootstocks that require acid soil conditions.

Although many of the soils, throughout the study area, have one or more physical and/or morphological properties that may be considered as limiting to root development and plant growth, most of these limitations are of such a nature that it does not make it totally unsuitable for fruit and grape production. Throughout the traditional fruit and grape producing areas in the Western Cape soils with similar properties and limitations are successfully used, provided that the correct amelioration measures are followed, and other management practices such as irrigation, fertilization, disease- and weed control, pruning, etc. are of a high standard.

Certain soil properties are of such a nature that it cannot be changed by man, and may play an important role in determining the suitability for different crops.

Texture (or clay content) is a permanent and non-changeable soil property. Although it might appear that there is no difference in the textural requirements of different crops, especially fruit, the effect of an increase in clay content on other soil factors such as bulk density and carbon dioxide concentration is extremely important. An increase in bulk density has a negative effect on the total as well as macro- and meso-pore volume that decreases the tempo of free water movement in the soil.

Indirectly, therefore, texture must have a great effect on crop/rootstock preference or adaptation, and plant performance. Citrus prefers a sandy to light loamy texture while different grape rootstocks are adapted to soil texture that range from sandy to clayey. Although citrus prefers sandy textured soils, they might grow reasonably well on heavier textured soils during the first number of years. It is, however, the general belief that the productive life gets shorter the heavier the soil texture. Fruit quality may also be negatively affected.

The wide texture adaptation listed for grapes is predominantly due to the very large range of rootstocks available for grapes. Certain rootstocks such as Ramsey do well on sands, while 140 Ruggeri is preferred on dense clayey soils.

The negative effect of sandy textures on plant performance is indirectly the low water holding capacity of sandy soils, and the risk of dry soils conditions that might occur during the growing season.

The preference of potatoes for sandy textured soils is also linked to the higher incidence of scab on neutral to alkaline soils than on acid, sandy soils.

Coarse fragments (gravel, stones and boulders) are generally no limitation for perennial crops and non-tuberous vegetables (e.g. tomatoes) except for the negative effect on water holding capacity. Tuberous crops, however, are seldom planted on gravely/stony soils due to the effect of the coarse fragments on tuber quality.

Based on **pH and alkalinity** the soils in the study area can be subdivided into the acid, non-alkaline soils in the higher rainfall localities, and the neutral to alkaline soils in the drier, low rainfall localities; the alkaline soils commonly contain free lime, and many are saline. Sub-tropical/tropical fruit is generally poorly adapted to soils with free lime and high pH values. Certain tropical fruit types are especially sensitive to trace element deficiencies (particularly iron) on calcareous soils.

Generally most grape rootstocks do well on soils containing free lime and with relatively high pH values (6.5 – 7.5).

Although citrus is considered sub-tropical, and therefore better suited to leached soils, certain rootstocks and scion material are fairly tolerant to high pH values and free lime. In certain parts of Israel and Spain highly productive citrus orchards are found on soils with up to 30% calcium carbonate.

Both grapes and citrus, however, are sensitive to free sodium and chlorine ions in the soil solution, and have a low salinity tolerance.

Olives and figs are suited to the particular soil conditions of the drier localities in the study area, while mangos prefer more acid, non-saline soils.

Another limiting factor in the drier areas is soil salinity. If the natural salinity levels could be lowered by initial over-irrigation, drainage of saline leaching water, and followed by judicious irrigation practices and high standard management practices, both adapted citrus and grape varieties should do well on these high pH, calcareous soils.

4.3 Climate suitability

4.3.1 Ehlers screening system

Although many publications are available that qualify and/or quantify the climatic conditions to which specific annual and perennial crops are adapted, the most comprehensive screening system is that developed by Ehlers (undated). In this system he grouped useful plants according to their temperature requirements.

He developed an X - Y diagrammatic key to identify different temperatures zones. The Y – axis is the average mean temperature of three summer (December – February) or three winter (June – August) months, while the X - axis is the average night temperature of three summer or three winter months. A temperature zone is identified by two numbers, e.g. $^{77}/_{25}$; it is called the temperature zone number. The upper part of the number indicates the average temperature regime of the three summer months and the lower part the average temperature regime for the three winter months. The incidence of frost in each temperature zone is qualified in terms of four classes (no symbol = with frost; A = zone is frost free on terrain with a slope, but in low lying, level terrain, along drainage channels of cold air, frost and even heavy frost can be expected; B = zone is more frost free than A; C = for all practical purposes zone is frost free).

The summer and winter temperature zones were calculated for ten ISCW weather stations (ARC, 2005) from Keerom to the coast and 31 temperature stations from Trawal to the coast (personal communication Mr J Joubert, VINPRO, Vredendal) (see **Appendix A: Table 4.1** and **4.2**). Based on the summer zone numbers the stations closer to the coast are cooler (zones 57 and 67; average mean summer temperature between 19°C and 22°C) than the more inland stations (zone 77; average mean summer temperature between 22°C and 24.5°C). According to both climatic data sets certain weather stations, e.g. HLS Augsburg and Citrusdal North, are even warmer (zones 87 and 88; average mean summer temperature between 24.5°C and 27.5°C). Most of the stations have a winter zone number of 35 or 36 (average mean winter temperature between 13°C and 15.5°C). The two most southerly weather stations, however, are colder in winter (zone 25; average mean winter temperature between 11°C and 13°C).

The average summer night temperature is fairly high and range from 15°C to 20°C. The average winter night temperature, however, has a greater variation between stations and range from 5.4°C to 15°C. The stations with the lowest average winter night temperature are in the southern part of the basin and near the coast. The average winter night temperature of stations from Lutzville to south of Citrusdal shows the greatest variation. From the data it appears that the night temperature of higher lying stations is higher than that of lower lying stations due to drainage of cold air from the higher to the lower positions.

Based on the temperature zone information in **Appendix A: Table 4.1** and **4.2** it was decided to do an extensive search for potentially climate adapted crops according to the Ehlers' screening method for summer temperature zones 57, 77 and 87. The results are presented in **Appendix A: Table 4.3**. Only crops that are optimally (O), sub-optimally (S) and undifferentiated (U) adapted to a particular temperature zone are listed. Undifferentiated means that the crop is adapted to a specific temperature zone but too little information is available to classify it as optimal or sub-optimal. Crops marginally (M) adapted are not listed.

In **Appendix A: Table 4.3** the crops are grouped into two levels. The first level is according to:

- crops currently grown in the study area;
- crops recommended in the WODRIS study;
- additional crops recommended by the Department of Agronomy, University of Stellenbosch; and
- additional climatically adapted crops according to Ehlers' screening method.

The second level was based on the primary use or type of crop and included:

- annual field crops;
- drink and oil crops;
- fruit and nuts;
- herbs, dyes, drugs and aromatics;
- soft berry fruits; and
- vegetable crops.

During the two round-table agricultural workshops held at Spruitdrif Cellar, Vredendal, and Citrus Juices Offices, Citrusdal, on 16 August and 17 August 2005 respectively, the attendants were given a copy of **Appendix A: Table 4.3**. The structure and information in this table was briefly discussed during the workshops. Due to a time constraint it was impossible to work through the information in detail and to finalise the selection of climatically adapted crops. For this reason the farmers/producers and technical advisors who attended the workshops were requested to study the information in the table. Based on personal experience they were asked to delete and/or add crops to the list and to make comments that could be used for a final selection of climatically adapted crops that could be produced commercially. Unfortunately only five individuals who attended the workshops reacted positively and made comments that could be used to refine **Appendix A: Table 4.3**.

4.3.2 Crops currently grown in the study area

Based on comments received from workshop attendants the recommendations in the Agricultural Development Plan and Economic Analysis Report of the WODRIS (Provincial Government Western Cape, 2004) with reference to adapted crops could be updated in the following manner.

Maize (especially sweet corn) is very well adapted to the climate along the Olifants River Basin from Keerom to the coast. It is widely planted under centre pivot by farmers/producers who have contracts with groups (e.g. Zettler, Stellenbosch) who supply fresh, pre-packed produce to large supermarkets chains. The plant rests are also a very good animal feed.

Most of the **vegetable crops** are climatically well adapted. Differences in climate (temperature) from Keerom to the coast determine the optimum planting date. A large number of the listed vegetable crops are produced on large scale for the larger local fresh markets. Vegetable crops that are exported include **canteloupe**, **onions**, **potatoes**, **sweet potatoes** and **butternuts**. A number of apparently successful producers have contracts with supermarkets for a wide range of the listed vegetables, especially in its young and immature (baby) stage in a pre-packed form. Vegetable crops such as **cabbage**, **cauliflower**, **chillies**, **lettuce**, and **green beans** are seldom or on small scale planted for the open market.

Potatoes are extensively planted in the Clanwilliam area under centre pivot or overhead irrigation. Due to the rotting effect on tubers of high mid-summer temperatures, potatoes are only planted during the cooler months. Summer production of potatoes is more suitable in the coastal zone near the sea with its cooling effect; e.g. Lutzville and Koekenaap. Due to the very high input cost for potato production, many producers make use of production contracts with the potato chip factory at Lamberts Bay.

Onions can be produced along the Olifants River from Keerom to the coast. Although a certain volume of onions is exported, most is produced for the local fresh market.

Tomatoes for the fresh market can be produced all along the Olifants River. To get better prices harvest dates are planned to fall in the so called "out of season" winter and early summer time slots. The milder Clanwilliam-Klawer-Trawal areas are especially suited as "out of season" production areas. Especially at Klawer with its very mild winter temperature, winter tomatoes can be produced. In the lower Olifants River Basin near Lutzville there is a tomato puree factory for the processing of jam tomatoes planted under production contracts.

Watermelons and **cantaloupes** are commonly planted in the warmer areas along the river from middle to the end of August to be marketed from the end of November to New Year on the large produce markets. A number of producers also export suitable cantaloupe varieties.

Pumpkins and **squash** are occasionally planted for "out of season" marketing. Because pumpkins and squash are easy to produce, local markets are easily glutted, leading to very low prices. In this group butternuts are regularly exported. **Cucumbers** have the same problems as the other cucurbit species.

Sweet potatoes for the fresh market can be produced all along the Olifants River. To realise better prices on local markets harvest dates are planned for "out of season" periods. To achieve this sweet potatoes are planted to mature during summer. The tubers are left in the soil to supply the markets during the following early summer. For this practice sandy, non-wet soils are used and the dry climate conditions in the Klawer-Lutzville areas are especially suitable to prevent rotting of the tubers. Sweet potatoes are also exported. Another potential use of sweet potatoes produced under centre pivot is as a starch source for fermentation and ethanol production (this is a renewable energy source in the production of "gasohol" in the USA).

Both **Bitter Seville** and **citron** are well suited to the climate in the southern section of the basin, but unfortunately the market for these niche market products is limited. One producer near Citrusdal delivers his Bitter Seville to canning factories for marmalade production. **Lemons** are only planted in the Citusdal region. The market is, however, limited and markets are easily glutted leading to low prices. Of the **clementine**, **satsuma** and **mandarin** (naartjie) group, clementines is the most widely planted variety in the Citrusdal region. It can, however, also be planted in cooler areas such as one large block that was planted near Lutzville (this farm was recently sold for mining of heavy minerals). Satsumas are the earliest "naartjie" type with a harvest date as early as March. It has a short harvest period and too large plantings can lead to harvesting problems. In this group preference is these days given to very late (August) patented/protected cultivars (e.g. Afurrer) as a late niche market product.

With reference to the present orange concentrated Citrusdal-Clanwilliam region, citrus farmers are apparently diversifying within both the **Navel** and **Valencia** groups. In the case of Navels, late Navel selections such as Robyn and selections that are less susceptible to "Valskodlingmot" such as Bahianina are selected to get a better harvest distribution. In the case of Valencias the emphasis is on improved and more seedless Valencia types such as Midnight and Delta, because ripening of the old late Valencia from middle September is too late and shifts the marketing date outside our Southern Hemisphere time slots. The only time niche market for local late Valencias is the very late local market during the summer months. The cooler coastal areas such as Lutzville-Koekenaap might be suitable for the production of Valencias for the very late market.

Grapes are adapted to the climatic conditions all along the Olifants River. The main consideration to produce grapes in a particular section of the basin would therefore be economy and not soil-climate adaptation. Grapes have a variety of marketing possibilities such as wine, table grapes, raisins, preserving and even "gasohol". Specific climate sub-zones in the Olifants River Basin have specific advantages in terms of grape production. In the ODRS study it was pointed out that, notwithstanding the potential negative effect of too warm conditions during certain periods of the year, the special climatic conditions in the lower Olifants River Basin should be exploited to produce early table grapes before the traditional table grape areas flood the export market. Because of the low rainfall during mid-late summer, the warm, dry localities are also exceptionally well suited for the production of seedless raisin grapes. In addition to table grapes, wine grapes can be grown throughout the basin. In contrast to table grapes, where warm conditions enhance early ripening, high temperatures favour vegetative growth but are considered as a negative quality factor for wine grapes; it may lead to an imbalance between growth and sugar production. The heat units that act upon a vine plant through the growing season were estimated from the average monthly temperature greater than 10°C during the growing season. The difference between 10ºC and the average temperature was multiplied by the number of days per month and summated for the growing season. There was a distinct increase in heat units from the most northerly weather station to Citrusdal in the south. The cooler conditions closer to coast will have an influence on time of ripening and will retain aromatic compounds that influence wine quality. Another approach to evaluate the suitability of a particular locality for grapes is based on the average temperature of the warmest month during the growing season. This parameter had the same tendency as heat units. **Table grapes** are mostly produced in the warmer areas south of Vredendal to Melkboom/Trawal due to the very early harvest time compared to the cooler Lutzville region.

4.3.3 Crops recommended in the WODRIS

Although vegetables crops such as **garlic**, **beetroot**, **rhubarb** and **eggplant** are climatically well adapted in the Olifants River Basin it is very seldom planted. This is true for all the vegetables recommended by the Department of Agronomy, University of Stellenbosch, and those additional climatically adapted vegetables.

A variety of subtropical fruit were listed in the Agricultural Development Plan and Economic Analysis Report of the WODRIS as crops currently produced in the Olifants River Basin. Most of these crops, e.g. avocado, mango, papaya and passion fruit, however, are only produced on a limited scale and will be treated as recommended crops.

Avocado trees can be seen in house gardens in Lutzville, Vredendal, Clanwilliam and Citrusdal and have been grown on a very small scale in Vredendal for over 20 years. Commercial planting, however, is not very successful due to wind, heat stress causing fruit drop, and diseases. The best avocados in the basin are away from the river on cooler, higher elevations. Avocados prefer cooler, moderate winter and summer temperature. According to Mr Christo Smit (personal communication) the maximum temperature in the Clanwilliam-Citrusdal region is too high, causing fruit drop. The most suitable areas for avocados in the basin appear to be the cooler coastal areas and high lying upper slopes.

Mangos have been tested to a limited extent in the study area and in many home gardens in Clanwilliam, Trawal, Klawer and Vredendal, healthy, well bearing trees are found. The main limiting factors appear to be wind and lime rich/saline soils. At Vredendal mangos in a particular block did better on sandy soils than on lime rich heuweltjies where various nutrient abnormalities occurred. Mangos apparently require a minimum number of heat units (hours) during the summer growing season to ensure sufficient growth flushes. Mangos in Citrusdal-Vredendal ripen later than in the northern production areas; the later the better the local prices. Very late cultivars such as Heidi, Kent, Keitt and Sensation are therefore planted. The very late cultivars have a slower growth rate than in the northern areas, because of fewer growth flushes. To reduce tree size (semi-dwarf trees) high-density plantings of 2 m by 5 m are established. The warm, dry summer conditions in the above areas promote disease-free tree and fruit; especially bacterial black spot. The local climatic conditions also promote very good internal and external fruit quality in terms of sugar, flavour and colour. Mangos apparently have a lower water requirement than citrus. In addition to a fresh market product, mangos can also be used for drying or freezing for later processing for juice or chutney. One firm in Johannesburg use fresh mangos combined with other fruit types to produce fruit salad in a sugar solution, for export.

The climatic adaptability of **papayas** is determined by two winter cold climatic parameters. The first is frost damage at temperatures below freezing point and secondly too little heat units above freezing point. Although papayas are found in home gardens in Citrusdal and Clanwilliam, trees did worse at Citrusdal, apparently because of too much cold during winter. Too much winter cold (too little heat) causes cold stress and yellowing and drop of older leaves. There are also genetic differences between selections. The selection Honey Gold is apparently better suited to cold winter conditions than other selections. The best suited area along the Olifants River for cold resistant selections is the Trawal area with the warmest winters. In this area, however, papayas would require wind protection.

Persimmons do well in home gardens between Citrusdal and Clanwilliam and downstream to as far south as Bo River. The problem with persimmons, however, is that the best cultivars are protected and can only be planted under contract with the registered owner of the protected cultivar. With the limited production the profitability of these persimmons is very high.

Originally the old purple **granadilla** (*Passiflora edulis subspecies edulis*) was the preferred product. The purple granadilla plant, however, has various deficiencies so that commercial production is rarely possible. The main limitation is soil borne and viral diseases. Improved cultivars, e.g. Charity, however, are more disease resistant and can get fairly old. This variety does not need cross pollination and bears good quality fruit throughout the year. During periods with low prices the fruit is used to make juice.

Figs are well adapted to the climatic conditions all along the Olifants River. Deane and numbered Smirna types with very large fruit were identified as the best cultivars for various uses on the Citrusdal experimental farm. Fresh figs are also a niche market product and can be used for drying or for green or ripe fig jam.

Guavas have a wide adaptation range and can be planted all along the Olifants River. Although ripening is affected by the differences in climatic conditions from Keerom to the coast, it bears well everywhere. The biggest problem with guavas, however, is available markets, that will largely determine price and profitability.

On the Citrusdal Experimental Farm there used to be a very successful orchard of selected **olive** cultivars that produced a lot of fruit. Well-growing and productive olives trees are also found in home gardens all along the Olifants River. The main problem in the commercial production of olives used to be markets for the fruit. This problem, however, has improved a lot over the last number of years. Although olives are presently mainly used for preserved olives and olive oil for human consumption, olive oil can also be used for the production of bio-diesel.

In addition to macadamias there are a variety of nuts types (e.g. almonds and pecan nuts) that are climatically adapted to the conditions along the Olifants River. **Macadamias**, e.g. Nelmak and other varieties, did well in an experimental planting on the Citrusdal Experimental Farm as well as in farm home gardens in the Clanwilliam district. Macadamias in the lower Olifants River Basin generally show severe chlorotic foliar symptoms on certain soils most probably due to the high pH (free lime) and saline nature of these soils.

Pineapples and **custard apples** are not recommended for commercial production in the Olifants River Basin due to climatic constraints; these crops prefer moderate climatic conditions.

Although **jojoba** can produce good and expensive oil, the low biomass production per plant makes it unsuitable for commercial production under irrigation.

4.3.4 Additional crops recommended by the Department of Agronomy, University of Stellenbosch

Carrots are occasionally produced under centre pivot in the Clanwilliam district for fruit juice factories at Ceres.

Cauliflower is planted seldom, or only on a small scale, for the open market.

4.3.5 Additional climatically adapted crops

Loquats and **pineapple guavas** are well adapted to the climatic conditions along the Olifants River. However, there are no market possibilities for these crops.

Although only **peach** and **nectarine** are mentioned in Ehlers' screening system as deciduous fruit adapted to the climatic conditions along the Olifants River, with the correct cultivar selection a variety of other deciduous fruit types can most probably be economically produced.

Pecan nuts are well adapted all along the Olifants River. It does especially well on the valley floor and tributaries and are commonly found in many home gardens in towns and on farms. Pecan nuts have a deep, strongly developed tap-root system and can make use of deep soil water. Improved cultivars such as Ukulinga, Moore, Chocktaw, Bester and Nellis can produce large crops. On the Citrusdal Experimental Farm there used to be a large selecting of **almonds** cultivars that produced well; certain French cultivars produced heavy crops.

None of the herbs, dyes, drugs and aromatics recommended in the WODRIS or listed by the Department of Agronomy or as additional climatically adapted crops are grown commercially in the Olifants River Basin, although many are regularly found in home gardens. Whether the non-commercial production of these crops is a reflection of insufficient economic incentives or other reason(s), production of these crops as niche market products on a small scale should be investigated.

5. AGRICULTURAL WORKSHOPS

5.1 Introduction

Land-use in the Olifants River Basin encompasses a relatively wide range of scenarios in terms of crops, water supply, irrigation systems, and horizontal and vertical intensity of irrigated land use. These scenarios range from:

- Drip and micro irrigated citrus production in the middle and southern sections of the basin.
- Drip or micro irrigated mass and quality wine grape production, with or without a small component of dry grapes.
- Micro or drip irrigated table grape production.
- Due to climatic factors quality wine grapes are preferentially produced in the cooler areas closer to the coast (Vredendal - Lutzville), while table grapes are more common in the warmer and less humid inland areas (Klawer - Trawal).
- Drip, overhead (sprinkle) and centre pivot irrigated vegetable production preferably on moderately deep sandy soils; on many farms vegetables are produced in combination with perennial crops.
- Sub-tropical crops, e.g. avocado and mango, are produced on a limited scale in combination with grapes and vegetables.

Climate- and soil suitability, as well as the availability of ensured additional irrigation water are the most critical factors that will determine the potential expansion of sustainable, economic viable irrigation in the Olifants River Basin. In an attempt to increase the reliability of qualitative soil suitability evaluations based on soil survey and chemical information, as well as the effect of climate, two round-table agricultural workshops were held at Spruitdrif Cellar, Vredendal, and Citrus Juices Offices, Citrusdal, on 16 August and 17 August 2005, respectively. Various farmers/producers in the study area, technical advisors and experts in the citrus, grape and vegetable industries were invited to these round-table discussions with the consultants for the raising of the Clanwilliam Dam. More than 25 farmers/producers, technical advisors and experts were invited to each of these workshops. Unfortunately the number of invited farmers/producers that attended the workshops, especially the one at Citrusdal, was far below the number that indicated that they would participate. The invited individuals that participated in these discussions are listed in attached **Appendix A: Table 5.1**. Names of farmers/producers and technical advisors who attended the workshops are highlighted.

5.2 Format of the workshop

The workshop consisted of following sessions, viz:

i) Information session

During this session the following aspects were briefly explained and discussed:

- Purpose of the study.
- Background to the study.

- Potential development scenarios.
- Physical and chemical properties of soil types in the study area.
- Climate of the study area.

ii) Questionnaire on the more important soils

During this session the participants were requested to complete a questionnaire that *inter alia* covered the following aspects pertaining to the soils in the study areas (see **Appendix A: Table 5.2)**:

- Deep soil tillage, drainage and chemical amelioration prior to planting.
- Soil type specific management practices.
- Preferred irrigation system and irrigation water requirement of different crops and leaching requirement.
- Soil suitability for the production of crops under irrigation.
- Planting date and length of growing season of annual crops.

iii) Average temperature and crop adaptability

During this session farmers/producers were given a list of climate adapted crops suitable for the Olifants River Basin. They were requested to make comments on their personal experience with the listed crops. (Only three farmers/producers reacted on this request.

iv) Economic-financial viability at farm level

v) Typical farm models in the different farming areas

For the second, fourth and fifth sessions the farmers/producers were divided into groups according to the locality of their respective farm(s) and crop programs. In **Appendix A: Table 5.3** the compiler groups that each completed a soils questionnaire are listed.

5.3 Soil types used in the questionnaire on soils

A very wide range of soil types is found in the Olifants River Basin. Results of the reconnaissance soil survey conducted in the basin showed that the dominant soil types in the northern section of the basin differ significantly from the dominant soils in the southern section. The boundary is roughly the Bulshoek Weir. Based on the surface area covered by the different soil complexes as determined from the digitised soil map, a list was compiled that reflect the more common soil types in the dominant soil complexes in the Klawer-Lutzville and Keerom-Clanwilliam sections of the basin (see **Table 5.1**).

Each of the compiler groups had to choose at least three soils types that are typical/dominant of their respective farms. A digitised soil map of the Olifants River Basin was available during the workshop to assist the groups in the selection of soil types. The selected soil types were the basis on which most of questions in the questionnaire had to be answered.

Table 5.1 Dominant soil types in the Klawer-Lutzville [1)] and Keerom-Clanwilliam [2)] sections of the Olifants River Basin

Soil depth (mm), colour of subsoil and other properties	Topsoil clay content	Gravel and stones	Calcareous heuweltjies
Hutton form	**Deep, dry, apedal red soils**		
>600 tot 1000 [1,2)]	< 5 %	None	Rare
>600 tot 1000 [2)]	5 – 10 %	Abundant	Rare
>600 tot 1000 [2)]	10 – 15 %	Abundant	Rare
Garies form	**Moderate deep to deep, dry, apedal red soils on duripan without lime**		
>1000 [1)]	< 5 %	None	Rare
600 – 1000 [1)]	< 5 %	None	Abundant
Clovelly form	**Deep, dry, apedal yellow soils**		
>600 tot 1000 [1,2)]	< 5 %	None	Very rare
>600 tot 1000 [1)]	5 – 10 %	Abundant	Rare
>1000 [1)]	5 - 10 %; clay increase with depth	None	Abundant
Oakleaf form	**Deep, dry soils with a prominent grey, brown or red subsoil**		
>1000; Yellow to grey [2)]	< 5 %	None	None
>600 tot 1000; Yellow to brown [1,2)]	6 – 10 %; clay increase with depth	None	Abundant
600 tot 1000; Red brown [2)]	10 – 15 %; with or without clay increase with depth	None	Rare
Oudtshoorn form	**Medium deep, dry soils with a prominent brown or yellow subsoil without lime on calcareous duripan**		
600 – 80; Yellow to brown [1)]	5 - 15 %; with or without clay increase with depth	None	Abundant
600 – 80; Red [1)]	5 - 15 %; with or without clay increase with depth	None	Abundant
Prieska form	**Medium deep, dry soils with a prominent calcareous, brown or yellow subsoil on duripan with free lime**		
600 – 80; Yellow to brown [1)]	5 - 15 %; with or without clay increase with depth	None	Abundant
Knersvlakte form	**Very shallow, dry soils directly on duripan with free lime**		
20 – 40 [1)]	5 - 10 %	None	Abundant
Fernwood form	**Deep, moderately dry, pale coloured sands**		
>1000; Grey to pale yellow [2)]	< 5 %	None	None
Longlands form	**Deep, wet, pale coloured sands**		
>1000; Grey to pale yellow [2)]	< 5 %	None	None
Kroonstad form	**Shallow to moderately deep sand on dense, wet clay**		
600 – 900 [2)]	< 5 %	None	None
400 – 900 [2)]	< 6 %	Abundant	None
300 – 450 [1]	5 - 10 %	None	Rare
Klapmuts/Estcourt form	**Shallow loam on dense, dry blocky/prismatic clay**		
<500 [1,2]	5 - 15 %	Locally	Abundant
Glenrosa/Cartref form	**Shallow soils on weathering sandstone or shale; occasionally with pale layer below topsoil**		
<500 [1,2)]	<5 %	Abundant	None
<400 [1,2)]	10 - 20 %	Abundant	None
Dundee form	**Stratified alluvial soils**		
>1000; Dry [2)]	< 6 %	None	None
>1000; Wet [2)]	< 6 %	Abundant	None
>1000; Dry to wet; No lime [1)]	> 6 %	None	None
>1000; Wet; Plus lime; Saline [1)]	> 6 %	None	None

The individual compiler groups had to complete the questions for each of the selected soil types. The information supplied by the compiler groups was transferred to a single worksheet. The information was subsequently grouped, *inter alia* by soil type, crop type, irrigation system, etc. The locality and surname of the compiler of the questionnaire were generally retained in the worksheet. Where possible, the information was subjected to some form of statistical analysis, e.g. average cost, ranges of values, etc.

In the following paragraphs the information dealing with the various aspects addressed by the questionnaire will be discussed. Conclusions reported are based on the questionnaire information and additional discussions during the workshop. The conclusions, however, do not necessarily convey the idea(s) of any particular individual or group.

5.4 Type, depth and cost of mechanical soil tillage

In **Appendix A: Table 5.4** the first and second selected mechanical soil tillage practices for perennial crops on different soils are presented. The tillage depth and cost (R/ha) are also given. In the following paragraphs the information in **Appendix A: Table 5.4** is briefly discussed.

5.4.1 Tillage practice

- In the Klawer-Lutzville section of the basin rip ploughing is the preferred tillage practice on most soil types, followed by mix ploughing.
- In the Keerom-Clanwilliam section of the basin the number of compiler groups that selected rip or mix ploughing as first tillage choice on B 2, B 2, C 2 and C 3 soil complex soils is more or less equal.
- In Klawer-Lutzville four groups use a combination of actions on soils with underlying hardpan (Garies and Oudtshoorn forms; A 3 and E 1 soil complexes respectively). The topsoil is first removed. This is followed by deep ripping into the subsoil/hardpan followed by spreading of the topsoil over the ripped subsoil/hardpan.
- In Keerom-Clanwilliam rip or mix ploughing, without or with ridging, is used on the dry alluvial soils (Dundee form; J 1 soil complex).
- In Klawer-Lutzville mix ploughing is the preferred tillage action on alluvial soils (Dundee form; J 3 soil complex). This is occasionally combined with terracing.
- Two compilers from Vredendal preferred trenching, without or with mix ploughing, as the ideal practice on deep alluvial soils (J 3 soil complex).
- Only one compiler from Clanwilliam preferred no tillage as first choice on moderately to well drained, deep, yellow to grey sandy soils (Pinedene and Clovelly forms; B 1 and B 2 soil complex).
- No compiler selected blade ploughing as the ideal tillage on any of the soil types/complexes.

5.4.2 Tillage depth

- In Klawer-Lutzville most compilers preferred a tillage depth of deeper than 900 mm on soil complexes A 1 and A 3, as well as alluvial soils (J 3 soil complex), usually combined with rip ploughing.
- In Klawer-Lutzville the preferred depth of mixed ploughing of complex E 1, E 2 and alluvial soils is 700 – 900 mm.
- In Keerom-Clanwilliam most compilers preferred a tillage depth of 700 - 900 mm on all soil types, irrespective whether it is rip or mix ploughing.
- Only one compiler from Citrusdal preferred a mix ploughing depth of > 900 mm on complex B 2, C 2 and I 1 soils.

5.4.3 Tillage costs

- The cultivation cost per hectare varies largely between compilers for a particular cultivation practice on a depth and locality basis (see **Table 5.2**).

Table 5.2 Tillage cost by tillage practice by depth and locality

Practice	Depth (mm)	Locality	Number of entries	Cost (R/ha)		
				Average (R)	Minimum (R)	Maximum (R)
Mix ploughing	700 - 900	Keer-Clan [1)]	5	5 600	5 000	6 000
		Klaw-Lutz [2)]	6	14 500	13 500	18 000
	>900	Keer-Clan	2	10 000	10 000	10 000
		Klaw-Lutz	2	10 000	10 000	10 000
Mix + Ridging	700 - 900	Keer-Clan	1	5 000		
Mix + Trenching	??	Klaw-Lutz	1	10 000		
Rip ploughing	<700	Keer-Clan	1	4 000		
	700 - 900	Keer-Clan	8	4 688	3 500	6 500
	>900	Keer-Clan	2	7 500	5 000	10 000
		Klaw-Lutz	9	16 333	12 000	20 000
Push away surface + Rip	>900	Klaw-Lutz	4	17 250	15 000	20 000
Trenching	>900	Klaw-Lutz	1	12 000		

1) Keerom-Clanwilliam
2) Klawer-Trawal

From **Table 5.2** it is clear that the average cost for most tillage practices are higher in the Klawer-Lutzville section than in Keerom-Clanwilliam. One reason could be that the compilers from Klawer-Lutzville gave the total cost of soil tillage per hectare while the cost for Keerom-Clanwilliam is in most cases only for one direction of tillage (see **Appendix A: Table 5.4**). The compilers unfortunately did not record whether they considered one direction sufficient to loosen the soil properly, or whether two or more directions of tillage are used in practice. This anomaly was not followed up.

The average cost per hectare of mix ploughing to a depth of 700 - 900 mm in Keerom-Clanwilliam is approximately half that of mix ploughing to a depth of > 900 mm (R 5 600 and R 10 000 respectively). The comparable values for Klawer-Lutzville, however, are R 14 000 and R 10 000. Mix ploughing combined with either ridging or trenching should be more expensive than only mix ploughing. This, however, is not the case. This anomaly was not followed up.

The average cost of rip ploughing in the Keerom-Clanwilliam section increases progressively from R 4 000 to R 7 500 with an increase in tillage depth from < 700 mm to > 900 mm. The average cost for Klawer-Lutzville for rip ploughing to a depth of > 900 mm is R 16 333, ranging from R 12 000 to R 20 000.

The average cost of the tillage practice to push away the surface soil layers, followed by deep rip ploughing and subsequent spreading of the surface material over the ripped subsoil is only R 17 250 per hectare which is only slightly more compared to the R 16 333 for rip ploughing alone. The first mentioned practice should be considerably more expensive. This anomaly was not followed up.

- The average tillage cost and standard deviation by soil group over all tillage practices was calculated for Keerom-Clanwilliam and Klawer-Lutzville (see **Table 5.3**).

Table 5.3 Tillage cost by tillage practice by depth and locality

Soil complex	Number of entries per locality		Tillage cost	
	Klawer-Lutzville	Keerom-Clanwilliam	Average	Standard deviation
A	8		R 18 000	R 2 507
B		7	R 5 429	R 2 168
C		5	R 6 100	R 2 247
E	6		R 15 250	R 3 062
I		3	R 7 167	R 2 566
J		5	R 4 875	R 854
J	8		R 11 938	R 1 782

From **Table 5.3** it is evident that the average tillage cost for Keerom-Clanwilliam range from as low as R 4 875 ± R 854 for soil group J (alluvial soils) to as high as R 7 167 ± R 2 566 for soil group I (shallow lithosolic soils).

For Klawer-Lutzville the values range from R 11 938 ± R 1 782 for soil group J (alluvial soils) to R 15 250 ± R 3 062 for soil group E (grey to yellow, predominantly moderately to well drained sandy soils on higher lying terraces) to as high as R 18 000 ± R 2 507 for soil group A (well drained red apedal soils).

The large difference in average tillage cost per soil group between the two localities cannot be explained.

5.5 Irrigation system and cost

In **Appendix A: Table 5.5** the preferred irrigation system for different crop types is presented. The locality, soil group and on-land system cost (R/ha) for each entry are also given. In **Table 5.4** average cost (R/ha) and standard deviation by crop type is given.

Table 5.4 Average cost of irrigation systems (R/ha) and standard deviation by crop type

Irrigation system	Choice	Number of entries	Cost (R/ha)	
			Average (R)	Standard deviation (R)
(i) Annual crops				
Centre pivot	First	1	10 000	
Drip	First	9	10 556	2 651
Overhead	Second	2	6 500	4 950
(ii) Tree crops				
Drip	First	10	12 450	6 768
Micro	Second	4	16 250	4 924
(iii) Wine grapes				
Drip	First	8	12 214	4 982
Micro	Second	1	??	

From **Table 5.4** it is evident that the average cost of drip irrigation per hectare ranges from R 10 566 for annual crops to R 12 450 for tree crops (mainly citrus). The very high standard deviation of R 6 768 for tree crops is due to one entry of R 28 000 by compiler group 6. This exceptionally high cost is probably due to a very sophisticated drip system designed for so-called "open hydroponics".

Compared to drip irrigation for tree crops, the average cost of micro systems is considerably more expensive; R 16 250 ± R 4 950.

The cost of a centre pivot system for vegetables (only one entry) is comparable to that of drip systems, while an overhead sprinkler system is considerably cheaper with a cost of R 6 500 ± R 4 950.

The average on-land cost by system type increases as follows:

Overhead < Centre pivot < Drip < Micro

From **Table 5.4** it is evident that drip irrigation is the first choice for tree crops and wine grapes followed by micro irrigation. In the case of vegetables, centre pivot and drip are the preferred irrigation systems with overhead as second choice.

5.6 Irrigation water requirement for different crops and irrigation systems

In **Appendix A: Table 5.6** the irrigation water requirement in cubic meter (m^3) water per hectare per growing season delivered at the edge of lands/blocks for different crops, grouped according to locality and irrigation system, is presented.

Although the data were not sufficient for statistical comparison of irrigation water requirements between crops, localities and irrigation systems, certain tendencies can be observed based on average water requirements (see **Table 5.5**). These tendencies are:

- The average irrigation water requirements for annual crops, *inter alia* canteloupe, cucurbits, potatoes, sweet potatoes, tomatoes, vegetables (general) and watermelon, under drip irrigation is range from 4 000 m^3/ha to 7 500 m^3/ha with a standard deviation of less than 1 500 m^3/ha. The reason for the high standard deviation for Klawer-Lutzville is due to the 10 000 m^3/ha water requirement for Baby Marrow. If this high volume is not included, the highest average drip irrigation water requirement for vegetables is 6 000 m^3/ha.
- The corresponding average water requirements for vegetables under overhead, centre pivot and micro irrigation is 7 000, 6 500 and 6 000 m^3/ha, respectively. These volumes are equivalent and higher than the highest volume for drip.
- There was no distinct difference in the volume of irrigation water used for vegetable production in Klawer-Lutzville and Keerom-Clanwilliam localities.
- According to compiler group 1 the summer and winter irrigation water requirement for potatoes under centre pivot in the Clanwilliam district is 7 500 and 5 500 m^3/ha, respectively. A similar difference was indicated by compiler 7 for summer and winter tomatoes under drip irrigation; 6 000 and 4 000 m^3/ha, respectively. Based on this data, a winter planting requires approximately 2 000 m^3/ha less irrigation water than a summer planting with the same irrigation system.
- According to one compiler from Klawer-Lutzville, tomatoes for the fresh market requires 2 000 m^3/ha per season less water than factory tomatoes; 4 000 and 6 000 m^3/ha, respectively.
- The average irrigation water requirement for citrus, mango, papaya and wine grapes under drip irrigation ranges from 7 000 to 8 000 m^3/ha.
- The irrigation water requirement of citrus in Keerom-Clanwilliam under micro irrigation is approximately 3 000 m^3/ha more than under drip irrigation; 10 000 and 7 000 m^3/ha respectively.
- Wine grapes under drip irrigation apparently require more irrigation water in Klawer-Lutzville than in Keerom-Clanwilliam; approximately 900 m^3/ha.
- The irrigation water requirement of wine grapes in Keerom-Clanwilliam under drip and micro irrigation is approximately the same; approximately 7 000 m^3/ha.
- Flood irrigated wine grapes in Klawer-Lutzville require approximately 3 000 m^3/ha more irrigation water compared to drip; 10 667 and 7 893 m^3/ha respectively.

Table 5.5 Average irrigation water requirement and standard deviation by crop type, irrigation system and locality

Crop type	Irrigation system	Locality	Number of entries	Irrigation water requirement (m^3/ha/season)	
				Average	Standard deviation
Annual crops					
Canteloupe	Drip	Keerom-Clanwilliam	1	4 000	
Cucurbits	Drip	Keerom-Clanwilliam	2	5 500	707
		Klawer-Lutzville	2	7 500	3 536
	Micro	Keerom-Clanwilliam	1	6 000	
Potato	Centre pivot	Keerom-Clanwilliam	2	6 500	1 414
Sweet potato	Drip	Keerom-Clanwilliam	1	6 000	
Tomato	Drip	Keerom-Clanwilliam	1	4 000	
Vegetables	Drip	Klawer-Lutzville	1	6 000	
	Overhead	Klawer-Lutzville	1	7 000	
Watermelon	Drip	Keerom-Clanwilliam	2	5 000	1 414
Perennial crops					
Citrus	Drip	Keerom-Clanwilliam	5	7 000	1 275
	Micro		3	10 000	1 000
Mango	Drip	Keerom-Clanwilliam	1	8 000	
Olive	Drip	Klawer-Lutzville	1	7 000	
Papaya	Drip	Keerom-Clanwilliam	1	8 000	
Red tea	Drip	Keerom-Clanwilliam	1	1 000	
Wine grapes	Drip	Keerom-Clanwilliam	1	7 000	
		Klawer-Lutzville	7	7 893	1 657
	Flood	Klawer-Lutzville	3	10 667	577
	Micro	Keerom-Clanwilliam	1	6 500	

5.7 Other soil amelioration measures

The responses to other actions that are considered essential following mechanical soil amelioration and before planting of perennial crops are summarised in **Appendix A: Table 5.7**.

5.7.1 Drainage and salt leaching

Most of the compilers considered drainage as unnecessary on all the soil types and crop combinations.

Two compilers, one each from Klawer-Lutzville and Keerom-Clanwilliam, considered drainage at a cost of between R 6 000 and R 9 000 R/ha to be locally necessary on B 2, C 3 and E 1 soils. Drainage was also considered as essential or locally necessary on J 1 and J 3 complex alluvial soils at a cost of approximately R 5 000 R/ha. Except for J 1 that is well drained, all the other soil complexes are moderately to well drained and might require drainage in localized wetter sections.

Notwithstanding the negative approach to drainage, the majority of compilers from Klawer-Lutzville considered salt leaching, at times combined with the application of gypsum, as an essential practice on new lands on most soil complexes. The different comments regarding leaching can be summarised as follows:

- A few compilers considered leaching as impractical.
- Under drip irrigation no leaching is required. The localised placement of irrigation water desalinises the zone of soil directly below the plants (e.g. grape vines) and moves the salts to the inter-row area. The degree of desalinisation is sufficient to ensure that moderately tolerant rootstocks and crops are not adversely affected by free salts.
- The cost of salt leaching, according to one compiler group from Klawer-Lutzville, is R 500 per hectare.
- Subsequent to deep soil tillage, new lands should be leached, with or without the application of gypsum. Generally, sprinkle irrigation is used for the initial leaching. The additional volume of water required for leaching, however, was not specified. During the WODRIS study it was established that the volume of water applied varies from as little as one normal water application, to a 150 mm application, to as high as a continuous 24 hour application of irrigation water.

QUESTION:

The anomaly between no drainage but with leaching of new lands leads to the question:

What happens to the salts that are leached from the soil profile?

Irrigation of similar soil types in fairly dry environments in parts of South Africa and Namibia, has led to moderate to severe salinisation of lower slope soils and above farm roads between irrigation blocks or lands. Although drainage is at present considered as not necessary in the proposed new irrigation areas, the high salt content of certain soil types should be kept in mind, and provision (spatially and financially) should be made for artificial subsoil drainage during the planning phases of any of these areas.

5.7.2 Levelling of soil surface

Depending on soil type, tillage practice and type of implement used, the surface of new lands tends to be fairly uneven after mechanical soil tillage. The response of most compilers to the question of leveling of the uneven surface was generally that it is an essential action with an additional cost that ranged from R 1 000 to R 2 000 R/ha.

According to two compilers from Keerom-Citrusdal, leveling is only required in localized sections of tilled lands or to evenly spread sand over the soil surface where small dunes occur.

5.7.3 Removal and crushing of stones

The main purpose of soil tillage prior to establishing deep-rooted perennial crops on Garies, Knersvlakte, Glenrosa, Mispah, Oudsthoorn, Prieska, Trawal and heuweltjie soil types, is the mechanical shattering of underlying subsoil hardpans or weathering rock into small fragments. Depending on the hardness and continuity of these hardpans or rock, as well as the depth of tillage, the hardpans and rock, are broken up into blocks/fragments that may vary in size from smaller than 200 mm to larger than 1.0 m in length. In addition to the negative effect of these fragments on the water retention capacity of the fine soil fraction, it acts as a mechanical limitation, e.g. normal movement of implements, mechanical weed control, etc.

The response of compilers to the question of removal and/or crushing of these hardpan blocks, can be summarised as follows:

- On soil complexes A 1, B 1, B 3, G 1, H 2 and alluvial soils most compilers responded that removal of stones is not necessary. These soils are deep without any hardpans or rock and coarse fragments and heuweltjies are absent or rare. It is therefore expected that no coarse fragments should be on the soil surface after deep soil tillage.
- In soil complexes with hardpans, rock or heuweltjies, most compilers responded that it is essential to remove stones/coarse fragments after deep soil tillage to make lands more accessible.
- Except for one compiler from Keerom-Citrusdal, all the other groups reported that for soil complex J removal of stones is not necessary.
- In those cases where coarse fragments are not removed from the land, two compilers from Klawer-Lutzville used crushing on the land, either with a rock crusher or with the tracks of a heavy caterpillar machine. Only the very large and extremely hard fragments that cannot be crushed are removed.
- That cost of removal and/or crushing of the stones/coarse fragments ranged from R 500 to R 3 000 per hectare.

5.7.4 Wind control

The response to wind control in the form of windbreaks varied a lot. With the exception of one compiler from Klawer-Trawal that considered wind control as essential, all the other groups considered it unnecessary. Most compilers from Keerom-Clanwilliam considered wind control as essential. The cost of establishing windbreaks around orchards is approximately R 1 000 per hectare.

5.7.5 Surface mulching

Most compilers considered the use of organic surface mulches and/or cover crops as non-essential measures for crop production as part of the standard management program.

Only two compilers (one each from Klawer-Lutzville and Keerom-Clanwilliam) considered surface mulching as essential. The compiler from Klawer-Lutzville used reeds at a cost of R 1 500 per hectare.

However, during an agricultural workshop for the WODRIS study most compilers of a questionnaire considered the use of organic surface mulches and/or cover crops as essential measures for grapes as part of the standard management practice. In addition, the following specific responses were given:

- During the first year triticale should be planted as an inter-row crop.
- Mulching should only be done on the uncultivated strip along the vine row and between the work rows (so-called "bankie"). The application rate is approximately 2 700 bales of straw with a cost of between R 8 000 and R 13 000 per hectare.

5.8 Chemical ameliorants

The individual responses of the compilers to the question of type and amount of chemical ameliorants by soil type applied during soil tillage are set out in **Appendix A: Table 5.8**. From this table it is evident that there are large differences in type and amount of ameliorant(s) applied by soil type. The only ameliorant that is applied by all the compilers is phosphorus, usually as single supers that contain sulphur and not double supers. In a number of cases the compilers only used "Yes" instead of specifying the actual mass of ameliorant(s) that they use. These "Yes" entries cannot be used for any calculation purposes. It is not clear from the questionnaires whether a non-response implies that no ameliorant is used for the soil type(s) selected by the compiler group.

The data in **Appendix A: Table 5.8** is so limited that no proper statistical analyses could be done on a soil type basis. In **Table 5.6** the total number of entries per locality as well as "Yes" entries, number of positive entries and average mass of different chemical ameliorants are summarised.

Table 5.6 Chemical ameliorants by locality

Statistical parameter		Chemical ameliorants						
		Calcitic lime (t/ha)	Dolomitic lime (t/ha)	Gypsum (t/ha)	Single supers (kg/ha)	Double supers (kg/ha)	KCl (kg/ha)	K_2SO_4 (kg/ha)
Keerom-Clanwilliam								
Count	Total	14						
	Yes answer	0	3	0	3	0	30	0
	Positive	6	10	7	5	4	6	2
Average positive		2.7	3.0	2.3	1080	662	2773	77
Klawer-Lutzville								
Count	Total	20						
	Yes answer	0	0	0	3	0	0	0
	Positive	3	5	7	14	0	0	0
Average positive		2.3	2.6	5.0	628			

From **Table 5.6** the following interpretations can be made:

- In Keerom-Citrusdal most compiler groups use calcitic and/or dolomitic lime. The average mass used is 2.7 and 3.0 t/ha calcitic and dolomitic lime, respectively. In cases where both types of lime are used (six entries), approximately 6 t/ha total lime will be applied.
- In Klawer-Lutzville less than 50 % of the compilers use either calcitic or dolomitic lime. Calcitic and dolomitic lime is never used in combination. The average mass is 2.3 and 2.6 t/ha calcitic or dolomitic lime, respectively.
- In both localities only seven compilers use gypsum. In Klawer-Lutzville the average mass is nearly double that used in Keerom-Clanwilliam; 5.0 and 2.3 t/ha, respectively. The greater mass of gypsum in Klawer-Lutzville is most probably due to more clayey and salt rich (especially sodium and magnesium) soils compared to Keerom-Clanwilliam.
- The majority of compilers included some form of phosphorus as an ameliorant during soil

tillage. The average quantity of phosphorous applied as single and double supers in Keerom-Clanwilliam is approximately 100 and 130 kg/ha, respectively. In Klawer-Lutzville no double supers is applied and the phosphorus as single supers is only 60 kg/ha.

- No potassium is applied at Klawer-Trawal. In Keerom-Clanwilliam the average quantity of potassium in the form of KCl is unrealistically high, while in the form of K_2SO_4 it is unrealistically low.

5.9 Suitability of soils and production levels for different crops

In **Appendix A: Table 5.9** the suitability rating of the dominant soil types, before and after soil amelioration, as well as production levels of different crops by soil complex and locality basis, are presented.

From **Appendix A: Table 5.9** it is evident that the range in qualitative ratings before amelioration of physical limitations for annual crops by the compilers for selected soil complexes varied from **Low** to **High**. In most cases the actual production figures (t/ha) was given. In certain cases, however, zero production figures or question marks (??) were given. The meaning of the zero values is not clear. Does it imply that actual production is 0 t/ha or that the compiler will not use that particular soil for that specific annual crop ? The ratings after amelioration were usually **High**, with a few **Medium** and **Medium-High** ratings.

The ratings for perennial crops followed a similar tendency. Most of the soil complexes that will not be used for planting were rated **Low** before amelioration. In Keerom-Clanwilliam all the soil complexes had a **High** rating after amelioration. For wine grapes in Klawer-Lutzville the ratings after amelioration were generally **High** with a few **Medium** and even **Low** ratings for well drained, red sandy soils, with or with dorbank.

From **Appendix A: Table 5.9** the average production per crop type and standard deviation was calculated. Based on **Table 5.7** the following interpretations can be made:

- The average production of annual crops is considerably higher after amelioration of physical limitations than before. The difference ranges from approximately 15 % better for sweet potatoes to more than 200 % for tomatoes, both in Keerom-Clanwilliam. Except for the addition of clay to sandy soils in Clanwilliam for the production of potatoes, the level to which the physical soil limitations are ameliorated, was never noted in the questionnaires. However, due to cost it is safe to assume that the soils were not primarily ameliorated for annual crops. The annual crops were planted as an interim crop on soils that were ameliorated for perennial crops.
- The average production of baby marrows and other curcurbits, mainly butternuts, increased from 10 and 23 t/ha to 15 and 34 t/ha, respectively when planted on ameliorated soils.
- The average production of onions increased greatly from 30 to 80 t/ha when planted on ameliorated soils.
- The average production of potato and sweet potato increased from 40 and 30 t/ha to 60 and 35 t/ha, respectively after soil amelioration.
- In both Keerom-Clanwilliam and Klawer-Lutzville the average production of tomatoes

increased by nearly 200 and 100 %, respectively to an average production of approximately 95 t/ha on ameliorated soils.

Table 5.7 Average production (t/ha) and standard deviation of different crops before and after amelioration of physical soil limitations

Crop	Locality	Number of entries	Production before amelioration		Production after amelioration	
			Average	Standard deviation	Average	Standard deviation
Annual crops						
Baby Marrow	Klawer-Lutzville	1	10.0		15.0	
Cucurbits	Keerom-Clanwilliam	7	23.1	8.0	34.3	13.7
Pumpkin	Klawer-Lutzville	1			100.0	
Canteloupe	Keerom-Clanwilliam	5	30.0	0.0	40.0	0.0
Onion	Klawer-Lutzville	2	30.0	0.0	80.0	0.0
Potato	Keerom-Clanwilliam	2	40.0	0.0	60.0	0.0
Sweet potato	Keerom-Clanwilliam	5	30.0	0.0	35.0	0.0
Tomato	Keerom-Clanwilliam	3	30.0	14.1	93.3	23.1
	Klawer-Lutzville	19	46.0	21.2	97.4	16.9
Watermelon	Keerom-Clanwilliam	8	40.0		32.0	17.9
Perennial crops						
Citrus	Keerom-Clanwilliam	14	25.0	0.0	40.7	7.1
Mango	Keerom-Clanwilliam	3			20.0	0.0
Olives	Klawer-Lutzville	3			12.5	3.5
Table grapes	Keerom-Clanwilliam	3			30.0	0.0
Wine grapes	Keerom-Clanwilliam	4	18.0	0.0	25.0	0.0
	Klawer-Lutzville - non-alluvial soils	18	9.3	8.3	24.2	7.1
	Klawer-Lutzville - alluvial soils	5	15.0	5.0	37.1	9.1

- Watermelon, however, is an anomaly with no apparent production increase with soil amelioration. Although the compilers rated the soils after amelioration as highly suitable for the production of watermelon, the production figures ranged from as low as 20 t/ha to as high as 60 t/ha.
- Perennial crops are rarely planted on non-ameliorated soils due to the low production levels, shallow rooting depth and associated management problems such as maintaining optimum soil water levels.
- The average citrus production of approximately 40 t/ha on ameliorated soils is fairly low. The high standard deviation is an indication that the production range is high. The one lemon entry of 30 t/ha is an indication that production levels could be greatly increased because a previous study showed that lemons could produce up to 100 t/ha in Citrusdal.
- The average production of mangos and olives on ameliorated soils is 20 and 12.5 t/ha, respectively.
- Although most of the table grapes are presently produced in the Trawal-Klawer area, the average table grape production of 30 t/ha came from Clanwilliam. This production level is good for an early production area.
- The average wine grape production in Keerom-Clanwilliam and Klawer-Lutzville is approximately 25 t/ha on non-alluvial soils. On alluvial soils in Klawer-Lutzville the average production is 37 t/ha. These average production levels are high to very high indicating that most of the grapes are still used for lower quality wines.

5.10 Planting dates and length of growing season of annual crops

In **Appendix A: Table 5.10** the first and second planting dates and length of growing season are listed for a range of annual crops. Although the number of entries for most of the crops is limited to two or three, the following tendencies can be observed:

- As first planting date August (8 entries) and September (6 entries) are the months specified by most compilers for a range of crops. Tomatoes and cucurbits are planted during the warm summer months (December 3 entries; January 3 entries; February 2 entries), while onions (2 entries) and baby marrow are planted during May.
- As second planting date the warm summer months are (December 3 entries; January 6 entries; February 3 entries) preferred for planting of cucurbits, tomatoes and watermelon. For baby marrow and tomato/potato April (2 entries) and August (2 entries) are the preferred planting dates respectively.
- In many cases the preferred first planting date differ between compilers for a specific crop. For certain crops, however, the same months are preferred as first and second planting dates; e.g. canteloupe and watermelon are only planted in August-September and December-January.
- The planting dates for tomatoes, the most commonly grown annual crop, are more or less the same as for cantaloupe and watermelon.
- The length of the growing season for a specific crop and planting date differs greatly between compilers. The greatest variation was for butternuts (13 to 24 weeks) and tomatoes (13 to 28 weeks).
- The average length of the first growing season for tomatoes is 20 weeks with 22 weeks for the second planting date. There is a tendency that the length of the growing season for tomatoes planted during August-September is slightly shorter than for the second planting season of December-February.
- The length of the growing season of the first (August-September) and the second (December-January) plantings is the same for cantaloupes and watermelons (16 weeks).
- The growing season for the February-March potato planting is approximately two weeks shorter than the June-August planting (14 and 16 weeks respectively).

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APPENDIX A

Tables

TABLE 1.1: DEFINITION OF MAP UNITS IN THE CITRUSDAL VALLEY (LAMBRECHTS *ET AL.*, 1988)

*) Occupies more than 60% of the map unit

i) SINGLE SOIL UNITS

Map unit	General description of soils	Soil families	
		Dominant *)	Sub-dominant
PREDOMINANTLY WELL DRAINED SANDY SOILS ON MID AND UPPER SLOPES			
A1	Shallow (<50 cm), stony lithosolic soils on sandstone; <6% clay; coarse and medium sand dominant	Cf 1200 Gs 2211 Cv 3100 (Rock)	Ms 1100 Ms 2100 Cv 3200
A2	Deep (>60 cm, generally >100cm), non stony, red and yellow sandy soils; <5% clay; coarse and medium sand dominant	Cv 3100 Hu 3100	Ct 1100 Fw 1120 Oa 2120
A3	Deep (>100 cm), non stony, bleached sandy soils; <5% clay; coarse and medium sand dominant	Ct 1100	Cv 3100 Fw 1120 Lo 2000 Kd 2000 Vf 2120
PREDOMINANTLY MODERATE TO WELL DRAINED LOAMY SOILS ON FOOT, MID AND UPPER SLOPES			
B1	Shallow (<40 cm), gravelly lithosolic soils on shales; 10-20% clay; fine sand dominant	Ms 2100 Gs 2121 Oa 1210	Sw 2111 Km 1200 Km 1100
B2	Moderately deep to shallow (<50 cm), duplex soils on shale; occasionally gravelly; 5-15% clay; coarse to fine sand dominant	Km 1200 Km 2200 Ss 2100 Es 1100 Es 2100	Sw 2121 Ss 1100 Kd 2000
WELL DRAINED LOAMY SOILS ON HIGHER LYING TERRACES AND PEDIMENTS			
C1	Moderate to deep (>60 cm, generally >100 cm), stony to gravelly red apedal soils; 10-15% clay; medium sand dominant	Hu 3100 Oa 1220 Oa 1210	Gc 3100 Oa 2220 Gs 1111
C2	Deep (>100 cm), non stony, weakly structured yellow soils with calcareous "heuweltjies"; 6-10% clay; medium sand dominant	Oa 2120 Cv 3200	Ga 2000 F59 2120
GREY TO DARK COLOURED, STRATIFIED SANDY SOILS ON YOUNG RIVER TERRACES			
D1	Predominantly deep (>100 cm), non stony, well drained soils; <6% clay; coarse to fine sand dominant	Du 1210 Du 1110	Oa 1110 Fw 1110 Cv 3100
D2	Predominantly deep (>100 cm), non stony, poorly drained soils; <6% clay; coarse to fine sand dominant	Du 1210 Lo 1000 Lo 2000	F56 1120 Fw 2110
GREY TO YELLOW, PREDOMINANTLY MODERATELY TO WELL DRAINED SANDY SOILS ON HIGHER LYING TERRACES			
E1	Predominantly deep (>100 cm), non stony, poorly drained sandy soils; <5% clay; coarse and medium sand dominant	Lo 1000 Lo 2000 Fw 1120 Fw 1220	Fw 1110 Fw 1210 Kd 2000
E2	Predominantly deep (>100 cm), well drained sandy soils; with or without stones; <6% clay; coarse and medium sand dominant	Cv 3100 Oa 1110	Oa 2110 Ct 1100 Fw 1120 Vf 2110
E3	Deep (120 cm), moderately drained grey coloured sandy soils; non stony; <5% clay; coarse sand dominant	Fw 1120 Fw 1110 Lo 1000	Ct 1100 Kd 1000 Fw 1220

Map unit	General description of soils	Soil families	
		Dominant	Sub-dominant
GREY, POORLY DRAINED DUPLEX SOILS ON HIGHER LYING TERRACES AND PEDIMENTS			
F1	Moderately deep (60-90 cm), non stony, poorly drained duplex soils; <5% clay; coarse and medium sand dominant	Kd 1000 Kd 2000 Lo 1000	Pn 3100 Lo 2000 Ka 1000
F2	Moderately shallow to moderately deep (40-90 cm), stony, poorly drained duplex soils; <6% clay; coarse and medium sand dominant	Kd 1000 Kd 2000 Es 1100 Es 2100	Pn 3100 Lo 1000 Ka 1000

ii) LAND CLASSES

Map unit	General description of soils
R1	Steep mountains, predominantly of sandstone origin
R1 + A1	Steep mountains with shallow stony lithosolic soils
R2	Steep hills and slopes, predominantly of shale origin
W	Rivers, streams and recent floodplains

iii) COMPLEX SOIL UNITS

A1 + A2	A1 + A3	A2 + E1	A3 + A1
B2 + F2	D2 + D1	E1 + D1	E3 + A3

TABLE 1.2: SOIL ASSOCIATION MAP LEGEND AND SURFACE AREA PER SOIL ASSOCIATION FOR THE WODRIS (PROVINCIAL GOVERNMENT WESTERN CAPE, 2003)

Soil group	Soil complex	Map symbol	Area (ha)
Well-drained, moderate deep to very deep, red sandy soils, locally with dorbank	Hutton/Clovelly-Garies-Heuweltjie association	Hu/Cv + Gr + Heuw	11 631
	Garies-Hutton association	Gr + Hu	17 466
	Garies-Hutton-Heuweltjie association	Gr + Hu + Heuw	3 875
	Garies-Clovelly-Pinedene-Heuweltjie association	Gr + Cv + Pn + Heuw	617
	Garies-Heuweltjie association	Gr + Heuw	5 725
	Garies-Heuweltjie-Dune association	Gr + Heuw + Dunes	2 029
	Garies-Knersvlakte-Heuweltjie association	Gr + Kn + Heuw	9 352
Moderate to well-drained, deep, yellow to grey sandy soils	Clovelly-Pinedene-Fernwood association	Cv + Pn + Fw	158
	Clovelly-Fernwood association	Cv + Fw	314
Well-drained, shallow to moderate deep, neocutanic loamy sand soils with dorbank	Oudtshoorn-Heuweltjie association	Ou + Heuw	3 017
	Oudtshoorn-Garies-Heuweltjie association	Ou + Gr + Heuw	1 967
	Oudtshoorn-Knersvlakte-Heuweltjie association	Ou + Kn + Heuw	24 640
Very shallow, loamy soils with dorbank	Knersvlakte-Heuweltjie association	Kn + Heuw	9 084
Shallow, loamy soils on structured clay	Duplex soil association	Duplex soils	3 618
Shallow lithosolic soils	Rock-Glenrosa-Mispah association	R + Gs + Ms	1 702
	Rock-Mispah association	R + Ms	372
Alluvial soils associated with Olifants/Doring and Hol Rivers	Non-calcareous, grey Dundee-Tukulu-Westleigh association	Grey alluvium	7 383
	Calcareous valley floor association	Calc valley floor	1 144
Moderately deep sandy to loamy sand soils on high lying terraces, locally with dorbank	Terrace soils-Heuweltjie association	Terrace mat + Heuw	1 080
	Knersvlakte-Terrace soils-Heuweltjie association	Kn + Terrace mat + Heuw	1 344
	Chromatic Oakleaf-Oudtshoorn-Knersvlakte-Heuweltjie terrace association	Chrom Terrace	6 901
Unstable dunes with deep red/yellow/grey sandy soils	Dunes-Clovelly association	Dunes + Cv	658
	Dunes-Hutton/Clovelly-Garies association	Dunes + Hu/Cv + Gr	7 143
	Grey coastal dunes	Coast Dunes	192
Dissected land	Highly dissected land	Dissec land	15 195
Saline vlei soils	Saline vlei soils	Vlei	1 049
Total area surveyed			137 656

TABLE 1.3: COMBINED SOIL MAP LEGEND FOR THE OLIFANTS RIVER BASIN FROM KEEROM TO THE COAST

Description of soil group	Map symbol	Description of soil complexes
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.
	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.

Description of soil group	Map symbol	Description of soil complexes
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.
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.

Description of soil group	Map symbol	Description of soil complexes
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	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

TABLE 1.4: DOMINANT AND SUBDOMINANT SOIL FORMS, FAMILIES AND HEUWELTJIES IN THE SOIL COMPLEXES DEFINED FOR THE OLIFANTS RIVER BASIN SOIL MAP

[1)] Occupies more than 60% of the soil complex

Description of soil group	Soil complex	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 higher lying river terraces and pediments)	D 1	Hu 3100 Oa 1220 Oa 1210 Tu 1210	Gc 3100 Oa 2220 Gs 1111 Heuw (10%)
	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%)

Description of soil group	Soil complex symbol	Dominant soil form/family	Subdominant soil form/family
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 Cv 3100 (Rock)	Ms 1100 Ms 2100 Cv 3200
	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	

Description of soil group	Soil complex symbol	Dominant soil form/family	Subdominant soil form/family
Land classes	L 1		
	L 2		
	L 3		
	L 4	Rock Ms 2100	
	L 5	Rock	
	L 6	Rock	Gs 2211

TABLE 1.5: SOIL FORMS AND FAMILIES LISTED ALPHABETICALLY ACCORDING TO SOIL FORM ABBREVIATION SYMBOL IN THE OLIFANTS RIVER BASIN

Abbre-viation **Soil form and vertical sequence of diagnostic horizons and/or materials**

Cf **CARTREF FORM**

Orthic A
E horizon
Lithocutanic B

Soil families
1000 Colour of E horizon "grey" when moist
 1200 B1 horizon hard

Cg **COEGA FORM**

Orthic A
Hardpan carbonate horizon

Soil families
1000 Non-calcareous A horizon

Ct **CONSTANTIA FORM**

Orthic A
E horizon
Yellow-brown apedal B

Soil families
1000 Non-luvic B1 horizon
 1100 Podzolic character absent beneath the yellow-brown apedal B horizon

Cv **CLOVELLY FORM**

Orthic A
Yellow-brown apedal B
Unspecified material

Soil families
3000 Eutrophic B1 horizon
 3100 Non-luvic B1 horizon
 3200 Luvic B1 horizon

Du **DUNDEE FORM**

Orthic A
Stratified alluvium

Soil families
1000 Non-red stratified alluvium
- 1100 Signs of wetness absent
  - 1110 Non-calcareous within 1500_mm of the soil surface
  - 1120 Calcareous within 1500_mm of the soil surface
- 1200 Signs of wetness present
  - 1210 Non-calcareous within 1500_mm of the soil surface
  - 1220 Calcareous within 1500_mm of the soil surface

Es **ESTCOURT FORM**

Orthic A
E horizon
Prismacutanic B

Soil families
1000 Colour of E horizon "grey" when moist
- 1100 B horizon lacks continuous black cutans on vertical ped faces

2000 Colour of E horizon "yellow" when moist
- 2100 B horizon lacks continuous black cutans on vertical ped faces

Fw **FERNWOOD FORM**

Orthic A
E horizon
Unspecified material

Soil families
1000 Light coloured A horizon
- 1100 Colour of E horizon "grey" when moist
  - 1110 Lamellae absent in E horizon
  - 1120 Lamellae present in E horizon
- 1200 Colour of E horizon "yellow" when moist
  - 1210 Lamellae absent in E horizon
  - 1220 Lamellae present in E horizon

2000 Dark coloured A horizon
- 2100 Colour of E horizon "grey" when mist

Ga **GARIES FORM**

Orthic A
Red apedal B
Dorbank

Soil families
1000 Non-luvic B1 horizon
2000 Luvic B1 horizon

Gc **GLENCOE FORM**

Orthic A
Yellow-brown apedal B
Hard plinthic B

Soil families
3000 Eutrophic B1 horizon
  3100 Non-luvic B1 horizon

Gs **GLENROSA FORM**

Orthic A
Lithocutanic B

Soil families
1000 A horizon not bleached
  1100 B1 horizon not hard
    1110 No signs of wetness in B1 horizon
      1111 Non-calcareous B horizon
2000 A horizon bleached
  2100 B1 horizon not hard
    2120 Signs of wetness in B1 horizon
      2121 Non-calcareous B horizon
      2122 Calcareous B horizon
  2200 B1 horizon hard
    2210 Signs of wetness in B1 horizon
      2211 Non-calcareous B horizon

Hu **HUTTON FORM**

Orthic A
Red apedal B
Unspecified material

Soil families
3000 Eutrophic B1 horizon
  3100 Non-luvic B1 horizon

Ka **KATSRUIT FORM**

Orthic A
G horizon

Soil families
1000 Non-calcareous G horizon

Kd **KROONSTAD FORM**

Orthic A
E horizon
G horizon

Soil families
1000 Colour of E horizon "grey" when moist
2000 Colour of E horizon "yellow" when moist

Km **KLAPMUTS FORM**

Orthic A
E horizon
Pedocutanic B

Soil families
1000 Colour of E horizon “grey” when moist
- 1100 Non-red B horizon
  - 1110 Subangular/fine angular B horizon
  - 1120 Medium/coarse angular B horizon

2000 Colour of E horizon “yellow” when moist
- 2100 Non-red B horizon
  - 2120 Medium/coarse angular B horizon

Kn **KNERSVLAKTE FORM**

Orthic A
Dorbank

Soil families
1000 Non-calcareous A horizon

Lo **LONGLANDS FORM**

Orthic A
E horizon
Soft plinthic B

Soil families
1000 Colour of E horizon "grey" when moist
2000 Colour of E horizon "yellow" when moist

Ms **MISPAH FORM**

Orthic A
Hard rock

Soil families
1000 A horizon not bleached
- 1100 Non-calcareous A horizon

2000 A horizon bleached
- 2100 Non-calcareous A horizon

Mu **MONTAGU FORM**

Orthic A
Neocarbonate B
Unspecified material with signs of wetness

Soil families

2000 A horizon bleached
- 2100 Non-red B horizon
  - 2120 Luvic B1 horizon

Oa **OAKLEAF FORM**

Orthic A
Neocutanic B
Unspecified material

Soil families

1000 A horizon not bleached
- 1100 Non-red B horizon
  - 1110 Non-luvic B1 horizon
- 1200 Red B horizon
  - 1210 Non-luvic B1 horizon
  - 1220 Luvic B1 horizon

2000 A horizon bleached
- 2100 Non-red B horizon
  - 2110 Non-luvic B1 horizon
  - 2120 Luvic B1 horizon
- 2200 Red B horizon
  - 2220 Luvic B1 horizon

Ou **OUDTSHOORN FORM**

Orthic A
Neocutanic B
Dorbank

Soil families

1000 A horizon not bleached
- 1200 Red B horizon
  - 1210 Non-luvic B1 horizon

2000 A horizon bleached
- 2100 Non-red B horizon
  - 2110 Non-luvic B1 horizon
  - 2120 Luvic B1 horizon
- 2200 Red B horizon
  - 2210 Non-luvic B1 horizon
  - 2220 Luvic B1 horizon

Pn **PINEDENE FORM**

Orthic A
Yellow-brown apedal B
Unspecified material with signs of wetness

Soil families

3000 Eutrophic B1 horizon
 3100 Non-luvic B1 horizon

Pr **PRIESKA FORM**

Orthic A
Neocarbonate B
Hardpan carbonate horizon

Soil families

2000 A horizon bleached
 2100 Non-red B horizon
 2110 Non-luvic B1 horizon
 2120 Luvic B1 horizon

Ss **STERKSPRUIT FORM**

Orthic A
Prismacutanic B

Soil families

2000 A horizon bleached
 2100 Non-red B horizon

Sw **SWARTLAND FORM**

Orthic A
Pedocutanic B
Saprolite

Soil families

2000 A horizon bleached
 2100 Non-red B horizon
 2110 Subangular/fine angular B horizon
 2111 Non-calcareous B and upper C horizons
 2120 Medium/coarse angular B horizon
 2121 Non-calcareous B and upper C horizons

Tr **TRAWAL FORM**

Orthic A
Neocarbonate B
Dorbank

Soil families

2000 A horizon bleached
- 2100 Non-red B horizon
  - 2120 Luvic B1 horizon

Tu **TUKULU FORM**

Orthic A
Neocutanic B
Unspecified material with signs of wetness

Soil families

1000 A horizon not bleached
- 1100 Non-red B
  - 1120 Luvic B1 horizon
- 1200 Red B horizon
  - 1210 Non-luvic B1 horizon

2000 A horizon bleached
- 2100 Non-red B
  - 2110 Non-luvic B1 horizon

Vf **VILAFONTES FORM**

Orthic A
E horizon
Neocutanic B

Soil families

2000 Colour of E horizon "yellow" when moist
- 2100 Non-red B horizon
  - 2110 Non-luvic B1 horizon
  - 2120 Luvic B1 horizon

We **WESTLEIGH FORM**

Orthic A
Soft plinthic B

Soil families

1000 Non-luvic B1 horizon

TABLE 1.6: SURFACE AREA (HA) OF DIFFERENT SOIL COMPLEXES PER QUATERNARY SUBCATCHMENT IN THE KEEROM TO BULSHOEK WEIR AND BULSHOEK WEIR TO THE COAST SECTIONS OF THE OLIFANTS RIVER BASIN

Keerom to Bulshoek Weir

Soil complex	Quaternary subcatchment							Total
	E10C	E10D	E10E	E10F	E10G	E10H	E10J	
A 1							130.4	130.4
A 8					412.7			412.7
B 1		120.4		106.6	100.4			327.3
B 3	64.3	1077.0	1370.2	569.1	246.0	20.7	2762.3	6109.6
B 3 + I 1					852.8			852.8
C 1		475.7	433.3	16.8				925.8
C 1 + J 1			307.6					307.6
C 2		34.4	278.9					313.3
C 3		7.3	850.6	53.4				911.2
D 1				20.7	83.3		486.0	590.1
D 2					63.4		412.1	475.5
D 3							173.7	173.7
G 1		228.8	262.7	1029.4	643.5		127.0	2291.4
G 2		138.8	521.1	102.2				762.2
H 1			330.0	191.9	44.2			566.2
H 1 + G 2				364.5				364.5
I 1	27.9	147.3	399.6	1005.2	1477.0		310.6	3367.5
I 1 + B 1				72.1	235.3			307.4
I 1 + B 3	8.8	18.0		49.0	849.5			925.3
I 1 + I 2					69.9			69.9
I 2			359.4	466.9	22.2		601.9	1450.4
J 1	19.5	388.1	168.5	353.4			355.6	1285.1
J 2	0.0	535.6	1159.3	278.2	58.1	27.8	496.5	2555.5
J 2+ J 1		109.6	351.2					460.8
L 1	103.6	704.7	546.5	468.6	1154.0		399.4	3376.8
L 4					27.4		99.9	127.3
L 5					71.1		72.7	143.8
L 6				74.4				74.4
	224.1	3985.8	7338.7	5222.6	6410.9	48.5	6428.1	29658.7

Bulshoek Weir to the coast

Soil complex	Quaternary subcatchment								Total
	E10K	E24M	E33C	E33E	E33F	E33G	E33H	G30H	
A 1			6811.6	2477.5	301.4	7888.0		0.3	17478.7
A 2				1311.2		2566.7			3877.8
A 3						2960.8	2767.6		5728.4
A 4							2030.9		2030.9
A 5				1746.1		3854.9	3745.6	11.5	9358.1
A 6						641.9			641.9
A 7						3707.4	2895.1	5036.9	11639.4
B 2						158.2			158.2
B 3	298.8								298.8
B 4	334.0								334.0
C 1	216.4								216.4
D 4							3019.1		3019.1
D 5				1968.4			9753.7		11722.2
D 6		24.3	79.6	1261.5	1582.2	10593.8		1282.6	14823.9
E 1	217.2			2.8		4812.9	2181.8		7214.8
E 2	469.3	288.9				535.7			1294.0
E 3	1758.7	768.0							2526.7
F 1				1947.4		3799.7	3342.4		9089.6
G 1	209.9								209.9
H 2						3403.2	270.3	7.2	3680.7
I 1	798.9								798.9
I 2	106.2								106.2
I 3	525.5	525.9				324.8			1376.3
I 4				1136.1		474.0	582.6	647.1	2839.7
I 5						335.7	36.1		371.8
J 1	315.4					53.5			368.9
J 2	0.6					50.9			51.5
J 3	254.4					3734.0	2873.7		6862.0
J 4						8.7			8.7
K 1	60.4	141.0				457.5			659.0
K 2			967.4	846.1		3092.9	759.9	1481.9	7148.3
K 3							96.9	12.9	109.8
L 1	294.3								294.3
L 2						131.1	914.9	2.9	1048.9
L 3	189.7	2.8			2961.7	12051.8			15206.1
	6049.5	1751.0	7858.6	12697.2	4845.3	65638.1	35270.5	8483.3	142593.6

TABLE 1.7: PHYSICAL AND CHEMICAL LIMITATIONS OF SOIL COMPLEXES, EXCLUDING LAND CLASSES, IN THE OLIFANTS RIVER BASIN

Notes:

i) The following classes and symbols were used to qualify the chemical and physical soil limitations of soil types

Limitation class	Abbreviation
None	(no symbol)
Low	Low
Moderate	Mod
Severe	Sev
Variable	Var

ii) Heuweltjies (termite mounds) are listed as a limitation because soils associated with heuweltjies are generally saline, calcareous, with a hardpan carbonate subsoil horizon

iii) The depth to any subsoil limitation is specified in metres (mm) following the limitation class.

Soil complex	Physical limitations						Chemical limitations		Heuweltjies	Wind erosion hazard on exposure
	Low clay in upper part of profile	Effective depth limiting materials					Alkalinity	Salinity		
		Wetness	Dense clay horizon	Weathering rock	Hardpan carbonate horizon	Dorbank				
A 1	Mod					Low >1.0				Mod
A 2	Mod					Low >1.0			Low	Mod
A 3	Mod					Low-Mod 0.6-1.0			Mod	Mod
A 4	Mod					Low-Mod 0.6-1.0			Mod	Mod-Sev
A 5	Mod					Mod 0.2-0.4	Var	Var	Mod	Mod
A 6	Mod	Low				Mod 0.5-0.7			Low-Mod	Mod
A 7	Mod					Low >1.0			Low-Mod	Mod
A 8									Low	
B 1	Mod	Low								Mod
B 2	Mod	Low								Mod
B 3	Mod	Low-Mod								Mod
B 4	Mod	Low								Mod
C 1	Mod	Mod								Mod
C 2	Mod	Low								Mod
C 3	Mod	Mod								Mod

Soil complex	Physical limitations						Chemical limitations		Heuweltjies	Wind erosion hazard on exposure
	Low clay in part of profile	Effective depth limiting materials					Alkalinity	Salinity		
		Wetness	Dense clay horizon	Weathering rock	Hardpan carbonate horizon	Dorbank				
D 1				Low-Mod 0.6-1.0					Low	
D 2				Low >1.0			Var	Var	Mod	
D 3				Low >1.0		Low-Mod >1.0	Mod-Sev	Mod-Sev	Low-Mod	
D 4						Mod-Sev 0.4-0.7		Mod	Mod	
D 5						Mod-Sev 0.6-0.8	Mod	Mod	Low-Mod	
D 6						Mod-Sev 0.2-0.4	Mod	Mod	Mod	
E 1						Low-Mod 0.6-0.8	Mod-Sev	Mod	Mod	
E 2					Mod 0.6-0.8		Sev	Mod	Mod-Sev	
E 3		Var	Var			Sev 0.2-0.4	Low	Low	Mod-Sev	
F 1						Sev 0.2-0.4	Low-Mod	Low-Mod	Mod-Sev	
G 1	Mod	Mod-Sev	Mod 0.6-0.9					Low		Low
G 2	Mod	Mod-Sev	Mod-Sev 0.4-0.9					Low-Mod		Low
H 1		Low-Mod	Sev <0.5					Low-Mod		
H 2		Low-Mod	Sev 0.3-0.5				Mod	Mod-Sev		
I 1	Mod	Low		Sev <0.5						
I 2		Low	Var	Mod-Sev <0.4				Low		
I 3			Var	Mod-Sev <0.4			Low	Low-Mod	Low	
I 4				Sev <0.4			Low	Low-Mod		
I 5				Sev <0.2			Low	Low-Mod		
J 1	Mod	Low								Low-Mod
J 2	Mod	Mod-Sev						Low		Low
J 3		Mod						Mod		
J 4		Low-Mod					Mod	Mod-Sev		
K 1	Sev									Mod-Sev
K 2	Mod-Sev									Mod-Sev
K 3	Sev									Sev

TABLE 1.8: POTENTIAL OF SOIL COMPLEXES FOR IRRIGATED ANNUAL AND PERENNIAL CROP PRODUCTION BEFORE AND AFTER AMELIORATION OF SOIL LIMITATIONS (AMELIORATION MEASURES INDICATED BY A UPPER SCRIPT) IN THE OLIFANTS RIVER BASIN

Map symbol	Soil potential [1)]			
	Annual crops		Perennial crops [4)]	
	Tuberous [2)]	Non- tuberous [3)]	Before amelioration	After amelioration
A 1	80	70	60	65 [5)]
A 2	70	70	50	70 [5)]
A 3	60	65	50	70 [5)]
A 4	60	50	50	55 [5)]
A 5	40	70	30	75 [5)]
A 6	70	65	45	65 [5)]
A 7	80	65	60	65 [5)]
A 8	50	70	70	80 [6)]
B 1	65	60	50	60 [7)]
B 2	65	50	45	50 [7)]
B 3	65	60	50	60 [7)]
B 4	50	40	40	45 [7)]
C 1	50	50	20	40 [7)]
C 2	70	65	70	70 [7)]
C 3	65	70	45	50 [7)]
D 1	50	70	60	70 [6,7)]
D 2	60	70	60	80 [5)]
D 3	50	60	50	50 [5)]
D 4	40	60	50	80 [5)]
D 5	55	65	75	75 [5)]
D 6	30	65	30	75 [5)]
E 1	40	70	40	75 [5)]
E 2	40	60	50	65 [5)]
E 3	20	45	30	65 [5)]
F 1	20	60	20	65 [5)]
G 1	45	50	25	45 [7)]
G 2	30	45	25	40 [7)]
H 1	20	40	20	30 [7,8)]
H 2	20	40	20	35 [7,8)]
I 1	20	40	30	50 [8)]
I 2	20	40	30	40 [8)]
I 3	10	10	10	10 [8)]
I 4	10	20	10	20 [8)]
I 5	10	10	10	10 [8)]
J 1	70	70	50	60 [9)]
J 2	50	50	30	50 [7,9)]
J 3	60	60	65	75 [7,9)]
J 4	10	20	20	25 [7,9)]

Map symbol	Soil potential			
	Annual crops		Perennial crops	
	Tuberous	Non- tuberous	Before amelioration	After amelioration
K 1	40	30	30	30
K 2	60	40	40	40
K 3	10	20	10	10
L 1	0	0	0	0
L 2	0	0	0	0
L 3	0	0	0	0
L 4	0	0	10	30 [8)]
L 5	0	0	0	0
L 6	0	0	0	0

Percentage of maximum potential	Recommendation for irrigated crop production
≤ 40%	Not recommended
>40 - ≤50%	Marginally recommended
>50 - ≤60%	Conditionally recommended
>60 - ≤80%	Recommended
> 80%	Highly recommended

1) This includes crops such as potatoes, onions, sweet potatoes, and carrots (usually without amelioration of subsoil limitations, e.g. dorbank).

2) 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.

TABLE 1.9: RECOMMENDED PHYSICAL AND CHEMICAL AMELIORATION MEASURES FOR SOIL COMPLEXES (EXCLUDING UNSTABLE DUNES AND LAND CLASSES) IN THE OLIFANTS RIVER BASIN

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.

Soil type symbol	Drainage	Ridging	Deep soil cultivation		Gypsum
			Shift plough	Rip plough	
A 1			Recom DE		
A 2			Recom DE	Recom VD	
A 3				Essen VD	
A 4				Essen VD	
A 5	Recom			Essen VD	Essen
A 6	Recom			Essen VD	Recom
A 7				Essen VD	
A 8				Essen DE	
B 1			Recom DE		
B 2	Recom		Recom DE		
B 3	Recom		Recom DE		
B 4			Recom DE		
C 1	Essen		Recom DE		
C 2			Recom DE		
C 3	Essen		Recom DE		
D 1			Essen DE		
D 2	Recom		Essen DE	Recom VD	Recom
D 3	Recom		Essen DE	Recom VD	Essen
D 4	Recom			Essen DE-VD	Recom
D 5	Recom			Essen DE-VD	Essen
D 6	Recom			Essen DE-VD	Essen
E 1	Recom			Essen DE-VD	Essen
E 2	Recom			Essen DE-VD	Essen
E 3	Recom			Essen DE-VD	Essen

Soil type symbol	Drainage	Ridging	Deep soil cultivation		Gypsum
			Shift plough	Rip plough	
F 1	Recom			Essen DE-VD	Essen
G 1	Essen		Recom MD	Recom DE	
G 2	Essen	Recom	Recom MD	Recom DE	
H 1	Essen	Essen		Recom 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
I 4	Recom			Essen DE	Essen
I 5	Recom			Essen DE	Essen
J 1			Essen DE		
J 2	Essen		Essen DE		
J 3	Recom		Essen DE		
J 4	Recom		Essen De		Essen

TABLE 2.1: ANALYTICAL DATA RECEIVED FROM PRODUCERS IN THE KEEROM TO BULSHOEK SECTION OF THE OLIFANTS RIVER BASIN

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions				
									H	K	Ca	Mg	Na
									(cmol$_c$/kg)				
Sample group 1: Brakfontein, Citrusdal; composite samples													
1.1	Oa/Cv 1	30			4	11	4.2	5 556	0.48	0.04	0.66	0.17	0.05
1.2	Oa/Cv 1	60			6	6	3.9	8 929	0.32	0.05	0.33	0.10	0.05
2.1	Tu 1	30			6	4	4.0	10 870	0.36	0.07	0.65	0.18	0.06
2.2	Tu 1	60			6	4	3.9	3 937	0.40	0.05	0.31	0.23	0.09
3.1	Fw 1	30			4	11	4.1	11 111	0.48	0.06	0.53	0.10	0.05
3.2	Fw 1	60			4	9	3.8	11 236	0.56	0.04	0.44	0.07	0.05
4.1	Kd 2	30			4	5	3.8	8 197	0.48	0.04	0.45	0.14	0.04
4.2	Kd 2	60			4	2	3.7	5 882	0.60	0.05	0.41	0.11	0.06
4.3	Kd 2	90			12	4	3.5	5 618	0.80	0.04	0.34	1.00	0.19
5.1	Kd 1	30			4	10	4.9	5 000	0.16	0.16	0.65	0.19	0.08
5.2	Kd 1	60			6	8	5.3	1 000	0.24	0.19	0.71	0.14	0.16
5.3	Kd 1	90			4	13	4.6	1 053	0.32	0.17	0.96	0.33	0.13
6.1	Tu/Ch 1	30			6	27	5.3	1 662	0.24	0.32	1.30	0.58	0.10
6.2	Tu/Ch 1	60			4	20	3.6	116	2.16	0.19	1.50	2.02	1.40
7.1	Fw/Kd 1	30			4	14	5.1	14 085	0.12	0.05	0.49	0.20	0.03
7.2	Fw/Kd 1	60			4	2	5.2	7 463	0.08	0.02	0.34	0.18	0.06
8.1	Hu 1	30			6	6	3.6	10 000	0.64	0.07	0.30	0.17	0.04
8.2	Hu 1	60			14	5	3.5	8 621	0.80	0.05	0.27	0.19	0.06
9.1	Tu 1	30			4	3	4.4	9 804	0.28	0.07	0.54	0.16	0.04
9.2	Tu 1	60			4	4	3.8	7 937	0.52	0.06	0.40	0.17	0.05
10.1	Pn/Bv 1	30			14	2	3.5	6 410	0.88	0.07	0.32	0.19	0.06
10.2	Pn/Bv 1	60			14	2	3.6	3 226	0.72	0.03	0.20	0.17	0.13
10.3	Pn/Bv 1	90			20	4	3.2	500	2.56	0.11	0.25	5.68	1.86
11.1	Tu/Pn 1	30			4	5	3.6	9 091	1.40	0.14	0.45	0.41	0.11
11.2	Tu/Pn 1	60			6	5	3.4	5 000	1.16	0.06	0.22	0.06	0.06
12.1	Pn/Bv 1	30			6	5	3.5	5 000	0.96	0.07	0.31	0.10	0.05
12.2	Pn/Bv 1	60			4	2	3.7	4 762	1.00	0.08	0.44	0.25	0.09
13.1	Tu 3	30			6	2	5.5	6 944	0.20	0.13	1.12	0.42	0.04
13.2	Tu 3	60			4	6	5.3	1 493	0.12	0.05	0.87	0.60	0.16
13.3	Tu 3	90			4	7	5.6	2 381	0.08	0.04	0.62	0.90	0.12
14.1	Fw1-Du1	30			4	17	5.8	5 435	0.08	0.10	1.07	0.22	0.06
14.2	Fw1-Du1	60			6	6	4.5	11 494	0.20	0.05	0.69	0.31	0.08
15.1	Du 1	30			4	18	5.0	3 448	0.52	0.13	1.60	1.01	0.13
15.2	Du 1	60			8	10	5.0	2 632	0.48	0.11	1.61	1.09	0.14

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions H	K	Ca	Mg	Na
									(cmol$_c$/kg)				
16.1	Tu 3	30			4	15	5.5	10 989	0.12	0.08	0.76	0.15	0.03
16.2	Tu 3	60			4	7	5.1	13 889	0.16	0.07	0.62	0.12	0.06
17.1	Tu 3	30			6	13	5.2	6 329	0.16	0.17	0.99	0.23	0.04
17.2	Tu 3	60			6	9	5.7	2 703	0.12	0.10	1.22	0.85	0.12
17.3	Tu 3	90			4	7	5.6	450	0.08	0.08	1.53	1.79	0.91
18.1	Tu 1	30			4	22	5.0	5 376	0.16	0.09	0.82	0.25	0.06
18.2	Tu 1	60			6	7	4.8	5 618	0.24	0.06	1.13	0.26	0.07
19.1	Tu/Se 1	30			6	11	5.2	4 762	0.28	0.08	2.31	0.66	0.05
19.2	Tu/Se 1	60			4	9	6.5	1 053	0.00	0.05	7.16	1.25	0.08
20.1	Tu 1	30			4	12	4.3	6 098	0.36	0.06	0.94	0.36	0.07
20.2	Tu 1	60			4	7	3.5	10 309	1.40	0.02	0.26	0.08	0.03
20.3	Tu 1	90			6	7	3.5	11 494	1.00	0.02	0.35	0.11	0.04
21.1	Fw 1	30			6	9	5.2	10 000	0.20	0.09	0.55	0.32	0.04
21.2	Fw 1	60			6	4	4.1	5 682	0.16	0.02	0.36	0.14	0.06
22.1	Oa 1	30			4	4	3.5	3 846	1.08	0.09	0.39	0.13	0.06
22.2	Oa 1	60			4	2	3.4	4 425	1.76	0.08	0.56	0.28	0.08
22.3	Oa 1	90			4	2	3.6	6 944	0.68	0.04	0.45	0.19	0.05
23.1	Tu 5	30			4	24	4.7	9 804	0.48	0.09	1.56	0.33	0.04
23.2	Tu 5	60			6	25	3.4	3 623	0.44	0.09	1.56	0.76	0.08
Sample group 2: Brakfontein, Citrusdal; profile samples													
1.1		30			16	38	6.0	2 222	0.00	0.35	3.27	0.71	0.06
1.2		60			14	2	6.9	1 471	0.00	0.26	15.09	7.90	2.41
2.1		30			14	30	5.7	4 505	0.46	0.15	1.56	0.42	0.07
2.2		60			14	4	3.8	2 500	1.68	0.09	1.18	0.62	0.10
3.1		30			8	76	5.6	820	0.29	0.11	1.95	1.57	0.40
3.2		60			6	11	6.4	653	0.00	0.04	1.14	1.13	1.29
3.3		90			6	5	4.9	89	0.71	0.04	1.67	3.31	4.37
3.4		120			6	10	4.5	99	0.71	0.02	0.93	1.98	4.26
4.1		30			8	27	5.5	2 778	0.29	0.17	1.11	0.21	0.06
4.2		60			6	6	4.3	4 545	0.42	0.05	0.42	0.19	0.06
5.1		30			14	23	5.0	862	0.71	0.20	2.39	1.77	0.61
5.2		60			14	2	4.0	1 333	2.06	0.13	1.60	2.14	0.59
6.1		30			6	2	3.9	10 586	1.26	0.05	0.27	0.09	0.01
6.2		60			7	2	4.0	22 727	0.92	0.04	0.17	0.06	0.01
6.3		90			2	3	4.0	25 641	0.84	0.03	0.13	0.04	0.00
7.1		30			6	4	4.0	18 099	0.67	0.03	0.39	0.13	0.01
7.2		60			6	4	4.1	12 048	0.92	0.08	0.32	0.13	0.01

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions				
									H	K	Ca	Mg	Na
									(cmol$_c$/kg)				
Sample group 3: Maanskloof, Citrusdal; composite samples													
1.1	Cv 1	30	0.36	0	≤5	2	4.2	6 700	0.30	0.07	0.27	0.23	0.04
1.2	Cv 1	60	0.28	0	5	1	4.1	13 000	0.44	0.03	0.07	0.20	0.04
1.3	Cv 1	90	0.24	0	5	1	4.1	9 100	0.40	0.03	0.07	0.19	0.04
2.1	Cv 2	30	0.44	0	3-8	2	4.2	7 600	0.50	0.05	0.15	0.20	0.04
2.2	Cv 2	60	0.36	20	3-8	19	4.2	10 900	0.66	0.05	0.12	0.21	0.04
2.3	Cv 2	90	0.28	50	3-8	112	4.1	14 200	0.72	0.03	0.06	0.20	0.04
3.1	Cv 3	30	0.52	0	≈5	21	4.6	5 600	0.20	0.05	0.26	0.22	0.04
3.2	Cv 3	60	0.28	0	5-7	7	4.2	10 700	0.36	0.03	0.09	0.20	0.04
4.1	Cv 4	30	0.76	0	≈5	9	4.2	9 300	0.40	0.07	0.28	0.22	0.05
4.2	Cv 4	60	0.52	20	5-7	36	4.0	10 700	0.70	0.05	0.07	0.19	0.04
5.1	Cv 5	30	0.40	0	5-10	35	4.8	6 000	0.22	0.07	0.52	0.27	0.04
5.2	Cv 5	60	0.32	0	5-10	18	4.1	7 200	0.50	0.05	0.17	0.19	0.05
5.3	Cv 5	90	0.24	0	5-10	8	4.0	10 200	0.70	0.03	0.06	0.20	0.04
6.1	Cv 6	30	0.60	0	5-10	20	4.2	9 300	0.30	0.05	0.24	0.19	0.05
6.2	Cv 6	60	0.28	0	5-10	21	4.0	15 300	0.70	0.04	0.07	0.20	0.04
6.3	Cv 6	90	0.20	0	5-10	5	4.0	13 000	0.70	0.04	0.43	0.29	0.08
7.1	Fw 1	30	0.28	3	<5	14	4.9	8 800	0.18	0.04	0.26	0.26	0.08
7.2	Fw 1	60	0.24	3	<5	16	4.5	7 700	0.18	0.04	0.18	0.25	0.23
7.3	Fw 1	90	0.24	0	<5	14	4.3	18 000	0.20	0.04	0.08	0.23	0.17
8.1	Fw 2	30	0.40	0	<5	4	4.2	5 800	0.20	0.06	0.18	0.25	0.28
8.2	Fw 2	60	0.40	0	<5	4	4.2	9 100	0.36	0.04	0.12	0.23	0.20
8.3	Fw 2	90	0.36	0	<5	3	4.2	15 600	0.28	0.03	0.08	0.23	0.16
9.1	Gs 1	20	0.64	0	5-10	8	4.1	4 900	0.62	0.08	0.12	0.24	0.15
9.2	Gs 1	60	0.72	80	5-10	32	4.0	9 100	1.00	0.06	0.10	0.25	0.23
10.1	Gs 2	20	0.80	10	≈5	7	4.1	4 500	0.50	0.10	0.17	0.27	0.10
10.2	Gs 2	60	0.64	40	≈5	12	4.2	5 100	0.48	0.07	0.12	0.24	0.09
11.1	Hu 2	20	0.60	10	7-12	2	3.9	7 000	0.70	0.08	0.18	0.31	0.09
11.2	Hu 2	60	0.36	0	10-12	2	3.9	7 200	0.80	0.07	0.10	0.28	0.10
11.3	Hu 2	90	0.32	0	10-12	2	3.9	8 400	0.80	0.04	0.06	0.24	0.07
12.1	Ms 1	20	0.80	0	≈5	8	3.9	4 200	0.60	0.11	0.12	0.24	0.09
13.1	Oa 1	30	0.52	0	5-10	16	4.5	5 300	0.28	0.05	0.22	0.29	0.07
13.2	Oa 1	60	0.44	0	6-10	16	4.0	8 100	0.48	0.05	0.10	0.25	0.05
13.3	Oa 1	90	0.32	20	6-10	16	4.0	9 100	0.70	0.04	0.09	0.23	0.05
14.1	Oa 2	30	0.64	0	5-10	18	4.2	7 000	0.30	0.06	0.24	0.26	0.06
14.2	Oa 2	60	0.48	0	6-10	48	4.0	8 400	0.70	0.04	0.09	0.22	0.06
14.3	Oa 2	90	0.28	30	6-10	15	3.9	10 000	0.76	0.03	0.06	0.21	0.06
15.1	Oa 3	30	0.60	0	5-10	31	4.9	4 400	0.20	0.09	0.62	0.33	0.07
15.2	Oa 3	60	0.44	0	10-15	11	3.9	7 700	0.96	0.06	0.14	0.23	0.06
15.3	Oa 3	90	0.12	0	10-15	6	3.8	6 000	1.40	0.04	0.09	0.22	0.07

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions				
									H	K	Ca	Mg	Na
									(cmol$_c$/kg)				
16.1	Tu 1	20	0.92	0	5-10	19	5.9	6 500	0.30	0.12	4.47	0.56	0.07
16.2	Tu 1	50	0.60	0	6-10	14	4.8	6 300	0.40	0.07	1.12	0.40	0.05
16.3	Tu 1	90	0.28	0	6-10	17	4.1	4 400	0.30	0.04	0.12	0.24	0.06
17.1	Tu 2	20	1.28	0	10-15	110	5.2	3 100	0.50	0.26	3.23	0.88	0.13
17.2	Tu 2	50	1.16	0	12-16	51	4.5	4 100	1.00	0.16	2.48	0.75	0.13
17.3	Tu 2	90	0.64	0	12-16	28	4.0	4 900	0.80	0.10	0.81	0.52	0.09
18.1	Vf 1	20	0.28	0	5-10	30	5.1	6 000	0.26	0.04	0.46	0.28	0.05
18.2	Vf 1	50	0.12	0	5-10	31	4.0	7 900	0.56	0.05	0.20	0.28	0.04
18.3	Vf 1	90	0.12	0	10-15	28	4.0	8 600	0.60	0.03	0.47	0.27	0.04
19.1	Vf 2	30	0.36	0	5-10	36	6.0	4 100		0.06	0.54	0.40	0.04
19.2	Vf 2	60	0.90	0	5-10	27	4.2	9 100	0.36	0.06	0.25	0.26	0.04
19.3	Vf 2	90	0.24	0	10-15	22	4.0	8 100	0.80	0.05	0.05	0.25	0.04
20.1	Vf 3	20	0.60	0	5-10	23	5.0	4 500	0.30	0.10	0.61	0.38	0.07
20.2	Vf 3	50	0.28	0	5-10	28	4.0	5 100	0.90	0.05	0.12	0.22	0.04
20.3	Vf 3	90	0.36	0	10-15	10	4.0	5 200	1.30	0.05	0.14	0.20	0.05
21.1	We 1	20	0.68	0	7-12	120	5.2	4 800	0.30	0.16	1.59	0.45	0.07
21.2	We 1	50	0.56	0	8-14	52	4.7	5 000	0.50	0.12	1.39	0.47	0.09
21.3	We 1	90	0.36	0	8-14	11	4.0	3 600	0.70	0.15	0.55	0.42	0.10
Sample group 4: Cape Mangos, Clanwilliam; profile samples													
1.1		30	0.34	1	11.0	7	3.6	9 040	0.91	0.09	0.18	0.08	0.02
1.2		60	0.15	1	10.6	3	3.6	7 890	0.91	0.06	0.07	0.04	0.02
2.1		30	0.84	2	9.4	2	5.5	1 290	0.38	0.27	2.55	0.80	0.16
2.2		60	0.64	5	0.8	11	6.7	50	0.00	0.53	11.15	5.88	1.67
3.1		30	0.75	3	10.8	2	3.5	2 850	1.39	0.12	0.58	0.26	0.08
3.2		60	0.37	5	19.0	1	3.2	930	1.55	0.18	0.58	0.63	0.23
4.1		30	0.36	1	2.6	1	4.0	14 640	0.54	0.03	0.11	0.05	0.03
4.2		60	0.34	1	2.2	0	4.0	19 140	0.54	0.03	0.06	0.02	0.01
5.1		30	0.46	1	5.0	4	4.5	10 730	0.38	0.06	0.37	0.12	0.02
5.2		60	0.22	0	6.4	3	4.3	8 650	0.38	0.06	0.29	0.11	0.02
Sample group 5: Die Vlei, Clanwilliam; profile samples													
1.1		30	0.75	0	Sand	163	5.2	1 340	0.41	0.21	1.51	0.61	0.09
1.2		60	1.04	0	Sand	50	3.6	1 770	1.53	0.09	0.27	0.15	0.03
1.3		90	0.74	0	Sand	31	3.6	1 560	1.26	0.06	0.17	0.09	0.03
2.1		30	0.63	0	Sand	159	4.4	2 200	0.54	0.17	0.98	0.34	0.06
2.2		60	0.44	0	Sand	67	3.8	3 400	0.81	0.08	0.60	0.12	0.03
3.1		30	0.65	0	Sand	183	5.5	580	0.41	0.16	1.95	0.51	0.15
3.2		60	0.84	0	Sand	63	3.8	490	1.67	0.13	1.53	0.27	0.16
3.3		90	0.48	0	Sand	50	4.0	850	1.13	0.08	0.55	0.14	0.16

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions				
									H	K	Ca	Mg	Na
									(cmol$_c$/kg)				
4.1		30	0.75	0	Sand	220	6.4	580	0.00	0.26	4.15	0.56	0.12
4.2		60	0.50	0	Sand	69	4.6	910	0.50	0.07	0.88	0.19	0.06
4.3		90	0.22	1	Sand	20	4.5	2 680	0.36	0.02	0.10	0.03	0.01
5.1		30	0.53	0	Sand	209	6.5	410	0.00	0.27	3.65	0.50	0.13
5.2		60	0.43	0	Sand	105	5.1	650	0.32	0.07	1.58	0.22	0.09
5.3		90	0.59	0	Sand	84	4.3	1 310	0.63	0.06	1.16	0.17	0.10
6.1		30	0.48	1	Sand	113	6.4	430	0.00	0.27	4.95	0.53	0.16
6.2		60	0.88	0	Sand	36	4.0	580	1.08	0.09	2.01	0.34	0.19
6.3		90	0.87	0	Sand	23	3.8	630	1.53	0.04	0.74	0.21	0.16
Sample group 6: Radyn, Clanwilliam; profile samples													
1.1		30	0.41	5	Sand	25	7.4	480	0.00	0.56	7.91	1.87	0.16
1.2		70	0.39	11	Sand	29	7.5	190	0.00	0.67	12.81	3.77	0.66
2.1		30	0.69	0	Sand	46	4.8	180	0.82	0.26	1.89	0.67	0.44
2.2		70	0.62	0	Sand	55	5.2	290	0.58	0.29	1.60	0.58	0.31
3.1		30	0.44	0	Sand	116	6.2	390	0.00	0.24	2.04	0.56	0.19
3.2		70	0.38	0	Sand	81	6.0	410	0.24	0.19	1.72	0.49	0.23
4.1		30	0.57	0	Sand	21	7.2	540	0.00	0.22	3.71	0.60	0.22
4.2		70	0.65	0	Sand	54	4.3	240	0.97	0.24	1.90	0.60	0.61
5.1		30	0.35	1	Sand	245	6.9	430	0.00	0.29	2.65	0.74	0.20
5.2		70	0.33	1	Sand	117	5.8	400	0.39	0.30	1.23	0.60	0.20
6.1		30	0.47	7	Sand	14	7.3	540	0.00	0.62	7.57	2.34	0.25
6.2		70	0.44	9	Sand	17	7.4	440	0.00	0.41	7.15	2.72	0.40
7.1		30	0.65	0	Sand	93	5.6	130	0.53	0.91	3.78	2.57	0.47
7.2		70	0.57	3	Sand	78	5.6	190	0.39	1.07	4.25	4.42	0.72
8.1		30	0.32	3	Sand	117	6.4	970	0.00	0.18	1.04	0.42	0.14
8.2		70	0.27	3	Sand	64	5.9	820	0.24	0.19	1.20	0.40	0.26
9.1		30	0.49	3	Sand	91	5.3	520	0.48	0.31	1.27	0.46	0.11
9.2		70	0.42	11	Sand	113	6.2	310	0.00	0.31	1.74	0.96	0.28
10.1		30	0.28	4	Sand	68	6.5	900	0.00	0.18	1.02	0.38	0.15
10.2		70	0.31	5	Sand	36	6.3	830	0.00	0.18	0.67	0.34	0.16
11.1		30	0.46	3	Sand	172	6.4	630	0.00	0.43	2.17	0.91	0.22
11.2		70	0.35	4	Sand	30	7.0	240	0.00	0.69	4.00	1.92	0.75
12.1		30	0.48	4	Sand	249	6.8	430	0.00	0.25	2.83	0.63	0.18
12.2		70	0.48	4	Sand	89	6.2	230	0.00	0.30	2.59	1.35	0.89
13.1		30	0.48	3	Sand	131	6.7	390	0.00	0.52	1.97	1.25	0.56
13.2		50	0.37	4	Sand	98	6.7	170	0.00	0.69	3.27	2.63	1.13
14.1		30	0.47	5	Sand	200	5.9	530	0.29	0.40	2.03	0.83	0.30
14.2		50	0.19	9	Sand	102	6.4	190	0.00	0.81	2.58	2.45	1.23
15.1		30	0.13	3	Sand	47	6.2	1 490	0.00	0.12	0.57	0.29	0.13
15.2		70	0.12	3	Sand	28	6.2	470	0.00	0.13	0.29	0.32	0.39

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions				
									H	K	Ca	Mg	Na
									($cmol_c/kg$)				
16.1		30	0.32	4	Sand	120	5.9	410	0.50	0.22	3.36	0.48	0.09
16.2		60	0.23	4	Sand	168	6.7	500	0.00	0.24	2.49	0.52	0.12
17.1		30	0.34	4	Sand	72	6.6	1 480	0.00	0.14	1.88	0.55	0.05
17.2		60	0.17	3	Sand	103	6.8	1 310	0.00	0.17	1.15	0.69	0.09
18.1		30	0.30	8	Sand	90	5.3	830	0.50	0.22	1.79	0.62	0.10
18.2		60	0.10	11	Sand	80	6.8	820	0.00	0.25	2.29	0.76	0.12
19.1		30	0.60	10	Sand	141	6.1	610	0.00	0.23	2.63	0.60	0.07
19.2		60	0.32	4	Sand	72	6.9	1 020	0.00	0.23	1.97	0.61	0.08
20.1		30	0.36	2	Sand	77	4.4	1 270	0.70	0.17	1.05	0.21	0.03
20.2		60	0.26	2	Sand	92	6.9	670	0.00	0.21	1.59	0.54	0.10
21.1		30	0.56	0	Sand	65	6.8	790	0.00	0.23	4.79	0.59	0.11
21.2		60	0.49	0	Sand	59	6.1	710	0.00	0.28	3.52	0.66	0.19
22.1		30	0.56	0	Sand	78	6.5	640	0.00	0.35	3.74	0.62	0.13
22.2		60	0.44	0	Sand	74	5.8	670	0.50	0.34	2.58	0.65	0.17
23.1		30	0.38	5	Sand	24	7.3	540	0.00	0.77	6.55	2.11	0.27
23.2		60	0.27	22	Sand	14	7.5	480	0.00	0.52	8.29	2.60	0.35
24.1		30	0.74	0	Sand	64	5.0	430	0.50	0.60	4.20	1.13	0.26
24.2		60	0.82	1	Sand	68	4.2	440	1.15	0.41	2.55	1.15	0.39
25.1		30	0.44	2	Sand	71	6.1	630	0.00	0.43	3.40	1.23	0.26
25.2		60	0.30	1	Sand	84	6.7	360	0.00	0.27	4.02	1.36	0.68
26.1		30	0.37	6	Sand	87	6.5	400	0.00	0.24	4.04	0.77	0.17
26.2		60	0.32	7	Sand	63	6.7	340	0.00	0.19	3.59	0.83	0.19
27.1		30	0.62	12	Sand	81	5.7	1 570	0.45	0.34	1.89	0.83	0.12
27.2		60	0.13	11	Sand	116	6.7	1 150	0.00	0.20	2.68	0.88	0.18
28.1		30	0.90	26	Sand	11	7.4	500	0.00	0.41	7.07	1.11	0.37
28.2		60	0.28	23	Sand	8	7.6	600	0.00	0.25	11.99	1.21	0.48
29.1		30	0.70	18	Sand	18	7.8	640	0.00	0.35	16.64	0.83	0.11
29.2		60	0.77	24	Sand	5	7.8	570	0.00	0.30	18.52	1.12	0.22
30.1		30	1.19	26	Sand	61	6.0	540	0.40	0.47	6.37	0.75	0.12
30.2		60	0.58	24	Sand	21	7.2	440	0.00	0.35	11.11	1.34	0.25
31.1		30	0.32	9	Sand	12	7.6	1 370	0.00	0.23	4.14	0.52	0.12
31.2		60	0.29	12	Sand	13	7.2	1 320	0.00	0.18	3.43	0.55	0.11
32.1		30	0.30	6	Sand	76	6.8	1 640	0.00	0.18	1.45	0.58	0.09
32.2		60	0.12	6	Sand	27	5.8	1 990	0.40	0.13	0.78	0.34	0.06
33.1		30	0.51	12	Sand	52	5.6	430	0.50	0.27	2.68	0.64	0.10
33.2		60	0.46	11	Sand	46	5.5	400	0.50	0.24	2.30	0.86	0.15
34.1		30	0.52	24	Sand	30	7.5	290	0.00	0.34	22.34	1.21	0.22
34.2		60	0.56	19	Sand	18	7.7	240	0.00	0.29	23.05	1.57	0.54
35.1		30	0.28	2	Sand	80	6.9	1 300	0.00	0.23	2.33	0.66	0.07
35.2		60	0.27	2	Sand	47	6.1	960	0.00	0.22	1.34	0.51	0.11

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions (cmol$_c$/kg)				
									H	K	Ca	Mg	Na
36.1		30	0.33	3	Sand	22	7.3	1 090	0.00	0.37	1.75	0.59	0.05
36.2		60	0.24	4	Sand	92	6.5	1 210	0.00	0.39	1.46	0.57	0.08
37.1		30	0.36	3	Sand	9	7.6	720	0.00	0.75	4.77	1.58	0.23
37.2		60	0.23	8		7	7.9	580	0.00	0.94	12.17	2.43	0.37
38.1		30	0.18	2		101	6.3	1 360	0.00	0.25	1.43	0.57	0.10
38.2		60	0.15	1		110	5.9	1 710	0.35	0.30	1.33	0.73	0.18
39.1		30	0.17	1		102	6.3	1 490	0.00	0.16	1.83	0.47	0.10
39.2		60	0.15	2		63	5.7	670	0.40	0.15	1.42	0.23	0.08
40.1		30	0.19	1		84	6.4	2 060	0.00	0.17	1.07	0.55	0.07
40.2		60	0.14	1		96	5.5	2 090	0.50	0.17	0.82	0.50	0.09
41.1		30	0.17	1		88	6.3	3 500	0.00	0.19	1.00	0.45	0.06
41.2		60	0.13	0		175	6.7	2 140	0.00	0.26	1.27	0.47	0.09
42.1		30	0.23	2		115	6.7	1 220	0.00	0.36	1.32	0.51	0.06
42.2		60	0.12	1		67	6.7	1 080	0.00	0.32	1.14	0.49	0.10
43.1		30	0.24	2		105	6.0	1 310	0.40	0.52	1.40	0.60	0.08
43.2		60	0.12	2		91	5.9	930	0.45	0.39	1.89	0.52	0.10
44.1		30	0.21	1		48	6.6	3 060	0.00	0.14	1.39	0.53	0.06
44.2		60	0.15	1		51	6.3	1 820	0.00	0.15	0.68	0.36	0.11
45.1		30	0.28	5		93	6.3	3 480	0.00	0.13	1.26	0.41	0.06
45.2		60	0.26	4		100	5.8	2 750	0.45	0.16	1.33	0.47	0.08
46.1		30	0.37	0		63	4.3	1 130	0.70	0.18	1.04	0.53	0.14
46.2		60	0.24	10		87	4.6	980	0.70	0.25	1.60	0.73	0.21
47.1		30	0.23	1		57	6.1	2 990	0.00	0.20	1.31	0.66	0.07
47.2		60	0.19	1		35	5.6	2 710	0.45	0.22	1.22	0.56	0.09
48.1		30	0.40	1		45	4.6	660	0.70	0.77	4.05	2.87	0.38
48.2		60	0.18	1		23	5.1	380	0.60	0.96	4.50	4.71	0.74
Sample group 7: Radyn, Clanwilliam; composite samples													
1.1	Du/Tu	30			Sa		5.6		0.38	0.41	1.59	0.62	0.12
1.2	Du/Tu	60			Sa		5.6		0.32	0.19	1.56	0.58	0.20
2.1	Du/Tu	30		30	Lm		5.7		0.28	0.33	3.28	1.03	0.09
2.2	Du/Tu	60		40	Lm		7.4			0.19	20.15	2.07	0.21
3.1	Tu/Oa	30		20	18.0		3.9		0.78	0.24	0.62	0.30	0.06
3.2	Tu/Oa	60		20	18.0		5.1		0.33	0.20	0.97	0.46	0.09
4.1	Cv/Cf	30		80	Sa		6.9			0.36	2.31	0.58	0.11
4.2	Cv/Cf	60		80	Sa		4.9		0.69	0.30	1.18	0.40	0.10
5.1	Du	30		20			5.8		0.26	0.28	1.51	0.49	0.10
5.2	Du	60		30			6.4	540		0.08	1.71	0.48	0.11
6.1	Fw/Cv	30		40	Sa		6.8			0.64	2.96	1.15	0.11
6.2	Fw/Cv	60		60	Sa		6.1			0.25	1.29	0.47	0.12

Sample number	Map symbol	Depth (mm)	Organic carbon (%)	Coarse fragments (volume %)	Clay (%)/ Texture	P (mg/kg)	pH (KCl)	Resistance (ohms)	Extractable ions (cmol$_c$/kg)				
									H	K	Ca	Mg	Na
Sample group 8: Radyn, Clanwilliam; profile samples													
1.1		30		20	Sa		7.3			0.23	1.48	0.41	0.01
1.2		80		35	Sa		6.1			0.21	0.94	0.43	0.04
2.1		30		15	Sa		6.9			0.24	2.04	0.43	0.01
2.2		80		60	Sa		5.7		0.18	0.19	0.88	0.29	0.03
3.1		30		15	Sa		6.0	290		0.40	1.29	0.99	0.49
3.2		80		60	Sa		6.3	96		0.36	1.70	3.25	2.04
4.1		30		35	Sa		6.7			0.26	3.23	0.65	0.08
4.2		80		80	Sa		6.1			0.14	2.89	0.55	0.19
5.1		30		35	Sa		6.0			0.36	1.47	0.59	0.04
5.2		80		80	Sa		6.4			0.22	1.96	0.33	0.04
6.1		30		35	Sa		5.5		0.19	0.31	0.73	0.42	0.05
6.2		80		80	Sa		5.2		0.28	0.16	0.97	0.42	0.13
7.1		30		70	LmSa		6.7			0.41	3.67	0.75	0.08
7.2		80		80	LmSa		4.1		1.17	0.17	1.19	0.42	0.13
8.1		30		70	Sa		5.7		0.25	0.26	1.99	0.67	0.19
8.2		80		80	Sa		3.9		1.16	0.18	0.97	0.40	0.23

TABLE 2.2: ESTIMATED GYPSUM, LIME, PHOSPHOROUS AND POTASSIUM TO A DEPTH OF 900 MM FOR SAMPLES RECEIVED FROM PRODUCERS IN THE KEEROM TO BULSHOEK SECTION OF THE OLIFANTS RIVER BASIN AND OTHER AVAILABLE DATA

Sample number	Gypsum	Dolomitic [1]	Calcitic	Phosphorus	KCl [2]	KCl [3]
	(t/ha)			(kg/ha)		
Sample group 1: Brakfontein, Citrusdal; composite samples						
1	0.0	0.8	6.2	302	429	54
2	0.0	0.0	7.2	351	377	17
3	0.0	2.1	8.5	275	429	69
4	0.0	0.0	12.1	356	537	108
5	1.7	0.5	2.8	266	0	0
6	10.9	0.0	27.2	104	0	0
7	0.0	0.0	0.9	324	517	51
8	0.0	0.5	14.9	333	557	0
9	0.0	0.4	8.0	356	342	3
10	17.8	0.0	25.8	369	576	432
11	0.0	2.3	23.9	338	239	67
12	0.0	1.5	19.0	365	271	60
13	0.0	0.0	0.0	338	297	167
14	0.0	0.0	1.3	275	324	62
15	0.0	0.0	5.3	234	64	297
16	0.0	0.8	0.8	275	289	0
17	5.3	0.0	0.0	275	134	46
18	0.0	0.1	2.0	243	306	102
19	0.0	0.7	-0.7	275	359	159
20	0.0	1.7	17.1	288	500	277
21	0.0	0.0	2.5	329	447	62
22	0.0	2.2	22.2	369	306	160
23	0.0	0.0	5.5	72	201	269
Sample group 2: Brakfontein, Citrusdal; profile samples						
1	0.0	0.0	0.0	252	0	0
2	0.0	0.0	24.1	234	366	200
3	19.1	0.0	0.0	198	342	197
4	0.0	0.4	6.1	230	275	28
4	4.4	0.0	27.3	284	174	521
5	0.0	2.7	18.8	374	464	137
6	0.0	1.7	15.7	351	342	56

1) Dolomitic lime with 8.7% magnesium

2) Optimum K concentration based on texture: sand 50 mg/kg; loam 70 mg/kg; clay 100 mg/kg

3) Based on potassium saturation in soil with pH <6.0, resistance >500 ohms and extractable Ca <5.0 cmol/kg: sand 5.5%; loam 4.5%

Sample number	Gypsum	Dolomitic [1)]	Calcitic	Phosphorus	KCl [2)]	KCl [3)]
	(t/ha)			(kg/ha)		
Sample group 3: Brakfontein, Citrusdal; composite samples						
1	0.0	0.0	7.7	387	447	30
2	0.0	0.0	9.7	166	333	28
3	0.0	0.0	6.1	248	482	24
4	0.0	0.0	10.6	95	322	10
5	0.0	0.0	9.5	153	412	39
6	0.0	0.0	11.6	198	447	91
7	0.0	0.0	3.3	203	455	13
8	0.0	0.0	5.5	356	447	34
9	0.0	0.0	6.2	66	112	20
10	0.0	0.0	6.7	176	173	0
11	0.0	0.0	16.1	370	606	15
12	0.0	0.0	7.8	176	307	23
13	0.0	0.0	10.6	101	395	63
14	0.0	0.0	17.8	194	522	58
15	0.0	0.0	3.9	183	318	255
16	0.0	0.0	12.7	12	220	37
17	0.0	0.0	9.5	12	590	94
18	0.0	0.0	7.4	50	467	0
19	0.0	0.0	19.9	150	473	77
20	0.0	0.0	9.1	114	196	0
Sample group 4: Mangos, Clanwilliam; profile samples						
1	0.0	2.5	13.6	343	571	0
2	9.8	0.0	0.0	286	0	0
3	5.9	0.0	21.5	370	101	0
4	0.0	1.5	8.0	397	512	28
5	0.0	0.5	4.4	359	358	0
Sample group 5: Die Vlei, Clanwilliam; profile samples						
1	0.0	1.2	18.3	0	187	50
2	0.0	1.8	10.5	0	169	0
3	3.5	3.3	14.1	0	85	36
4	0.2	2.4	0.0	45	290	31
5	0.0	3.4	0.0	0	222	147
6	0.0	5.6	3.8	32	222	317

Sample number	Gypsum	Dolomitic [1)]	Calcitic	Phosphorus	KCl [2)]	KCl [3)]
	(t/ha)			(kg/ha)		
Sample group 6: Radyn, Clanwilliam; profile samples						
1	0.0	0.0	0.0	29	0	0
2	3.6	0.0	5.6	0	0	0
3	3.0	0.0	0.0	0	0	0
4	1.6	2.2	0.4	41	0	0
5	4.4	0.0	0.0	0	0	0
6	2.4	0.0	0.0	173	0	0
7	21.1	0.0	0.0	0	0	0
8	5.4	0.0	0.0	0	0	0
9	5.4	0.0	0.0	0	0	0
10	5.9	0.0	0.0	0	0	0
11	6.7	0.0	0.0	0	0	0
12	5.1	0.0	0.0	0	0	0
13	13.0	0.0	0.0	0	0	0
14	12.0	0.0	0.0	0	0	0
15	4.5	0.0	0.0	17	14	0
16	0.0	1.8	0.0	0	0	0
17	0.0	0.0	0.0	0	0	0
18	4.2	0.0	0.0	0	0	0
19	0.4	0.0	0.0	0	0	0
20	3.0	0.0	0.0	0	0	0
21	0.0	3.1	0.0	0	0	0
22	1.0	1.3	0.0	0	0	0
23	0.1	0.0	0.0	138	0	0
24	4.3	0.0	4.5	0	0	0
25	3.7	0.0	0.0	0	0	0
26	0.0	0.0	0.0	0	0	0
27	0.0	0.0	0.0	0	0	0
28	0.0	11.4	0.0	216	0	0
29	0.0	30.6	0.0	215	0	0
30	0.0	9.7	0.0	62	0	0
31	0.0	3.1	0.0	208	0	0
32	0.0	0.0	0.5	25	0	0
33	2.8	0.0	0.0	0	0	0
34	0.0	38.1	0.0	88	0	0
35	3.8	0.0	0.0	0	0	0
36	0.0	0.0	0.0	35	0	0
37	0.0	0.0	0.0	282	0	0
38	0.0	0.0	0.0	0	0	0
39	1.7	1.3	0.0	0	0	0
40	0.0	0.0	1.9	0	0	0
41	0.0	0.0	0.0	0	0	0
42	0.0	0.0	0.0	0	0	0
43	2.6	0.0	1.0	0	0	0
44	0.0	0.0	0.0	0	0	0
45	0.0	0.0	0.1	0	0	0
46	4.2	0.0	6.8	0	0	0
47	0.0	0.0	0.0	0	0	0
48	24.5	0.0	0.0	62	0	0
Sample group 7: Radyn, Clanwilliam; composite samples						
1		0.0	0.0		0	0
2		10.7	0.0		140	0
3		0.0	4.4		181	0
4		0.0	0.5		0	0
5		0.0	0.0		244	0
6		0.0	0.0		0	0

Sample number	Gypsum	Dolomitic [1)]	Calcitic	Phosphorus	KCl [2)]	KCl [3)]
	(t/ha)			(kg/ha)		
Sample group 8: Radyn, Clanwilliam; profile samples						
1		0.0	0.0		0	0
2		0.0	0.0		0	0
3	9.5	0.0	0.0		0	0
4		0.2	0.0		0	0
5		0.0	0.0		0	0
6		0.0	0.1		0	0
7		0.3	0.7		7	0
8		0.0	2.1		0	0
Sample group 9: NIWW experimental farm, Lutzville; profile samples						
1	4.4	0.0	0.0		0	0
2	0.0	0.0	0.0		0	0
3	0.0	0.0	0.0		0	0
4	3.7	0.0	0.0		0	0
5	23.6	0.0	0.0		0	0
6	0.0	0.0	0.0		0	0
7	0.0	0.0	0.0		0	0
8	22.0	0.0	0.0		0	0
9	0.0	0.0	0.0		0	0
Sample group 10: De Wet, Trawal; profile samples						
1	4.5	0.0	0.0		0	0
2	0.0	0.0	0.0		0	0
3	0.0	0.0	0.0		0	0
4	0.0	0.0	0.0		0	0
5	4.7	0.0	0.0		0	0
6	0.0	0.0	0.0		0	0
7	17.2	0.0	0.0		0	0
8	0.0	0.0	0.0		0	0
9	0.0	0.0	0.0		0	0
10	0.0	0.0	0.0		0	0
11	0.0	0.0	0.0		0	0
12	0.0	0.0	0.0		0	0
Sample group 11: Rudman et al. 1978, Vredendal-Vanrhynsdorp; profile samples						
1	80.9	0.0	0.0		0	0
2	0.0	0.8	0.0		17	0
3	54.9	0.0	0.0		0	0
4	0.0	0.0	0.0		269	0
5	0.0	0.0	0.0		243	0
6	137.4	0.0	0.0		243	0
7	47.2	0.0	0.0		0	0
8	5.5	0.0	0.0		99	0
9	31.2	0.0	0.0		0	0
Sample group 12: Brink farm samples, Vredendal-Vanrhynsdorp; profile samples						
1	0.0	0.0	0.0		0	0
2	0.0	0.0	0.0		0	0
3	0.0	0.0	0.0		54	0
4	8.4	0.0	0.0		0	0
5	5.2	0.0	0.0		0	0
6	0.0	0.0	0.0		0	0
7	0.0	0.0	0.0		68	106
8	0.0	0.0	0.0		36	114
9	8.2	0.0	0.0		18	0
10	3.0	0.0	0.0		72	0
11	0.0	0.0	0.0		0	0
12	0.0	0.0	0.0		180	0
14	0.7	0.0	0.0		0	0
15	18.9	0.0	0.0		0	0

TABLE 5.1: ATTENDANCE REGISTER FEASIBILITY STUDY FOR THE RAISING OF THE CLANWILLIAM DAM COMMERCIAL FARMERS WORKSHOPS

Note: **Names of farmers/producers and technical advisors are highlighted.**

Name & Surname	Company/Farm	Telephone	Fax	Cell	Email	Postal Address
Vredendal – Klawer – Trawal workshop held on 16 August 2005 at Spruitdrif Cellar, Vredendal						
Basson, Mr. TJ	Zandrug	027 482 2505	027 482 2505	072 122 3760		PO Box 94, Clanwilliam, 8135
Brand, Mr. DG	Sandkraal			082 896 2200		PO Box 466, Vredendal 8160
Brink, Mr. P	Kynoch	027 213 1992	027 213 1992	082 658 6005		PO Box 114, Van Rynsdorp.co.za
Coetzee, Mr. IJ	Eldorado		027 217 1846	082 578 2214		PO Box 107, Lutzville 8165
De Lange, Mr. P	Dept. of Agriculture	027 213 2000/1	027 213 2712	082 907 3395	pieterdl@elsenburg.com	PO Box 130, Vredendal 8160
Du Randt, Mr. ML	Dept. of Agriculture, WC	027 213 2000	027 213 2712	082 907 1134	mariusdr@elsenburg.com	PO Box 130, Vredendal 8160
Ellis, Dr. Freddie	University of Stellenbosch	021 808 3659	021 808 4791	082 552 5475	fe@sun.ac.za	Dept. Soil Science, Private Bag X1, Matieland 7602
Engelbrecht, Mr. SA	Kapel	027 216 1434	027 216 1799	083 630 1388		PO Box 355, Vredendal 8160
Erasmus, Mr. Rassie	Spilhaus	027 213 4507	027 213 4509	082 773 9643	rassie@kingsley.co.za	PO Box 722, Vredendal 8160
Joubert, Mr. Jeff	Vinpro	027 213 5089	027 213 5837	083 455 5190	joubertj@vinpro.co.za	Karee street, Vredendal 8160
Lambrechts, Mr. JJN	University of Stellenbosch	021 808 4787	021 808 4791	072 063 8172	jjnl@sun.ac.za	Dept. Soil Science, Private Bag X1, Matieland 7602
Laubscher, Mr. Nico	Vleiland	027 213 2525	027 213 2825	084 800 5890	alzanne@kingsley.co.za	PO Box 627, Vredendal 8160
Louw, Mr PJ	SAD (Pioneer Foods)	027 213 1996	027 213 1992	082 901 0688	mwplouw@mweb.co.za	34 Van Riebeeck Str, PO Box 952, Vredendal 8160
Mannel, Mr. SP		027 217 1882	027 217 1930	082 610 2433	emprc@techtonics.co.za	PO Box 43, Ebenhauser 8149
Mostert, Mr. Jannie	Vlentervallei	027 217 1040	027 217 1040	082 907 2100	janniem@netactive.co.za	PO Box 22, Lutzville 8165
Mouton, Mr. D	De Vlei	027 482 1202	027 482 1202	082 415 4874	devlei@lando.co.za	PO Box 393, Clanwilliam, 8135
Pienaar, Mr. Francois	Farmers Association		027 213 4555	082 888 2578	fpienaar@new.co.za	PO Box 789, Vredendal 8160
Stephan, Mr. HPC	Rooisand	027 216 1416	027 216 1450	082 801 1888	cstephan@kingsley.co.za	PO Box 25, Klawer 8145

Name & Surname	Company/Farm	Telephone	Fax	Cell	Email	Postal Address
Vredendal – Klawer – Trawal workshop held on 16 August 2005 at Spruitdrif Cellar, Vredendal						
Van der Berg, Mr. Erik	Ninham Shand	021 481 2462	021 424 5588	082 553 5795	Erik.vanderberg@shands.co.za	
Van der Merwe, Mr. WG	Het Sluis			082 802 2323		PO Box 102, Klawer
Van Heerden, Mr. FD	Dept. of Water Affairs	027 482 2233	027 482 2232	082 807 3539	vheerdf@dwaf.gov.za	Private Bag X4, Clanwilliam 8135
Van Zyl, Mr. Gideon	Wilgenhof	027 213 2578	027 213 2518	083 628 9398	wilgenhof@kingsley.co.za	PO Box288, Vredendal 8160
Citrusdal - Clanwilliam workshop held on 17 August 2005 at Citrus Juice Offices, Schalk Pienaar Street, Citrusdal						
Barbour, Mr. Tony	Independent Consultant	021 789 1112	021 789 1112	082 600 8266	tbarbour@telkomsa.net	PO Box 1753, Sun Valley 7975
De Witt, Mr Kobus	Uitsig	022 921 3623	022 921 3623	082 925 7813		PO Box 148, Citrusdal 7340
Ellis, Dr. Freddie	University of Stellenbosch	021 808 3659	021 808 4791	082 552 5475	fe@sun.ac.za	Dept. Soil Science, Private Bag X1, Matieland 7602
Hofmeyer, Mr. Pieter	Wilhelm Soete Trust, Karnmelksvlei	022 921 3610	022 921 3640	082 467 4499	wst@kinglsey.co.za	Posbus 98, Citrusdal 7340
Hugo, Mr R	HB Besproeiing	022 921 2712	022 921 2712	082 874 0411	rhug@netactive.co.za	Posbus 178, Citrusdal 7340
January, Ms. Mariam	Environmental Evaluation Consultant	021 650 2866	021 650 2791	083 508 5049	January@science.uct.ac.za	University of Cape Town
Kotze, Mr. Gert	Koedoeskop	022 921 2636	022 921 2760	083 236 2157	gert@cedarpack.com	Posbus 287, Citrusdal 7340
Mouton, Mr. Johan	MPCL, Brakfontein	022 921 3405	022 921 3165	082 800	johan@moutoncitrus.co.za	PO Box 110, Citrusdal 7340
Ellis, Dr. Freddie	University of Stellenbosch	021 808 3659	021 808 4791	082 552 5475	fe@sun.ac.za	Dept. Soil Science, Private Bag X1, Matieland 7602
Roux, Mr. André	Dept. of Agriculture	021 808 5340	021 808 5370	082 907 1127	andrer@elsenburg.com	Private Bag X1, Elsenburg 7007
Smit, Mr. Christo	Die Poort/ Klawervlei	022 921 3902	022 921 3902		desense-christo@kingsley.co.za	PO Box 20, Citrusdal 7340
Van der Berg, Mr. Erik	Ninham Shand	021 481 2462	021 424 5588	082 553 5795	Erik.vanderberg@shands.co.za	
Van der Heever, Mr. B	Cape Mango's Pty Ltd, Rondegat			082 807 5882	capemango@telkomsa.net	PO Box 403, Clanwilliam
Van der Merwe, Mr. Schalk	Independent Consultant	021 461 4579	021 461 4579	082 080 0521	lilah@mweb.co.za	12 Glen Alpine, Vredehoek, CT, 8001
Van Heerden, Mr. Francois	DWAF, Clanwilliam	027 482 2233	027 482 2232	082 807 3539	vheerdf@dwaf.gov.za	P/BagX5, Clawilliam 8135
Zenani, Mr. Vuyisile	Environmental Evaluation Consultant	021 650 2866	021 650 2791	073 292 2789	zenani@science.uct.ac.za	University of Cape Town

TABLE 5.2: QUESTIONNAIRE USED FOR THE SOILS DISCUSSION SESSIONS

Note: Because all the producers were Afrikaans speaking, the questionnaire was in Afrikaans.

Naam			
Telefoon/selfoon			
Produsent (Ja/Nee)		**Spesialis (Ja/Nee)**	
Plaasnaam		**Spesialiteitsrigting**	
Naaste dorp		**Organisasie**	

1 Kort beskrywing van belangrikste grondtipes op plaas:
Tipe 1
Tipe 2
Tipe 3

2	**Tipe en diepte van meganiese grondvoorbereiding vir meerjarige gewasse**				
Tipe voorbereiding	**Keuse**		**Diepte (mm)**		
	1st	**2nd**	**<700**	**700 – 900**	**>900**
Grondtipe 1					
Geen					
Skeurploeg					
Mengdolploeg					
Lembewerking					
Operd					
Terrasse/Beddings					
Grondtipe 2					
Geen					
Skeurploeg					
Mengdolploeg					
Lembewerking					
Operd					
Terrasse/Beddings					
Grondtipe 3					
Geen					
Skeurploeg					
Mengdolploeg					
Lembewerking					
Operd					
Terrasse/Beddings					

3	Beraamde koste van meganiese grondvoorbereiding			
Tipe voorbereiding	**Diepte**	**Koste (R/ha)**		
		Grondtipe 1	**Grondtipe 2**	**Grondtipe 3**
Skeurploeg	<700 mm			
	700 - 900 mm			
	>900 mm			
Mengdolploeg	<700 mm			
	700 - 900 mm			
	>900 mm			
Lembewerking	<700 mm			
	700-900 mm			
	>900 mm			
Operd				
Terrasse/Beddings				

4	Chemiese verbeteringsmiddels met voorbereiding tot by voorkeur bewerkingsdiepte toegedien					
Produk	**Grondtipe 1**		**Grondtipe 2**		**Grondtipe 3**	
	Noodsaaklik	**Miskien**	**Noodsaaklik**	**Miskien**	**Noodsaaklik**	**Miskien**
Kalsitiese kalk (t/ha)						
Dolomitiese kalk (t/ha)						
Gips (t/ha)						
Enkelsupers (10% P) (kg/ha)						
Dubbelsupers (20% P) (kg/ha)						
KCl (kg/ha)						
K_2SO_4 (kg/ha)						

5	Dreinering			
Grondtipe	**Noodsaaklikheid**			**Koste (R/ha)**
	Essensieel	**Miskien**	**Geen**	
Tipe 1				
Tipe 2				
Tipe 3				

6 Kommentaar oor ander aksies wat as essensieel beskou word na meganiese grondvoorbereiding maar voor plant/vestiging van meerjarige gewasse	
Verwydering van klippe/rotse of hardebank blokke/fragmente	
Terrassering / Beddings	
Gelykmaak van landoppervlak	
Oorbesproeiing vir loging van oplosbare soute	
Windbeskerming	
Organiese deklae	

7 Gewasgeskiktheid					
Grondtipe	**Spesifiseer gewas**	**Voor grondvoorbereiding**		**Na grondvoorbereiding**	
		Geskiktheid (Hoog; Matig; Laag)	**Produksie** (t/ha)	**Geskiktheid** (Hoog; Matig; Laag)	**Produksie** (t/ha)
Eenjarige gewasse					
Tipe 1					
Tipe 2					
Tipe 3					
Meerjarige boomgewasse of wingerd					
Tipe 1					
Tipe 2					
Tipe 3					

8	Voorkeur besproeiingsisteem en stelselkoste (water gelewer op die kant van blok of land)								
Sisteem	**Eenjarige gewasse**			**Meerjarige boomgewasse**			**Wingerd**		
	Keuse		**Koste**	**Keuse**		**Koste**	**Keuse**		**Koste**
	1st	**2nd**	**(R/ha)**	**1st**	**2nd**	**(R/ha)**	**1st**	**2nd**	**(R/ha)**
Vloed									
Sprinkel									
Mikro									
Drip									
Spilpunt									

9	Besproeiingswaterbehoefte (m^3/ha of millimeter per seisoen toegedien)					
Tipe gewas	**Spesifiseer gewas**	**Sisteemtipe**				
		Vloed	**Sprinkel**	**Mikro**	**Drip**	**Spilpunt**
Eenjarig						
Meerjarig						

10	Eenjarige gewasse: Plantdatum en Lengte van groeiseisoen			
Spesifiseer gewas	**Eerste plantdatum**	**Lengte van groei-seisoen (weke)**	**Tweede plantdatum**	**Lengte van groei-seisoen (weke)**

TABLE 5.3: LIST OF COMPILER GROUPS THAT COMPLETED SOIL QUESTIONNAIRES

Compiler group	Name	Farm/Institution	Nearest town
1	Basson, Mr. TJ	Zandrug	Clanwilliam
	Mouton, Mr. D	De Vlei	Clanwilliam
2	Smit, Mr. Christo	Die Poort/Klawervlei	Clanwilliam
3	De Witt, Mr Kobus	Uitsig	Citrusdal
4	Kotze, Mr. Gert	Koedoeskop	Citrusdal
5	Van der Heever, Mr. B	Cape Mango's Pty Ltd, Rondegat	Clanwilliam
6	Hofmeyer, Mr. Pieter	Wilhelm Soete Trust, Karnmelksvlei	Citrusdal
	Hugo, Mr R	HB Besproeiing	Citrusdal
	Mouton, Mr. Johan	MPCL, Brakfontein	Citrusdal
7	Pienaar, Mr. Francois	Farmers Association, Alderton	Vredendal
8	Van Zyl, Mr. Gideon	Wilgenhof	Vredendal
9	Laubscher, Mr. Nico	Vleiland	Vredendal
10	Brand, Mr. DG	Sandkraal	Lutzville
	Coetzee, Mr. IJ	Eldorado	Lutzville
	Du Randt, Mr. ML	Dept. of Agriculture, WC	Lutzville
	Mostert, Mr. Jannie	Vlentervallei	Lutzville
11	Stephan, Mr. HPC	Rooisand	Klawer
12	Engelbrecht, Mr. SA	Kapel	Klawer
13	De Lange, Mr. P	Dept. of Agriculture	Klawer
	Van der Merwe, Mr. WG	Het Sluis	Klawer

TABLE 5.4: MECHANICAL SOIL TILLAGE PRACTICES FOR PERENNIAL CROPS AND COST

Soil complex symbol	Locality	Compiler group	Deep soil tillage				
			Choice	Type	Depth (mm)	Number of directions	Cost (R/ha)
A 1	Klawer	11	First	Rip	>900		R 15 000
A 1	Klawer	12	First	Rip	>900		R 20 000
A 1- A 3	Vredendal	10	First	Rip	>900		R 20 000
A 3	Klawer	11	First	Rip	>900		R 20 000
A 3	Klawer	12	First	Rip	>900		R 20 000
A 3	Vredendal	7	First	Push away surface + Rip	>900	??	R 19 000
A 3	Vredendal	8	First	Push away surface + Rip	>900	??	R 15 000
A 3	Vredendal	9	First	Push away surface + Rip	>900		R 15 000
B 1 - B 2	Clanwilliam	2	First	None			
B 2	Citrusdal	4	First	Mix plough	>900	??	R 10 000
B 2	Citrusdal	3	First	Rip	700 - 900	One	R 5 000
B 2	Citrusdal	4	First	Rip	<700	??	R 4 000
B 2	Citrusdal	6	First	Rip	700 - 900	One	R 4 500
B 2	Citrusdal	6	Second	Mix plough	700 - 900	One	R 6 000
B 3	Clanwilliam	1	First	Mix plough	700 - 900	One	R 5 000
B 3	Clanwilliam	1	Second	Rip	700 - 900	One	R 3 500
C 2	Citrusdal	4	First	Mix plough	>900		R 10 000
C 2	Citrusdal	3	First	Rip	700 - 900	One	R 5 000
C 2	Citrusdal	3	Second	Mix plough	700 - 900	One	R 5 000
C 3	Citrusdal	6	First	Rip	700 - 900	One	R 4 500
C 3	Citrusdal	6	Second	Mix plough	700 - 900	One	R 6 000
E 1	Klawer	13	First	Mix plough	700 - 900		R 14 000
E 1	Vredendal	9	First	Rip	>900		R 12 000
E 1	Vredendal	10	First	Push away surface + Rip			R 20 000
E 1	Vredendal	10	Second	Mix plough	700 - 900		R 13 500
E 2	Klawer	13	First	Mix plough	700 - 900		R 18 000
E 2	Vredendal	7	First	Rip	>900	??	R 14 000
G 1	Clanwilliam	2	First	None (pastures/vegetables)			
H 2	Klawer	13	First	Mix plough	700 - 900		R 14 000
I 1	Clanwilliam	1	First	Rip	700 - 900	One	R 6 500
I 1	Citrusdal	4	First	Rip	>900	??	R 10 000
I 1	Citrusdal	4	Second	Mix plough	>900		
I 2	Clanwilliam	2	First	Rip	>900	One	R 5 000
J 1	Clanwilliam	1	First	Mix + Ridge	700 - 900	One	R 5 000
J 1	Citrusdal	6	First	Rip	700 - 900	One	R 4 500
J 1	Citrusdal	6	Second	Mix plough	700 - 900	One	R 6 000
J 1	Clanwilliam	1	Second	Rip	700 - 900	One	R 4 000
J 3	Vredendal	7	First	Mix plough	700 - 900	??	R 14 000
J 3	Vredendal	10	First	Mix plough	700 - 900		R 13 500
J 3	Klawer	11	First	Mix plough	>900		R 10 000
J 3	Klawer	12	First	Mix plough	>900		R 10 000
J 3	Vredendal	8	First	Mix + trenching		??	R 10 000
J 3	Vredendal	9	First	Rip	>900		R 12 000
J 3	Vredendal	7	Second	Rip	>900	??	R 14 000
J 3	Vredendal	10	Second	Terraces			
J 3	Vredendal	9	Second	Trenching	>900		R 12 000

TABLE 5.5: COST OF DIFFERENT IRRIGATION SYSTEMS BY CROP TYPE

Irrigation system	Choice	Locality	Respondent group	Cost (R/ha)
Vegetables				
Centre pivot	First	Clanwilliam	1	R 10 000
Drip	First	Clanwilliam	2	??
Drip	First	Citrusdal	5	R 10 000 - R 20 000
Drip	First	Citrusdal	6	R 10 000
Drip	First	Vredendal	7	R 14 000
Drip	First	Vredendal	8	R 8 000
Drip	First	Vredendal	9	R 10 000
Drip	First	Vredendal	10	R 12 000
Drip	First	Klawer	11	R 7 000
Drip	First	Klawer	13	R 10 000
Drip	Second	Clanwilliam	1	R 9 000
Overhead	Second	Citrusdal	6	R 10 000
Overhead	Second	Klawer	11	R 3 000
Tree crops				
Drip	First	Clanwilliam	1	R 9 000
Drip	First	Clanwilliam	2	??
Drip	First	Citrusdal	3	R 18 000
Drip	First	Citrusdal	4	R 18 000
Drip	First	Citrusdal	5	R 10 000
Drip	First	Citrusdal	6	R 28 000
Drip	First	Vredendal	7	R 8 500
Drip	First	Vredendal	8	R 8 000
Drip	First	Vredendal	9	R 10 000
Drip	First	Vredendal	10	R 8 000
Drip	First	Klawer	11	R 7 000
Micro	Second	Clanwilliam	1	R 9 000
Micro	Second	Citrusdal	3	R 18 000
Micro	Second	Citrusdal	4	R 18 000
Micro	Second	Citrusdal	6	R 20 000
Wine grapes				
Drip	First	Clanwilliam	1	??
Drip	First	Citrusdal	6	R 18 000
Drip	First	Vredendal	7	R 8 500
Drip	First	Vredendal	8	R 8 000
Drip	First	Vredendal	9	R 10 000
Drip	First	Vredendal	10	R 8 000
Drip	First	Klawer	12	R 20 000
Drip	First	Klawer	13	R 13 000
Micro	Second	Clanwilliam	1	??

TABLE 5.6: IRRIGATION WATER REQUIREMENT BY CROP TYPE AND IRRIGATION SYSTEM

Crop type	Locality	Compiler group	Irrigation system	Irrigation water requirement: Individual volumes (m^3/ha/season)	Irrigation water requirement: Average by crop type and irrigation system (m^3/ha/season)
Annual crops					
Baby Marrow	Klawer	13	Drip	10 000	
Butternut	Citrusdal	6	Drip	5 000 - 7 000	
Cucurbits (general)	Clanwilliam	1	Drip	5 000	
Pumpkin	Vredendal	7	Drip	5 000	6 500
Cucurbits (general)	Clanwilliam	1	Micro	6 000	6 000
Canteloupe	Citrusdal	5	Drip	4 000	4 000
Potato (summer)	Clanwilliam	1	Centre pivot	7 500	
Potato (winter)	Clanwilliam	1	Centre pivot	5 500	6 500
Sweet potato	Citrusdal	6	Drip	5 000 - 7 000	6 000
Tomato	Citrusdal	5	Drip	4 000	
Tomato	Vredendal	10	Drip	4 000	
Tomato	Klawer	13	Drip	10 000	
Tomato (factory)	Vredendal	9	Drip	6 000	
Tomato (factory; summer)	Vredendal	7	Drip	6 000	
Tomato (factory; winter)	Vredendal	8	Drip	6 000	
Tomato (market)	Vredendal	9	Drip	6 000	
Tomato (market; winter)	Vredendal	7	Drip	4 000	
Tomato (market; winter)	Vredendal	8	Drip	4 000	5 556
Vegetables (general)	Klawer	11	Drip	6 000	6 000
Vegetables (general)	Klawer	11	Overhead	7 000	7 000
Watermelon	Citrusdal	5	Drip	4 000	
Watermelon	Citrusdal	6	Drip	5 000 - 7 000	5 000
Perennial crops					
Citrus (general)	Clanwilliam	1	Drip	6 500	
Citrus (general)	Citrusdal	3	Drip	7 000 - 8 000	
Citrus (general)	Citrusdal	6	Drip	6 000	
Navel/valensia	Citrusdal	4	Drip	9 000	
Soft citrus	Citrusdal	4	Drip	6 000	7 000
Citrus (general)	Clanwilliam	1	Micro	11 000	
Citrus (general)	Citrusdal	3	Micro	8 000 - 10 000	
Citrus (general)	Citrusdal	6	Micro	10 000	10 000
Mango	Citrusdal	5	Drip	8 000	8 000
Olive	Vredendal	7	Drip	7 000	7 000
Papaya	Citrusdal	5	Drip	8 000	8 000
Red tea	Citrusdal	5	Drip	1 000	1 000
Wine grapes	Citrusdal	6	Drip	7 000	
Wine grapes	Vredendal	7	Drip	9 000	
Wine grapes	Vredendal	8	Drip	9 000 - 10 000	
Wine grapes	Vredendal	9	Drip	9 000	
Wine grapes	Vredendal	10	Drip	5 000	
Wine grapes	Klawer	11	Drip	8 500	
Wine grapes	Klawer	12	Drip	4 000 - 8 500	
Wine grapes (mass)	Klawer	13	Drip	7 000 - 9 000	7 781
Wine grapes	Vredendal	7	Flood	11 000	
Wine grapes	Vredendal	8	Flood	11 000	
Wine grapes	Vredendal	9	Flood	10 000	10 667
Wine grapes	Citrusdal	6	Micro	5 000 - 8 000	6 500

TABLE 5.7: OTHER ACTIONS CONSIDERED AS ESSENTIAL FOLLOWING MECHANICAL SOIL AMELIORATION BEFORE PLANTING OF PERENNIAL CROPS AND DRAINAGE

Soil complex symbol	District	Complier group	Removal of stones	Terracing	Levelling	Leaching	Windbreaks	Surface mulching	Addition of clay	Drainage	
										Necessity	Cost per ha
A 1	Klawer	11			Essential					None	
A 1	Klawer	12			Essential					None	
A 1- A 3	Vredendal	10	Essential R 3 000		Essential R 2 000	Essential R 500		Reeds R 1 500		None	
A 3	Vredendal	7			Essential					None	
A 3	Vredendal	8	Essential + Crusher		Essential	Essential	Essential			None	
A 3	Vredendal	9	Essential + Crusher		Essential	Essential				None	
A 3	Klawer	11	Essential		Essential	Essential				None	
A 3	Klawer	12	Essential		Essential	Essential				Essential	
B 1 - B 2	Clanwilliam	2			Essential					None	
B 2	Citrusdal	3	Essential		Essential		Essential			None	
B 2	Citrusdal	4	Essential		Essential		Essential			Locally	
B 2	Citrusdal	5	Essential		Essential			Essential			
B 2	Citrusdal	6	Locally R 500-R 3 000		Locally R 1 000		Essential R1 000			Locally	R 6 000 - R 9 000
B 3	Clanwilliam	1			Only dunes				200 mm layer	None	
C 2	Citrusdal	3	Essential	Occasionally	Essential		Essential			None	
C 2	Citrusdal	5	Essential		Essential			Essential		None	
C 3	Citrusdal	6	Locally R 500-R 3 000		Locally R 1 000		Essential R1 000			Locally	R 6 000 - R 9 000
E 1	Vredendal	9	Essential + Crusher		Essential	Essential				None	
E 1	Vredendal	10	Essential R 3 000		Essential R 2 000	Essential R 500		Reeds R 1 500		None	
E 1	Klawer	13	Essential		Essential					Locally	R 7 000
E 2	Vredendal	7	Essential		Essential					None	
E 2	Klawer	13	Essential		Essential					None	
G 1	Clanwilliam	2			Essential					Yes	
H 2	Klawer	13			Essential					None	

Soil complex symbol	District	Complier group	Removal of stones	Terracing	Levelling	Leaching	Windbreaks	Surface mulching	Addition of clay	Drainage	
										Necessity	Cost per ha
I 1	Clanwilliam	1	Essential							None	
I 1	Citrusdal	5	Essential		Essential			Essential			
I 2	Clanwilliam	2	Essential		Essential					None	
J 1	Clanwilliam	1								None	
J 1	Citrusdal	6	Locally R 500-R 3 000		Locally R 1 000		Essential R1 000			Locally	R 6 000 - R 9 000
J 3	Vredendal	7			Essential					Essential	R 5 000
J 3	Vredendal	8			Essential					Locally	R 5 000
J 3	Vredendal	9			Essential					Locally	R 5 000
J 3	Vredendal	10		Essential	Essential R 2 000	Essential R 500		Reeds R 1 500		Essential	R 3 000
J 3	Klawer	11			Essential	Essential				None	
J 3	Klawer	12			Essential	Essential				Locally	

TABLE 5.8: CHEMICAL AMELIORANTS AND DRAINAGE REQUIREMENT BY SOIL COMPLEX

Soil complex symbol	Locality	Compiler group	Chemical ameliorants						
			Calcitic lime (t/ha)	Dolomitic lime (t/ha)	Gypsum (t/ha)	Single supers (kg/ha)	Double supers (kg/ha)	KCl (kg/ha)	K_2SO_4 (kg/ha)
A 1	Klawer	11	2		3	500			
A 1	Klawer	12		3		500			
A 1- A 3	Vredendal	10			6	500			
A 3	Vredendal	7				800			
A 3	Vredendal	8		2		500			
A 3	Vredendal	9		3		800			
A 3	Klawer	11	3		4	500			
A 3	Klawer	12		3		500			
B 1 - B 2	Clanwilliam	2		Yes		Yes		Yes	
B 2	Citrusdal	3		2.6	2	1200		8000	
B 2	Citrusdal	4		2.6	2	10?		40	25
B 2	Citrusdal	6	3	4			800	200	
B 3	Clanwilliam	1	2	2	3	1000			
C 2	Citrusdal	3		2.6	2	1200		8000	
C 2	Citrusdal	4	3	3	1.1		250		130
C 3	Citrusdal	6	3	4			800	200	
E 1	Vredendal	9		2		800			
E 1	Vredendal	10			10	500			
E 1	Klawer	13				Yes			
E 2	Vredendal	7			3	800			
E 2	Klawer	13				Yes			
G 1	Clanwilliam	2		Yes		Yes		Yes	
H 2	Klawer	13				Yes			

Soil complex symbol	Locality	Compiler group	Chemical ameliorants						
			Calcitic lime (t/ha)	Dolomitic lime (t/ha)	Gypsum (t/ha)	Single supers (kg/ha)	Double supers (kg/ha)	KCl (kg/ha)	K_2SO_4 (kg/ha)
I 1	Clanwilliam	1		3	3	1000			
I 1	Citrusdal	4							
I 2	Clanwilliam	2		Yes		Yes		Yes	
J 1	Clanwilliam	1	2	2	3	1000			
J 1	Citrusdal	6	3	4			800	200	
J 3	Vredendal	7				800			
J 3	Vredendal	8			3	500			
J 3	Vredendal	9	2			800			
J 3	Vredendal	10			6				
J 3	Klawer	11	0	0	0	0			
J 3	Klawer	12							

TABLE 5.9 SOIL SUITABILITY AND PRODUCTION (T/HA) OF VARIOUS ANNUAL AND PERENNIAL CROPS BEFORE AND AFTER AMELIORATION OF PHYSICAL SOIL LIMITATIONS BY SOIL COMPLEX

Crop	District	Compiler group	Soil complex	Before amelioration		After amelioration	
				Suitability	Production	Suitability	Production
Annual crops							
Baby Marrow	Klawer	13	H 2	M	10	M	15
Butternut	Citrusdal	6	B 2	M	25	H	28
Butternut	Citrusdal	6	C 3	M	25	H	28
Butternut	Citrusdal	6	J 1	M	25	H	28
Butternuts	Klawer	13	H 2	M	15	H	25
Cucurbits	Clanwilliam	1	B 3	H	35	H	50
Cucurbits	Clanwilliam	1	I 1	L	20	H	50
Cucurbits	Clanwilliam	1	J 1	M-H	30	H	50
Pumpkin	Vredendal	7	E 2	L	??	H	100
Canteloupe	Clanwilliam	2	B 1 - B 2	L	20	L	20
Canteloupe	Citrusdal	5	B 2	H	??		
Canteloupe	Citrusdal	5	C 2	H	??		
Canteloupe	Citrusdal	5	I 1	H	??		
Canteloupe	Clanwilliam	2	I 2	M	30	H	40
Onion	Vredendal	8	A 3	L	0	H	80
Onion	Vredendal	8	J 3	L	30	H	80
Pastures	Clanwilliam	2	G 1	M	??		
Potato	Clanwilliam	1	B 3	M	40	H	60
Potato	Clanwilliam	1	J 1	M-H	40	H	60
Sweet potato	Citrusdal	6	B 2	M	??	H	??
Sweet potato	Citrusdal	6	C 3	M	??	H	??
Sweet potato	Klawer	13	E 1	M	30	H	35
Sweet potato	Klawer	13	E 2	M	30	H	35
Sweet potato	Citrusdal	6	J 1	M	??	H	??
Tomato	Vredendal	10	A 1- A 3	L	??	M-H	100
Tomato (factory)	Vredendal	7	A 3	M	80	H	100
Tomato (factory)	Vredendal	9	A 3	L	0	H	120
Tomato (market)	Vredendal	7	A 3	M	60	H	80
Tomato (market)	Vredendal	8	A 3	L	0	H	80
Tomato (market)	Vredendal	9	A 3	L	0	H	80
Tomato	Clanwilliam	2	B 1 - B 2	M	60	M-H	60
Tomato	Klawer	13	E 1	M	60	H	100
Tomato	Vredendal	10	E 1	L	??	M	110
Tomato (factory)	Vredendal	9	E 1	M	40	H	120
Tomato (market)	Vredendal	9	E 1	M	20	H	80
Tomato	Klawer	13	E 2	M	60	H	100
Tomato (factory)	Vredendal	7	E 2	L	??	H	120
Tomato (market)	Vredendal	7	E 2	L	??	H	80
Tomato	Klawer	13	H 2	M	60	H	100
Tomato	Clanwilliam	2	I 2	M	50	H	100
Tomato	Clanwilliam	1	J 1	M-H	30	H	100
Tomato	Vredendal	10	J 3	L	??	H	120
Tomato (factory)	Vredendal	9	J 3	M	40	H	120
Tomato (market)	Vredendal	7	J 3	L	??	H	80
Tomato (market)	Vredendal	8	J 3	L	20	H	80
Tomato (market)	Vredendal	9	J 3	M	20	H	80

Crop	District	Compiler group	Soil complex	Before amelioration		After amelioration	
				Suitability	Production	Suitability	Production
Vegetables	Klawer	11	A 1	M	50	M	50
Vegetables	Klawer	11	A 3	M	50	M	50
Vegetables	Klawer	11	J 3	M	80	M	80
Water melon	Clanwilliam	2	B 1 - B 2	M	40	M	40
Water melon	Citrusdal	5	B 2	H	??		
Water melon	Citrusdal	6	B 2	M	??	H	20
Water melon	Citrusdal	5	C 2	H	??		
Water melon	Citrusdal	6	C 3	M	??	H	20
Water melon	Citrusdal	5	I 1	H	??		
Water melon	Clanwilliam	2	I 2	M	40	H	60
Water melon	Citrusdal	6	J 1	M	??	H	20
Wheat	Clanwilliam	1	B 3	M	4	H	6
Wheat	Clanwilliam	1	I 1	L	3	H	6
Perennial crops							
Lemon	Citrusdal	3	B 2			H	30
Navel	Citrusdal	3	B 2			H	40
Valensia	Citrusdal	3	B 2			H	38
Navel/valencia	Citrusdal	4	B 2				31
Soft citrus	Citrusdal	4	B 2				38
Citrus	Citrusdal	6	B 2	M	25	H	45
Citrus	Clanwilliam	1	B 3	L	25	H	50
Lemon	Citrusdal	3	C 2			H	30
Navel	Citrusdal	3	C 2			H	40
Valensia	Citrusdal	3	C 2			H	38
Citrus	Citrusdal	6	C 3	M	25	H	45
Citrus	Clanwilliam	1	I 1	L	25	H	50
Citrus	Clanwilliam	1	J 1	L	25	H	50
Citrus	Citrusdal	6	J 1	M	25	H	45
Mango	Citrusdal	5	B 2	L	??	H	20
Mango	Citrusdal	5	C 2	L	??	H	20
Mango	Citrusdal	5	I 1	L	??	H	20
Olives	Vredendal	7	A 3	M	??	H	10
Olives	Vredendal	7	E 2	L	??	H	15
Olives	Clanwilliam	1	I 1	L	??	H	??
Red tea	Citrusdal	5	B 2	H (irrigated)	0.6		
Red tea	Citrusdal	5	C 2	H (irrigated)	0.6		
Red tea	Citrusdal	5	I 1	H (irrigated)	0.6		
Red tea	Citrusdal	6	B 2	M	1	H	1
Red tea	Citrusdal	6	C 3	M	1	H	1
Red tea	Citrusdal	6	J 1	M	1	H	1
Table grapes	Clanwilliam	1	B 3	L	15	H	30
Table grapes	Clanwilliam	1	I 1	L	??	H	??
Table grapes	Clanwilliam	1	J 1	L	15	H	30

Crop	District	Compiler group	Soil complex	Before amelioration		After amelioration	
				Suitability	Production	Suitability	Production
Wine grapes	Klawer	11	A 1	L	10	M	25
Wine grapes	Klawer	12	A 1	L	0	M	25
Wine grapes	Vredendal	10	A 1- A 3	L	??	H	17
Wine grapes	Vredendal	7	A 3	L	??	H	30
Wine grapes	Vredendal	8	A 3	L	0	H	30
Wine grapes (red)	Vredendal	9	A 3	L	??	H	15
Wine grapes (white)	Vredendal	9	A 3	L	??	L	12
Wine grapes	Klawer	11	A 3	L	10	M	30
Wine grapes	Klawer	12	A 3	L	0	M	30
Wine grapes	Citrusdal	6	B 2	L	18	H	25
Wine grapes	Citrusdal	6	C 3	L	18	H	25
Wine grapes (red)	Vredendal	9	E 1	L	??	M	14
Wine grapes (white)	Vredendal	9	E 1	L	??	L	12
Wine grapes	Vredendal	10	E 1	L	??	H	20
Wine grapes	Klawer	13	E 1	L	??	H	30
Wine grapes	Vredendal	7	E 2	L	??	H	35
Wine grapes	Klawer	13	E 2	L	??	H	30
Wine grapes	Klawer	13	H 2	L	??	H	30
Wine grapes	Clanwilliam	1	I 1	L	??	H	??
Wine grapes	Citrusdal	6	J 1	L	18	H	25
Wine grapes	Vredendal	7	J 3	L	??	H	45
Wine grapes	Vredendal	8	J 3	L	20	H	40-50
Wine grapes (red)	Vredendal	9	J 3	L	??	H	20
Wine grapes (white)	Vredendal	9	J 3	L	??	H	40
Wine grapes	Vredendal	10	J 3	L	??	H	30
Wine grapes	Klawer	11	J 3	M	10	H	40
Wine grapes	Klawer	12	J 3	M	15	H	40

TABLE 5.10: FIRST AND SECOND PLANTING DATES AND LENGTH OF GROWING SEASON OF ANNUAL CROPS

Crop	Locality	Compiler group	First planting		Second planting	
			Planting date	Season length (weeks)	Planting date	Season length (weeks)
Cucurbits	Clanwilliam	1	Aug	12	Jan	10-11
Baby Marrow	Klawer	11	May	12	Apr	12
	Klawer	13	1 Jan	18	1 April	18
Butternuts	Citrusdal	6	Mid Sep	13	Mid Jan	15
	Klawer	13	15 Aug	24	1 Jan	21
Pumpkin	Vredendal	7	Mid Dec	16		
Canteloupe	Clanwilliam	2	End Aug	16	Mid Dec	16
	Citrusdal	5	Mid Aug	15		
Onions	Clanwilliam	1	May	20		
	Vredendal	8	1 May - 1 Jul	17		
Potato	Clanwilliam	1	Feb - Mar	14	Jun - Aug	16
Sweet potato	Citrusdal	6	Mid Sep	13		
	Klawer	11	Dec	22		
Tomato (unspecified)	Clanwilliam	1	Aug	28	Jan	28
	Clanwilliam	2	Mid Aug	20	Mid Aug	20
	Citrusdal	5	Mid Feb	20		
	Vredendal	10	10 Oct	16	Mid Dec	17
	Klawer	11	Jan	22	Mar	22
	Klawer	13	1 Jan	26	1 June	26
Tomato (factory)	Vredendal	7	15 Dec - 1 Jan	16		
	Vredendal	9	1 Sep	16	Mid Feb	24
Tomato (market)	Vredendal	7	Mid Sep	20	Mid Feb	24
	Vredendal	8	1 Sep	13	1 Jan	14
	Vredendal	9	Mid Sep	20	Mid Feb	24
Water melon	Clanwilliam	2	Mid Aug	16	Mid Dec	16
	Citrusdal	5	Mid Aug	15		
	Citrusdal	6	Mid Sep	13	Mid Jan	15

APPENDIX B

Definition of Diagnostic Horizons and Materials used for Soil Form Identification and Family Criteria

DEFINITION OF DIAGNOSTIC HORIZONS AND MATERIALS USED FOR SOIL FORM IDENTIFICATION AND FAMILY CRITERIA

1 DIAGNOSTIC HORIZONS AND MATERIALS

1.1 General

For a horizon to be diagnostic, it has to occur within 1.5 m of the soil surface, if not totally, then partially. In some instances a classifiable soil may be submerged under a recent aeolian or colluvial soil deposit. If the recent deposit is shallower than 500 mm, the buried soil is classified. If the deposit is deeper than 500 mm, the young deposit is classified. If the deposit is shallower than 500 mm, but occurs above the material that is not rated as classifiable soil, the recent deposit is classified.

The most important characteristics of diagnostic horizons are the following:

1.2 Diagnostic topsoil horizon

Only one diagnostic surface horizon was described in the survey area:

Orthic A horizon

a) *Because of the absence of prominent characteristics such as abnormally high organic carbon content, wetness, swelling, dark colour and/or high base status, it does not qualify as an organic, humic, vertic or melanic topsoil.*

1.3 Diagnostic subsoil horizons and materials

Subsoil horizons and materials occur below diagnostic topsoil horizons, except when it has been exposed at the surface through the erosion of the soil profile. A portion, at least, of a diagnostic subsoil horizon or material must occur within 1 500 mm from the soil surface. The following subsoil horizons and materials were described in the WODRIS:

Dorbank (Duripan)

a) *Occurs below an orthic A-, a neocutanic B- or a neocarbonate B horizon;*
b) *is hard to extremely hard in the moist state and usually red-brown in colour;*
c) *has a massive or platy structure; and*
d) *is cemented with silica.*

E horizon

a) *This is lighter (higher Munsell colour value) than the overlying topsoil horizon;*
b) *has a light "grey" matrix colour in the dry state;*
c) *may contain mottles or streaks in higher chroma than the matrix;*
d) *is loose or friable in the moist state, but very hard and brittle in the dry state;*
e) *has a very poorly developed structure;*
f) *has undergone a noticeable loss of iron oxides, silicate clay and/or organic material; and*
g) *does not qualify as a regic sand.*

Hardpan carbonate horizon

a) *Is continuous through the pedon;*
b) *is cemented with carbonates to the extent that it becomes a barrier to roots and is only slowly permeable by water;*
c) *is massive, vesicular or platy and extremely hard in the dry state, and hard or very firm in the moist state; and*
d) *occurs below a orthic A- or a neocarbonate B horizon.*

Lithocutanic B horizon

a) *Occurs below an A- or an E horizon;*
b) *gradually changes into weathering rock;*
c) *has colour, structure or consistency that is related to the underlying parent rock in parts;*
d) *has cutanic characteristics;*
e) *does not present a laterally continuous horizon; and*
f) *when the horizon shows signs of moisture, more than 25% of its volume has saprolitic characteristics.*

Neocarbonate B horizon

a) *Occurs directly below an A- or E horizon;*
b) *contains free calcium- or calcium-magnesium carbonate within 1 500 mm from the surface;*
c) *occurs in unconsolidated material (usually transported); and has a structure, in the moist state, that is weaker than moderately blocky or prismatic (CEC at pH7 is < 11 $cmol_c$ per kg soil).*

Neocutanic B horizon

a) *Occurs directly below an A horizon;*
b) *contains no free calcium- or calcium-magnesium carbonate;*
c) *occurs in unconsolidated material (usually transported); and*
d) *has a structure, in the moist state, that is weaker than moderately blocky or prismatic (CEC at pH7 is < 11 $cmol_c$ per kg soil).*

Red apedal B horizon

a) *Has uniform "red" colours in both the dry and the wet states (although the colour should essentially be uniform, a minor deviation is allowed, e.g. red mottles in a red matrix); colour that is "yellow" in the dry state and "red" in the moist state, is diagnostically "red" and not diagnostically "yellow";*
b) *has a structure, in the moist state, that is weaker than moderately blocky or prismatic (CEC at pH7 is < 11 $cmol_c$ per kg soil);*
c) *is not calcareous; and*
d) *occurs directly below a diagnostic topsoil horizon or a yellow-brown apedal B horizon.*

Regic sand

a) *This is a recent deposit, usually aeolian;*
b) *is coarse-textured;*
c) *has no structure (fine aeolian stratification may occur);*
d) *the colour usually is "grey", but may be "red" or "yellow" if stratified;*
e) *mineralogically, it varies little from the parent material;*
f) *it is loose, friable or soft; and*
g) *occurs directly below an orthic A horizon.*

Soft carbonate horizon

a) *Has a morphology that is determined by calcium- and/or calcium-magnesium carbonates; and*
b) *occurs below a orthic A-, a neocutanic B- or a neocarbonate B horizon.*

Unspecified material without signs of wetness

a) *Occurs below a neocutanic or neocarbonate B horizon;*
b) *can vary from unconsolidated soil material to partially weathered rock; and*
c) *shows no signs of wetness.*

Yellow-brown apedal B horizon

a) Has no "grey" colouring in the dry state, as in an E horizon;

b) has uniform "yellow" colouring in the moist state (although the colour should essentially be uniform, a minor variation is allowed, e.g. mottles and concretions that are not sufficient to qualify the horizon as a diagnostic plinthic B; animal activity could also result in colour variations that are allowable);

c) is not calcareous;

d) has the structure of the red apedal B; and

e) occurs directly below a diagnostic topsoil horizon or an E horizon.

2 FAMILY CRITERIA

Bleached orthic A horizon

In the dry state A horizons may have a bleached "grey" colour similar to that of reduced horizons. Although bleached A horizons overlie diagnostic subsoil horizons that have undergone reduction and loss of iron, in many instances, however, such bleached A horizons occur on diagnostic subsoil horizons that have not undergone any noticeable reduction. Bleaching is used as differentiating criterion at family level because bleaching indicates structural instability due to low iron content.

Calcareous horizons and layers

A horizon or layer is calcareous if it has sufficient calcium carbonate or calcium-magnesium carbonate in any section to be visibly effervescent when it is treated with cold 10%-hydrochloric acid. It is not regarded as calcareous when it contains discrete, relic nodules of lime in a non-calcareous matrix.

Continuous black cutans in prismacutanic B horizons

Prismacutanic B horizons in Estcourt form which have continuous black cutans on vertical ped faces are distinguished from those which do not have such black cutans. The presence of black (as opposed to other dark colours) cutans is usually an indication of a wet soil climate. Free lime is then usually absent from the C horizon which normally shows signs of gleying.

Dark and light coloured A horizons overlying the E horizon in Fernwood form

The formation of the E horizon is the result of weathering and the removal of iron. In some cases this has taken place in mildly reducing or podzolizing conditions and the A horizon is light coloured. In other instances, conditions (usually marked wetness) have favoured the accumulation of organic matter and, in turn, a marked darkening in the colour of the A horizon. The latter, darker coloured topsoil horizons (with moist colour values of 4 or less and chromas of 1 or less) are distinguished at family level from those with lighter colours.

Eutrophic B horizons

This term is used to distinguish soils that have undergone a very low degree of leaching. It is expressed as the sum of exchangeable (in contrast with soluble) Ca, Mg, K and Na per kg clay, and is calculated as follows:

Exchangeable cations ($cmol_c$/kg soil) ÷ clay % x 100.

The qualitative and quantitative description of this term is as follows:

Cations ($cmol_c$/kg clay)	> 15
Degree of leaching	Low
Base status	High

Grey and yellow E horizons
Some E horizons have, in the moist state only, a "yellow" (occasionally "red" with hue 5YR) colour as defined for the diagnostic yellow-brown apedal B horizon. In the dry state, however, they have a "grey" E horizon colour. An incomplete covering of the mineral soil particles by ferric oxides is probably the reason for this difference in colour between the dry and moist state.

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Hard and non-hard lithocutanic B horizons and saprolite
More than 70 % of the volume of a hard lithocutanic B horizon or saprolite consists of fresh or partially weathered rock that has a hard consistency at least in the dry, moist and wet states. Horizons that do not meet these requirements are not hard. The latter commonly occur in regions with higher rainfalls where weathering frequently occurs to considerable depths.

Luvic B horizon
A soil has a luvic B horizon if it has the following characteristics:

- If any part of the A horizon contains ≤ 15% clay, the B1 horizon must as least have 5 % more clay than the A.

- If any part of the A horizon has more clay than 15 %, the ratio of the percentage of clay in the B1 horizon to that of the A horizon must be 1.3 or greater.

Non-red and red colours in B horizons and stratified alluvium
In instances where iron oxides have caused a red colour throughout most of a horizon, the soil structure usually is more stable with regard to water than similar soils that are not red. At family level, a distinction is made between non-red and red in certain soil forms.

Podzolic character beneath a diagnostic yellow-brown apedal B horizon
Constantia form has an horizon sequence of orthic A - E horizon - yellow-brown apedal B horizon. Some members of the form have an horizon beneath the yellow-brown apedal B which, if it had been directly beneath an A or E horizon, would have qualified as a diagnostic podzol B horizon. Such members are distinguished at family level from those which do not have such podzolic character below the yellow-brown apedal B.

Presence and absence of lamellae in the E horizon of Fernwood form
Lamellae are wavy, horizontally orientated layers, in vertical section often branched, which, relative to the surrounding soil, are enriched in one or more of aluminosilicate clays, sesquioxides and organic matter. When present, the first lamellae in a profile usually occur within 400 mm to 1000 mm of the soil surface. In the upper part of the profile, lamellae are thin (a few mm thick) becoming thicker (sometimes up to 120 mm) with depth and eventually, at greater depth, thinner. They are not the boundaries between depositional layers.

Signs of wetness
Signs of wetness comprise grey colours with low chromas, sometimes with blue or green tints, with or without sesquioxide mottling. When present, the mottling is yellow-brown, olive brown, red, or black. Signs of wetness must occur within 1 500 mm of the surface.

Subangular/fine angular and medium/coarse angular structure in pedocutanic B horizons
By definition such structure must be at least moderately developed in the moist state. A distinction is made at family level between medium and coarse angular structures on the one hand, and subangular and fine angular structures on the other. The former generally are more common and, in terms of root and water penetration, less suitable for crop production than the latter.