The Development of a Spatial Decision Support System to Optimise Agricultural Resource Use in the Western Cape

C.E. Pretorius

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science (Agriculture) at the University of Stellenbosch.

Prof. T. E. Kleynhans

March 2000

The financial assistance of Agrifutura, CSD/NRF and Environmentek/CSIR institutions towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at are those of the author and are not necessarily to be attributed any of the institutions listed above.

Declaration:

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Date: 9 Februarie 2000

Summary

INTRODUCTION

This thesis describes the development of a decision support model for regional agricultural resource utilisation. The analysis was generated in a spatial context and the optimisation technique was interactive with a geographical information system (GIS). Economic and operational research methodologies were linked to the GIS in the process of determining the appropriate resource uses for the region. The optimisation technique was applied for the Western Cape Province for eight crops.

The spatial decision support system (SDSS) developed by this research was constructed through an eclectic approach, utilising a number of features of economic models and geographic information systems. The FAO/IIASA study on resource optimisation in Kenya provided the starting point for the development of the optimisation methodology. A partial equilibrium multi-market model was used for the study.

APPLICATION OF THE SDSS

The model was applied for the Western Cape Province for eight crops or product groups, viz. apples, citrus, olives, peaches, pears, plums, table grapes, and wine grapes. The LP matrix had 72 557 activities and 22 032 constraints. The results of the model - pertaining to the utilisation of resource units for specific crops were exported to a mapping module to enable the spatial representation of results.

Three examples of the model results were extracted to illustrate the utility of the model as decision support system. The first case was in support of public sector information needs. Thereafter the model results were interpreted from an agribusiness perspective. Finally, the individual investor's information requirements were analysed.

The public sector - as provider of infrastructure and other public goods - needs to ensure maximum effectiveness and efficiency in its activities. In a market economy, the public sector has a limited number of economic and other tools at its disposal to support the development of the agricultural sector. Most important are to provide incentives and infrastructure to guide farm-level decision-making - and thus resource-use patterns - towards efficient production systems at a national or provincial level. The public sector also needs to ensure that it obtains maximum 'returns' or benefit on its expenditure. The spatial decision support system was applied successfully in this regard by identifying and evaluating areas that need to be earmarked for future development for selected crops.

The spatial decision support system was also applied in support of location decisions for agribusiness. For example, in the case of deciduous fruit packaging and canning, a location closer to the source of the products could be profitable since the handling conditions may be less restrictive for the processed product than the inputs. The land-use pattern foreseen for deciduous fruit production, for example peaches, was examined in this regard.

Linear programming models are widely used for farm-level investment decisions. The particular advantage of using this spatial decision support system is its ability to include region-wide competitive forces and local, national and international market constraints.

CONCLUSION AND FURTHER APPLICATION OF THE SDSS

The most apparent advantages of the optimisation technique can be summarised as follows:

- The technique integrated resource potential and economic determinants in predicting land-use patterns. This interactive capability determined the relative profitability and competitive advantage of each of the selected crops vis-à-vis the resource units.

- Each component enhanced the modelling capacity of the other - the GIS (in the land capability model) and linear programming (the multi-market partial equilibrium model) - in the optimisation technique. Greater levels of detail concerning the particular characteristics of the resource units could be included in the optimisation model.
- The visual representation of the solution of a mathematical model of this size greatly assisted the analysis and interpretation of the model results. The integration of the model results into the GIS makes further spatial analysis of the solution possible (for example, overlay analysis).
- The visual representation also assisted in the verification of the model results. This was a major advantage of using a GIS indicate the spatial distribution or address of the model results that would otherwise be listed in tables in terms of quantities only.

Further applications of the optimisation model are possible through changes in any of its components and/or level of detail of the analysis. For example, the spatial decision support system could be applied to simulate the effect of global climate change on the (agricultural) resource-use patterns of a region. Changes to the resource characteristics in the land capability model could simulate the anticipated change in temperature and rainfall regimes. The subsequent change in resource potential for the selected crops can then be incorporated in the linear programming model.

Secondly, the effect of wide spread adoption of changes in technology can be determined in the spatial decision support system. The way in which technology changes are incorporated in the model depends on where in the production process it is developed.

The spatial decision support system was flexible with regard to level of detail of the analysis. The optimisation model can be applied for district, provincial, national and regional level analyses. Evidently, the decision-maker needs to be conscious of the trade-offs between level of detail of the spatial (and economic) data and model size. The large data requirements of the model are implicit to all spatial decision support systems and linear programming models.

Finally, the opportunities for developing the model to determine competitive advantages and guide agricultural development at national and regional level are numerous. Regional applications - for example, for Southern Africa - could also be useful for agribusiness, which are planning business expansion to the region. However, some generalisation of the resource and economic data would be necessary to keep the information load to manageable levels.

Opsomming

Die ontwikkeling van 'n ruimtelike besluitnemingsondersteuningstelsel (RBOS) vir die benutting van landbouhulpbronne van 'n streek word beskryf in hierdie navorsing. Die analise word in 'n ruimtelike konteks gegenereer en is met 'n geografiese inligtingstelsel (GIS) geskakel. Ekonomiese en operasionele navorsingsmetodieke word met die GIS geskakel ten einde die optimale hulpbron gebruike vir die streek te bepaal. Die model was toegepas vir die Wes-Kaap vir agt produkte, naamlik apples, olywe, pere, perskes, pruime, sitrus, tafeldruiwe en wyndruiwe.

Die volume data benut in die model het 'n groot lineêre programmeringsmatriks tot gevolg gehad, met meer as 72 500 aktiwiteite en 22 000 beperkings. Die resultate van die lineêre programmeringsmodel is teruggevoer na die GIS ten einde die resultate ruimtelik voor te stel. Die resultate van die RBOS is vanuit drie perspektiewe ontleed, naamlik die owerheidsektor, landbou industrieë en díe van die individuele investeerder. Die drie voorbeelde van die model interpretasie is uitgesonder om die nut van die model as 'n besluitnemingsondersteuningstelsel te illustreer.

Die belangrikste voordele van die RBOS kan soos volg opgesom word:

- Hulpbron kwaliteit en ekonomiese aspekte word in die bepaling van toekomstige grondgebruikspatrone geïntegreer. Hierdie integrasie weerspieël die dinamika tussen die relatiewe winsgewendheid en mededingende voordeel tussen die verskillende gewasse ten opsigte van die hulpbron potensiaal.
- Elke komponent van die model - ekomomiese modellering en die GIS - het die vermoë van die ander verbeter in die RBOS.
- Die visuele voorstelling van die model oplossing het die analise en interpretasie van die resultate aansienlik vergemaklik. Die integrasie van die model resulate in die GIS maak die verdere (ruimtlike) analise van die resultate ook moontlik.
- Die visuele voorstelling van die resultate het ook bygedra tot die verifiëring van die model oplossing. Hierdie funksie kon inligting wat gewoonlik in terme van hoeveelhede gegee word ook ruimtelik voorstel in terme van ligging en verspreiding.

Verdere toepassing van die model is moontlik deur geringe aanpassings in detail vlak van analise en struktuur van die model. Die model kan byvoorbeeld aangewend word om effek van die wêreldwyde klimaatsverandering op die benutting van landbou hulpbronne te simuleer, asook veranderinge in landboutegnologie.

Die RBOS kan op distriks-, provinsiale-, nasionale- en streeksvlak toegepas word. Die besluitnemer moet egeter bewus wees van die aansienlike data benodighede van die model wat inherent aan beide ekonomiese modellering en 'n GIS is. Daar is egter heelwat geleenthede waar die RBOS landbouontwikkeling op streeks en nasionale vlak kan ondersteun, asook verdere toepassings in terme van sub-kontinentale ontwikkeling in Suider-Afrika.

Acknowledgements:

The research would not have been possible without the expertise and the many hours of assistance provided by the following people:

Mr. Francois Knight - Land capability model
Mr. Daan Louw - Multi-market partial-equilibrium model
Mr. Ryk Taljaard - Mapping of results

Their patience and untiring support are highly valued.

Financial support was received from the following institutions:
Agrifutura - Department of Agriculture: Western Cape
Centre for Science Development / NRF, South Africa
Environmentek - CSIR

The financial assistance of the above institutions towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at are those of the author and are not necessarily to be attributed any of the institutions listed above.

Table of Contents

List of Figures

List of Boxes

List of Tables

Annexes

Chapter One: The Research Problem

1.1 Introduction

The past institutional context of agriculture in South Africa affected the structure, efficiency and competitiveness of the sector. Market liberalisation during the early nineties required a range of changes for government, farmers and agribusiness to adapt to new information and sourcing challenges of the global market. Decision-makers need to utilise the limited resources available to them to their best advantage in the competitive global market. In this context, static comparative advantage in the international arena is defined by broad regional resource endowment - including soil, climate and water, while dynamic comparative advantage is based on infrastructure, skills and technological innovations built through an enabling policy regime. However, to attain competitive advantage in the agricultural sector the individual entrepreneur needs to strengthen his ability to capitalise on the existing static and dynamic comparative advantages.

Decision support systems provide policy-makers and entrepreneurs with means to analyse static and dynamic advantages of the regional agricultural sector. The economically efficient utilisation of agricultural resources is an essential step towards achieving a competitive agricultural sector. The underlying approach to efficient regional resource allocation is therefore one of optimisation: the attainment of economic goals, but within the context of constraints fashioned by the ecological, technological and institutional characteristics of the region.

1.2 Development of the research problem

Investors need to know *where* to locate in order to capitalise on existing static and dynamic comparative advantages. Entrepreneurs want to know whether production opportunities exist that are not currently exploited within a regional (spatial) context. From this, input-providers and output processors need to ensure that their location is spatially advantageous. In the same vein, government as provider of infrastructure and other public goods needs to ensure maximum effectiveness and efficiency in its activities.

In all these cases the different role-players aims to internalise the spatial context into their specific economic activity. No simplistic cause-effect relationships exist between a specific economic determinant, for example, resource quality according to the Ricardian tradition, and welfare. The evolution of theoretical paradigms from comparative advantages to competitive advantages indicates a greater complexity of factors. Furthermore, theories of the spatial economy have also developed to incorporate greater complexity (Nijkamp, 1986).

An analytical tool was developed against this background. It was based on optimisation and incorporates the influence of resource quality, transport costs and demand relations. The particular decision support model also incorporated the spatial or location characteristics (the "address") of the resource base, in contrast with optimisation models where optimal resource allocation is calculated in terms of quantities only. The spatial information was obtained from a spatial database in a geographic information system (GIS) on the agricultural resources of the Western Cape.

The aim of this research was to determine the practical feasibility and value of combining optimisation techniques and a GIS for spatial planning purposes and decision support.

1.3 Overview of the research process

This study aimed to combine a number of existing techniques to develop a decision support model for efficient agricultural resource utilisation. The analysis was generated in a spatial context, with the result that the optimisation technique was interactive with a geographical information system (GIS). Economic and operational research methodologies were linked to the GIS in the process of determining the appropriate resource uses for the region.

Figure 1 provides an overview of the research process. The spatial decision support model is unique in the sense that it combines an optimisation procedure with a location dimension, i.e. not only *what* would be the optimal product combination, but also *where* that needs to be cultivated. The model was applied at provincial level, which is advantageous since it sets the framework for broad provincial level planning and policy formulation. In addition, sub-optimised resource patterns resulting from the aggregation of district-level analyses could thus be avoided.

The data input for the spatial decision support model included both land capability information, which was generated in a Geographic Information System (GIS), and economic data. The resource data set used for the land capability model was comprehensive and included soil, climate, topographical and hydrological characteristics of the region. The spatial location of these characteristics was retained throughout the model.

The economic data set provided information on the structure of domestic and international markets, as well as on production cost for the selected crops. The results of the model was mapped to present the results spatially.

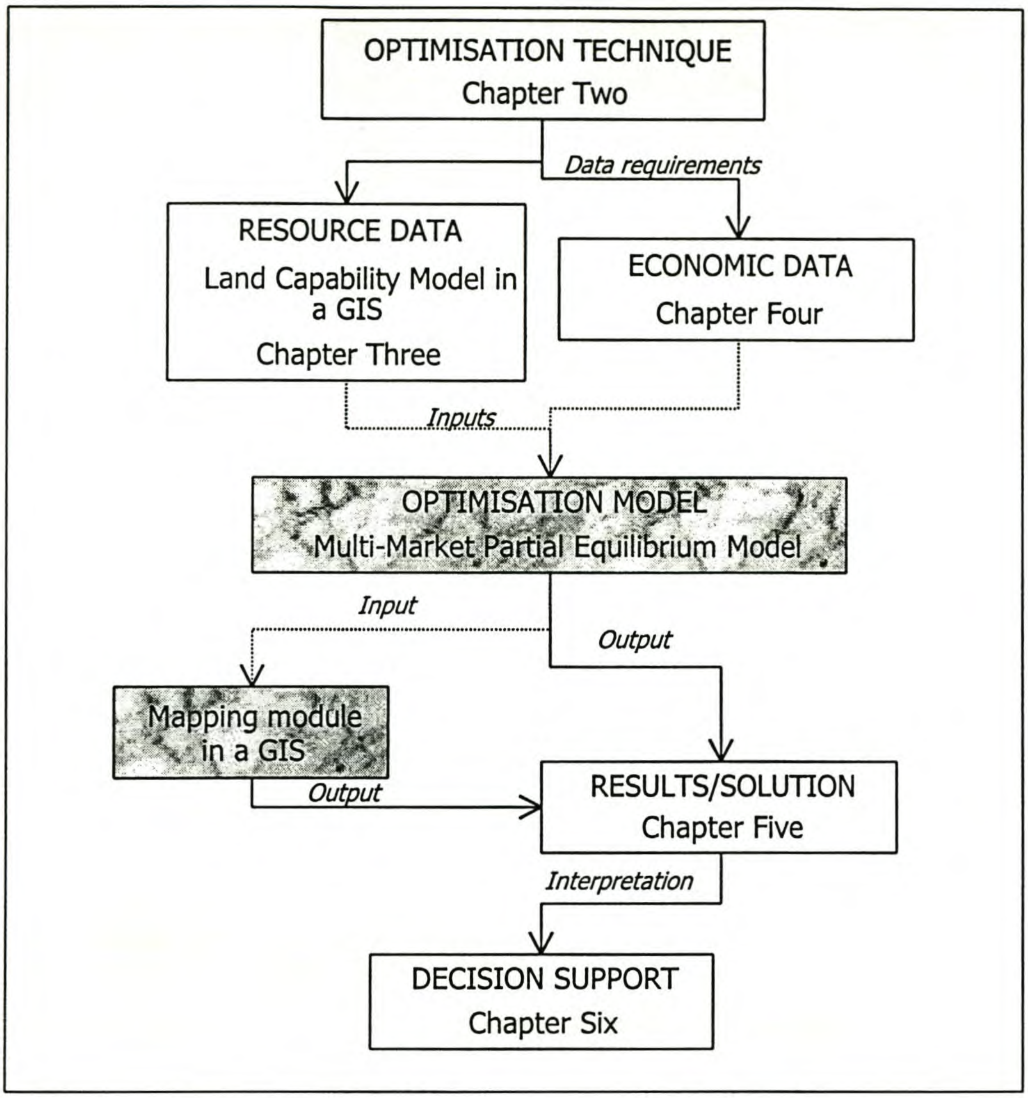


Figure 1.1: Overview of the research process

The economic significance of such a resource optimisation model is that it can indicate to decision-makers which activities are suitable options utilising our fixed stock of agricultural resources, given the current objectives and constraints.

The purpose of the decision support system is not to develop a "blue print" for land-use on a regional scale since that could not be enforced in a market economy. The model should rather be utilised to indicate spatially where production potential exists and highlight areas where there is a discrepancy between the actual production pattern and the optimal production pattern. The analysis can also contribute to the identification of institutional obstacles, for example, the lack of technical assistance as a possible effect of traditional production patterns.

Through the identification of such areas, government efforts to support agriculture can be targeted spatially and in terms of the potential of the specific crops that would serve the policy goals best. This could consequently contribute to the realignment of research and infrastructure expenditure to best support the agricultural potential of the region. In addition, information on regionally optimised production patterns could assist farmers and agribusiness in long-term restructuring of their operations in pursuit of competitiveness.

1.4 Objectives of the study

The following objectives were defined for this study:

1.4.1 Overall objective

- To develop a spatial decision support system (SDSS) for optimisation of agricultural resource use by means of spatial and economic modelling.

1.4.2 Specific objectives

- To develop the optimisation technique to support spatial decision making; and
- To apply the technique for the Western Cape Province.

1.5 Organisation of the study

The organisation of the study follows the outline provided in Figure 1. The design of the optimisation technique is described in Chapter Two. The resource and economic data used in the model is described in Chapters Three and Four respectively. The model results are presented in Chapter Five, while Chapter Six concludes with recommendations and final comments on spatial decision support systems.

Chapter Two: The Optimisation Methodology

2.1 Introduction

This chapter details the development of the spatial decision support system. An overview of economic modelling applied for resource allocation decisions is given in the first section. A description of the value of spatial decision support systems follows this. A number of applications were reviewed in each instance. The final section of this chapter describes the spatial decision support system developed by this study. Figure 2.1 gives an overview of this process.

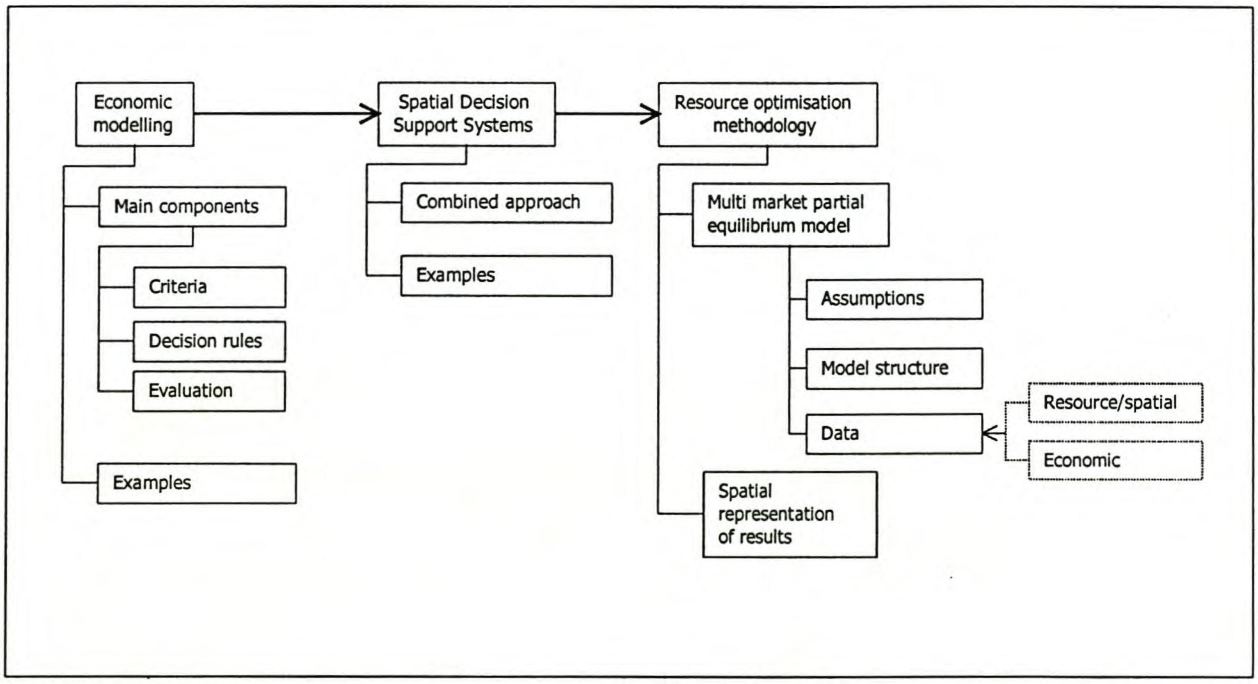


Figure 2.1: Overview of the development of the spatial decision support system

The general point of departure of the study was optimal resource allocation, while agricultural and rural land-use issues were of particular interest as reflected in the selection and review of literature.

2.2 Economic modelling

The prescriptive analysis of decisions emphasises the development, evaluation and application of techniques to facilitate decision-making. The main components of such decision support techniques are criteria, decision rules and the evaluation thereof.

Mathematical programming is a technique designed to assist a decision-maker in the allocation of scarce resources. A linear relationship between the dependent variables and its determinants is usually assumed in the basic formulation of programming applications (Bierman *et al.*, 1981). Although non-linear formulations have also been developed, they are generally not applied as widely as linear formulations.

2.2.1 Main components

Criteria

A criterion is some basis for a decision that can be measured and evaluated. It is the evidence on which the decision is based. Criteria can be of two kinds, viz. factors and constraints.

Factors

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore measured on a continuous scale. These values can be measured independently from a decision-maker's desires and in many cases can be expressed as a mathematical function of variables. Factors are also known as decision variables in the mathematical programming literature and structural variables or attributes in linear goal programming. Examples include gross margin, level of employment, etc.

Constraints

A constraint serves to limit the alternatives under consideration. For example, a constraint would be the exclusion from development of areas designated as nature reserves. Another might be the stipulation that no development can proceed on slopes exceeding 20 per cent gradient. In some instances, the constraint will be expressed as some characteristic that the final solution must possess, i.e. an aspiration level or target. A target is an acceptable level of achievement for any one of the attributes.

Decision rules

The procedure, by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. A decision rule might be as simple as a threshold applied to a single criterion or it may be as complex as one involving the comparison of several multi-criteria evaluations. Decision rules typically contain procedures for combining criteria into a single composite index and a statement of how alternatives are to be compared using this index.

Choice function or objective function

Objective functions provide a mathematical means of comparing alternatives. The concept of an objective represents directions of improvement of one or more of the attributes. The improvement can be interpreted in the sense either "more of the attribute, the better" or "less of the attribute, the better". The first case means a maximisation process and in the second situation, minimisation is at work. Therefore, the objectives imply the maximisation or minimisation of the functions representing one or several attributes reflecting the values of the decision-maker. An objective is thus a perspective that serves to guide the structuring of the evaluation.

Choice heuristic

Choice heuristics specify a procedure to be followed rather than a function to be evaluated. In some cases, they will produce an identical result to a choice function, while in other cases they may simply provide a close approximation. Choice heuristics are commonly used because they are often simpler to understand and easier to implement. Choice heuristics were used to determine the resource potential, as calculated in the GIS-based land capability model.

In general, two kinds of decision rule prevail - those in which the decision rule involves the evaluation of alternative hypotheses about individual features, and those in which it involves a decision about alternative features to include in a set. For example, a decision about areas that is prone to landslides or not is indicative of the first type, while one that selects the best regions for agriculture exemplifies the second. In essence, the first kind of decision is one of classification while the second is one of selection. This study is typical of the second type of decision rule, since the activities that make the "best" contribution to the objective function are selected.

Evaluation

The actual process of applying the decision rule is called evaluation.

2.2.2 Selective review of literature on optimisation techniques

Operations research techniques, of which economic models are part, have been widely used and applied in various fields. These models focus on specific decisions, and on supporting rather than replacing the user's decision-making process (Keenan, 1995).

Several economic modelling procedures and variation in these techniques to accommodate special circumstances (such as non-linearity, risk and uncertainty, time, multi- objectives and/or -criteria, and the combination of discrete and continuous data) have been developed (Romero, *et al.*, 1989). Van Huylenbroeck (undated) applied a combination of such specialised techniques for a trade-off analysis between economic and environmental objectives in rural planning.

Specialised economic models are often applied in the field of resource and environmental management since it allows for the inclusion of both quantified and qualified criteria (Munasinghe, 1993). Bazaraa *et al.* (1981) presented a linear goal-programming model for the agricultural sector in Egypt. This study incorporated objectives usually associated with developing economies and marked a departure from conventional models, which stress maximisation of economic welfare defined as efficiency through maximum social product without consideration for income distribution. The emphasis on income distribution was reflected in the model in the delineation of regional employment goals. In addition, foreign exchange expenditures and regional demand satisfaction goals reflected the importance of limiting foreign trade deficit and providing basic nutrition for the population (Bazaraa, *et al.*, 1981:396).

Many of these applications have, however, identified the need to integrate such procedures with a spatial data component, such as GIS, in order to facilitate the use of spatially related data and to enable the visualisation of acquired solutions. These applications include, for example, the case of water resources policy planning and management (Stewart, *et al.*, 1993); the identification of suitable sites for radioactive waste satisfying certain criteria (Carver, 1991), routing and location analysis (Keenan, 1995); and decision support for pond aquaculture planning and management (Nath *et al.*, 1995).

2.3 Spatial Decision Support Systems (SDSS)

Geographic information systems (GIS) make use of geographical and attribute data. It is the handling of geographical data that distinguishes a GIS from a mapping programme: by allowing linkages between different types of data and the ability to query this spatial data (Keenan, 1995).

Current GIS applications include a wide range of activities - from simple inventory and management of spatial data to sophisticated analysis and modelling of environmental processes. According to Goodchild *et al.* (1993:8) GIS is seen as a general-purpose technology for handling geographic data in digital form, and satisfying, among others, the following needs:

- the ability to pre-process data from large stores into a form suitable for analysis, including such operations as reformatting, change of projection, re-sampling, and generalisation;
- direct support for analysis and modelling, such that forms of analysis, calibration of models, forecasting, and prediction are all handled through instructions to the GIS; and
- post-processing of results, including such operations as reformatting, tabulation, report generation and mapping.

Everard, *et al.* (1996) showed that GIS could be effectively used as a decision-tool in land-use planning at district level, given the availability of a number of strategic data sets. GIS also provided a better structure for analysing spatial information, since various spatial attributes can be integrated into a single digital database and no longer need to be analysed separately. Spatial analytical techniques are therefore particularly useful in land-use planning and the management of natural resources.

However, standard GIS overlay analyses, are of limited use when multiple and conflicting criteria and objectives are concerned (Carver, 1991:338). The need to integrate GIS with specialised economic modelling arises from simultaneous developments in each of these fields. i.e. the increasing importance of spatially related data in decision-making and the requirement to reduce and analyse complex spatial phenomena into a format conducive to decision-making (Keenan, 1995).

2.3.1 Combined approach

The availability of appropriate inexpensive technology for manipulating spatial data enables spatial decision support systems (SDSS) to be created (Keenan, 1995). The benefits of using GIS based systems for decision-making are increasingly recognised. However, Keenan (1995) pointed out that the value of such a spatial decision support system is not determined by its innovative use of technology, but rather by how well they support the need for a spatial component in decision-making.

The combination of economic models and GIS is a relatively recent phenomenon, given the history of economic modelling. Carver (1991:338) concluded with the following advantages of pursuing such an integrated approach:

- that GIS is an ideal means of performing deterministic analyses on all types of geographical data;
- 'GIS provides a suitable framework for the application of spatial analysis methods, such as linear programming models, which do not have their own data management facilities for the capture, storage, retrieval, editing, transformation and display of spatial data;
- Economic modelling provide the GIS with the means of performing complex trade-offs on multiple and often conflicting objectives while taking multiple criteria and the expertise of the decision-maker into account; and
- GIS-and-economic model systems have the potential to provide a rational and objective approach to making decisions on land use.

2.3.2 Selective review of literature on combining economic modelling and Geographic Information Systems (GIS)

The advantages outlined above have been proved in a number of case studies. The United Nations Food and Agriculture Organisation (FAO) and the International Institute for Applied Systems Analysis developed an integrated model for the agro-ecological assessment of land resources for agricultural development planning (FAO/IIASA, 1994). This model was applied for Kenya. The model comprises of two main components: a detailed assessment of the land resources of the country in a GIS, and deriving development policies from this assessment by optimising land/resource use through a linear programming application. The volume of data dictated the use of a workstation for the linear programming application.

Janssen and Rietveld (1990) illustrated the usefulness of a GIS and economic modelling combination by an application for the reallocation of agricultural land in the Netherlands. In this policy problem, two types of conflicts had to be dealt with. These were conflicts among regions; and conflicts between agricultural interests on the one hand, and interests in the field of recreation and environment on the other. Although this was a first attempt, the combination of specialised economic modelling with adequate map presentations allowed for an optimal use of available data. The GIS component was utilised to determine the characteristics of the resource in question, while the economic modelling evaluation was done external to the GIS.

Campbell, et al. (1992), derived agricultural land-use strategies for Antigua through the application of linear programming (LP) in combination with a GIS. The first step in the methodology was to obtain an assessment of the natural resources available to agriculture. The GIS was used to delineate land-use conflicts and provide reliable information on the natural resource base. The second step was to combine, in a LP model, the data on natural resources with other quantifiable information on available labour, market forecasts, technology and cost information in order to estimate the economic potential of the agricultural sector. Finally, the GIS was applied again to map the crop and land allocation patterns generated by the LP model. The results were concrete suggestions for resource allocation, farm size mix, policy application and implementation projects (Campbell, *et al.*, 1992:535).

Two studies by Moxey *et al.*, (1994 and 1995) were of particular interest providing even more interaction through the incorporation of environmental processes in GIS and economic modelling. The first paper considered the effect of three different nitrate abatement policies for agricultural practices for the Tyne catchment in Northern England. The analysis was based on an aggregate-level LP model that predicted producers' production decisions and estimated the resulting spatial distribution of nitrogen applications and nitrate emissions (Moxey, *et al.*, 1994:27). The approach adopted was to divide the catchment into land classes and to define hydrological zones using a GIS. The land classes were then defined in terms of its different production and pollutant possibilities. Finally, an aggregate linear programming model was used to integrate the information on financial and physical production processes in a form which accounted for the distribution of changes in the pattern and intensity of crop and livestock production across different land classes (Moxey, *et al.,* 1994:34).

The second paper by Moxey, *et al.*, (1995) presented an approach to linking an ecological model of vegetation (GIS-based) with a regional economic model of agricultural (production) management practices to provide a means of estimating the costs of achieving a given area of a desired vegetation type. The economic model defined a set of management parameters that form part of the input data for the ecology model. In other words, the economic model predicted the extend to which a particular policy (set of management practices) will be adopted while the ecology model predicts what effect this will have on vegetation. This approach highlighted the need for policy measures to take account of both spatial linkages within agriculture and temporal links between ecological processes and agricultural productivity.

2.4 Resource optimisation methodology

The optimisation technique developed by this research was constructed through an eclectic approach, utilising a number of features of the combined models described above. The FAO/IIASA study on resource optimisation in Kenya provided the basis. This section describes the attributes of the multi-market partial-equilibrium model, and the spatial representation of research results. The land capability model is described in the next chapter dealing with the resource data of the decision support system. The basic model structure is illustrated in Annexure 1.

2.4.1 Multi-market partial-equilibrium model

Multi-market models detail the nature of one (country as a whole or a region) or more (for several regions, farm sizes or farming systems) agricultural production systems, each of which is represented by a profit function from which product supplies are derived. The producer core is complemented with systems of final demand, income equations and market equilibrium conditions. Multimarket models are sectoral as opposed to general equilibrium models. Multimarket models do not equilibrate a number of balances that are fundamental to general equilibrium models. For example, savings and investment, the supply and demand of foreign exchange and fiscal revenues and expenditures are included in general equilibrium models (Sadoulet & de Janvry, 1995).

A partial equilibrium multi-market model was used for the study. Mr D Louw, an agricultural economist that specialises in programming models, developed the model. The agents in the model comprised of the following: a supply of production factors, producers, transporting agents and consumers. The structure of the spatial decision support system is summarised schematically in Annex 1.

2.4.1.1 Assumptions

The following general assumptions were implicit to the model:

- The decisions of the agents were not integrated because the agents were specialised and can only partake in any one of these decisions.
- The state of technology was assumed fixed.
- All the relations in the model were linear.
- Substitutability existed in production since all the private and public fixed factors were common to all activities.
- All the agents exhibited profit maximising behaviour.
- All the products were tradable.
- Equilibrium conditions were obtained in the product markets through price and quantity adjustments.
- The model was static and doesn't include adaptation in product prices and quantities due to the substitution effects of price changes or any other dynamic effects forthcoming from year-to-year changes.

2.4.1.2 Structure

a) Factor supply

The basic factors of production included in the model were land quality, water availability and labour usage. The key determinants of potential yield were land quality and water availability. The resource assessment was done in a GIS. The cropping models applied were based on the resource characteristics of each land parcel in order to determine the potential yield per activity.

b) Input cost and labour requirements

The input costs were calculated on a per hectare basis. The average annual expenditure for long-term crops was used for this figure in order to make comparisons between varying investment and income cycles of the different crops possible. The labour requirement per year was also specified for each activity.

c) Cost minimising/profit maximising production

Production was based on cost minimisation (profit maximisation). Decisions on land allocation to any of the activities were based on the comparative advantage of an activity for the respective parcel of land (i.e., in terms of suitability).

The production of irrigated crops was constrained by the water supply for agricultural purposes in the particular catchment in which the land unit was located. The water requirements of the irrigated crops were determined in the resource assessment.

d) Transportation cost

Transportation cost was added to the production costs in order to discriminate against spatially dispersed markets. Transportation costs were determined to each of the three product markets.

e) Product markets

Three product markets were specified for the model. Cape Town was the consumption centre for the Western Cape, while Beaufort West was the exit point for consumption in the rest of South Africa. An international entry/exit point was specified at the Cape Town harbour for imports and exports of products. The model was "forced" to satisfy the provincial and national markets first before produce can be exported. This requirement had been built in to take account of the quality requirements of the export market and the fact that some portion of the total production was not of export quality and will consequently be consumed locally. This restriction could also be manipulated with local consumption/export ratios, for example 65 per cent of a particular crop was consumed locally while 35 per cent was exported.

f) Demand

A demand curve was constructed for each of the products in the model and consists of ten possible consumption points. Price elasticity of demand was specified for each of the demand curves in order to calculate the equilibrium price. Basic quantities demanded served as a constraint on volume produced for those crops with limited product markets.

g) Objective: Maximisation of total welfare

Total welfare was calculated by the summation of producer welfare and consumer welfare at market equilibrium. Welfare and producer income curves were specified for each product under consideration.

The data matrices were constructed in Quattro Pro and the model itself is executed in "Xa Professional Linear Programming Systems".

2.4.1.4 Data

The resource and economic data requirements for the application of the optimisation technique were discussed in detail in Chapters Three and Four respectively.

2.4.2 Spatial representation of results

The optimisation model result (with regard to the allocation of land to the various activities) was drawn back into the GIS and can be compared with the existing land-use pattern in the Western Cape. The spatial references were retained through keeping the soil types per polygon as separate alternatives for crop cultivation. By using geo-referenced polygons, it was thus possible to generate maps of spatial allocation of resources to various crops, including projected areas where a crop can be cultivated in the province; projected categories of yield per crop at various locations in the province; and projected crop combinations for any area.

The model could be applied in support of longer term planning needs of individual investors, local and provincial authorities, private/public institutions and agribusiness. Such analyses would attempt to determine the difference between current and projected land use patterns (expansion, intensification and/or substitution of crops); future infrastructure requirements based on projections; required institutional development based on projections; and impact on forward and backward linkages with agribusiness.

Further scenario analyses on the model results could include restricting the total water availability, increases in production costs and market price fluctuations. Another possible application is to model the effects of climate change on the agricultural production potential of the Western Cape.

Chapter Three: The Resource Base

3.1 Introduction

The model was applied at provincial level for the Western Cape (See Annex 2). The aim of this chapter is to provide information on the resource data utilised in the model, i.e. the agricultural resource base of the Western Cape Province. The natural resource base will be described in the first instance and secondly, a description of the cropping models applied to determine the resource potential of the region. The third section of the model will highlight the data characteristics of the results of the cropping models. Figure 3.1 is a schematic representation of the manipulation of the resource data in the optimisation technique.

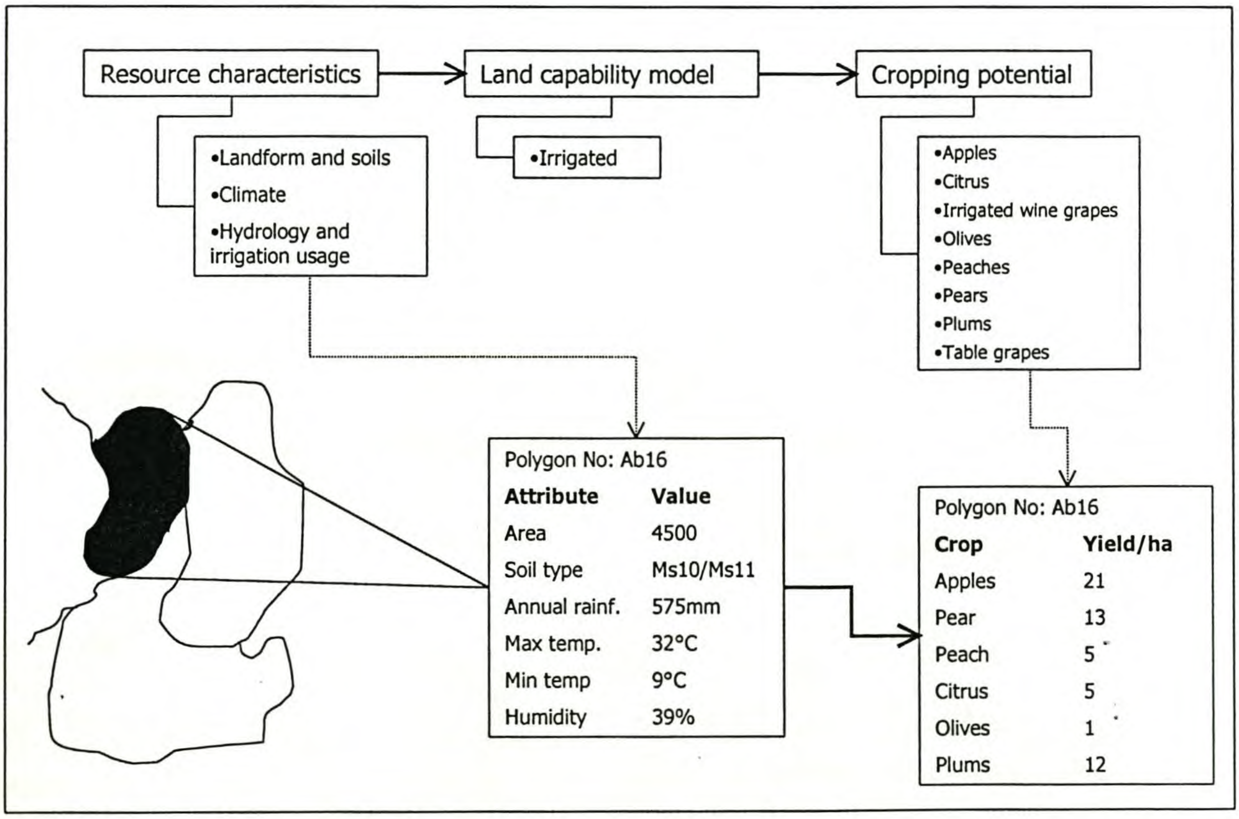


Figure 3.1: Schematic representation of manipulation of resource data

3.2 The Western Cape Resource Base

3.2.1 Landform and soils

The description of the physical land resources of the Western Cape Province was based mainly on the work of Moolman and Lambrechts in Lipton *et al.* (1996). This section is focused on the arable land area that formed the resource input to the optimisation model.

Two broad physiographic elements - the Cape Folded Belt and the Coastal Foreland - are characteristic of the study area. These physiographic elements each have distinct terrain morphology, geology and soils.

The Cape Folded Belt encompasses the pronounced mountain ranges with a north-south trend along the West Coast and an east-west trend along the south coast. The slopes are generally steep to very steep, with resistant quartzite rock outcrops or with a thin soil cover. These mountain ranges cannot be utilised for agricultural purposes, while some afforestation is possible. However, the folded mountain zone contains many valleys as well as extensive upland plains which can be cultivated. The Elgin-Grabouw area in the Boland region and the Koue Bokkeveld in the North West are two examples of extensive upland plains.

Easily weatherable rocks usually underlie the valleys with high clay forming potential. Some of these valleys, such as the upper reaches of the Olifants River, are very narrow and sediments from the mountain slopes cover the clay forming rocks of the valley bottom. Other valleys such as the Breede River and the Little Karoo are wide and a large variety of soils, ranging from sandy to clays, are found.

The upland Koue Bokkeveld and Elgin-Grabouw plains are underlain by clay forming rocks and the soils materials are generally loamy to clayey. The slope away from the level floodplain zone varies from 0,5 percent on the lower footslopes to ≥15 percent, and even ≥25 percent, on the mid and upper slopes.

The Coastal Foreland is the zone between the folded mountain belt and the coast. The western foreland is a smoothly undulating plain, rising to less than 200m above mean sea level, underlain by easily weatherable rocks. The soils are generally clayey with a tendency to be saline and even sodic/magnesic. The degree of dissection of the land surface can vary considerable depending on the proximity to rivers - for example the Berg River - affecting the slope of the land. Slopes are similar to those of the upland plains in the more intense dissected zones. Elsewhere slopes seldom exceed 15 percent.

Along the west coast, terminating on the Cape Flats (Philippi farming area), is an old coastal plain less than 50m above mean sea level, covered by a strip of deep wind transported sand extending three to 50km inland. The slope on the coastal plain is less than 8 percent.

The western Coastal Foreland is, however, broken by a number of intrusive rock-bodies (granite rocks) to form the low Paarl and Paardeberg of the high Darling and Vredenburg hills. These intrusions are associated with moderate to fairly deep, red and brown, clay loam to clay soils, with moderately steep to steep slopes.

The southern Coastal Foreland contains discontinuous fold ridge remnants, as at Caledon and Hermanus, with sandy soils. The rest of the foreland gradually slopes from about 300m above mean sea level towards the sea, and are underlain by clay forming rocks. The landscape is moderately to strongly dissected with steep slopes. Depending on the slope, the soils vary from extremely shallow to moderately deep, with a silty to clayey texture.

A well-developed coastal plain extends from Hermanus eastwards along the coast. Recent calcareous sands, limestone and local marine clays cover the plain. The limestone are characterised by low dune-like hills, while the clayey saline/sodic sediments occur on flat, low-lying plains at elevations more than 15m above mean sea level.

The large range in rock and terrain types, elevation and age of land surfaces, and differences in climate in the study area, have led to the development of a large range of soil types. They may vary from well to poorly drained, from acid to calcareous, from sandy to clayey, from extremely shallow to very deep, with or without coarse fragments in the topsoil.

The detailed pedological information on the soils was simplified to create so-called "resource units", because of the large number of soil forms and series identified. A resource unit can be described as groups of soils with similar morphological, physical and chemical properties. All the soils in a resource unit would require similar management practices - for example fertilisation, cultivation, erosion protection methods - and the range of adapted crops and production potential would be similar under defined climate and terrain conditions.

3.2.2 Climate

The study area has a Mediterranean climate, except for the eastern part of the North West sub-region. The Swartland and Boland sub-regions have 80 percent of the annual rain from April to September while the Little Karoo and the South Coast have 60 percent.

In the North West, the average annual rainfall varies from 50mm in the northern part to 1000mm in sections of the Cedarberg. However, the rainfall is generally low and erratic and more than 80 percent of this sub-region has an annual rainfall between 75mm and 250mm. Strong winds, especially during summer are common and lead to severe erosion. Although low winter temperatures and frost are common in the mountains and high plateaux, the coastal zone and the Olifants River irrigation area are usually frost-free.

The Swartland sub-region is characterised by relatively wet winters with moderately low temperatures. Very low temperatures and frost, with occasional snow, are restricted to the mountains of the Piketberg-Porterville area.

In the Boland sub-region, the Ceres-Karoo farming area has a predominantly summer rainfall while the rest has a winter rainfall. The climate ranges widely from moderate coastal in the south to severe extremes in the Koue Bokkeveld and Ceres-Karoo. The average annual rainfall varies from 1000-1200mm in Franschoek, Jonkershoek and Slanghoek to 600-800mm in the western zone of the sub-region, 250-500mm in the east, and 75mm in the Ceres-Karoo. Temperature differs markedly from the frost-free coastal zone and valleys to the Koue Bokkeveld where frost and snow are common. The Boland often has strong to gale force south-easterly winds in spring and summer, and north-west winds in winter. Hence, wind protection measures are common in fruit, wine and vegetable farming.

Except for several small-farming areas in wetter zones, the Little Karoo is semi-arid. Total rainfall and seasonal distribution are highly variable. Sporadic droughts are therefore common.

The western zone of the South Coast has a typical winter rainfall, but it changes to a non-seasonal nature towards the east. The average annual rainfall increases from south to north and ranges from 300mm in the Ruens farming area to as high as 900mm near the mountains.

3.2.3 Hydrology and irrigation water usage

The study area includes the drainage basins of four principal rivers:

- The Olifants River along the West Coast - drainage region E of the Department of Water Affairs;
- the Berg river - drainage region G;
- the Breede river - drainage region H; and
- the Riviersonderend - drainage region H.

Small rivers such as the Eerste (G), the Lourens (G), Palmiet (G) and Duivenhoks (H) also form part of these drainage basins. Table 3.1 shows the catchment sizes, mean annual precipitation (MAP), mean annual runoff (MAR) and runoff coefficients for the three drainage regions.

TABLE 3.1: Hydrological characteristics of the three principal drainage basins in the Western Cape

Principal Rivers	Primary Catchment/Drainage region		
	E	**G**	**H**
	Olifants, Doorn Tankwa, Hantam	**Berg, Eerste, Lourens, Diep**	**Breede, Sonderend**
Total area (sq. km)	48 880	25 415	15 658
MAP (mm/a)	231	506	604
MAR (million m³/a)	1 015	2 158	1 954
Runoff coefficient (percent)	9,0	16,8	20,7
Storage capacity of dams (million m³)	165,2	354,5	1 008,3

MAP = mean annual precipitation; MAR = mean annual runoff
Runoff coefficient = (MAR/MAP) x 100, with MAR and MAP in volumetric units

Source: Moolman & Lambrechts, 1996.

In the Western Cape, as in the rest of South Africa, agriculture and specifically irrigation is the biggest consumer of water. Three types of irrigation schemes exist, namely, state water schemes, irrigation board schemes, and private irrigation schemes comprising 19 percent, 22 percent and 59 percent of South Africa's irrigated areas respectively.

Table 3.2 shows water usage in 1986 by main user types and the estimated requirements until 2010 within each of the drainage basins E, G and H. Although the data given in Table 3.2 could have changed slightly since 1986, the general trends remain the same:

- In regions E and H, agriculture will remain the biggest consumer of water into the next century.
- In region G (Berg River drainage basin), the urban water demand of Cape Town and environs will grow faster than for agriculture.
- Most water used for irrigation is owned by private irrigators or by irrigation boards. In region E however, the Olifants River State Water Scheme accounts for approximately 35 percent of all water used for irrigation.
- By 2010, the total water requirement will account for approximately 60 percent of the mean annual runoff in drainage regions G and H.
- Estimated annual water requirement (Table 3.2) already exceeds the total storage capacity of the large dams listed by the Department of Water Affairs (in 1986) in regions E and G. By 2000 the annual water requirement in region H will also exceed the existing storage capacity. In order to meet growth in water demand, both demand side management and alternative supply options need to be assessed.

TABLE 3.2: Actual water use in 1986 and estimated water requirements until 2010 for drainage basins E, G and H relating to urban, irrigation, livestock and environmental needs

Category	Units	1980	1990	2000	2010
Drainage Region E					
Urban	million m^3	8,0	8,0	9,0	10,0
Irrigation	*million m^3*	*389,0*	*401,0*	*408,0*	*414,0*
Environment	million m^3	77,0	77,0	77,0	77,0
Stock watering	million m^3	2,0	3,0	3,0	3,0
Total	million m^3	476,0	489,0	497,0	504,0
Irrigation: % total requirem.	percent	82,1	82,5	82,6	82,6
State irrigation: % total irr.	percent	37,3	36,2	35,5	35,0
Requirement/MAR		46,9	48,2	49,0	49,7
Drainage Region G					
Urban	million m^3	224,0	327,0	469,0	628,0
Irrigation	*million m^3*	*252,0*	*460,0*	*460,0*	*488,0*
Environment	million m^3	143,0	143,0	143,0	143,0
Stock watering	million m^3	5,0	6,0	7,0	8,0
Total	million m^3	624,0	936,0	1079,0	1267,0
Irrigation: % total requirem.	percent	40,7	41,5	42,9	38,8
State irrigation: % total irr.	percent	0,0	0,0	0,0	0,0
Requirement/MAR		28,9	39,9	50,0	58,7
Drainage Region H					
Urban	million m^3	23,0	30,0	41,0	53,0
Irrigation	*million m^3*	*594,0*	*725,0*	*831,0*	*914,0*
Environment	million m^3	149,0	149,0	149,0	149,0
Stock watering	million m^3	3,0	3,0	3,0	4,0
Total	million m^3	769,0	907,0	1024,0	1120,0
Irrigation: % total requirem.	percent	77,5	80,2	81,4	81,9
State irrigation: % total irr.	percent	2,4	2,5	2,2	2,3
Requirement/MAR		39,4	46,4	52,4	57,3

Source: Moolman & Lambrechts, 1996.

3.3 Land capability model

A land capability model was used to determine the potential yield for each crop on each soil type in every polygon under static technological conditions. In addition to the crop requirements relating to soil type and climatological regime, other aspects such as distance to sources of irrigation water and specific crop requirements such as intensely cold periods or units (for example, for apples) were also included. Only the polygons that were available for agricultural production activities were included in the analysis. Thus, land parcels with unsuitable slopes and/or with permanent existing non-agricultural land-uses - such as urban areas or nature reserves - were excluded from the analysis.

The basic methodology used for the land capability model can be summarised as follows (Knight, 1997). The land capability model was applied for the Western Cape Province and was operational in a Geographic Information System (GIS). All the resource units/polygons were evaluated for each of the crops included in the study in terms of an array of environmental criteria (See Box 3.1). Average yields for the different varieties obtained at experimental farm conditions were taken as the starting point of the evaluation. A factor was calculated for each soil type in every resource unit reflecting the extent to which the environmental conditions influence the attainment of the optimal yields of experimental farms.

The factor value was a multiplication of the criteria scores of each soil type in a land parcel based on the different criteria's deviation from the experimental farm conditions with regard to soil- and climatological conditions. The reference tables used for each of the criteria taken into account in this process can be found in Annexure 3.

Attributes/criteria:

1. Identify polygons suitable for irrigated crops:
    - Areas within a two-kilometre buffer zone of rivers; and
    - Areas within a one-kilometre buffer zone of existing irrigation schemes.
2. Soil criteria:
    - Soil depth;
    - Clay content of the A- and B-horizon;
    - Mechanical constraints on cultivation;
    - Soil wetness and drainage (as a function of clay content and soil depth); and
    - Soil coarseness and stone content.
3. Climate criteria:
    - Monthly minimum and maximum temperature;
    - Cold unit requirements (where applicable);
    - Heat unit requirements (where applicable); and
    - Humidity requirements in February for table grape harvesting.
4. Water requirements:
    - Figure per crop per soil type calculated by multiplying the crop factor with the A-pan evaporation rate.

Box 3.1 Environmental criteria scored for selected irrigated crops

Climatological risk was taken into account in that the median values was used for all the environmental criteria data series and not the average values. The most probable situation was thus evaluated. The climatological data comprised of a set of point data in raster/grid format for aspects such as monthly minimum and maximum temperatures, rainfall, evaporation and the like. The point data were extrapolated to acquire the necessary information for all the polygons.

The Division for Resource Utilisation at the Department of Agriculture: Western Cape assisted in the evaluation of the spatial data. The spatial analysis component of the model had significant data requirements. The data to be used for the spatial analysis had to be in digital format, which was fortunately relatively easily obtained. Unfortunately, all the data required were not available on a similar level of detail. The soil data posed the greatest problem being only available in land type and terrain format. The analysis therefore had to be done on the level of the available terrain data.

The data were in vector format with the sizes of the polygons ranging from a few hundred to thousands of hectares. A polygon is a vector of geo-referenced points and represents a parcel of land with relatively homogenous terrain characteristics. Any number of attributes can be differentiated for each of the land parcels. Data on the slope, soil type and texture, terrain and other features were included in the terrain data set. Although the area of the polygons and the ratio of the different soil types in each polygon were known, the location of each of the different soil types within each polygon cannot be determined. The area covered by each of the soil types within a polygon was calculated based on its percentage share in the polygon as a whole. This implies that the land capability can only be spatially presented for the whole polygon (average yield for the particular polygon), although variation might occur for each of the specific components of the polygon.

3.4 Resource potential

Table 3.3 details the result of the land capability model for three (out of a possible eight) crops for one of the approximately 1400 polygons. The Land type number is the polygon identification number and Land type area the area of the whole polygon in hectares. The soil series present in each polygon and its associated area is given in the next two columns. The last three columns give the potential yields in tonnes per hectare for each of the three crops. The land capability or crop suitability for each of the selected crops is given in Annex 4.

TABLE 3.3: Land capability of two polygons

Land type number	Land type area	Soil Series	Series area (ha)	APPLE (t/ha)	PEAR (t/ha)	PEACH (t/ha)
Ab16	4500	We31We32	106	21	13	5
Ab16	4500	Ms11	45	34	27	12
Ab16	4500	Ms10	187	34	27	12
Ab16	4500	Vf12Vf15	869	35	21	12
Ab16	4500	Wa21Wa31	196	38	30	13
Ab16	4500	Co	232	48	38	17
Ab16	4500	Gs12Gs15	196	50	30	19
Ab16	4500	Cf22Cf32	196	72	43	27
Ab16	4500	Hu26Hu27	2050	72	43	20

The land capability model resulted in a large data set of potential yields for each of the crops on the different soils per polygon. This data set was "cleaned" in order to obtain a more manageable data set and reduce the number of activities in the model. The manipulation of the original data set included firstly the elimination of the zero values, i.e. where a zero yield was expected for all the crops on a soil type within a polygon. Table 3.4 is a summary of the number of resource units suitable per crop, the total area suitable per crop and the average yield per crop, as calculated by the land capability model.

The second round of data reduction attended to the elimination soil types where the yields attained were below 50 percent of the average yields, i.e. marginal soil types within a polygon that was relatively unsuitable for the cultivation of a specified crop. This elimination was based on the argument that marginal yields may not be considered in the optimal solution if more suitable cultivation options exist.

TABLE 3.4: Average yield per crop calculated from land capability model

Crop	Number of Entries	Total Area	Average Yield (t/Ha)
Apples	1787	940622	43.2
Citrus	3383	2720731	21.0
Wine Grapes	3610	2814887	29.4
Olives	3263	2543520	4.9
Peaches	3277	2444626	17.5
Pears	3123	1992667	24.7
Plums	3643	2852856	23.4
Table Grapes	3950	3279005	18.2

Thirdly, where different soil types within a polygon have the same potential yields for all of the crops considered, these soil types within the polygon were added and therefore resulting in a greater combined area. The resulting data set was used in the linear programming model. It reflected the independent production potential of each of the crops in the study area. The production potential was constrained by environmental characteristics, such as soil quality, rainfall, temperature regimes and availability of irrigation water.

The large resource data set was imported into the mathematical model, whilst retaining the geo-referenced identity ('address') of each of the resource units. The results of the land capability model were not disputed and imported into the multi-market partial equilibrium model as is. The next chapter gives details on the management of the economic data in the spatial optimisation model.

Chapter Four: The Economic Data

4.1 Introduction

Both geographic information systems and linear programming models traditionally present the analyst with large data requirements. The fact that the spatial decision support system was a combination of the techniques and applied at provincial level, at a relatively disaggregated level, compounded the data requirements. However, a systematic approach to the collation of input data and utilising surrogate measures or proxies where data in the required format were not available, contributed to fulfilling the data needs of the combined model as described below. The range of economic data used in the model is schematically represented in Figure 4.1. The list of experts consulted is given in Annex 5.

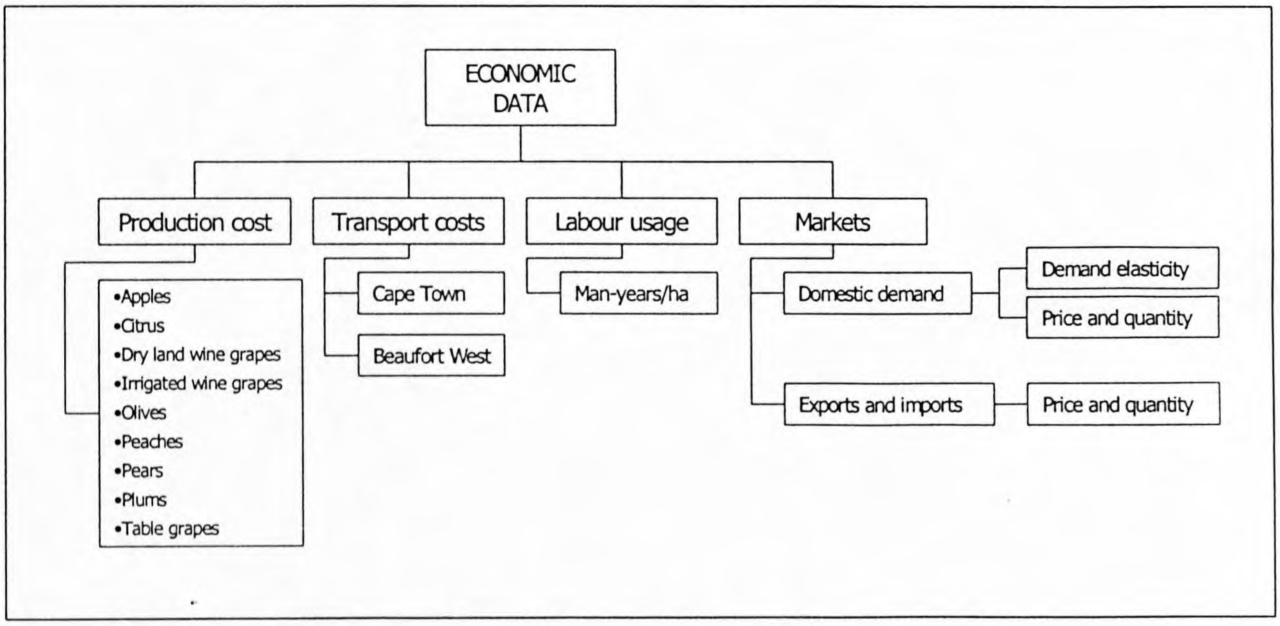


Figure 4.1: Schematic representation of economic data used in model

4.2 Production cost

The production cost data were obtained from various sources associated with the different industries. Although it was accepted that production costs may vary from region to region in the Western Cape, an assumption was made to apply the same average production cost figure per activity (but differentiated with regard to yield) for all the polygons.

The fact that the information was obtained from different sources required careful integration of the data into the model. Each of the industries had a different accounting system that makes inter-industry comparisons difficult. Furthermore, great variability exists within the industries, especially in the deciduous fruit industry, where the calculation of the share of the collective capital outlays (e.g. for packaging) is a very controversial issue. Some steps were taken to counteract these differences in the calculation of the production cost data. Such steps included subjecting the figures available to verification by experts. The following table is a summary of the production cost estimates and the respective sources of information that were used for the study.

TABLE 4.1: Production costs of long term crops

Apples							
Tons/ha	20	30	40	50	60	70	80
R/ha	20 259	21 881	23 503	25 125	26 747	28 369	29 991
Production cost = 17 015 + 162.2x *-1.2							
Pears							
Tons/ha	20	30	40	50	60		
R/ha	18 256	19 916	21 576	23 235	24 895		
Production cost = 14 937 + 165.97x *1.2							
Peaches							
Tons/ha	20	30	40				
R/ha	20 420	23 778	27 135				
Production cost = 13 706 + 335.75x * 1.2							
Soft citrus							
Tons/ha	20	30	40	50	60		
R/ha	16 745	18 423	20 100	21 778	23 455		
Production cost = 13 390 + 176.75x * -1.2							
Table grapes							
Tons/ha	10	15	20	25	30	35	
R/ha	31 814	34 472	37 130	39 788	42 446	45 104	
Production cost = 26 498 + 531.6x							
Plums							
Tons/ha	20	25	30	40			
R/ha	18 736	19 681	20 626	22 516			
Production cost = 14 956 + 189x * 1.2							
Olives							
Tons/ha	2	6	8	10			
R/ha	7 046	7 806	10 344	14 350			
Production cost = 4 346 + 860x							
Wine grapes							
Tons/ha	20	40	60	70			
R/ha	9 570	10 560	11 220	11 550			
Production cost = 8 865 + 39.15x * 2							
Source: Ferrandi, C., for deciduous fruit. Unifruco for plums. Unifruco and SA Olive Growers Association for information on olives. KWV provided information on wine grapes.							

Another important point was that the production costs need to be comparable between the different cropping activities. The production-cycle and pattern of investment and returns between various crops rendered a year-to-year comparison infeasible. On the advice of experts in the field (Smit, 1998), the production costs of the long-term crops therefore needed to be scaled down to an average annual figure.

In the case of deciduous fruit and wine grapes, the production cost was calculated based on differentiated intervals of yield attained per hectare. However, the yields calculated from the resource assessment resulted in continuous values. A simple linear regression analysis was used to extrapolate the interval-based production cost figures to approximate the corresponding continuous values. Through this calculation it was assumed that the production cost function was linear for that segment of the cost function between the lower average yield and the higher average yield of the product in question.

4.3 Transportation cost

The production cost associated with each polygon was loaded with transportation cost factor according to its distance to the markets. Transport costs of R 110.00 per tonne and R 132.00 per tonne were assumed for the Cape Town and Beaufort West destinations respectively, based on figures applied in models for the strategic micro and macro modeling (SM^3) research project of the Department of Agriculture: Western Cape. Beaufort West served as the exit point for produce consumed in the rest of South Africa. Produce due for the export market was loaded with the travel cost to Cape Town.

Due to the size of the model, the simplified proxy values were used for transportation costs to discriminate against spatially remote markets. Initial attempts were made to calculate the transportation costs based on each individual polygon/resource unit's distance to the three consumption points. However, the addition of three cost functions for each of the 1400 polygons would have increased the size of the model and calculation burden significantly.

4.4 Labour requirement

A major area of uncertainty is the labour need of each activity. The initial approach was to obtain information on both the permanent and seasonal workforce. This proved to be unrealistic. Some industries have only very recently started to collect data on employment levels on farms. However, in many other areas no indication on the labour requirement of the cropping activity can be given. Again, the great variability of activities included on-farm and those considered off-farm inhibits the generalisation of figures. The average labour requirements per crop (estimated number of labourers per hectare per year) and the source of the information are detailed in Table 4.2.

TABLE 4.2: Number of labourers required per hectare per year

Pome fruit	Stone fruit	Table grapes	Citrus	Dry land wine	Irrigated wine	Olives
1.33	2.0	2.5	1.33	0.2	0.3	1.5

Source: Industrial Development Corporation for fruit.
KWV for dry land and irrigated wine grapes.
Olive information supplied by SA Olive Growers Association.

It should be noted that labour is a highly flexible input in farming systems in general and can be adjusted with relative ease. This was even more so in the context of the Western Cape provincial model where the labour surplus poses no restriction to the production process. It need to be emphasised that the information on labour use and employment levels will only be utilised to present findings on relative differences among the various production activities and between scenarios rather than provide absolute figures on levels of employment.

4.5 Markets

4.5.1 The domestic demand curve

The model utilises a technique whereby the demand for each product is modelled enabling endogenous generation of equilibrium prices. In order to include such stepped demand functions, price elasticity estimates for each product and the current mean quantity consumed and the price - at each of the product markets - were the data requirements.

Use of linear demand curves confronting a region enables product prices to be generated within the model. In addition, in a competitive market system, consumer and producer surplus are maximised. Consequently, maximisation of the total area under the demand curve less the total area under the product supply curve results in a market equilibrium solution. Assuming a linear demand and no cross effects, the demand can be specified as:

$P = A - BMX$

Where P = n x 1 vector of prices
A = n x 1 vector of constants
B = n x n diagonal coefficient matrix
M = n x n diaginal matrix of yields
X = n x 1 vector of total hectares

A ten-point demand curve was calculated for each of the products with quantities demanded for +20 per cent to -25 per cent changes (at 5 per cent intervals) in the basic price.

Substitution in demand was not included in this model due to the large number of additional activities the inclusion of cross-elasticities would have introduced into the model. It is also difficult to introduce substitution of demand when more than two commodities are involved, and the response surface then becomes multi-dimensional. For this reason, the model may be overstating/understating the effects of price changes on demand, depending on the situation.

Changes in income can also cause shifts in the demand for products. However, if the change in the agricultural income indicated by the model's solution is a sufficiently small part of income in the entire regional economy then it would be safe to ignore the effects. In this particular study the income effects were assumed to be small and were therefore not included as an additional activity.

Information on price elasticities was obtained from a number of secondary sources, but most notably from a similar economic model commissioned by the Department of Agriculture of the Western Cape provincial administration - the Strategic Micro and Macro Modelling Project (SM3). The figures for the basic price and quantity of consumption for most of the activities included in the model were obtained from the Division for Agricultural Statistics of the national Department of Agriculture. The figures used were for 1996. The basic price and quantity account only for the portion of the production that is traded on the domestic fresh produce markets and could therefore be a conservative estimate of the total production. Table 4.3 is a summary of the data used for the model. The values for the Western Cape relates to trade on the Cape Town market, while the basic prices for the rest of South Africa is the average prices obtained at the twelve main fresh produce markets nation-wide.

TABLE 4.3: Basic price and quantity

Product	Basic price (R/t)		Basic quantity (t)	
	WC	SA	WC	SA[1]
Apples	1389,81	1632,91	470 000	137 069
Pears	1057,85	1452,75	135 000	56 137
Peaches	1888,80	2041,50	37 000	71 930
Plums	1770,33	2361,0	24 000	254
Citrus	752,19	819,89	243 564	974 307
Table Grapes	1870,63	2571,10	99 040	11 372
Wine Grapes	1088[2]	-	1029 858	118 256
Olives	3765,0	3765,0	3 000	8 500

Source: Agricultural Statistics, National Department of Agriculture.
Average basic price for wine grapes supplied by KWV.
Olive information supplied by SA Olive Growers Association.

[1] Figures for South Africa excluding the Western Cape.

[2] Price equivalent of 1 000 t wine grapes (750 l wine/t at R 1.45/l).

The ten-point demand curve for apples with the basic price and quantity of domestic consumption and the income elasticity of demand is depicted for apples in Table 4.4.

TABLE 4.4: Ten-point domestic demand curve for apples

Region 1: APPLES	Western Cape			
Change in price [%]	Price [R/ton]	Consumption- [ton]	Income	Welfare
-25.00	1042.50	505250.00	526723120	1785006000
-20.00	1112.00	498200.00	553998400	1777411400
-15.00	1181.50	491150.00	580293680	1769326800
-10.00	1251.00	484100.00	605609080	1760752200
-5.00	1320.50	477050.00	629944520	1751687800
0.00	1390.00	470000.00	653299960	1742133200
5.00	1459.50	462950.00	675675520	1732088800
10.00	1529.00	455900.00	697071120	1721554400
15.00	1598.50	448850.00	717486720	1710530000
20.00	1668.00	441800.00	736922400	1699015400
			Consumption	470000.00
			Selling price	1280.00
			Transport cost	110.00

4.5.2 Export and import prices and quantities

In addition to the basic prices and quantities traded in the domestic markets (Western Cape and the rest of the country) as outlined above, the relative size of the export markets for each of the products was determined by the 1996 export and import prices and quantities. Since the model aimed to find a long-term solution in the optimisation of resource use, some growth in the export markets was allowed. The growth in the export markets was however, constrained (see Table 4.5). Restricting the volume exported was also a proxy for the quality requirements of the export market in addition to the restriction of satisfying the domestic markets prior to the export market.

TABLE 4.5 Export and import prices and quantities

Product	Exports		Export	Imports[2]	
	Price	Quant.	Max.	Price	Quant.
Apples	2560	181 250	+50%	N/A	N/A
Pears	2480	100 000	+50%	N/A	N/A
Peaches	6400	25 000	+50%	N/A	N/A
Plums	4400	25 000	+50%	N/A	N/A
Citrus	1760	653 919	+50%	N/A	N/A
Table Grapes	5000	100 000	+50%	N/A	N/A
Wine Grapes	5250	134 000	+30%		
Olives[1]	6000	8395	+50%	1600	8 500

Source: Agricultural Statistics, National Department of Agriculture (1997).
Unifruco for deciduous fruit.
Outspan for citrus.
KWV for wine grapes.
Olive information supplied by SA Olive Growers Association.

[1] Price equivalent of 1 t olive oil.

[2] N/A: The volume imported is minimal, if any, and no exact figures are available.

Chapter Five: Results of the Analysis

5.1 Introduction

In this chapter, the solution to the allocation problem outlined in the previous chapters is presented as data tables and maps. The model had 72 557 activities and 22 032 constraints. Although the size of the partial equilibrium model renders the inclusion of all the data tables in the research report impractical, summary tables are reproduced in the text. The results of the model - pertaining to the utilisation of resource units for specific crops were exported to a mapping module to enable the spatial representation of results. The results are interpreted from three perspectives, viz. the public sector, agribusiness and the individual investor. Figure 5.1 gives a diagrammatic layout of the process followed.

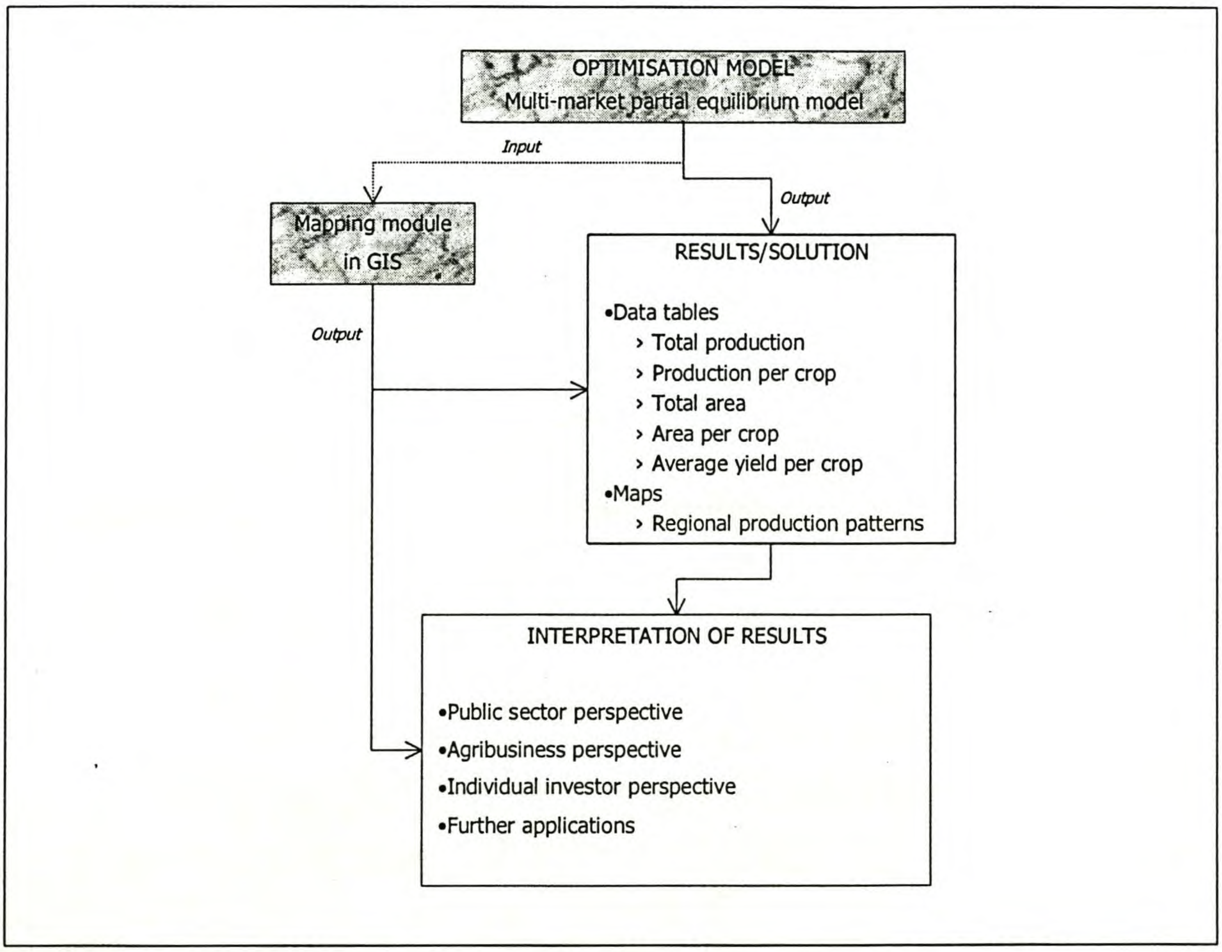


Figure 5.1: Interpretation of model results

5.2 Summary of model results

A summary of the model results is given in Table 5.1. The summary pertains to area allocated, total production and market allocation.

5.2.1 Area allocated

A total area of 93737.1 hectares was allocated to the selected crops. This area represents only 0.6 percent of the total area that was available for crop cultivation in the model. According to the existing land-use statistics of the Resource Directorate of the Department of Agriculture: Western Cape, 3.3 percent or 429 312 hectares are currently devoted to the production of deciduous fruit, citrus and grapes. The relatively small area allocated to these crops in the optimisation model could be the result of more efficient land-use allocation simulated through mathematical programming, which did not take cultural and managerial aspects of production practices into account. More importantly, the optimisation model also did not deal adequately with risk in the production process making average yields higher than actual practice, with the consequence that the area used to supply in the quantity demanded is smaller in the model. This is a key area that needs to be included in future research and refinement of the optimisation model. The proportionate area allocated to the selected crops in the model is presented by the pie-diagram in Figure 5.2.

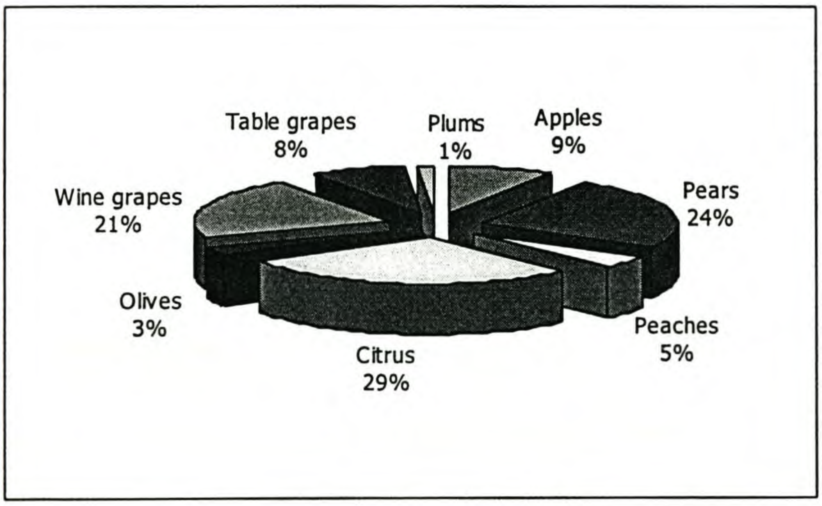


Figure 5.2: Percentage area allocated to selected crops

5.2.2 Total production

The total production and average yield obtained and for each crop is given in Table 5.1. The average yield per hectare obtained in the model results were significantly higher than in the case of the land capability model, implying that the high potential areas were first selected to fulfil the market quantity demands.

Table 5.1: Summary of the results of the model pertaining to area allocated, total production and allocation to each of the three markets for the selection of crops in the optimisation model

	APPLES	PEARS	PEACHES	CITRUS	WINE GRAPES	TABLE GRAPES	PLUMS	OLIVES
Total Area (ha)	8,357.4	22,907.4	4,509.6	26,787.1	19,927.9	7,149.1	1,372.3	2,726.4
Total Production (t)	605,615.6	369,807.6	164,270.2	902,292.4	1,214,888.0	246,148.4	61,754.0	24,092.5
Ave. Yield (t/ha)	72.5	16.1	36.4	33.7	61.0	34.4	45.0	8.8
Total Export market (t)	25,960.4	150,000.0	37,500.0	345,000.0	201,000.0	150,000.0	37,500.0	12,592.0
Export price R/ton	2,560.0	2,480.0	6,400.0	1,760.0	5,250.0	5,000.0	4,400.0	6,000.0
% Total Production	4.3	40.6	22.8	38.2	16.5	60.9	60.7	52.3
Total Western Cape market (t)	470,000.0	163,204.9	44,770.0	209,465.0	906,275.1	85,174.4	24,000.0	3,000.0
WC Price R/ton	1,390.0	870.0	1,606.0	900.0	1,437.0	2,364.0	1,770.0	3,910.0
% Total Production	77.6	44.1	27.3	23.2	74.6	34.6	38.9	12.5
Total Rest of SA market (t)	109,655.2	56,739.8	82,000.0	347,827.4	107,613.0	10,974.0	254.0	8,500.0
SA Price R/ton	1,512.0	886.5	1,720.0	926.4	1,403.0	2,091.6	1,792.0	3,932.0
% Total Production	18.1	15.3	49.9	38.5	8.9	4.5	0.4	35.3

The average yield is calculated across all the resource units that were used for the particular crop. The volume of produce exported varies greatly between the different crops - from as little as 4,3 per cent for apples to just more than 60 percent for table grapes and plums. Most of the produce were traded on the Cape Town market.

The average yield obtained for pears were the exception to the above, possibly indicating that the production thereof was relatively less profitable and that lower potential resource units were therefore selected for its production. The total production was constrained by the size of the three markets, as explained below.

5.2.3 Market allocation

The model selected different points on the Western Cape demand curve for each of the products. The selection of point 6 on the demand curve implied that the existing basic price and quantity were the optimum price and quantity for the model. However, the model results also indicated new optimum prices and quantities for crops such as citrus, table grapes and wine grapes (20 per cent increase in the existing price), as well as a 15 per cent and 25 per cent decrease in the existing prices for peaches and pears respectively. The changes in optimum prices were associated with the respective changes in basic quantities demanded along each crop's demand function. Similar adjustments occurred for the optimum prices and quantities demanded for the 'rest of South Africa' market - as indicated below.

Western Cape market optimum price and quantities (price change from basic price in brackets):

- point 6 for apples (basic price) or 470 000 tones;
- point 10 for citrus (+20 per cent); or 209 465 tonnes
- point 6 for olives (basic price) or 3 000 tonnes;
- point 3 for peaches (-15 per cent) or 44 770 tonnes;
- point 1 for pears (-25 per cent) or 182 250 tonnes;
- point 6 for plums (basic price) 24 000 tonnes;
- point 10 for table grapes (+20 per cent) or 85 174 tonnes; and
- point 10 for wine grapes (+20 per cent) or 906 275 tonnes.

Rest of South Africa market optimum price and quantities (price change from basic price in brackets):

- 'point 6 for apples (basic price) or 109 655 tones;
- point 10 for citrus (+20 per cent); or 335 162 tonnes
- point 6 for olives (basic price) or 8 500 tonnes;
- point 4 for peaches (-10 per cent) or 82 000 tonnes;
- point 1 for pears (-25 per cent) or 75 785 tonnes;
- point 6 for plums (basic price) 254 tonnes;
- point 7 for table grapes (+20 per cent) or 10 974 tonnes; and
- point 9 for wine grapes (+20 per cent) or 107 612 tonnes.

All the crops - except apples and citrus - approached their maximum export market levels (volume) as indicated in Table 4.5. The under-performance of apples could be attributed to the limited area where this crop can be cultivated due to cold unit requirements. The nonexpansion of citrus could be attributed to water demands of relatively more profitable crops, for example wine grapes. The maps indicating the model's spatial land-use pattern for each of the selected crops are provided in Annex 6.

Due to the volume of data generated by the model, and the purpose of this research, an in-depth analysis of the model results was not undertaken. However, three examples of the model results were extracted to illustrate the utility of the model as decision support system. The first case was in support of public sector information needs. Thereafter the model results were interpreted from an agribusiness perspective. Finally, the individual investor's information requirements were analysed.

5.3 Public sector perspective

The public sector, as provider of infrastructure and other public goods needs to ensure maximum effectiveness and efficiency in its activities. In a market economy, the public sector has a limited number of economic and other tools at its disposal to support the development of the agricultural sector. Most important are to provide incentives and infrastructure to guide farm-level decision-making - and thus resource-use patterns - towards efficient production systems at a national or provincial level. The public sector also needs to ensure that it obtains maximum 'returns' or impact on its expenditure. The spatial decision support system can be applied successfully in this regard by identifying and evaluating areas that need to be earmarked for future development for selected crops.

The existing land-use pattern in the Western Cape is indicated in Annex 7. The results of the optimisation model with that of the existing land-use pattern for stone fruit are compared in Annex 7. As can be seen from this overlay analysis, substantial potential exists for stone fruit production in the Riviersonderend area. The divergence between existing and predicted stone fruit production could be the result of traditional cultivation patterns combined with lack of required infrastructure and skills in such areas.

Given the results from the analysis, further research on the provision of infrastructure (especially improved transport networks) can be focused in the above-identified areas. Further public sector support can also involve training opportunities in the areas where stone fruit has not traditionally been produced.

Another aspect related to the provision and management of public goods is the supply of irrigation water. Water allocation to agriculture and the possible introduction of tradable water rights is currently the subject of much debate and research. The spatial decision support system can contribute to the debate in that it provides a region-wide allocation of water relative to the competitive advantages of the physical location qua resource characteristics and market structure. For example, the model results indicated that the expansion of irrigated agricultural production is in some areas restricted to the availability of irrigation water.

5.4 Agribusiness perspective

The spatial decision support system can also be applied to verify a planning decision of an agribusiness, which would like to determine whether its proposed location as an input provider or output-processor is spatially advantageous or would like to explore production expansion opportunities. For example, in the case of deciduous fruit packaging and canning, a location closer to the source of the products could be profitable since the handling conditions are less restrictive for the processed product than the inputs. The land-use pattern foreseen for deciduous fruit production, for example peaches, can be examined in this regard.

The land capability model identified approximately 2,5 million hectares with low to high suitability for peach production. The average yield for these polygons was 17.5 tonnes per hectare. A total of 4509.6 hectares from seven resource units - with an output of 164270.2 tonnes - were allocated to peach production in the optimisation model. The spatial distribution of these areas is indicated in Annex 8.

Table 5.2 provides extracts from the sensitivity analysis of the solution. Although it is advantageous to have the resource characteristics at this level of detail in the model, the volume of activities does present practical problems in evaluating the results of the sensitivity analysis.

Table 5.2: Opportunity costs for peach production associated with a selection of polygons

ACTIVITY	LEVEL (ha)	GROSS MARGIN	OPPORT. COST	SOLUTION	LOW. BOUND. DESCRIPTION	LOWER BOUNDARY	UPP. BOUND DESCRIPTION	UPPER BOUNDARY
CA38HPR	1261.785	0	4111.8	UPPER	(RS)	-4111.8	(NB)	0
FB53DPR	1059.75	0	3535.512	UPPER	(RS)	-3535.512	(NB)	0
FB49DPR	613.35	0	3734.232	UPPER	(RS)	-3734.232	(NB)	0
FB39DPR	596.61	0	3823.656	UPPER	(RS)	-3823.656	(NB)	0
FB48CPR	509.5	0	3830.28	UPPER	(RS)	-3830.28	(NB)	0
AE113FPR	240	0	4115.112	UPPER	(RS)	-4115.112	(NB)	0
CA38GPR	228.586	0	0	IN	DB13PRT	-17.885	FB53DPR	2828.41
FA200IPR	0	0	0	IN	FA200HPR	-28195.858	FA200PRT	7706.41
FA199HPR	0	0	0	IN	FA199GPR	-28195.858	FA199PRT	7736.218
FA201JPR	0	0	0	IN	(NB)	0	(NB)	0
CA28HPR	0	0	0	IN	CA28GPR	-4184.863	CA28PRT	41.597
≈								
DA17APR	0	0	-22515.258	LOWER	(NB)	0	(RS)	22515.258
FA199APR	0	0	-22613.078	LOWER	(NB)	0	(RS)	22613.078
FA203APR	0	0	-22770.282	LOWER	(NB)	0	(RS)	22770.282
DB47APR	0	0	-22790.356	LOWER	(NB)	0	(RS)	22790.356
FA204APR	0	0	-23059.484	LOWER	(NB)	0	(RS)	23059.484
FB58BPR	0	0	-23073.887	LOWER	(NB)	0	(RS)	23073.887
AG190APR	0	0	-23142.728	LOWER	(NB)	0	(RS)	23142.728
FB58APR	0	0	-23394.358	LOWER	(NB)	0	(RS)	23394.358
DB101BPR	0	0	-23488.95	LOWER	(NB)	0	(RS)	23488.95
DB101APR	0	0	-24068.852	LOWER	(NB)	0	(RS)	24068.852
AB22APR	0	0	-24150.768	LOWER	(NB)	0	(RS)	24150.768
DB75BPR	0	0	-24421.316	LOWER	(NB)	0	(RS)	24421.316

Constructing the optimisation model at district level can in this regard reduce the number of alternative location options. The smaller number of activities would enable the analyst to include additional decision variables pertinent to the firm's location decision in the model. For example, more detailed transport cost structures, industrial property costs, labour costs, and the like.

5.5 Individual investor perspective

Linear programming models are widely used for farm-level resource allocation problems. The particular advantage of using this spatial decision support system was its ability to include region-wide competitive forces and local, national and international market constraints. Water availability and transportation costs were some of the important aspects that were considered in the regional perspective provided by the model.

For example, an individual farmer would like to investigate options relating to the resource unit Db97, which has a total area of 1320 hectares. Table 5.3 below gives the results from the optimisation model for this particular polygon, while the crop combination for polygon Db97 is illustrated in Figure 5.3.

Table 5.3: Potential and realised allocation for polygon Db97

Db97	Potential Ave Yield (t/ha)	Potential Max Area (ha)	Area Alloc. (ha)	Tot. Prod. (tons)	Ave yield (t/ha)	Market Allocated	Shadow price Resource use
Unutilized		1320	21				
Apples	0	0	0	0	n/a	n/a	n/a
Citrus	23.4	986.7	435	16573.79	38.1	Export	-389.4
Olives	4.7	834.9	0	0	n/a	n/a	-1197.6
Peaches	19.2	940.5	0	0	n/a	n/a	-712.6
Pears	17.6	986.7	0	0	n/a	n/a	-772.6
Plums	28.9	986.7	0	0	n/a	n/a	549.2
Table Grapes	21.4	986.7	429	13811.49	32.2	Export	0.0
Wine Grapes	42.8	940.5	435	27922.36	64.2	Cape Town	0.0

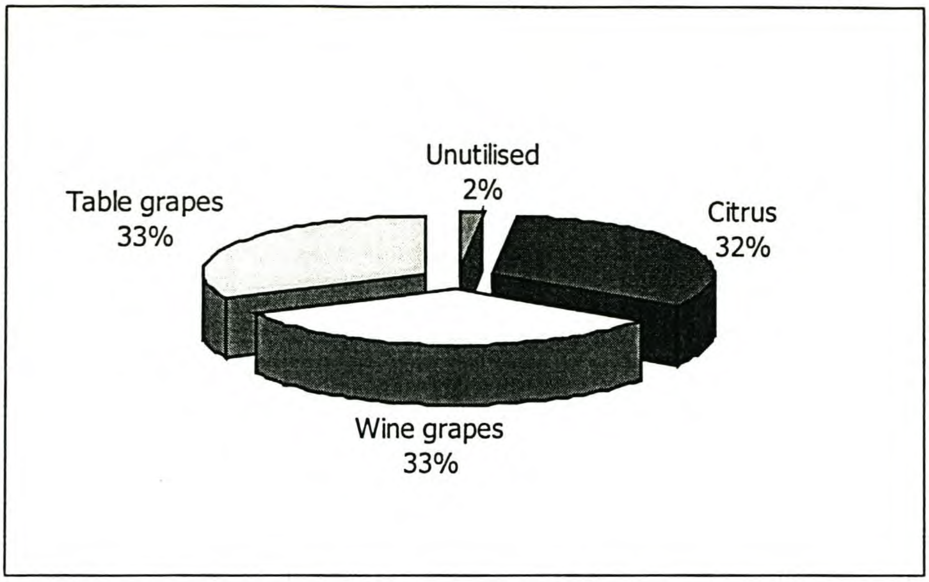


Figure 5.3: Area allocation of crops to polygon Db97

Through the GIS mapping module, maps with pie charts indicating the crop combinations for a district can also be generated. This provides the investor with a visual pattern of the district's crop production potential. Annex 9 indicates the crop combinations for a selection of polygons. The crop combination pie charts indicate at a glance the percentage area per polygon allocated to each crop. For example, citrus in the Swellendam area dominated the optimum land use patterns, pears in Montagu and wine grapes in the Wellington district.

5.6 Further applications

Further applications of the optimisation model are possible through changes in any of its components and/or level of detail of the analysis. Such options will be briefly discussed in the remainder of this chapter.

5.6.1 Changes in resource characteristics

One interesting application of this spatial decision support system could be to simulate the effect of global climate change on the (agricultural) resource-use patterns of a region. Changing the resource characteristics in the land capability model could simulate the anticipated change in temperature and rainfall regimes as indicated by Figure 5.4 below. The subsequent change in resource potential for the selected crops can then be incorporated in the linear programming model.

The amount of irrigation water available to agricultural production can also be limited to be aligned with new national and provincial figures, by simply changing the right hand side values in the linear programming model.

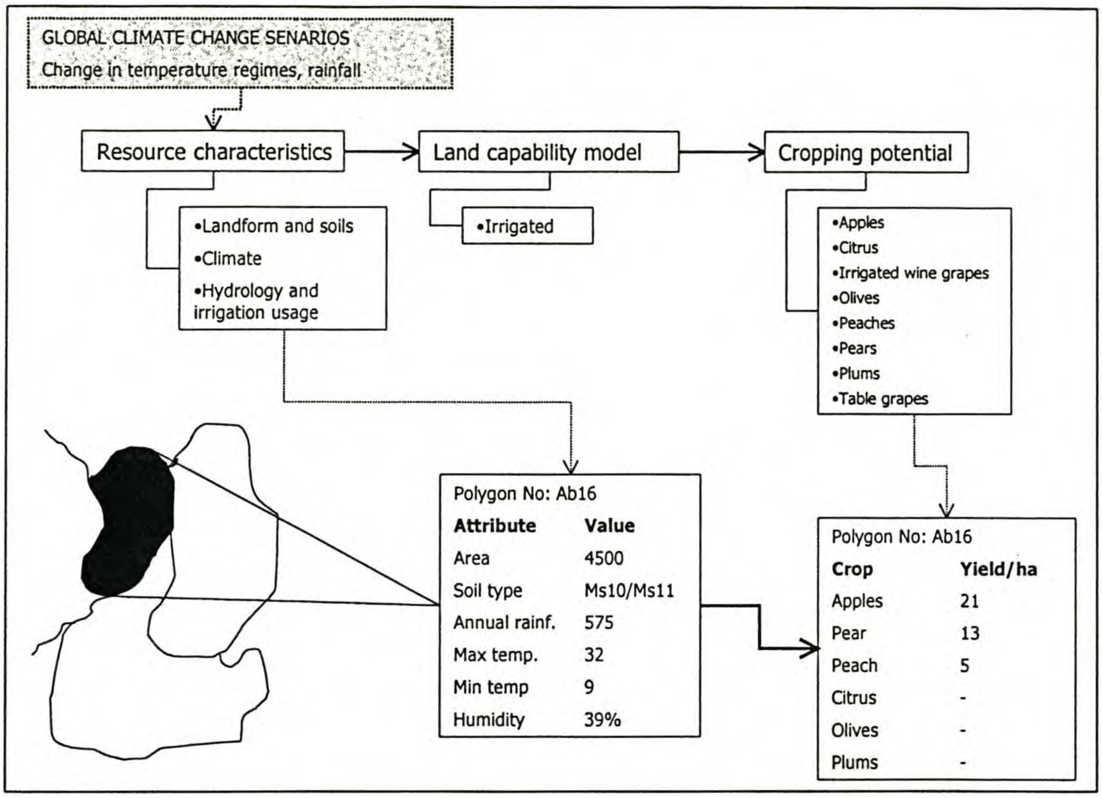


Figure 5.4: Schematic representation of incorporating Global Climatic Change considerations in spatial decision support system

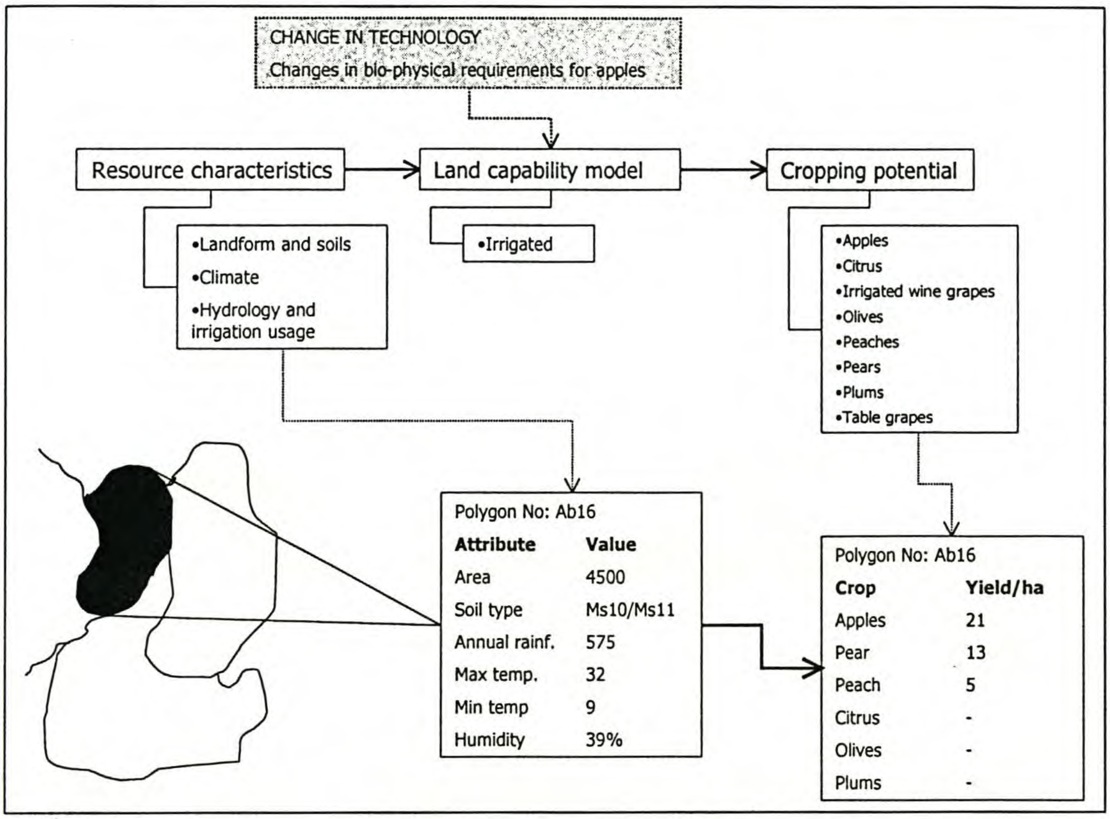
5.6.2 Changes in economic conditions

Apart from updating the economic data and adding or reducing the number of economic agents in the model (producers and consumer markets), the number of activities can also be changed. The relative profitability of each of the selected crops are influenced by the production cost structures and local, national and export demand curves. The impact of changes in the economic conditions will depend on the magnitude of the change taking place vis-à-vis the production potential, the total number of activities, relative profitability and quantity demanded.

For example, in the above application of the model, very limited changes were effected by changes in the production cost structure of the selected crops, as opposed to the effects of changes in the quantities demanded. This could be attributed to the fact that - in general - the resource potential is greater than the combined volume demanded at the three markets.

5.6.3 Changes in technology

The effect of wide spread adoption of changes in technology can be determined in the spatial decision support system. The way in which technology changes are incorporated in the model depends on where in the production process it is developed. For example, the introduction of a chemical means to replace the cold unit requirement of apple production could have wide spread implications for the cultivation thereof. Currently, apple cultivation is restricted to limited areas as a result of this requirement, but could be substantially expanded should it be replaced by the use of a chemical product. This change in technology can be introduced into the spatial decision support system in the land capability model - where the production requirements for each of the crops are defined - as indicated in Figure 5.5.



Polygon No: Ab16

Attribute	**Value**
Area	4500
Soil type	Ms10/Ms11
Annual rainf.	575
Max temp.	32
Min temp	9
Humidity	39%

Polygon No: Ab16

Crop	**Yield/ha**
Apples	21
Pear	13
Peach	5
Citrus	-
Olives	-
Plums	-

Figure 5.5: Introducing changes in production technology

Similarly, changes in technology could effect higher yields or reduce production costs, which could also be incorporated in the land capability model or economic data respectively.

5.6.4 Changes in level of analytical detail

One of the important characteristics of the spatial decision support system is its flexibility with regard to level of detail of the analysis. The optimisation model can be applied for district, provincial, national and regional level analyses.

Evidently, the decision-maker needs to be conscious of the trade-offs between level of detail of the spatial (and economic) data and model size. The large data requirements of the model are implicit to all spatial decision support systems and linear programming models.

District level analysis can be useful since the fewer resource units in the model would allow for more production activities and constraints. For example, analysis at district level could enable competing farming systems - as opposed to single land-uses - where transfer activities from planted pastures to livestock production could be incorporated in the linear programming model. Also, more detailed analysis of the dynamics between different varieties in stead of product groups, could refine the predicted resource use patterns. The model can be applied for a product diversification exploration at district level.

Provincial level analysis, as applied in this report, was useful as a decision-making aid to evaluate existing and potential resource use patterns. As outlined above, it can also be of benefit to agribusiness and even individual farmers, since it incorporates some of the dynamics between resource potential, cost relations and market conditions. The application of the model at provincial level could be used as a first step in the research process - to guide more in-depth studies.

Finally, the opportunities for developing the model to determine competitive advantages and guide agricultural development at national and regional level are numerous. Regional applications - for example, for Southern Africa - could also be useful for agribusiness, which are planning business expansion to the region. However, some generalisation of the resource and economic data would be necessary to keep the information load to manageable levels.

Chapter 6: Conclusion

6.1 Introduction

In this final chapter an evaluation of the spatial decision support system (SDSS) is given. The main advantages of the developed methodology are summarised in the first section, while major shortcomings are listed in the second section. The summary of advantages and disadvantages aimed to move beyond the accepted critique of linear programming and the assumptions on which its applications are based, i.e. the linearity of all relations, static conditions, single objective functions, and the like. The purpose of this chapter is to critically assess the value-added derived from combining GIS procedures and economic modelling tools. Some conclusions are drawn in the last section of this chapter.

6.2 Advantages of the Spatial Decision Support System

Through the combination of two existing powerful tools to support decision-making, the advantages of both are strengthened. The most apparent advantages of the SDSS can be summarised as follows:

- The SDSS integrated resource potential and economic determinants in predicting land-use patterns. This interactive capability determined the relative profitability and competitive advantage of each of the selected crops vis-à-vis the resource units.
- Each component enhanced the modelling capacity of the other - the GIS (in the land capability model) and linear programming (the multi-market partial equilibrium model) - in the optimisation technique.
- The visual representation of the solution of a mathematical model of this size greatly assisted the analysis and interpretation of the model results. The integration of the linear programming results into the GIS makes further spatial analysis of the solution possible (for example, overlay analysis).
- The visual representation also assisted in the verification of the model results. This was a major advantage of using a GIS indicate the spatial distribution or address of the model results that would otherwise be listed in tables in terms of quantities only.
- The SDSS is flexible and a large number of applications are possible incorporating phenomena such as global climate change, changes in technologies and regional analyses.

6.3 Disadvantages and shortcomings

The disadvantages and shortcomings of the SDSS relate mostly to practical aspects of the analyses and are summarised as follows.

- Through the combination of two existing techniques - each with significant data requirements - the volume of data required for the optimisation technique is extensive. Where sufficient data was available, conversion of it to the unit of analysis - polygons - posed the greatest challenge.
- The size of the linear programming matrix - at 72 557 activities and 22 032 constraints for the Western Cape application - bordered on impractical as the large data requirements are converted into voluminous solutions, especially in the numeral analysis and interpretation of the results.
- Although the model was developed for desktop/personal computer-based research, it was to some extent demanding in terms of hard disk capacity, processor speed and random access memory (RAM).
- Throughout this research period, the SDSS was integrated as a methodology, but not physically at one workstation. Integration at this level could make the research process much more interactive and responsive since the model results can immediately be displayed visually to verify the results.

6.4 Conclusions

The model demonstrated its ability to support decision-making relating to spatial aspects of agricultural resource use. The SDSS is a tool for decision-makers and provides insights on the agricultural land use patterns from a regional perspective. The flexibility of the model contributes to its utility for generating scenarios for future resource use patterns. Further research and feasibility studies can be based on the results of the SDSS.

Bibliography and Reading List

Bazaraa, M.S. & Bouzaher, A. 1981. A linear goal programming model for developing countries with an illustration from the agricultural sector in Egypt. *Management Science.* Vol. 27, No. 4, April 1981, p396 - 413.

Bierman, H., Bonini, C., & Hausman, W. 1981. *Quantitative Analysis for Business Decisions.* Richard D. Irwin Inc., Illinois.

Bouzaher, A. & Mendoza, G.A. 1987. Goal programming: Potential and limitations for agricultural economics. *Canadian Journal of Agricultural Economics.* Vol. 35, March 1987, p89 - 107.

Campbell, J.C., Radke, J., Gless, J.T., & Wirtshafter, R.M. 1992. An application of linear programming and geographic information systems: cropland allocation in Antigua in *Environment and Planning A.* Vol. 24, p535-549.

Carver, S.J. 1991. Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems.* Vol. 5(3), p 321 - 339.

Cocklin, C., Smit, B. & Johnston, T. (eds.) 1987 *Demands on rural lands: planning for resource use.* Westview special studies in natural resources and energy management, Westview Press, London.

Densham, P.J. & Rushton, G. 1992. Strategies for solving large location-allocation problems by heuristic methods. *Environment and Planning A.* Vol. 24, p289 - 304.

De Smit, M. (eds.) 1983 *Rechtvaardigheid en Doelmatigheid in het Ruimtelijk Beleid.* Geografisch Instituut Rijksuniversiteit Utrecht, Nederland.

Diamond, J.T. & Wright, J.R. 1989. Efficient Land Allocation. *Journal of Urban Planning and Development.* Vol. 115(2), p81 - 96.

Diamond, J.T. & Wright, J.R. 1988. Design of an integrated spatial information system for multi-objective land-use planning. *Environment and Planning B: Planning and Design.* Vol. 15, p205 - 214.

Eastman, R. & P. Kyem, J. Toledano & Jin, W. 1995. Raster procedures for multi-criteria/multi-objective decisions. *Photogrammetric Engineering and Remote Sensing.* Vol. 61, No. 5, May 1995, p539 - 547. American Society for Photogrammetric Engineering and Remote Sensing.

Eastman, R. & P. Kyem, J. Toledano & Jin, W. 1993. GIS and Decisionmaking. *Explorations in GIS Technology.* Vol. 4, Clark University, Worcester.

Eckert, J., D.van Seventer &. Viljoen, K. 1995. Commercial agriculture in the Western Cape: Selected micro- and macro-perspectives. Paper submitted to the *Sustainable Rural Livelihoods Project*, Stellenbosch.

Eckert, J. & Van Seventer, D. 1995. *Agriculture and the economy in the Western Cape: Analysis with extended, multi-regional input-output model.* Center for Policy Analysis, Development Bank of Southern Africa.

Eckert, J., Liebenberg, G.F. & Troskie, D.P. 1997. *Compiling an agricultural SAM for the Western Cape.* Strategic micro and macro modeling (SM^3) project, Sub-directorate of Agricultural Economics, Department of Agriculture of the Western Cape.

Everard, D. & Fairbanks, D.A.K. & Hassan, R. 1996. *Development of a methodology for natural resources management analysis in the Eastern Cape Province.* Division of Water, Environment and Forestry Technology, CSIR. CSIR Report No. FOR-I 657.

FAO/IIASA. 1994. *Agro-ecological land resources assessment for agricultural development planning: A case study of Kenya.* World Soil Reports No. 71/1 - 9, Land and Water Division of the FAO, Rome.

Fiske, W.A., D'Souza, G.E, Fletcher, J.J., Phipps, T.T., Bryan, W.A. & Prigge, E.C. 1994. An economic assessment of alternative forage-resource production systems: a goal programming approach. *Agricultural Systems.* Vol. 45, p259 - 270.

Giaoutzi, M. & Nijkamp, P. 1993. *Decision Support Models for Regional Sustainable Development.* Avebury/Ashgate Publishing Limited, Aldershot, U.K.

Goodchild, M.F. 1992. Geographical Information Science. *International Journal of Geographic Information Systems.* Vol. 6(1), p31 - 45.

Goodchild, M.F., Parks, B.O. & Steyart, L.T. (eds.). 1993. *Environmental modeling with GIS.* Oxford University Press, New York.

Hanf, C. & Schiefer, G.W. (eds.). 1983. *Planning and Decision in Agribusiness: Principles and Experiences.* Elsevier Scientific Publishing Company, Amsterdam.

Hunt, J.D. & Simmonds, D.C. 1993. Theory and application of an integrated land-use and transport modeling framework. *Environment and Planning B: Planning and Design.* Vol. 20, p221 - 244.

Jankowski, P. & Richard, L. 1994. Integration of GIS-based suitability analysis and multi-criteria evaluation in a spatial decision support system for route selection. *Environment and Planning B: Planning and Design.* Vol. 21, p323 - 340.

Janssen, R. & Rietveld, P. 1990. Multicriteria analysis and geographical information systems: An application to agricultural land-use in The Netherlands. *Geographical Information Systems for Urban and Regional Planning,* eds. H.J. Scholten&I.C.H. Stillwell. Kluwer Academic Publishers, Amsterdam.

Joubert, A., & Leiman, A. (Undated). *Multicriteria decision and cost-benefit analysis in the developing world: a critical evaluation.* Department of Statistical Science and The School of Economics, University of Cape Town.

Keenan, P. 1995. *Using a GIS as a DSS Generator.* Department of Management Information Systems, Michael Smurfit Graduate School of Business, University College Dublin. Working Paper MIS 95-9.

Knight, F. 1997. Personal Communication. Division for Resource Utilisation, Depart of Agriculture: Western Cape.

Lee, D.J., Tripton, T. & Leung, P. 1995. Modeling cropping decisions in a rural developing country: a multiple-objective programming approach. *Agricultural Systems.* Vol. 49, p101 - 111.

Lipton, M., De Klerk, M. & Lipton, M. (eds.).1996. *Land, labour and livelihoods in rural South Africa. Volume 1: Western Cape.* Indicator Press, Durban.

Marble, D.F.& Amundson, S.E. 1988. Microcomputer-based geographic information systems and their role in urban and regional planning. *Environment and Planning B: Planning and Design.* Vol. 15, p305 - 324.

Millan, J.S. & Berbel, J. 1994. A multi-criteria model for irrigated agricultural planning under economic and technical risk. *Agricultural Systems.* Vol. 44, p105 - 117.

Moxey, A.P., White, B., Sanderson, R.A. & Rushton, S.P. 1995. An approach to linking an ecological vegetation model to an agricultural economic model in *Journal of Agricultural Economics.* Vol.. 46 (3), p381-397.

Moxey, A.P. & White, B. 1994. Efficient compliance with agricultural nitrate pollution standards in *Journal of Agricultural Economics.* Vol. 45 (1), p27-37.

Nijkamp, P. (eds.). 1986. *Handbook of regional and Urban Economics, Volume 1: Regional Economics.* North Holland Publishing Company, Amsterdam.

Rosenthal, R.E. 1985. Concepts, theory and techniques: principles of multi-objective optimization. *Decision Sciences.* Vol. 16(2), p133 - 152.

Romero, C., F. Amador & Barco, A. 1987. Multiple objectives in agricultural planning: A compromise programming application. *American Journal of Agricultural Economics.* Vol. 69, No. 1, February 1987, p78 - 86.

Romero, C. & Rehman, T. 1989. *Multi criteria analysis for agricultural planning.* Elsevier Press, Amsterdam.

Romero, C. & Rehman, T. 1987. Natural resource management and the use of multiple criteria decision-making techniques: A review. *European Review.* Vol. 14-1, p61 - 89.

Sadoulet, E. & De Janvry, A. 1995. *Quantitative Development Policy Analysis.* The Johns Hopkins University Press, Baltimore and London.

Sankhayan, P.L., Prihar, R.S. & Cheema, H.S. 1988. Developing optimum cropping plans for a typical Punjab farm with multiple objectives by using compromise programming. *Indian Journal of Agricultural Economics.* Vol. 43, No. 2, p163 - 174.

Van Huylenbroeck, G. (Undated). *A multi-criteria approach for trade-off analysis between economic and environmental objectives in rural planning.* Department of Agricultural Economics, University of Ghent, Belgium.

Van Lier, H., Jaarsma, C., Jurgens, C. & De Buck, A. (eds.). 1994. *Sustainable Land Use Planning.* Elsevier Press, Amsterdam.

Vink, N., Van Zyl, J., Van Seventer, D. & Eckert, J. (Undated). *The macroeconomics of rural livelihoods creation in the Western Cape Province.* Strategic micro and macro modeling (SM^3) project, Sub-directorate of Agricultural Economics, Department of Agriculture of the Western Cape.

Voogd, H. 1988. Multi-criteria evaluation: measures, manipulation and meaning - a reply. *Environment and Planning B: Planning and Design.* Vol. 15, p65 - 72.

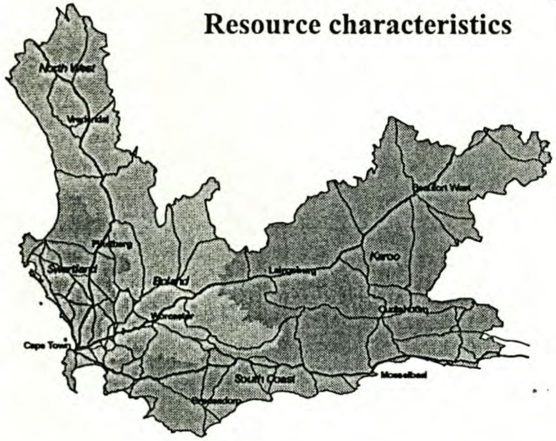
Webster, C.J. 1994. GIS and the scientific inputs to planning; Part 2: prediction and prescription. *Environment and Planning B: Planning and Design.* Vol.21, p145 - 157.

Annex 1

Spatial Decision Support System - Model Structure

SPATIAL DECISION SUPPORT SYSTEM - MODEL STRUCTURE

Resource characteristics



Crop suitability scores for the resource attributes:

- Temperature ranges
- Drainage
- Soil depth
- Soil texture
- Soil moisture

Land capability tables & maps

Land unit	Series Area (ha)	APPLE (t/ha)	PEAR (t/ha)	PEACH (t/ha)
Ab16	106	21	13	5
Ab16	45	34	27	12
Ab16	187	34	27	12
Ab16	869	35	21	12
Ab16	196	38	30	13
Ab16	232	48	38	17
Ab16	196	50	30	19
Ab16	196	72	43	27
Ab16	2050	72	43	20

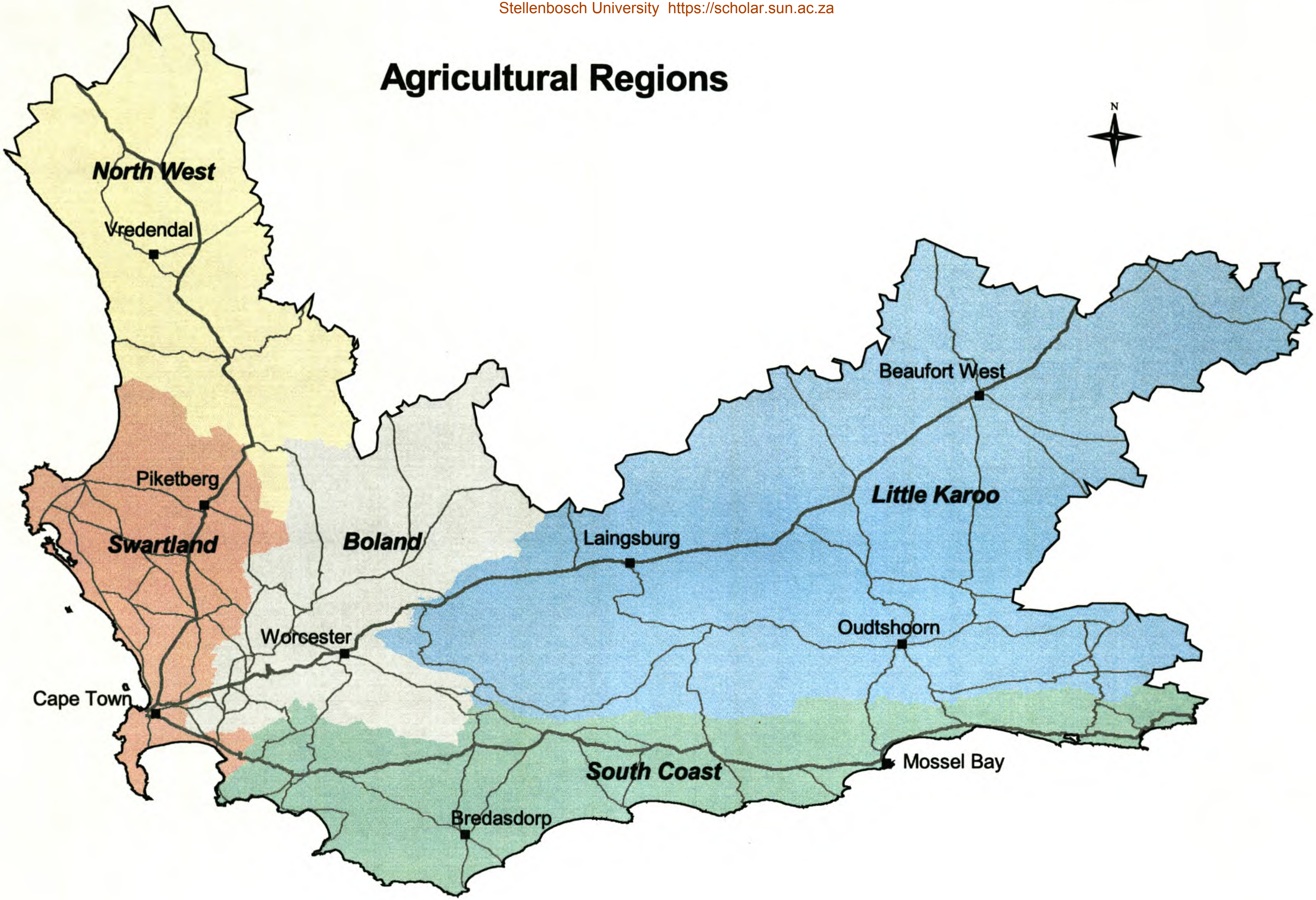
LP Matrix

Factors / Constraints	*Relationship with each of the activities/crops*	*RHS*
Land capability	Potential yield per crop	Less than
- polygon	……	< area
- polygon	……	
- polygon	……	
- polygon	……	
Irrigation water	Water requirements and availability	Less than
Labour	Labour use per crop	Not limited
Production costs	Cost structure per crop	Not limited
Transport costs	Cost to market	Not limited
Demand curves	Demand curve per crop for two domestic markets	
Export market	Price and quantity per crop	Less than
Maximise Welfare	Producer welfare + consumer welfare	Not limited

Annex 2

Agricultural regions, towns and major roads of the Western Cape

Agricultural Regions



Annex 3

Criteria scores for land capability model

Criteria scores for resource attributes (Look-up tables)

Temperature

Temp	Apple	Pear	Peach	Plum	Olive	Grapes	Citrus
0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0.07	0	0
7	0.25	0	0	0.25	0.13	0	0
8	0.5	0	0.08	0.5	0.2	0	0
9	0.75	0	0.15	0.75	0.27	0	0
10	1	0	0.23	1	0.33	0	0
11	1	0.1	0.3	1	0.4	0.125	0
12	1	0.2	0.38	1	0.47	0.25	0
13	1	0.3	0.46	1	0.53	0.375	0
14	1	0.4	0.54	1	0.6	0.5	0.1
15	1	0.5	0.62	1	0.67	0.625	0.2
16	1	0.6	0.69	1	0.73	0.75	0.3
17	1	0.7	0.77	1	0.8	0.875	0.4
18	1	0.8	0.85	1	0.87	1	0.5
19	1	0.9	0.92	1	0.93	1	0.6
20	1	1	1	1	1	1	0.7
21	1	1	1	1	1	1	0.8
22	1	1	1	1	1	1	0.9
23	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1
26	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1
31	0.8	1	1	1	1	0.875	0.917
32	0.6	1	1	1	1	0.75	0.833
33	0.4	1	1	1	1	0.625	0.75
34	0.2	1	0.5	0.67	1	0.5	0.667
35	0	1	0	0.33	0.83	0.375	0.583
36	0	0.5	0	0	0.67	0.25	0.5
37	0	0	0	0	0.5	0.125	0.417
38	0	0	0	0	0.33	0	0.333
39	0	0	0	0	0.17	0	0.25
40	0	0	0	0	0	0	0.167
41	0	0	0	0	0	0	0.08
42	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0

Drainage

Criteria 1	
% Clay	Factor
0	1.4
5	1.3
10	1.2
20	1.1
30	1

Criteria 2	
Depth mm	Factor
0	1
250	1.1
450	1.2
600	1.3
900	1.4

Depth

Depth mm	Apple	Pear	Peach	Plum	Olive	Grapes	Citrus
0	0.1	0.1	0.1	0.2	0.1	0.2	0.1
250	0.5	0.5	0.3	0.5	0.2	0.5	0.3
450	0.6	0.8	0.5	0.6	0.45	0.75	0.7
600	0.9	0.9	0.8	0.9	0.75	0.9	0.9
900	1	1	1	1	1	1	1

Texture

% Clay	Apple	Pear	Peach	Plum	Olive	Grapes	Citrus
0	0.5	0.5	0.5	0.3	0.5	0.5	0.6
5	0.8	0.6	0.8	0.6	0.9	0.7	0.8
10	1	1	1	1	1	1	1
20	0.9	0.9	0.6	1	0.8	0.8	0.7
30	0.7	0.8	0.5	0.8	0.5	0.6	0.5

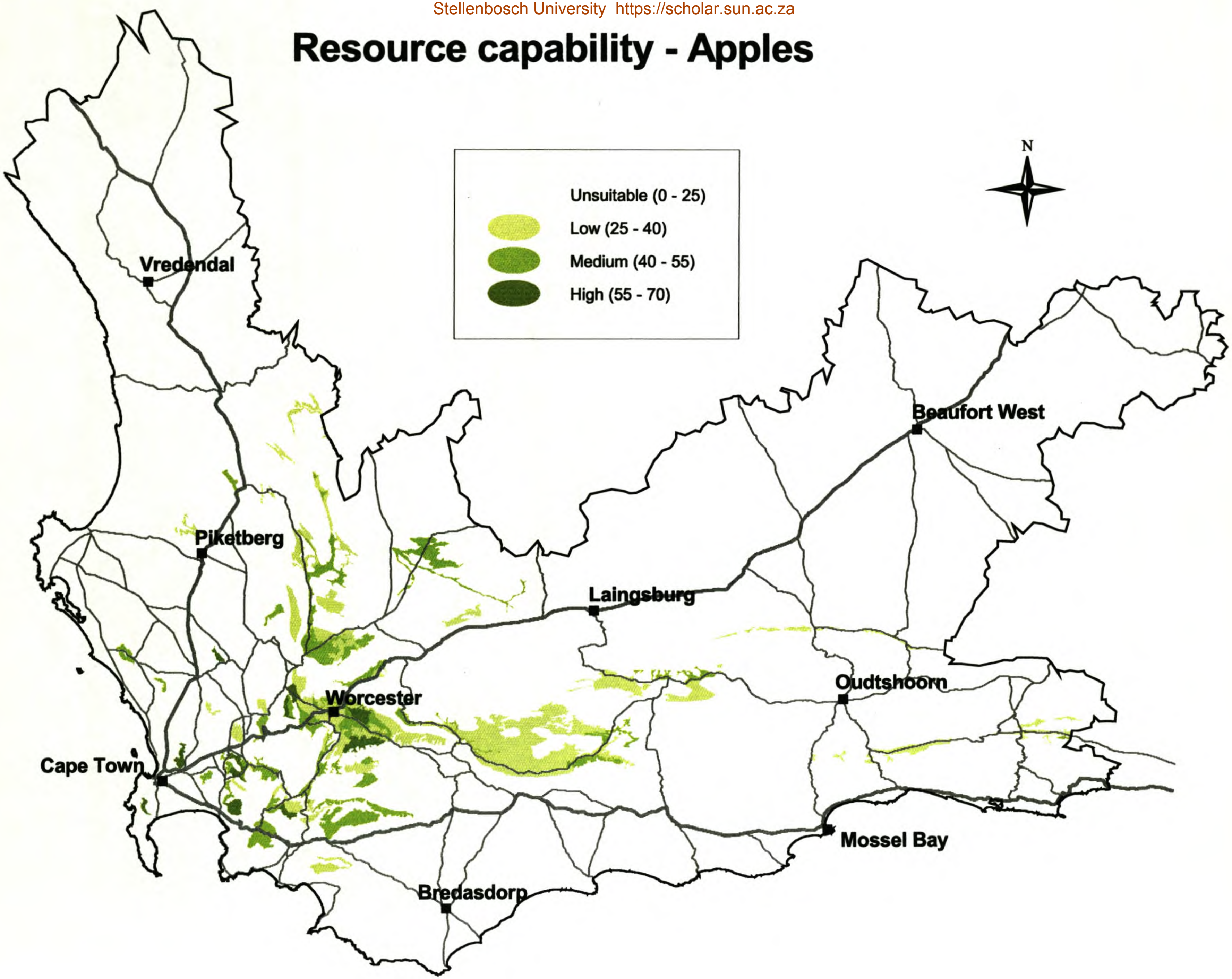
Land type description

Number	Description
Aa	With humic horizon
Ab	Red, dystrophic and/or mesotrophic
Ac	Red and yellow dystrophic and/or mesotrophic
Ad	Yellow, dystrophic and/or mesotrophic
Ae	Red, high base status > 300mm deep (no dunes)
Af	Red, high base status > 300mm deep (with dunes)
Ag	Red, high base status > 300mm deep
Ah	Red and yellow, high base status, usually <15% clay
Ai	Yellow, high base status, usually <15% clay
Ba	Dystrophic and/or mesotrophic, red soils widespread
Bb	Dystrophic and/or mesotrophic, red soils not widespread
Bc	Eutrophic, red soils widespread
Bd	Eutrophic, red soils not widespread
Ca	Undifferentiated
Da	Red B horizons
Db	B horizons not red
Dc	In addition, one or more of: vertic, melanic, red structured diagnostic horizons
Ea	Undifferentiated
Fa	Lime rare or absent in entire landscape
Fb	Lime rare or absent in upland soils, but generally present in low-lying soils
Fc	Lime generally present in entire landscape
Ga	Predominantly deep (Lamotte from)
Gb	Predominantly shallow (Houwhoek form)
Ha	Regic sands dominant
Hb	Regic sands and other soils
Ia	Undifferentiated deep deposits
Ib	Rock areas with miscellaneous soils
Ic	Rock with little or no soils

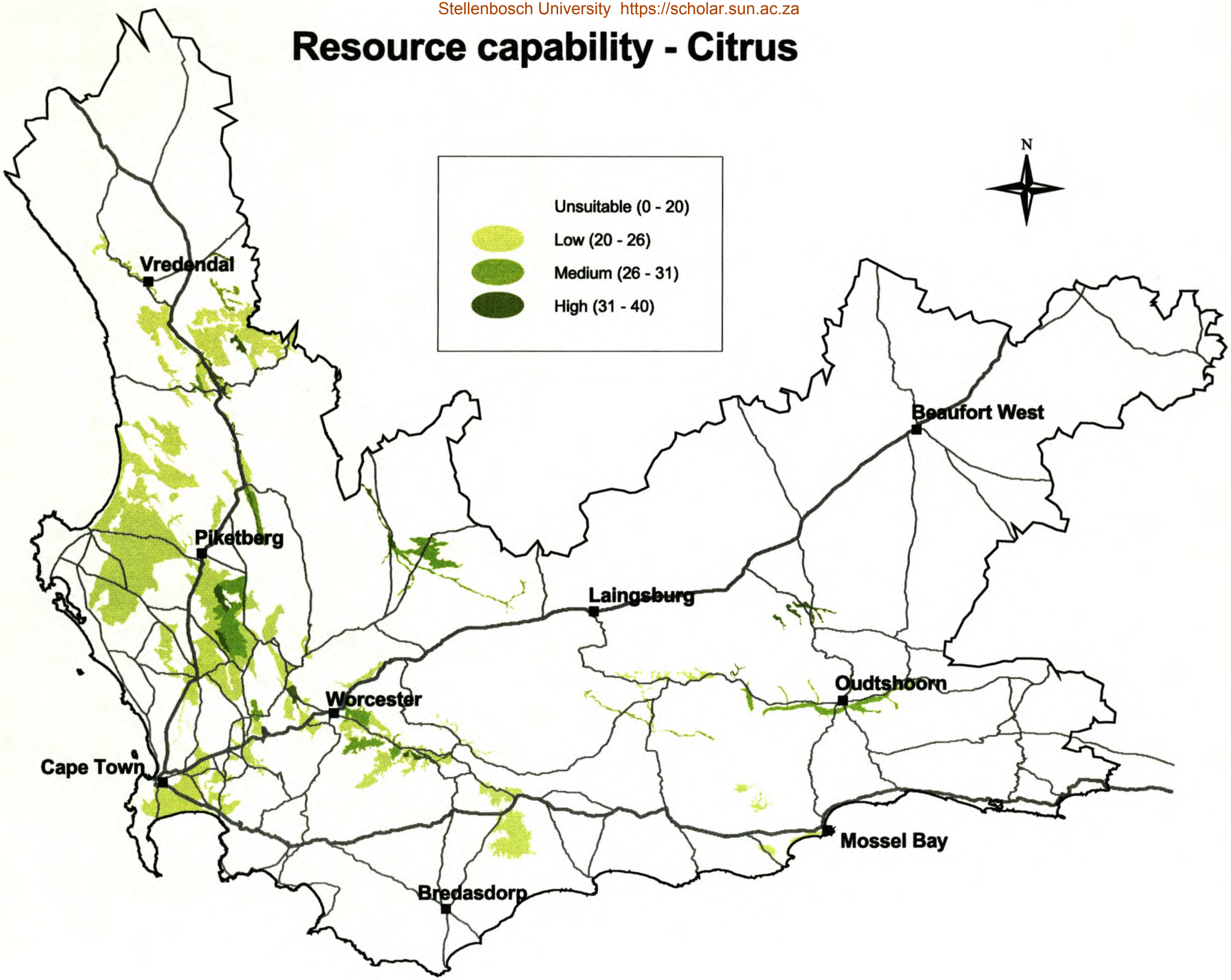
Annex 4

Land capability maps - Production potential for selected crops (Categorised according to yield in tonne per hectare)

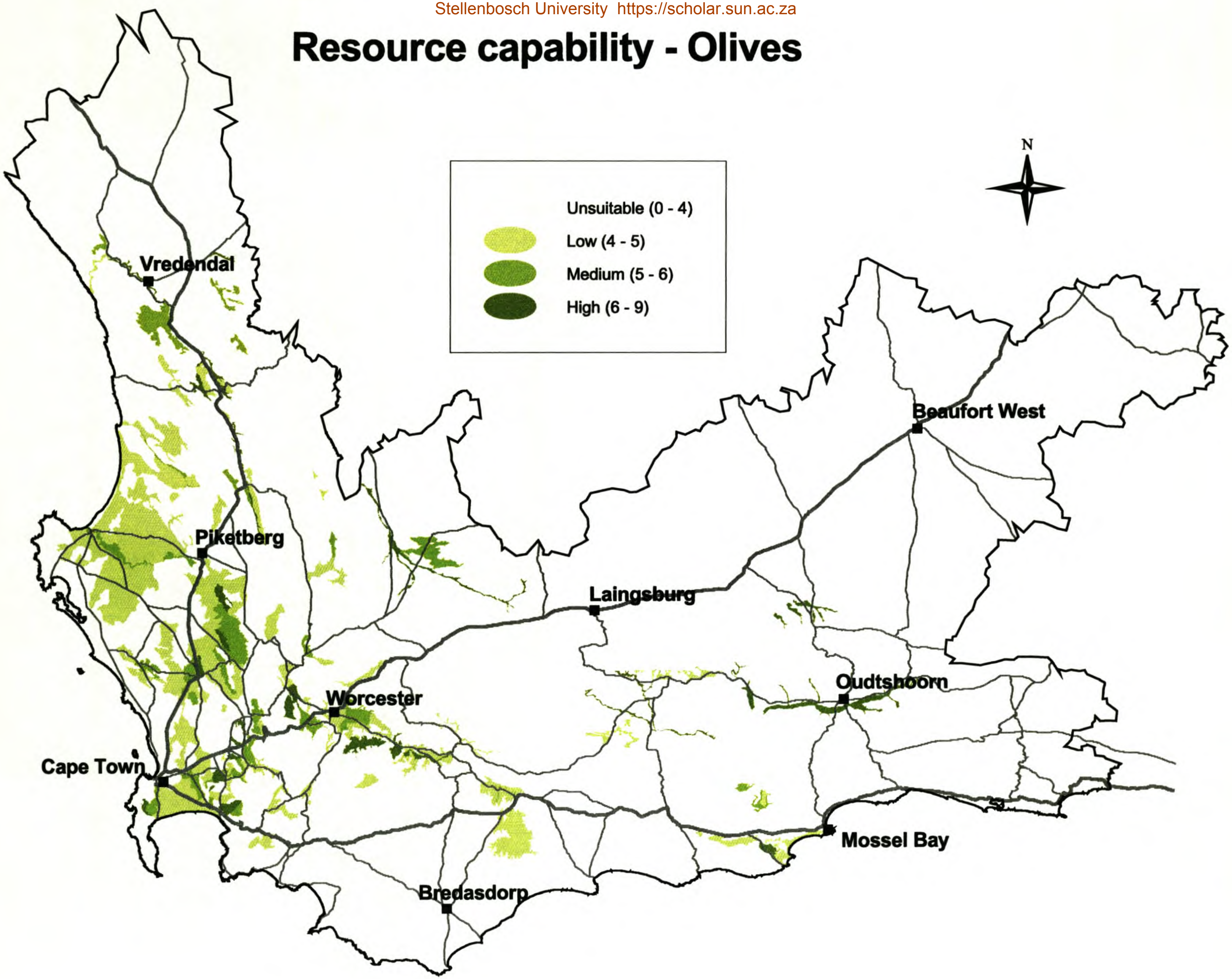
Resource capability - Apples



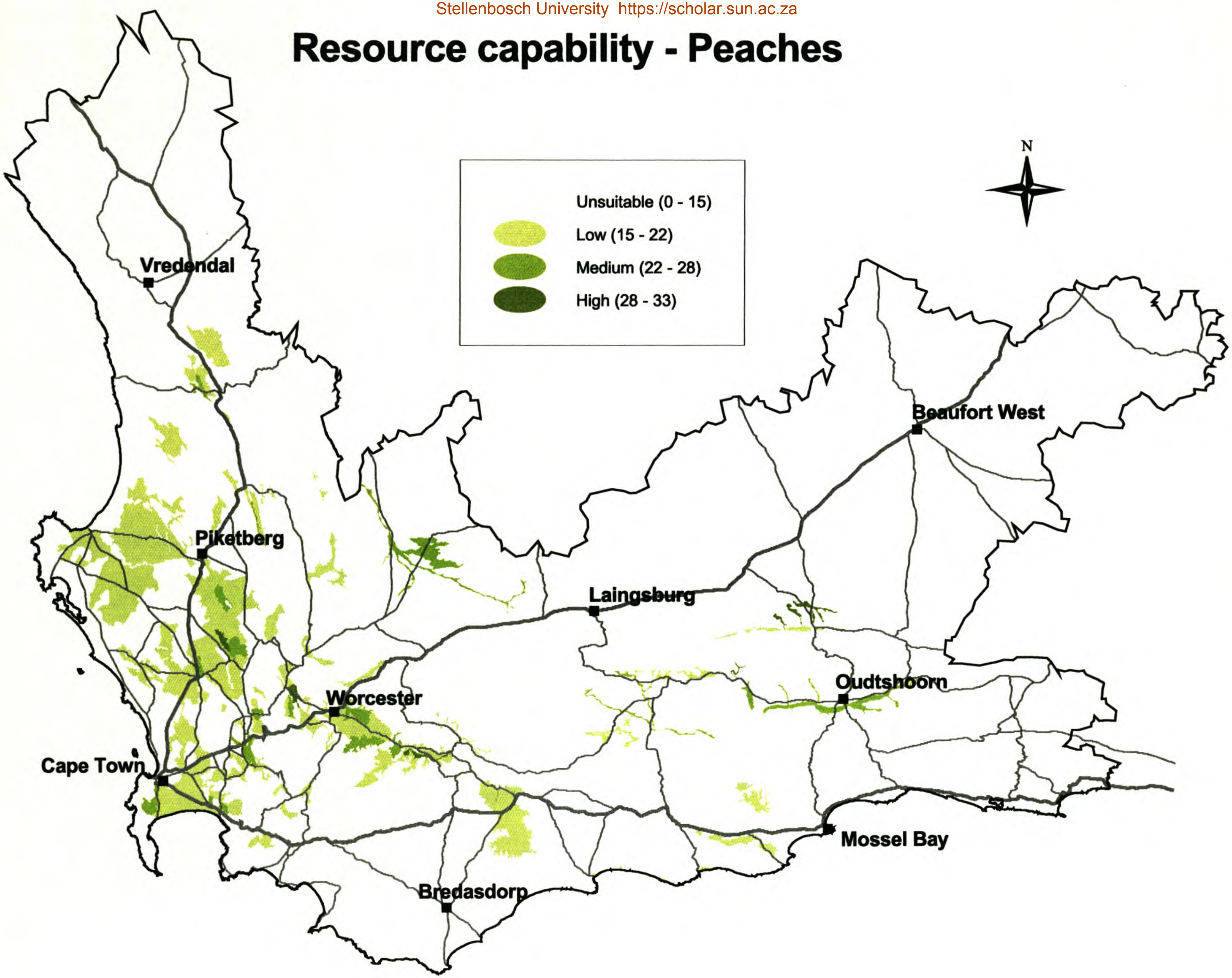
Resource capability - Citrus



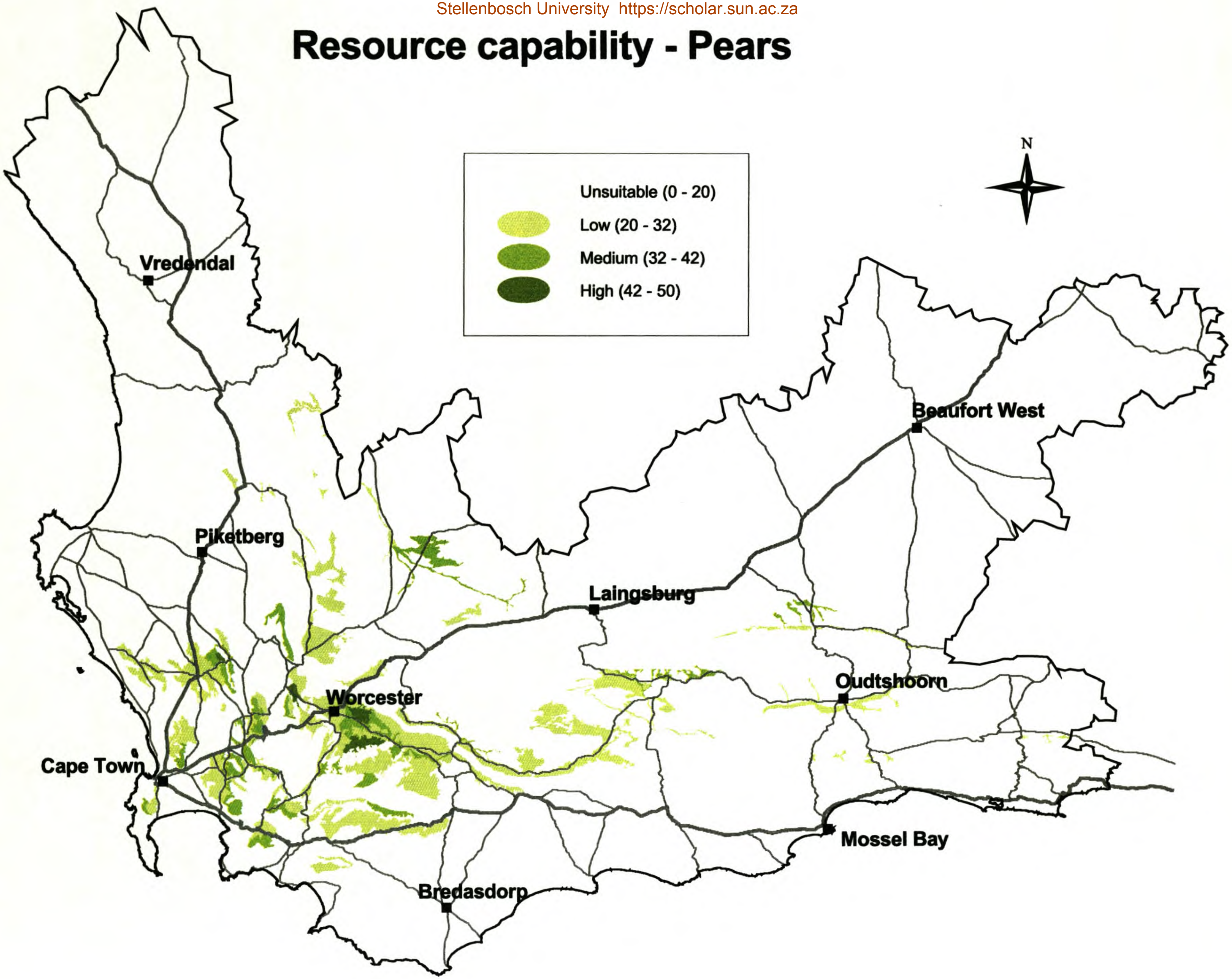
Resource capability - Olives



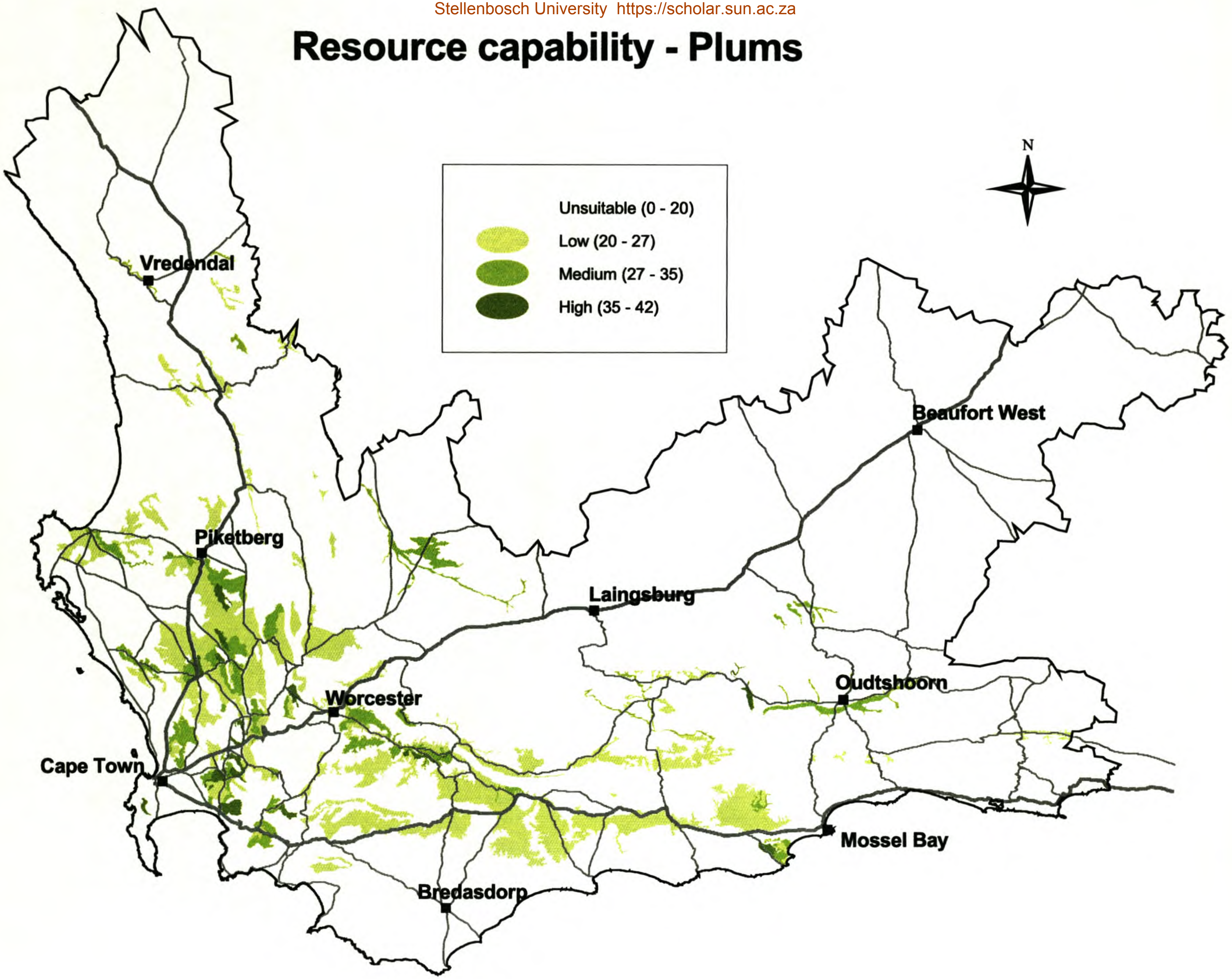
Resource capability - Peaches



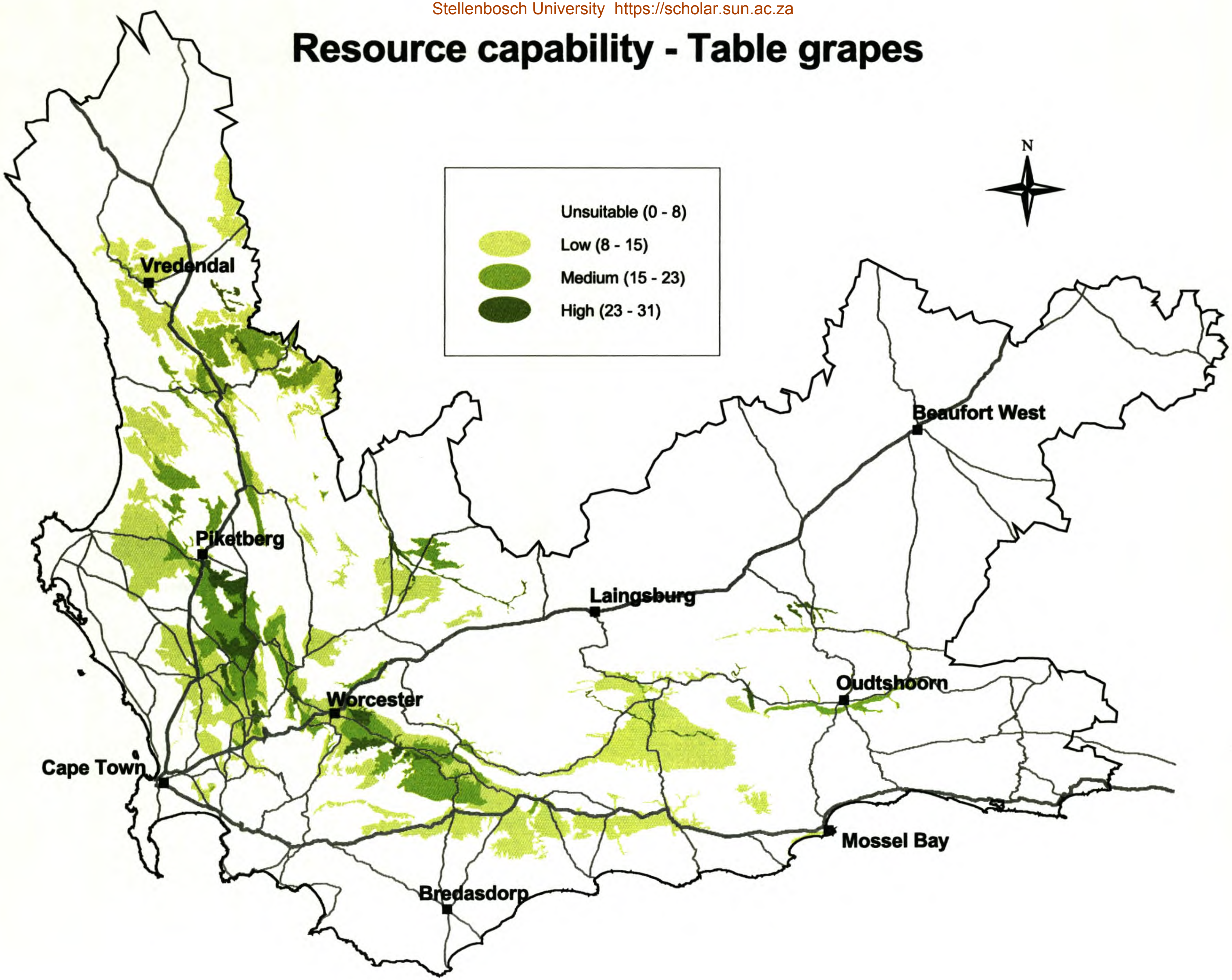
Resource capability - Pears



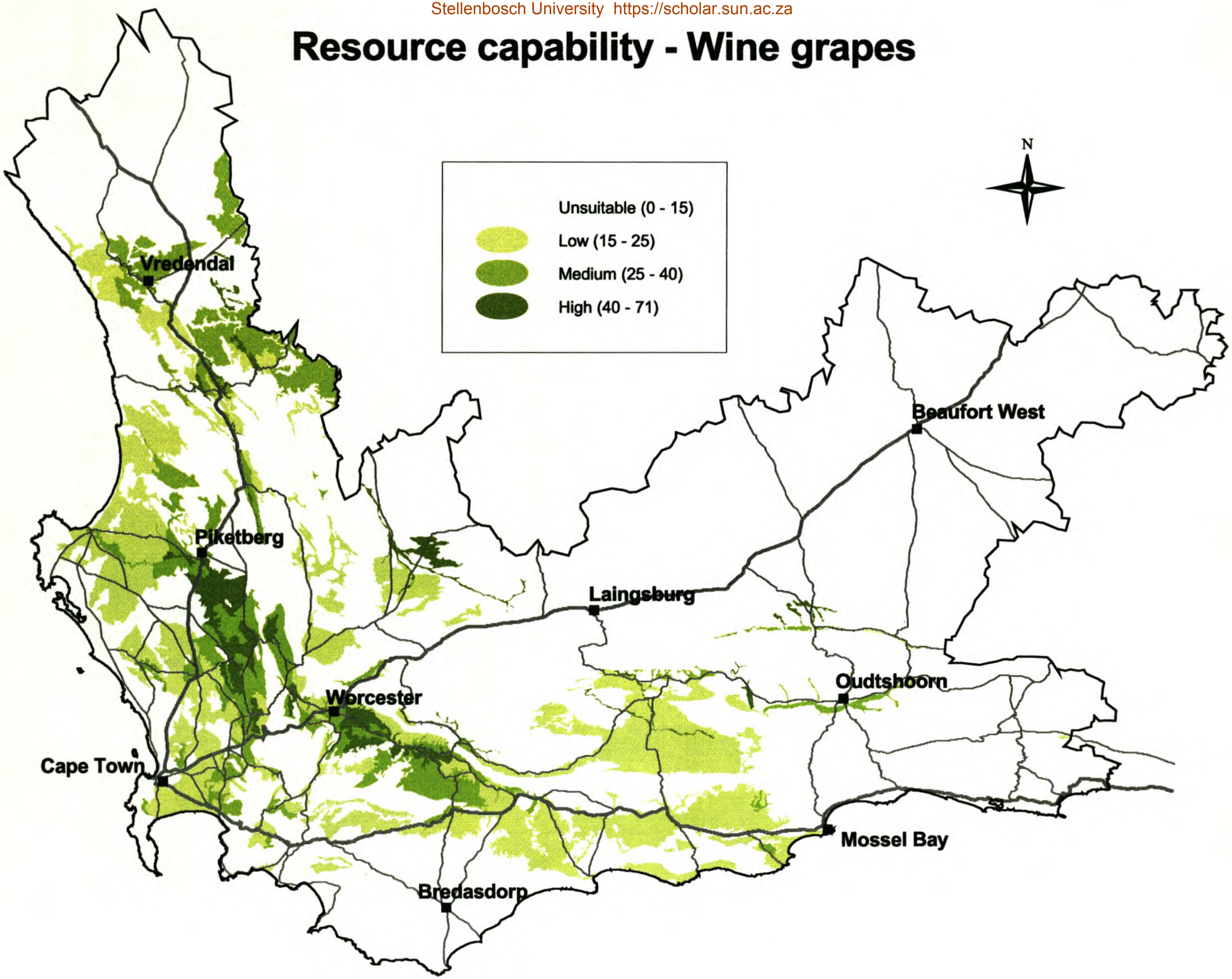
Resource capability - Plums



Resource capability - Table grapes



Resource capability - Wine grapes



Annex 5

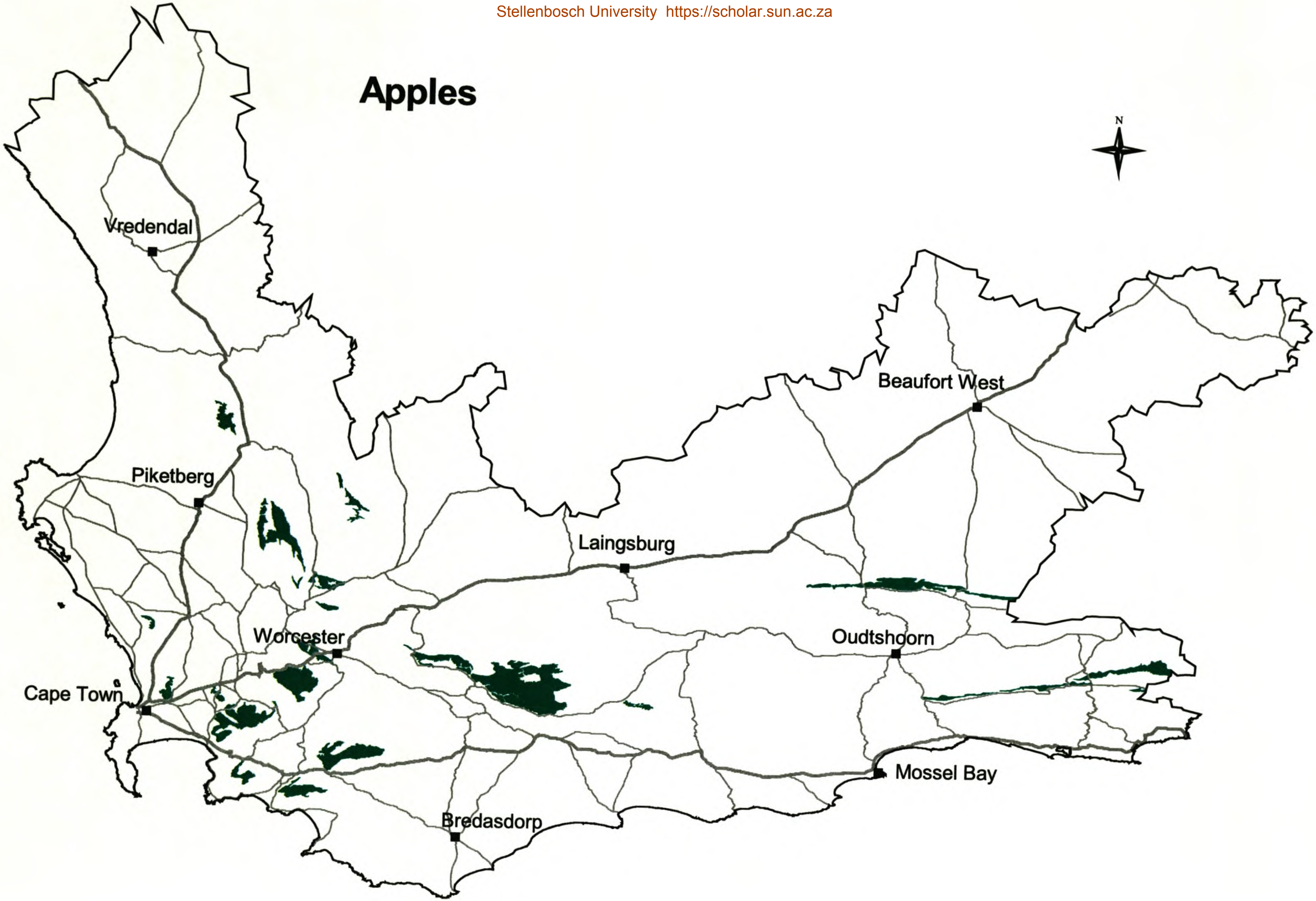
List of experts consulted for economic data

List of experts and institutions consulted for economic data

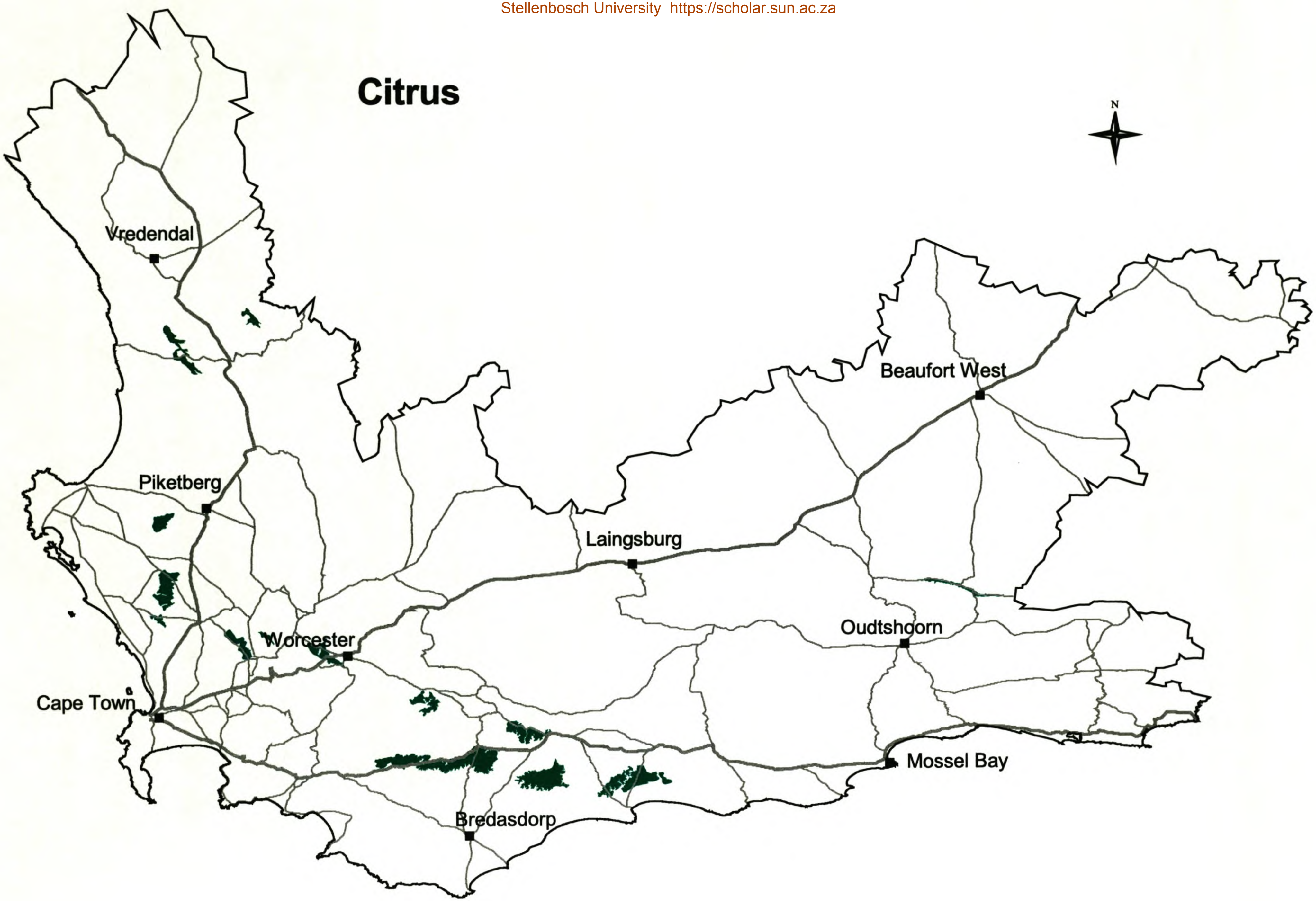
1. Agricultural statistics, National Department of Agriculture, Pretoria.
2. Botha, P. KWV Head Office, Paarl.
3. Combud Enterprise Budgets July 1995, compiled by Sub-directorate: Farm Management, Department of Agriculture Western Cape, Elsenburg.
4. Division for Resource Management, Department of Agriculture Western Cape, Elsenburg.
5. Ferrandi, C., Consulting agricultural economist, Somerset West.
6. Industrial Development Corporation, Johannesburg.
7. Liebenberg, F., Agricultural economist, Agricultural Research Council, Pretoria.
8. Louw, T. TRADEX, Cape Town.
9. Outspan/Citrus marketing board, Pretoria.
10. Protein Research Trust, Pretoria and Stellenbosch.
11. SA Olive Growers Association, Paarl.
12. Smit, A. Personal Communication.
13. Unifruco, Bellville.
14. Van Rensburg, R., Department of Transport Economics, University of Stellenbosch, Stellenbosch.

Annex 6

Spatial distribution of crops according to optimisation model



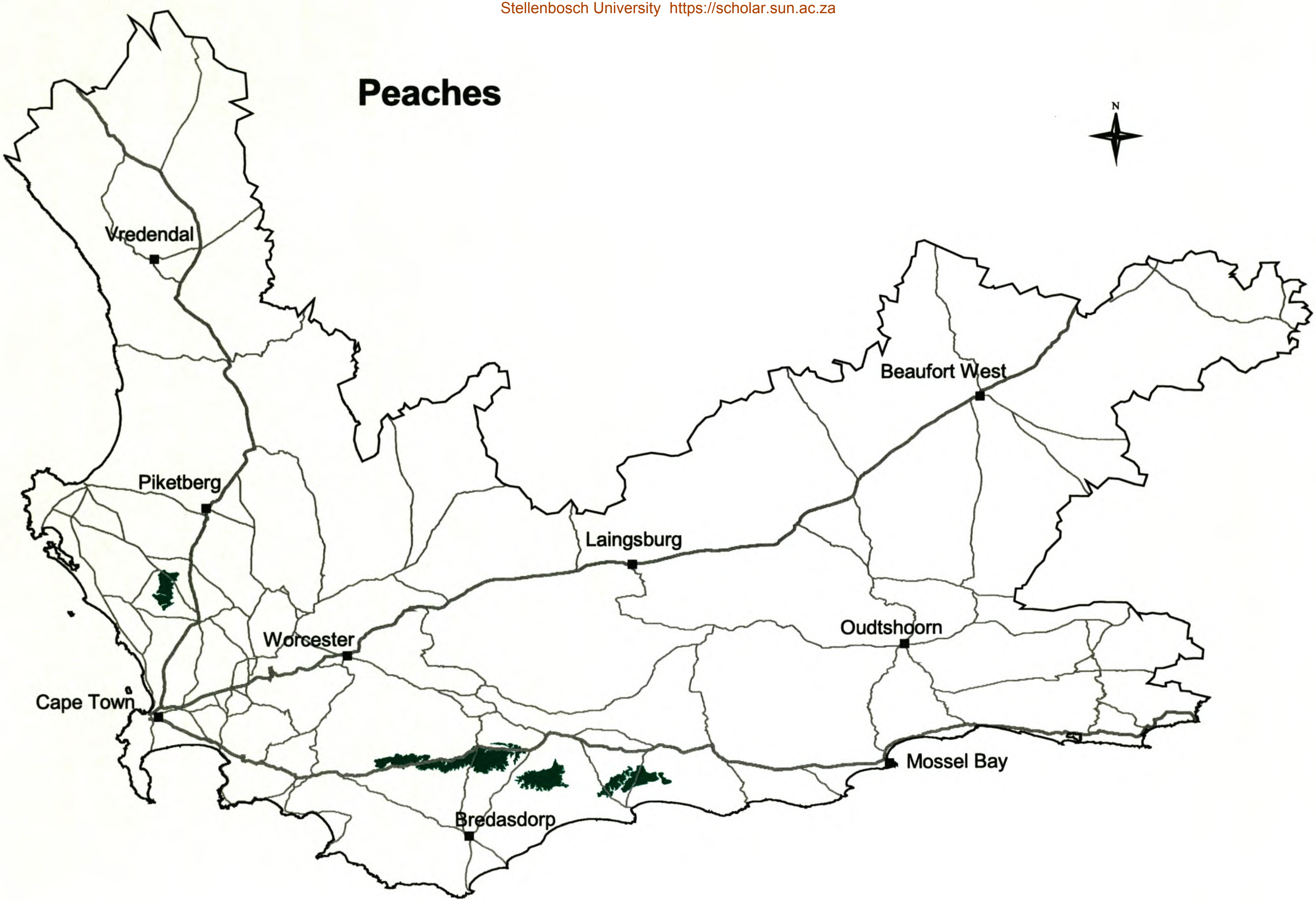
Apples
N
Vredendal
Piketberg
Laingsburg
Beaufort West
Worcester
Oudtshoorn
Cape Town
Mossel Bay
Bredasdorp

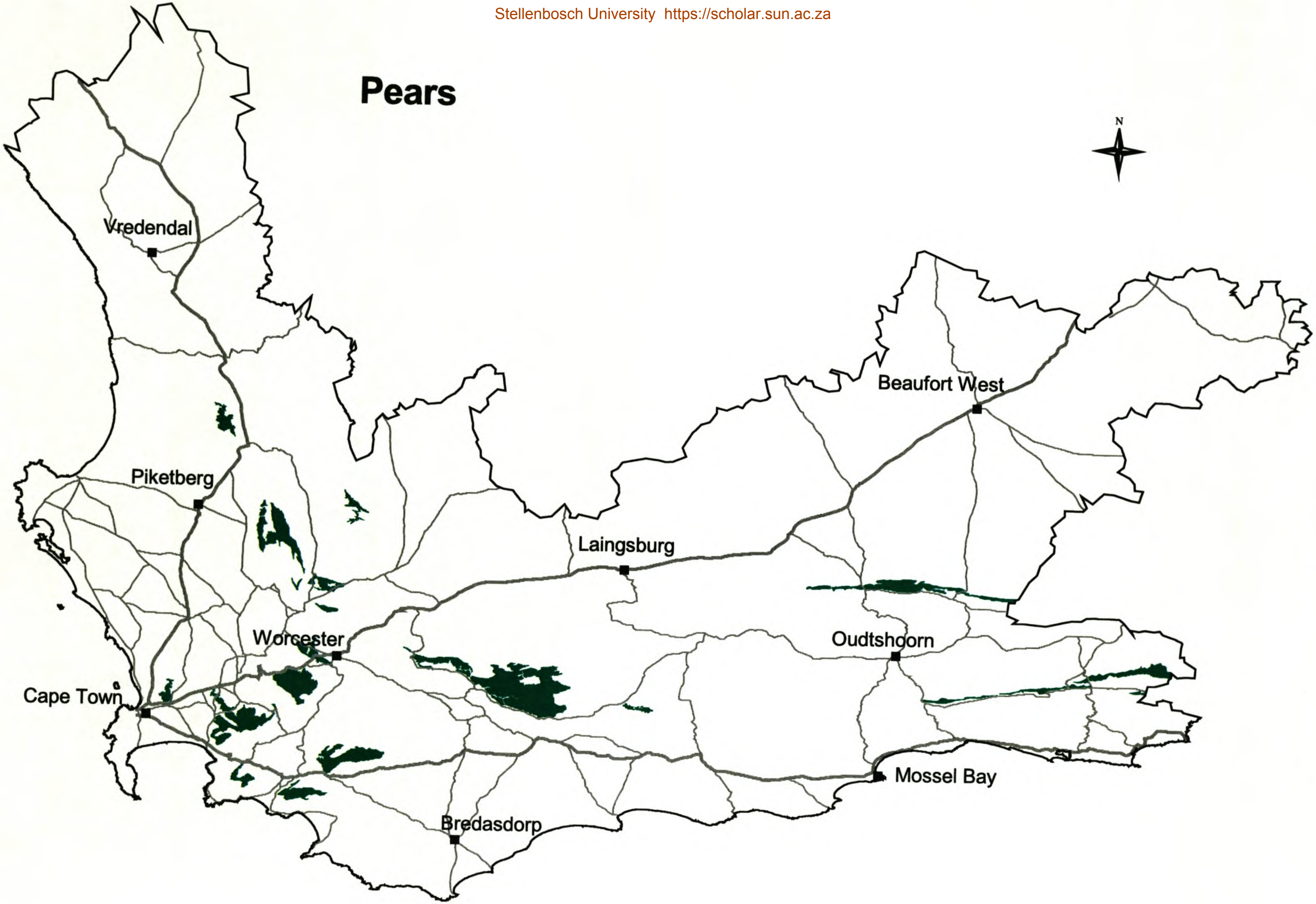

Citrus
N
Vredendal
Beaufort West
Piketberg
Laingsburg
Oudtshoorn
Worcester
Cape Town
Mossel Bay
Bredasdorp

Olives


N
Vredendal
Piketberg
Beaufort West
Laingsburg
Worcester
Oudtshoorn
Cape Town
Mossel Bay
Bredasdorp

Peaches


N
Vredendal
Piketberg
Worcester
Cape Town
Laingsburg
Beaufort West
Oudtshoorn
Mossel Bay
Bredasdorp


Pears
N
Vredendal
Piketberg
Beaufort West
Laingsburg
Worcester
Oudtshoorn
Cape Town
Mossel Bay
Bredasdorp

Plums

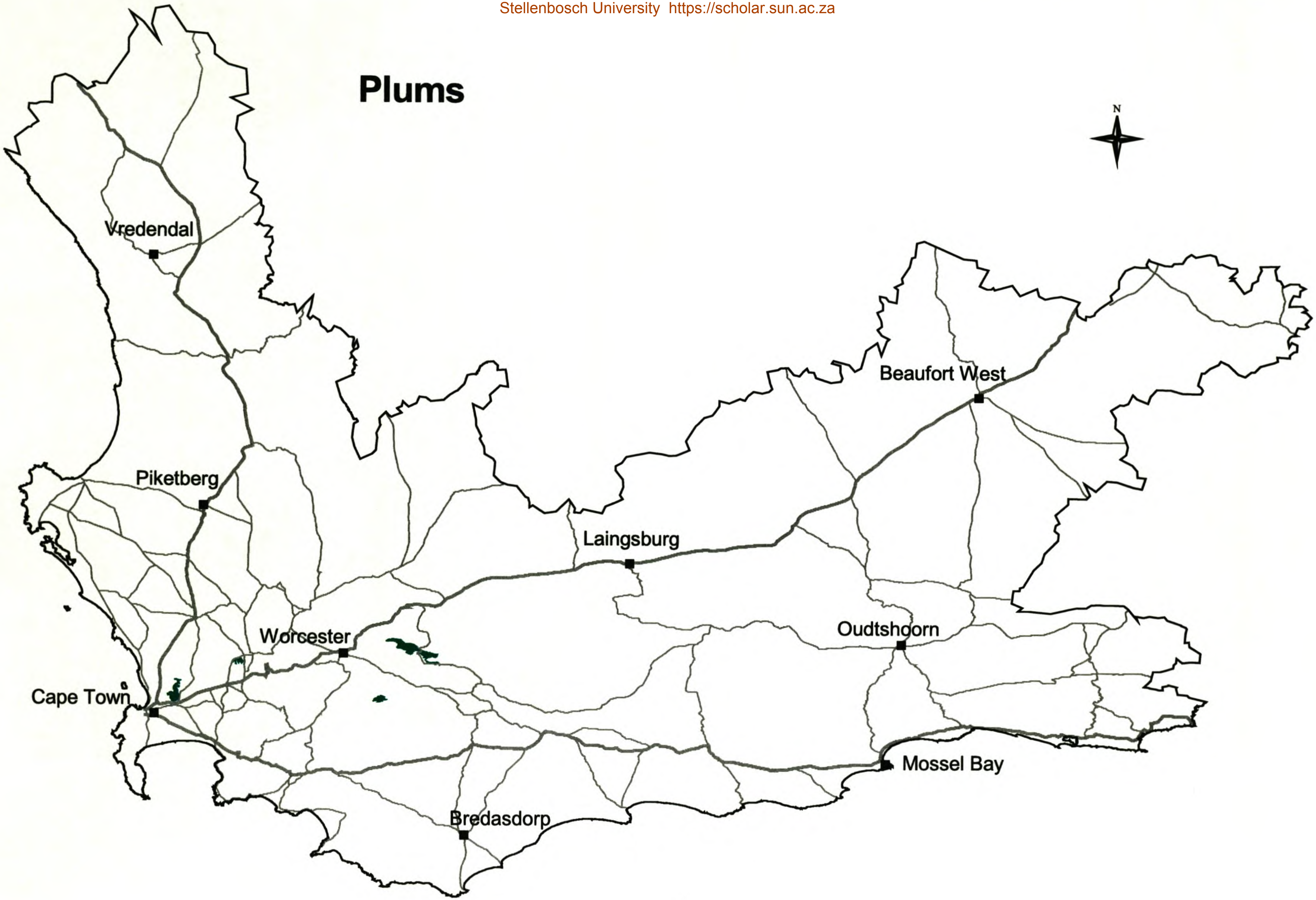
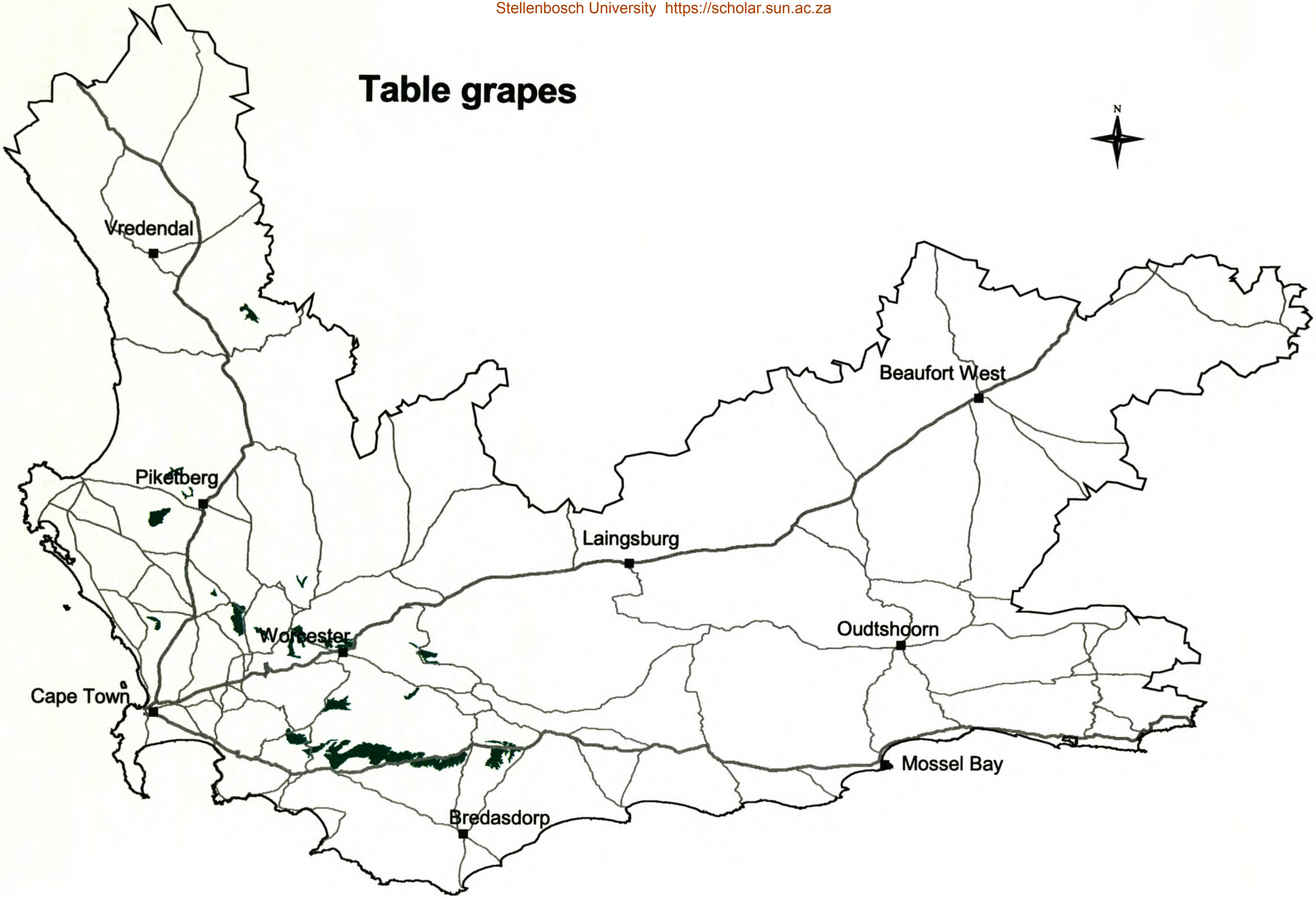
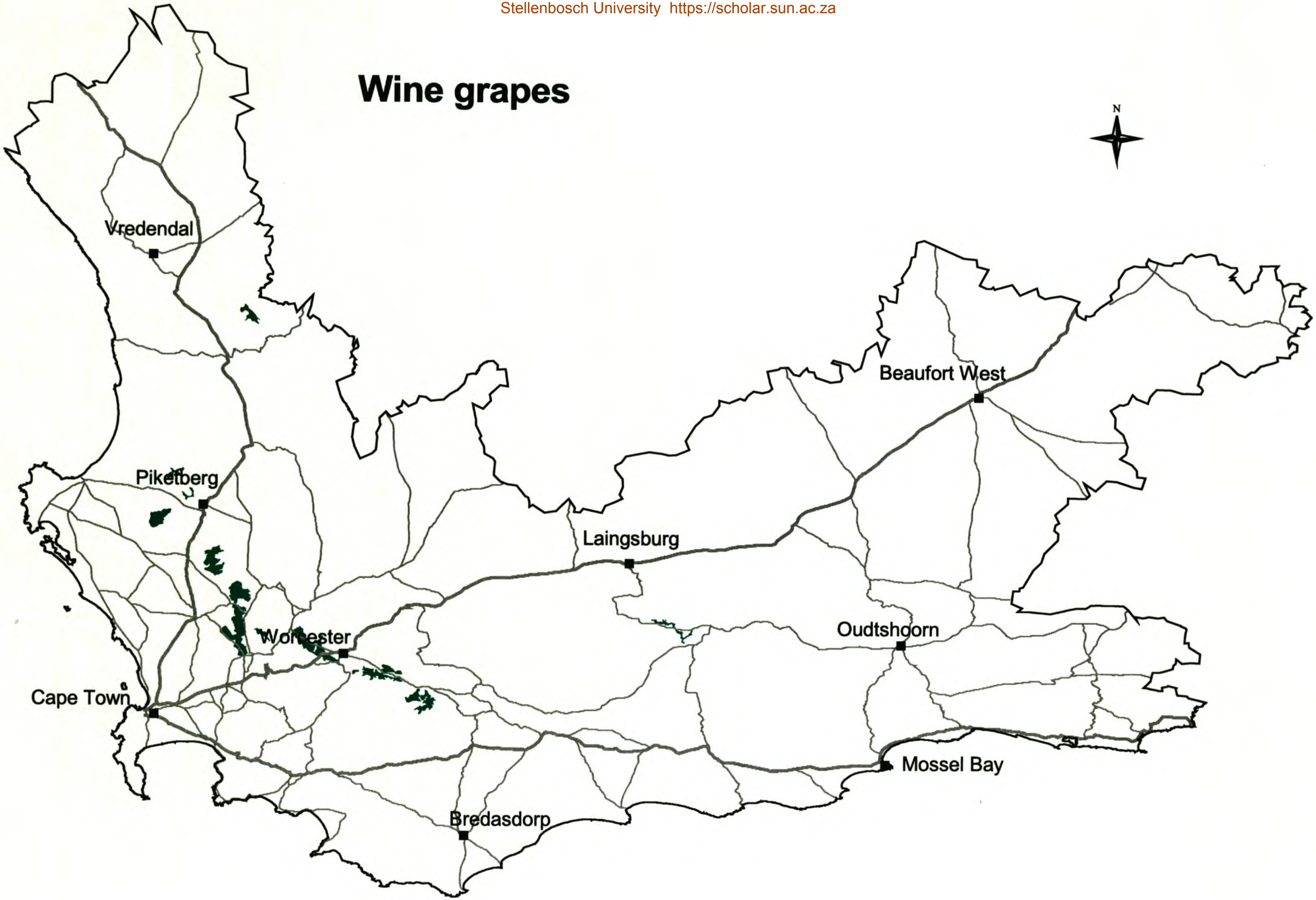

N
Vredendal
Piketberg
Laingsburg
Beaufort West
Worcester
Cape Town
Oudtshoorn
Mossel Bay
Bredasdorp

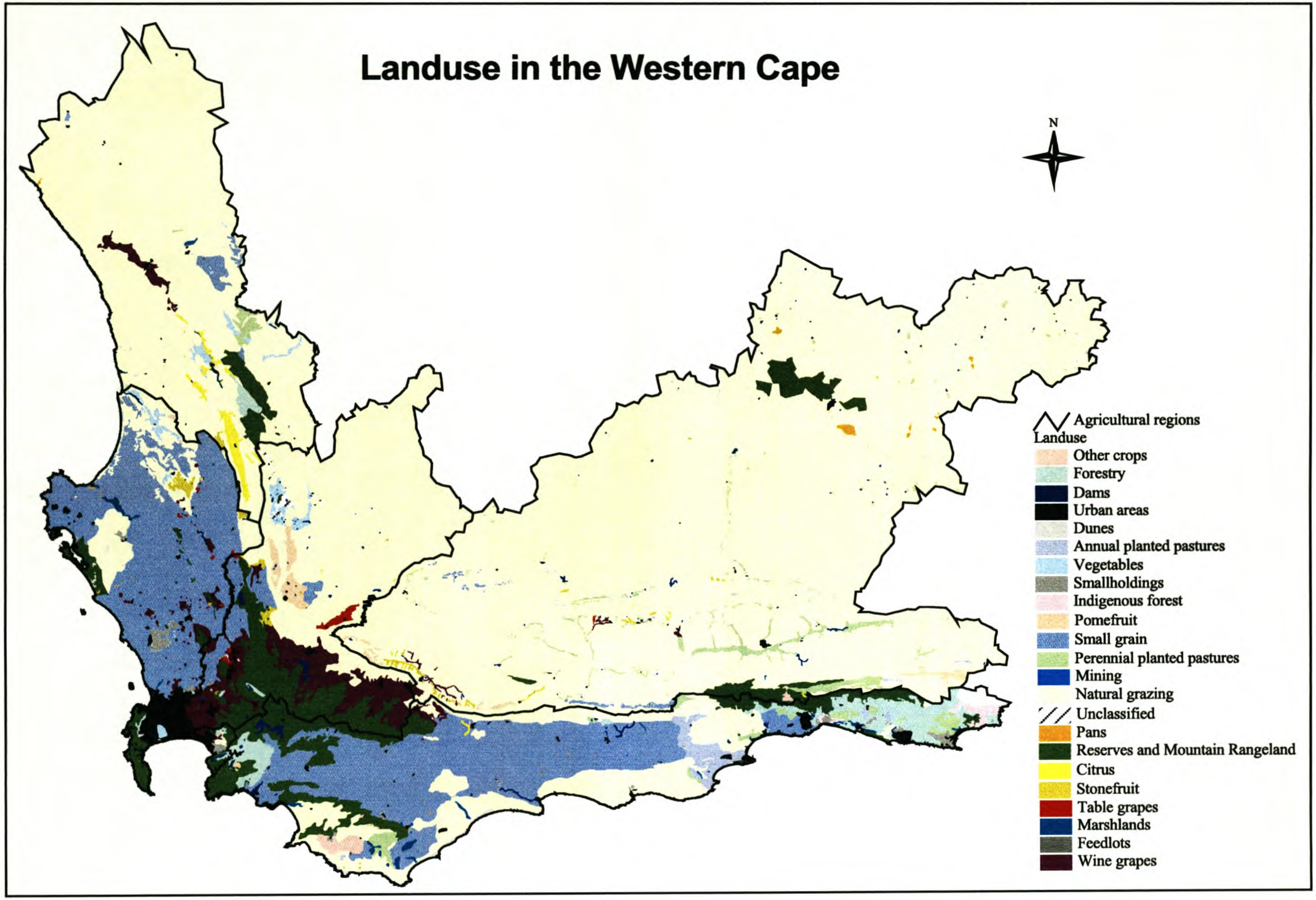
Table grapes




Wine grapes
N
Vredendal
Piketberg
Worcester
Cape Town
Laingsburg
Beaufort West
Oudtshoorn
Mossel Bay
Bredasdorp

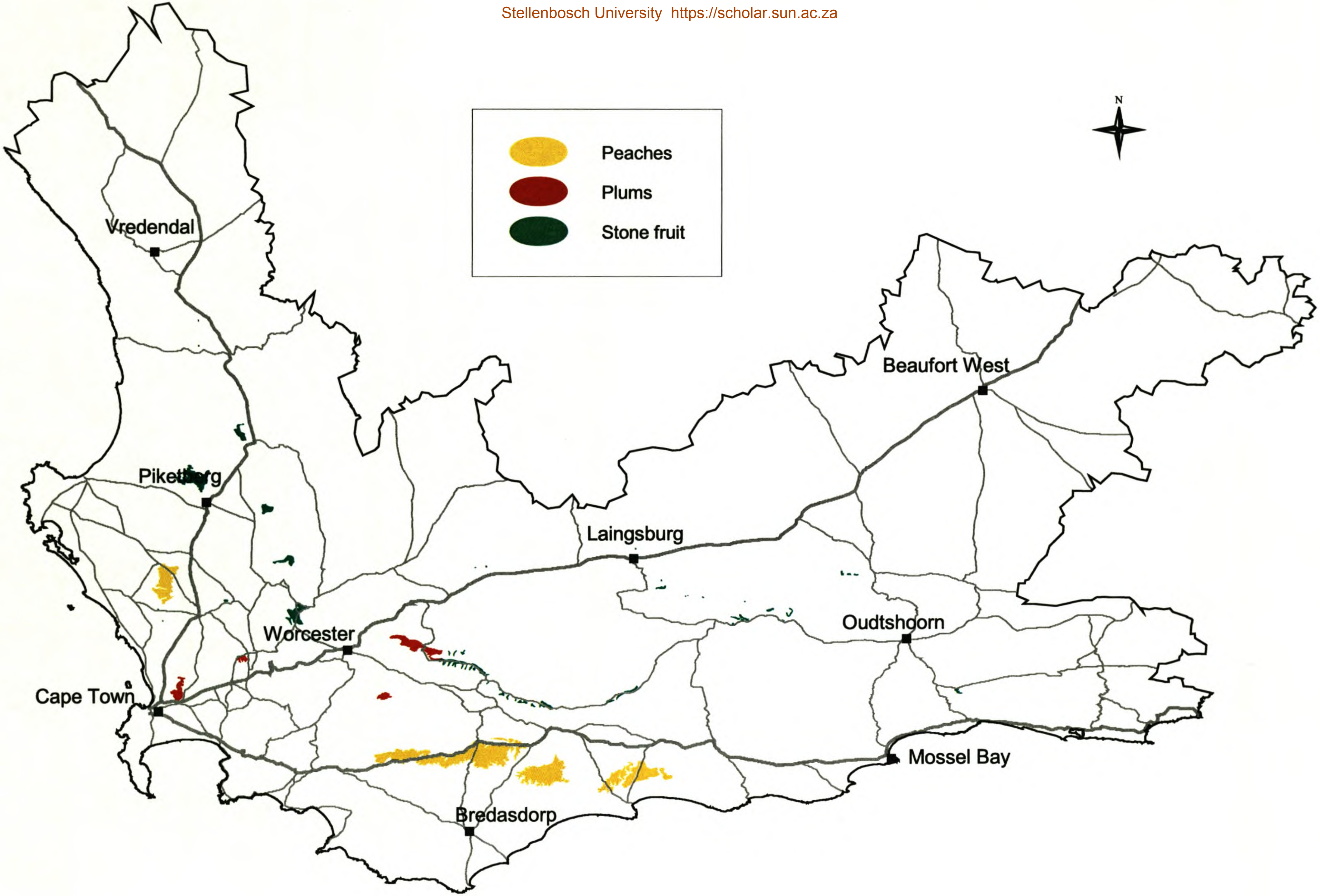
Annex 7

Existing agricultural land use pattern of the Western Cape


Landuse in the Western Cape
N
Agricultural regions
Landuse
Other crops
Forestry
Dams
Urban areas
Dunes
Annual planted pastures
Vegetables
Smallholdings
Indigenous forest
Pomefruit
Small grain
Perennial planted pastures
Mining
Natural grazing
Unclassified
Pans
Reserves and Mountain Rangeland
Citrus
Stonefruit
Table grapes
Marshlands
Feedlots
Wine grapes

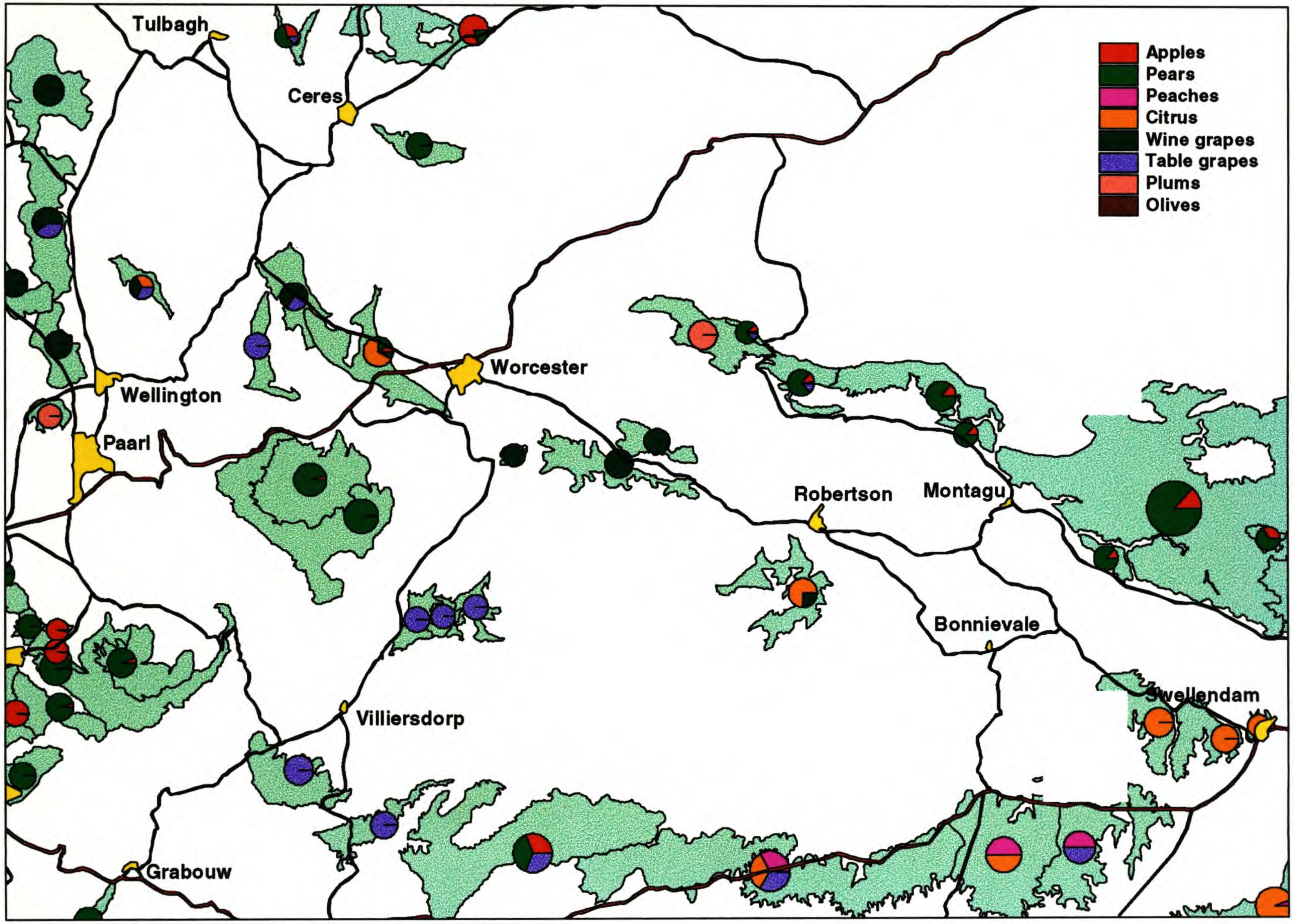
Annex 8

Comparison of existing land use pattern for stone fruit and model results for peaches and plums


Peaches
Plums
Stone fruit
N
Vredendal
Piketberg
Worcester
Cape Town
Laingsburg
Beaufort West
Oudtshoorn
Mossel Bay
Bredasdorp

Annex 9

Pie charts indicating the crop combinations for a district


Apples
Pears
Peaches
Citrus
Wine grapes
Table grapes
Plums
Olives
Tulbagh
Ceres
Worcester
Wellington
Paarl
Robertson
Montagu
Bonnievale
Swellendam
Villiersdorp
Grabouw