ALTERNATIVE LAND USES TO FORESTRY IN THE WESTERN CAPE: A CASE STUDY OF LA MOTTE PLANTATION

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Thesis presented in partial fulfillment of the requirements for the degree of Master of Science at the University of Stellenbosch.

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December 2003

AUTHOR'S 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.

Signature:

Date:

ABSTRACT

The South African government started the restructuring process of the state's forest assets in 1998. The privatisation process includes all the assets of the South African Forestry Company (SAFCOL) and half of the former homelands' 150 000 hectares of forest. In August 2000 SAFCOL released their "Operational Plan for Implementing Exit from Forestry in the Southern-Cape Portion of the Western Cape Region". This plan identified only major land uses (agriculture, forestry, and conservation). A more detailed and intensive land evaluation study was required to specify land utilisation types that are tailor-made to each land unit of the study area.

The main intention of this research study is to develop a more detailed evaluation process that elaborates on the land uses proposed by SAFCOL, which is site-specific in terms of the type of agricultural system to be used on specific areas, or the type of indigenous vegetation to be restored in conservation areas. La Motte plantation was taken as the case study and the SAFCOL digital database for the study area was used as the input data.

The Automated Land Evaluation System (ALES) was the computer software package used to build the expert system to evaluate land according to the method presented in the FAO 1976 report. The ALES model built in this research study had 15 decision trees (one per land utilisation type) resulting in a total of 1678 branches, which relate land characteristics to severity levels of land qualities. During the computation of an evaluation ALES attempts to place each map unit into one of the four severity levels of land qualities within each land-utilisation type. Physical suitability of each land unit for each land utilisation type was determined by the maximum limitation method. ALES is not a GIS and does not by itself display maps. The evaluation result matrix was exported into ArcMap for further optimisation and geographical analysis to enable the spatial representation of the results. After completion, taking into account the theoretical background, optimal terrain units were identified for the different land uses considered and the results are presented as tables and maps.

Fynbos is the most suitable alternative land use for the study area followed by Pears, Sauvignon Blanc and Chardonnay vines. Pinotage, Shiraz, Cabernet Sauvignon and Cabernet Franc vines were least suitable as alternatives. The study found that the SAFCOL's database is not sufficient to meet the requirements of a detailed site-specific land evaluation process. The polygon attribute table of the soil coverage only provided a subset of the land characteristics necessary to build and run the model. Data fields like soil form, depth, drainage, wetness, terrain type, aspect and climatic information had to be created because most of the data provided were in a non-digital form. The database was not complete and more precise data are needed to improve the system.

OPSOMMING

Die Suid-Afrikaanse regering het in 1998 met die herstruktureringsproses van die bosbou-bates van die Staat begin. Die privatiseringsproses het al die bates van die Suid-Afrikaanse Bosboumaatskappy (SAFCOL) en die helfte van die vorige tuislande se 150 000 hektaar ingesluit. In Augustus 2000 het SAFCOL sy Operasionale Plan vrygestel vir die implementering van sy onttrekkingsprogram van bosbou uit die Suid-Kaap gedeelte van die Weskaap-streek. Hierdie plan het slegs die hoof landgebruike geïdentifiseer, bv. landbou, bosbou en natuurbewaring. 'n Meer gedetaileerde en intensiewe grondgebruikstudie was nodig om geskikte gebruikstipes te identifiseer wat optimale alternatiewe gebruike spesifiseer vir elke landeenheid in die studie-area.

Die hoofdoel van hierdie navorsingstudie is om 'n meer gedetaileerde proses te ontwikkel ter uitbreiding van die alternatiewe landgebruike wat deur SAFCOL voorgestel was. Hierdie voorstel moet meer ligging-spesifiek wees in terme van die tipe landbougewas of die tipe inheemse plantegroei wat in natuurbewaringsgebiede gevestig moet word. Die La Motte-plantasie is as voorbeeld gebruik om hierdie gevalle-studie te doen en die inligting is vanaf die SAFCOL digitale databasis verkry.

Die rekenaar sagteware-pakket wat gebruik is om die land-evalueringstelsel te bou, is die "Automated Land Evaluation System" (ALES). Dit berus op die metode wat in die verslag van die FAO in 1976 voorgestel is. Die ALES model wat in hierdie navorsingstudie benut is, het 15 beslissingsbome ("decision-trees") (een per landgebruikstipe) wat 'n totaal van 1678 vertakkings lewer. Landeienskappe word hierdeur in verband gebring met verskillende geskiktheidsvlakke vir verskillende gewasse. Gedurende die berekening van hierdie evaluasie, het ALES elke gebiedseenheid in een van die vier geskiktheidsvlakke per grondgebruikstipe geplaas. Fisiese geskiktheid van elke landeenheid vir elke grondgebruikstipe is bepaal deur die maksimum beperkingsmetode. ALES is nie 'n GIS nie en op sy eie vertoon dit nie kaarte nie. Die uitslag van die geskiktheidsmatriks is na ArcMap uitgevoer vir verdere optimisering en geografiese analises ten einde die resultate ruimtelik voor te stel. Na afhandeling, met inagneming van die teoretiese agtergrond, is

optimale terrein-eenhede geïdentifiseer met inagneming van die verskillende landgebruike en is die resultate in tabel en kaartvorm aangebied.

Fynbos is die mees geskikte alternatiewe landgebruik vir die studiegebied gevolg deur Pere, Sauvignon Blanc en Chardonnay wingerde. Pinotage, Shiraz, Cabernet Sauvignon en Cabernet Franc wingerde is minder geskikte alternatiewe. Die studie het bevind dat die SAFCOL databasis nie voldoende was om aan die vereistes van 'n gedetaileerde liggingspesifieke landevalueringsproses te voldoen nie. Die poligoon-attribuuttabel van die grondoorleg het net 'n subversameling van die landeienskappe verskaf wat benodig was om die model te bou en uit te voer. Datavelde soos grondvorm, diepte, dreinering, vogtigheid, terreintipe, hellingrigting en klimaatinligting moes geskep word, omdat meeste van die data wat verskaf is nie in 'n digitale vorm beskikbaar was nie. Die databasis was nie volledig nie en meer presiese data word benodig om die stelsel verder te verbeter.

ACKNOWLEDGMENT

To The Lord: “You never let me down”

My parents: ‘por su ejemplo, constacia y apoyo”

Ursula Fernandez and Diego: “porque sois mi hermana y sobrinos favoritos”

Joaquin and Aurora: ‘because you always believe in me”

Tannie Otti: “for being my mum”.

The Snyders (Oom Fred, Anty Lina, Danny, Mona, Theodore and Havanna): “for your warm welcome and love”. Thank you.

Ursula Snyders: “my inspiration my strength”

Shaienen Snyders: “my boy”.

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CHAPTER 1: INTRODUCTION

In 1998 the South African government, with Mr Kader Ashmal as Minister of Water Affairs and Forestry at the time, started the restructuring process of the state's forest assets. By restructuring, the government meant to go beyond 'simplistic definitions of privatization' (Radebe & Kasrils, 2000), and included in the process far-reaching decisions such as removing forestry from 57 000 hectares of land (17% of the total area) in favour of better alternative land uses. This decision opens a niche for land-evaluation exercises and applications research. The sections below elaborate on the studies made so far and justify the need for this research. The main objectives and goals, together with the software selected for this land evaluation, are also described.

1.1 RESTRUCTURING PROCESS OF THE STATE'S FOREST ASSETS

The government divided the state forestland to be sold into seven different packages and interested parties could bid for the asset as a whole, for any one of the seven packages, or for a combination of packages (Chalmes, 2001). The privatisation process includes all the assets of the South African Forestry Company (SAFCOL) and half of the former homelands' 150 000 hectares of forests (Chalmes, 1999).

In a joint statement by Mr Jeff Radebe (Minister of Public Enterprises) and Mr Ronnie Kasrils (Minister of Water Affairs and Forestry) in September 2000 it was announced that forestry currently managed by SAFCOL will be phased out of 15 000 hectares in the Boland area of the Western Cape and 30 000 hectares in the Southern Cape. The ministers indicated that "the plantations are not commercially viable and timber no longer represents the best land use option in these areas" and that "the phase out will open opportunities for other land uses including agriculture (particularly fruit and grapes), tourism and conservation". The process of conversion will be carefully managed over a period of 10 to 15 years. The remaining forestry areas (3 000 hectares in the Western Cape and 30 000 hectares in the Southern Cape) will still be managed by SAFCOL and be re-offered for sale in coming years.

There are many reasons why the Western Cape forest region must be reconsidered as a business unit (SAFCOL Western Cape Region, 1999). The region has never been profitable and during the years under SAFCOL management it almost always posted losses. The low yield (mean annual increment (MAI20) less than 10 m3/ha/year) that can be achieved from the poor growing sites that dominate the region's planted area makes the region a marginal operation that needs to sell its full sustainable yield just to break even. However, the non-existent pulp market makes full sales virtually impossible.

Although the company policy is to close down plantations that are not profitable, a series of actions were planned by SAFCOL to continue investing in the future of the region. Unfortunately, extreme weather conditions over the past five years, with the driest and hottest periods in 100 years, contributed to fires destroying over 8000 ha of planted area (15% of the total planted area). The fires, with the increased cutting tempo in poor sites and the backlog built up through cost postponement during the past two years, resulted in a skewed age class distribution. This in turn almost doubled the total volume of expenses in silviculture management, while reducing the available sales volume by 40 000 m^3. The effect of the fires was to increase costs and to reduce harvest volumes, which equates to a loss in income after harvesting of R3,8 million.

Table 1.1: Extent of the fire damage up to 26 March 1999 in the Boland region

Plantation	Date of fire	Estimated damage (Ha)	Estimated affected timber volume (m^3)
La Motte	13/02/1999	591	37565
La Motte	26/03/1999	1686	294735
Grabouw	29/11/1999	3589	29331

Source: SAFCOL Western Cape Region 2000

A recovery plan consisting of a series of further possible actions and interventions was planned subsequent to the fires (SAFCOL Western Cape Region, 1999). One of the possible and most likely actions was an exit strategy to remove the poor sites permanently from forestry. As indicated earlier, this action was officially announced by the government in September 2000. The exit strategy planned to strip the assets by harvesting all the existing trees over the optimum financial time period and to return the area to natural vegetation. However, significant portions would be available for utilisation for other financially viable land uses, including deciduous fruit, vines, vegetables and municipal development such as housing, water and electricity facilities and recreation. Trees will still remain in areas where growth is feasible and competing land uses are not. The remaining forestry areas will, however, be in small, scattered pockets within other land uses for the purpose of supplying timber to small sawmills. The cash that would flow from the sale could be utilised to increase forest holdings in profitable operations elsewhere, or it could be re-invested in the cleared areas by establishing other profitable land uses.

1.2 SAFCOL'S IDENTIFICATION OF ALTERNATIVE LAND USES

On 28 August 2000 SAFCOL internally released an "Operational Plan for Implementing Exit from Forestry in the Southern-Cape Portion of the Western Cape Region". This plan forms the backbone to exit plantation forestry and it states as its objectives that "All the unprofitable operational units, or portions of operational units that cause those units to be unprofitable, are to be withdrawn from plantation forestry". The plan identifies possible future land uses, but does not cater for their actual establishment. The aim is to remove the trees and leave the land utilisable for the next designated land user.

A land evaluation study was also undertaken for the Boland portion of the Western Cape Region in 2001. This document accepts that the future land uses will in some cases change from the one identified by the SAFCOL management and that an ongoing decision-making procedure will have to be employed to control changes in the future land uses.

1.2.1 Alternative land uses for the Western Cape region

SAFCOL identified and allocates the future land uses for the Southern Cape portion of the Western Cape using the following decision tree.

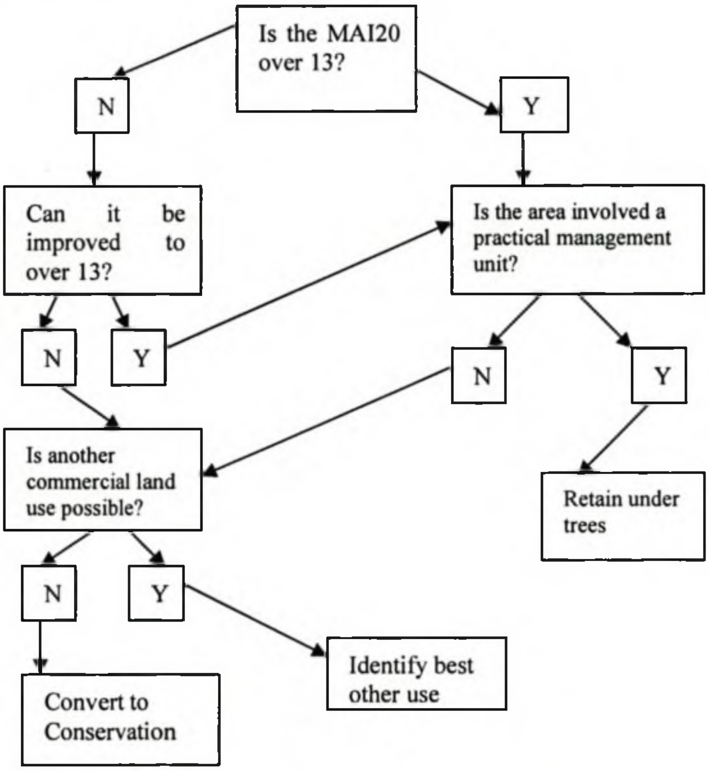

Figure 1.1: Decision tree to plan future land uses in the Western Cape

According to the diagram, the only criteria used to decide which units are unprofitable and which units should remain under forestry are productivity and yield (MAI20). Von Gadow & Bredenkamp (1992) and Loveday & Kassier (1994) defined MAI20 as the mean annual increment (m^3/ha) at an age of 20 years for a stand which has been given a standard treatment very close to the saw-timber regimes. This is as near as possible to an absolute site definition, especially for comparing the yields of different species.

The soils in the Southern Cape are generally poor and result in a low to very low yield (SAFCOL Western Cape Region, 2000). This impacts severely on the profitability of growing trees. Not only does it mean less sales volume from the same cost input compared to the rest of the country, but because of the smaller trees the harvesting cost are adversely affected.

1.2.2 Alternative land uses for the Boland

The data available in the SAFCOL (2001) spatial database for the Boland area as well as input from experienced managers were used as a basis for evaluation. The following factors were considered: topography (slopes), soil production classes, water features, conservation considerations and other practical issues (SAFCOL Western Cape Region, 2001).

Retaining forestry was only considered where the public interest would exceed any other consideration, as at Tokai, Cape Town and Jonkershoek, Stellenbosch or where it is dictated by sales contract requirements, as at Lourensford, Somerset West.

A conversion period of 20 years was used by SAFCOL to assess the viability. The 20-year period is the shortest period for harvesting timber of suitable dimensions. If the rate of conversion is increased, the timber harvested decreases in size to uneconomical dimensions.

The effect of the proposed land-use conversion is illustrated in Table 1.3.

Table 1.2: Boland land-use conversion. Source, SAFCOL Western Cape 2001.

Management Unit	Agriculture (ha)	Conservation (ha)	Dam development (ha)	Ecoturism (ha)	Forestry (ha)	Fynbos Conservation (ha)	Housing Development (ha)	Grand Total (ha)
Garcia					2067			2067
La Motte	1465	72	476	248	1056	1827	58	5202
Grabouw	1598					5194	337	7129
Kluitjeskraal	1955					1571		3526
Tokai	165			30	1877	135		2207
Grand Total	5184	72	476	278	2933	8727	395	18066

Accordingly, the forest management units at Grabouw and Kluitjieskraal are totally converted to other land use types and at La Motte, Franschhoek only small portions remain under forestry. The Jonkershoek and Tokai units are to remain under forestry.

1.3 RESEARCH GOALS

The "Operational Plan for Implementing Exit from Forestry in the Southern-Cape Portion of the Western Cape Region" identified only major land-use types (agriculture, forestry and conservation). A more detailed and intensive land-evaluation study is required to specify land utilisation types that are tailor-made to each land unit of the study area. It is the intention of this research study to develop a more detailed evaluation process that elaborates on the land uses proposed by SAFCOL, which are site-specific in terms of the type of agricultural system to be used on specific areas, or the type of indigenous vegetation to be restored in conservation areas and also by considering the socio-economic setting of production.

A more precise description of the agricultural systems concerned will be undertaken by undertaking an extensive and precise quantitative agronomic study to determine the relationships between land-use requirements and local land characteristics.

1.4 OBJECTIVES

The objectives of this research study are:

(i.) To develop a methodology for application of GIS in identifying alternative uses for land currently under forestry;

(ii.) To assess the proposed methodology;

(iii.) To expand the SAFCOL's land-evaluation study (SAFCOL Western Cape Region, 2000) with a more detailed evaluation process that elaborates on the land uses proposed, and is site-specific in terms of the type of agriculture to be used, or the type of indigenous vegetation to be restored in conservation areas;

(iv.) To assess whether SAFCOL's database is sufficient to meet the requirements of a detailed site-specific land-evaluation process.

To achieve these objectives the Automated Land Evaluation System (ALES) was selected as the computer program used to build the expert system to evaluate land according to the methods presented in the FAO "framework for land evaluation" (FAO, 1976).

1.5 THE AUTOMATED LAND EVALUATION SYSTEM (ALES)

ALES was intended for use in project or regional scale land evaluation. The entities evaluated by ALES are map units, which may be defined either broadly (as in reconnaissance surveys and general feasibility studies) or narrowly (as in detailed resource surveys and farm-scale planning). Since each model is built by a different evaluator to satisfy specific needs, there is no fixed list of land-use requirements whereby land uses are evaluated, and no fixed list of land characteristics from which land qualities are inferred. Instead, these lists are determined by the evaluator in accordance with local conditions and objectives. ALES has seven components:

a) A framework for a knowledge base describing proposed land use in both physical and economic terms;
b) A framework for a database describing the land areas to be evaluated;
c) An inference mechanism to relate these two, thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses;
d) An explanation facility that allows model builders to understand and fine tune their models;
e) A consultation mode that allows a casual user to query the system about one land use at a time;
f) A report generator; and
g) Import/export modules that allow data to be exchanged with external databases, geographic information systems and spreadsheets. This includes the ALIDRIS interface to the IDRISI geographic information system.

ALES has proved to be a significant advance in land evaluation. Among its most important innovations are that a) it is a microcomputer realisation of the FAO's framework for land evaluation; b) it provides the land evaluator at project level with a highly interactive environment in which to build and refine evaluation models; c) it uses decision trees to represent the model builder's reasoning explicitly, allowing classified data to be used effectively in decision-making procedures. Its quantitative approach has proven to be especially effective in practice (Rossiter, 1990). ALES can be downloaded for free from its website http://www.css.cornell.edu/landeval/ales/ales.htm

CHAPTER 2: LITERATURE REVIEW

The major trends in land evaluation since 1950 have been a shift from broad to specific assessment, increasing use of non-soil factors and increased quantification. This has led to diversity in approaches, ranging from straightforward soil survey interpretations to more sophisticated multidisciplinary integrated regional studies and the application of simulation techniques. These approaches were not adopted in a historically sequential way. Conventional and modern procedures are employed side by side, depending on the purpose, scale and detail of study and usually when a new, more quantitative land evaluation procedure was developed, the previous empirical approach was not abandoned, as it remained necessary as a first approximation (Vink, 1960, as quoted by Van Diepen *et al.*, 1991). The aims of this chapter are to provide a definition of land evaluation and the logic behind it, and to present an overview of the most common land evaluation approaches developed.

2.1 LAND EVALUATION DEFINITION

When trying to define land evaluation, it is imperative to take into account two important aspects:

a) The problem

In this particular case this equates to *inappropriate land use*, which leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems. The land is the ultimate source of wealth and the foundation on which civilization is constructed.

b) The solution

A practical solution is to be found in *land evaluation* leading to *rational land-use planning* and *appropriate* and *sustainable use of natural and human resources.*

Considering these two aspects, land evaluation may be defined as "the process of assessment of land performance when (the land is) used for specified purposes" (FAO, 1985), or as "all methods to explain or predict the use potential of land" (Van Diepen *et al.*, 1991).

2.1.1 The logical basis of land evaluation

The basic logic that makes land evaluation possible and useful is the fact that (FAO, 1976):

a) Land varies in its physical and human-geographic properties ("land is not created equal");

b) This variation in land properties affects land uses: for each use, there are areas more or less suited to it in physical and/or economic terms;

c) The variation in land characteristics is at least in part systematic (with definite and knowable physical causes), so that

d) The variation (physical, political, economic and social) can be mapped, i.e. the total area can be divided into regions with less variability than the entire area;

e) The behavior of the land when subjected to a given use can be predicted with some degree of certainty, depending on the quality of data on the land resource and the depth of knowledge of the relation of land to land use, therefore

f) Land suitability for the various actual and proposed land uses can be systematically described and mapped, so that

g) Decision makers such as land users, land-use planners and agricultural support services can use these predictions to guide their decisions.

2.2 LAND EVALUATION IN THE CONTEXT OF LAND USE PLANNING

The demands for arable land, grazing, forestry, wildlife, urban development, rural settlement and industrial development are often greater than the land resources available (SACCAR, 1994). By ensuring that the most appropriate use is made of limited resources, efficient land-use planning can play a significant role in meeting these demands (Adeyoju, 1983). FAO (1976) described the following stages in the land use planning process:

a) Recognition of a need for a change;
b) Identification of aims;
c) Formulation of proposals, involving alternative forms of land use and recognition of their main requirements;
d) Surveying and delineation of the different types of land present in the area;
e) Comparison and evaluation of each type of land for the different uses;
f) Selection of the preferred use for each type of land;
g) Project design;
h) Decision to implement;

i) Implementation and monitoring of the operation.

Land evaluation is only part of the land-use planning process and plays a major part in stages c), d) and e) of the above sequence. The evaluation process does not in itself determine the land use changes, but provides information for the subsequent activities on the basis of which such decisions can be taken (Booth and Saunders, 1985).

2.3 THE FAO METHODOLOGY FOR LAND EVALUATION

The land evaluation concept of the FAO may be the most universally accepted level of multi-resource evaluation (Anon, 1976). Most of the literature consulted refers to this methodology as a point of departure. The concern of the FAO method is with the assessment of the land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soil, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. In Van Diepen *et al.* (1991) judgment the FAO framework represented the state of the art, borrowing the best from the then-existing land classification methods.

2.3.1 Key points of the FAO framework

The following four key points distinguish the FAO framework from previous land classification systems (Van Diepen *et al., 1991)*:

a) *Evaluate separately for each specific use, then compare.* There is not one scale of 'goodness' of land from 'excellent' to 'poor'; instead one must speak of very suitable through unsuitable land for a specific use. There are no bad land areas, only inappropriate land uses.

b) *A broad definition of 'land'.* Not just 'soil' or even 'physical resource base'.

c) *A broad definition of 'land use'.* The land utilisation type is a detailed description, at an appropriate level of detail, of the land use. It includes all the characteristics of the production system and social context which influence suitability, including: (i) products, (ii) inputs, (iii) production calendar, (iv) markets and other external influences.

d) *Land should be evaluated in both physical and economic terms.* Ideally, both a physical and an economic land evaluation are undertaken.

A physical land evaluation is based only on physical factors that determine whether a land utilisation type can be implemented on a land area and considers the nature and severity of physical limitations or hazards. An economic land evaluation is based on some economic measure of net benefits, should a given land utilisation type be implemented on a given land area.

The physical evaluation reveals the nature of limitations and hazards, which is useful information to the land manager; however, the economic evaluation reveals the expected economic benefits, which in general drive the decision-making process, or at least are a *sine qua non* for successful land use.

2.3.2 Steps of the FAO land evaluation method

The FAO (1985) recommend the following steps for land evaluation:

a) Defining objectives;
b) Collecting the data;
c) Identifying land uses;
d) Identifying land units;
e) Assessing suitability;
f) Identifying environmental and socio-economic issues;
g) Identifying the most suitable land use;
h) Planning land use.

The essence of the FAO method of land evaluation is to compare or match the requirement of each potential land use with the characteristics of each kind of land. The result is a measure of the suitability of each kind of land use for each kind of land. These suitability assessments are then examined in the light of economic, social and environmental considerations in order to develop an actual plan for the use of land in the area. When this has been done, development can begin. Of all the steps, (a) has already been discussed in Chapter 1, (b) will be dealt with in detail in Chapter 3, while steps (f), (g) and (h) form the borderline between land evaluation and land use planning and are outside of the scope of this study. Steps (c), (d) and (e) are explained in detail in this chapter.

2.3.3 Identifying land uses

The aim of this step is to identify and describe land utilisation types that are either in existence or that could be developed. A plot of land can often be put to any one of several possible uses, but rarely with the same degree of success (FAO, 1985). One of the objectives of land evaluation is to inform this choice by assessing the suitability of each land use for each land unit, and vice versa. The first step in this procedure is to determine which forms of land use are worth considering.

The key points of a land utilisation type that should be considered are the socio-economic context in which the land utilisation type is to be implemented, and the technical details of the land use system. Both must be specified for the definition of the land utilisation type to be complete (Vink, 1975).

The definition of a land utilisation type cannot be a complete description of the farming or other land-use system, although if such a description exists, it can form the basis of a land utilisation type definition. The definition of a land utilisation type must include only those characteristics that (a) serve to differentiate land areas from the point of view of land evaluation, i.e., that which can be expressed as land-use requirements with critical values in the study area, or (b) serve to limit the land-use options (FAO, 1976; FAO, 1985)

A land evaluation study can be defined as an exercise in matching demand with supply. Land-use requirements are the 'demand' side of the land land-use equation: what the land use requires of the land. On the other hand, land qualities are the 'supply' side of the land land-use equation: what the land can offer to the land-uses. In a sense, this is just a semantic distinction, or a different point of view. Once the land utilisation types have been identified and described, they must be defined in terms of their land use requirements and their severity levels of land qualities (Rossiter & Van Wambeke, 1997).

2.3.3.1 Selecting land-use requirements

A land-use requirement refers to a condition of the land which is necessary for successful and sustained implementation of a specific land utilisation type. Each land utilisation type is defined by a set of land-use requirements. A land utilisation type can be thought of as 'requiring' certain general properties of land; these are the land-use requirements (FAO, 1976; FAO, 1985). They are at the same level of generality as land qualities (see below).

Of the many land use requirements that can be included in the definition of a land-use type and hence in the evaluation, it is usually sufficient to select a small subset. More than ten land requirements are generally unworkable, and it is usually the case that the most important five land requirements can be used to correctly classify almost all land.

There are four criteria by which we can select land-use requirements:

(a) *Importance for the type of use*. The requirement must be important for the use, or it is omitted from the analysis. This is where a careful definition of the land utilisation type will repay the effort.

(b) *Existence of within-zone variations*. There must be differences in the levels of the corresponding land quality in the zone, or the land use requirement becomes a constant, i.e., part of the context of the land utilisation type, not a variable, i.e., a determinant of suitability.

(c) *Availability of data with which to evaluate the corresponding land quality*. Even an important land-use requirement with differences in the corresponding land quality cannot be included in the evaluation if there are not sufficient land data on the diagnostic land characteristics which would be used to evaluate the land quality. It may be possible to use a surrogate set of land characteristics. In this case, the final evaluation must include a cautionary note that if an important factor was not considered, so that the results must be regarded as provisional, and suggestions on how the necessary data might be collected are made.

(d) *Availability of knowledge with which to evaluate the corresponding land quality*. A land-use requirement cannot be included if there is not sufficient knowledge on the relationship of the requirement with the diagnostic land characteristics. This is a motivation for applied agricultural research.

2.3.3.2 Effects of land qualities

Land qualities are very helpful in matching land units with land-use requirements. A land quality is "a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use" (FAO, 1983).

The effects of each land quality on the land use must be specified, or, looking at the 'demand' side of the equation, the reason that each land-use requirement is included in the evaluation must be specified (FAO, 1985). This information determines the number of severity levels that are relevant to each land quality. Land qualities can affect physical suitability, reduce yields and increase costs.

(a) *Effects on physical suitability*. This kind of land-use requirement is typically a 'hazard', and influences the land use in a negative manner. Excessive severity levels of the corresponding land qualities make the land unfit for the land use and higher severity levels increase the management requirement.

(b) *Reduction in yields*. These land use requirements typically have to do with intrinsic factors of plant growth, such as water, light, temperature and nutrients. Some limitations to cultivation can also be included here: e.g. planting conditions or harvesting conditions.

(c) *Increased costs*. Land quality limitations can result in reduced yields; however, in the context of a land utilisation type we may choose to correct or compensate for (completely or partially) a limitation by increasing inputs. If certain severity levels of a land quality increase costs, the model builder expresses this by listing the additional inputs, which can be either annual (recurring) or once-off. Each severity level may have a different amount of the input needed to correct the limitation.

2.3.3.3 Defining severity levels of land qualities

For each land use requirement selected, the evaluator must decide how many severity levels are to be distinguished for the corresponding land quality. The severity levels are the number of classes into which the land quality will be classified (FAO, 1976; FAO 1985).

In the original FAO framework there are four or five severity levels, corresponding directly to the physical suitability classes S1, S2, S3/N1 (these are separate for economic evaluation) and N2, possibly with some levels omitted because the land quality is never too limiting or because the land quality cannot be determined with the precision implied by that number of severity levels.

These classifications of the land quality indicate the degree of limitation or hazard associated with the land quality in a particular land area. These values range from Level 1, no limitation, increasing to some maximum value. For example, for each land quality, a linguistic scale is established, such as 'high', 'moderate', 'low', and 'very low', and procedures are developed for classifying each land area according to this scale (Rossiter & Van Wambeke, 1997).

Severity levels are defined in relation to the four effects of land quality defined in the previous section. In addition, the number of severity levels should not exceed the required precision of the evaluation, which is determined by the objectives.

Each of these four effects is discussed further below.

(a) *Physical suitability* (management differences or risks). Firstly, the proposed differences in physical suitability must be distinguishable in the field. Secondly, there must be enough data to differentiate them at this degree of resolution. Thirdly, the number of severity levels may be grouped into classes, in which case the 'natural' number of classes should be evident.

(b) *Decreasing yields*. If the land quality affects yield, the number of severity levels should correspond to observable or predicted yield levels. In general, the FAO practice is to let the 'best' class correspond to 80-100% of optimum yield, the 'moderate' class to 40-80%, and the 'marginal' to <40%.

(c) *Increasing costs*. If limiting properties of the land quality will be overcome by increasing inputs, the number of different levels of the input defines the number of severity levels.

(d) *Precision of natural resources data*. The number of severity levels of the land quality cannot exceed the precision of the diagnostic land characteristics that will be used to evaluate it.

2.3.4 Identifying land units

Land units can be described in terms of their characteristics, their qualities or both. A land characteristic is a simple attribute that can be directly measured or estimated in a routine survey. Land qualities are usually complex attributes of the land, which usually reflects the interaction of many characteristics and cannot be directly measured or estimated in a routine survey. Therefore, land qualities must be inferred from a set of diagnostic land characteristics, with a variety of analytical methods (FAO, 1985).

In general, the effects of a land characteristic on suitability are not direct, but are manifested through its effect on land qualities. This is because a single land characteristic may affect several qualities, often in contradictory ways. Land qualities act more or less independently to affect suitability. This is to avoid a proliferation of land qualities in the evaluation. In practice, land qualities may interact (e.g., moisture availability and soil fertility) but much of the complexity is avoided by abstracting from land characteristics to land qualities (FAO, 1976).

2.3.4.1 Evaluating land qualities from diagnostic land characteristics

Since land qualities, by definition, cannot be directly measured in routine surveys, their severity levels for each evaluation unit must be inferred from one or more diagnostic land characteristics. Diagnostic land characteristics are the land characteristics that will be used to evaluate the land quality (Rossiter & Van Wandeke, 1997). They must be measurable at the appropriate scale and be well related to the land quality (which is why they are called 'diagnostic').

Given data values for each diagnostic land characteristic, the way to assign an evaluation unit to its correct severity level of the land quality is the most difficult analytical problem in land evaluation, and requires great skill and careful judgement. There are five main methods to infer the severity levels of the land quality from the set of diagnostic land characteristics: (a) matching tables; (b) decision trees; (c) parametric indices; (d) empirical-statistical methods; (e) dynamic simulation. The first two methods work exclusively with classified (categorical) data, the last two with continuous data exclusively, and method (c) with either (Rossiter & Van Wandeke, 1997).

ALES, the land evaluation software used in this study, only allows classified discrete (categorical) data using the first two methods. In ALES formulas can be used to relate a set of continuous diagnostic land characteristics to a single continuous land characteristic, which is then classified into a discrete land characteristic, and subsequently used as a classified discrete diagnostic to a land quality. Two of these five methods – the ones relevant to ALES – are discussed in the subsections that follow.

2.3.4.1.1 Matching tables

These are also called 'maximum limitation' tables. They are in the form of a matrix, with the rows being the different diagnostic land characteristics, the columns being the (classified) land quality ratings, and the cells being the value of the diagnostic land characteristic (row) that must be met or exceeded in order for the land quality to be rated at the severity level indicated by the column. Thus, matching tables limit the land quality rating to the most limiting value of the set of diagnostic land characteristics. In other words, matching tables simply find the column corresponding to the land characteristic value for each row and then uses the right-most column as the final rating (FAO, 1985).

The advantages of this method are its simplicity, easy comprehensibility and graphical presentability. The disadvantages are that it cannot account for interactions between diagnostic land characteristics (this is a serious disadvantage).

2.3.4.1.2 Decision trees

These are hierarchical multi-way keys, in which values of the diagnostic land characteristics form the diagnostic criteria and the result is the severity level of the (classified) land quality to be evaluated. Decision trees are: (a) hierarchical, in that one decision may lead to others until all factors are taken into account; (b) multi-way, in that they may offer more than two choices for a decision, and (c) they have keys. Answering the questions asked by the tree leads to a decision, in this case, a severity rating of a land quality (Rossiter & Van Wandeke, 1997).

Decision trees are more expressive than tables, i.e., any table can be transformed into a decision tree but not vice-versa. They allow complete control over interactions. ALES uses this as its primary method to evaluate land qualities. The advantages are its full expressiveness, it can explicitly rate any combination of land characteristic values, i.e., any interaction between diagnostic land characteristics, and its hierarchical structure is fairly easy to understand. The major disadvantage is that an effective graphical presentation is difficult.

2.3.5 Assessing overall suitability from land qualities

Land suitability is rated for a given use by comparing the requirements of that use with the qualities of the land unit. Therefore, the final objective of a land evaluation exercise is a single measure of suitability of the land unit for each land use. To do this, the severity levels of the individual land qualities must be combined in some way into an overall measure of suitability. The ways in which this combination can be performed is the topic of this section.

Land suitability can be described at three levels of detail, from the most general to most specific; these are (FAO, 1976; FAO, 1985):

a) *Suitability orders*. All land is divided into two suitability orders, according to whether the land is suitable or not for a given land utilisation type, where 'S' = suitable and 'N' = not suitable, for the land use;

b) *Suitability classes*. These are divisions of suitability orders that indicate the degree of suitability, not simply suitable vs. not suitable. So that 'S1' = suitable, 'S2' = moderately suitable, 'S3' = marginally suitable, 'N1' unsuitable for economic reasons but otherwise marginally suitable, 'N2' = unsuitable for physical reasons.

2.3.5.1 Methods of evaluating overall physical suitability

a) *The maximum limitation method.* For this method to be meaningful, the degree of limitation of a particular severity level number must be equivalent over all the land qualities and the number of physical suitability classes must be the same as the maximum number of severity levels (Rossiter and Van Wambeke, 1997). During computation of the physical suitability, the severity levels of the land qualities are examined and a physical suitability class would be assigned from the highest-numbered severity level.

b) *Algebraic combinations of land-quality ratings*. This is a more flexible version of the maximum limitation method. The individual land-quality scales must again be commensurate. The overall physical suitability of a land area for a land utilisation type is computed according to a formula based on the individual factor ratings.

c) *Ad hoc combination of land-quality ratings*. The overall physical suitability of a land area for a land utilisation type is computed according to a decision tree. The advantages are that land qualities can be weighted and they do not have to be on the same scale of 'goodness'. The major disadvantages are that it needs a lot of work and that the combinations are subjective.

In short, each land use has requirements and limitations that relate separately to its objectives, its management needs and to environmental issues. The requirements and limitations of each land use can usually be specified in terms of a limited number of land qualities. If suitability classes have been defined in terms of a range of values for each factor, the assessment is relatively straightforward.

The first step in classifying suitability is to decide which factors should be used to define each suitability class. Upper and lower limits for each relevant land characteristic or quality are then set for each class. That done, the properties of each land unit are reviewed and compared to the class limits. Each land unit can then be assigned a suitability classification for each type of land use.

2.4 OTHER LAND CLASSIFICATION METHODS

Many other systems have been devised to classify land for specific purposes and many studies have been completed using them. Most of these are useful when used for their intended purpose. The methods can be divided into (a) land classification methods that were developed before the creation of the FAO framework for land evaluation, and (b) land classification methods developed since the FAO framework, but which are outside of the framework.

2.4.1. USDA land capability classification and international variants

This is undoubtedly one of the most widely used pre-FAO land classification systems in the world. The system is explained in Klingebiel & Montgomery, (1961) and summarised by McRae & Burnham (1981).

The system is used to classify soil-mapping units (at the phase of soil series level of detail) according to their ability to support general kinds of land use without degradation or significant off-site effects for farm planning. The original users were district conservationists of the USDA soil conservation service, who advised farmers on the most appropriate use of their fields.

The land capability classification influenced the FAO framework; however, it is a very narrowly focused interpretative soil classification. It is still useful for conservation farm planning and for grouping soil survey map units into general management groups. Its major problems are: a) that it completely ignores economic factors, and b) that land is not evaluated for specific uses.

2.4.2 USBR land suitability for irrigation

This system was originally developed by the US Department of the Interior (1951). Further development was made by Maletic & Hutchings (1967), McRae & Burnham (1981), Landon (1984), FAO (1985) and EUROCONSULT (1989).

The purpose of this system is to select land for irrigation development and to characterise the main management factors. The suitability maps are used to plan the location of major and minor irrigation and drainage works, and to make project-level decisions on financing. The view of land is very much as a resource which can be modified, but whose modification must be sustainable and cost effective. It follows an engineering approach and its point of departure is phylosophy ("nature to be commanded").

The USBR system heavily influenced the FAO framework, especially the idea that only economic considerations can truly classify land for development projects. The emphasis on the specifications of a typical farm in its social context is similar to the emphasis on the land utilisation type. The subclasses are referred to as general land-use requirements; the other map unit codes (e.g., land development cost) can be considered as specific land-use requirements.

2.4.3 Soil survey interpretations

The basic idea in this pre-FAO land classification approach is to take the map units of a detailed soil survey and interpret them directly for anticipated land uses. The result is a suitability for the use based on the severity of relatively permanent limitations. It is not an economic evaluation, although the relative difficulty of overcoming the limitations is implicitly taken into account. Most often this approach is adopted for evaluating non-agricultural uses, such as engineering uses, whose limitations and 'productivity' cannot easily be quantified in the context of a soil survey.

References to this method appear extensively in the literature. The textbook by Olson (1981) propagates this approach. An earlier text by the same author (Olson, 1973) is an example of engineering applications such as for suburban construction. Any post-1970 soil survey from the USA has interpretative tables that follow this approach. The National Soils Handbook (US Department of Agriculture, 1983b) explains the approach and has sample tables. In these tables the ‘properties’ (left-most column) are land characteristics that are known for each soil unit to be rated. The table is a maximum limitation table: the right-most columns of ‘slight’, ‘moderate’ and ‘severe’ gives the ratings. Each map unit is rated and given a list of the restrictive features.

Its biggest advantage is its direct application to planning; if a decision procedure was developed, it provides insight into the land use. The type of limitation is made explicit. Its disadvantage is that in most reports the way that the map units were rated is not often given (i.e., the report itself does not include the rating table).

2.4.4 Parametric indices

Single numeric factors (usually values of land characteristics) are combined to reach a final single numeric rating. Thus all land is rated from excellent (100) to useless (0), and this is assumed to be a ratio scale, i.e., land rated 80 is 'twice as good as' land rated 40. Factors can be combined by adding (point system) or multiplying (land index or productivity index), and possibly normalising the data, depending on the system (Van Diepen *et al.*, 1991; Sys, 1985; Koreleski, 1988; Storie, 1933; McRae & Burnham, 1981).

2.4.5 Yield estimates

Yield estimates are a direct estimate of crop yield per land-mapping unit. This is only possible where the crop is widely grown and where sufficient yield data have been collected. Yield estimates refer to long-term averages and, possibly, variability of yields (Dumanski & Onofrei, 1989).

The National Soils Handbook (US Department of Agriculture, 1983b) explains one approach to direct yield estimation. Here the land utilisation type is a combination of the input level, cropping system and variety. The approach works best where one or two land utilisation types represent most of the area dedicated to a crop.

In this method the aim is to establish an expected yield and, if possible, a range of probable yields of each adapted crop on each map unit for a specific land utilisation type. Because yield is so variable and affected by so many factors, a large amount of expert judgement goes into making the estimates.

The process takes place in two steps: a) a quantified estimate is made on several benchmark soils, i.e., important and extensive soils which between them cover most of the range of soil properties in a region, and then b) an expert judgement of yields on other soils is made, with reference to the benchmark soils and the differences between the benchmark soils and other soils with respect to key properties known to affect yield (from step a), such as water-holding capacity.

2.4.6 The fertility capability soil classification system (FCC)

This is a modern land classification method that does not follow the FAO framework. The system is explained in detail by Sánchez *et al.* (1982). Christopher Smith of the USDA/SCS, a student of Stan Buol's, expanded and updated the system in his PhD thesis (Smith, 1989).

FCC is a soil classification system that serves a specific purpose without pretending to be a land evaluation system. The system was developed in an attempt to bridge the gap between the subdisciplines of soil classification and soil fertility. Fertility capacity soil classification is an example of a technical soil classification system in which soils are classified for a particular purpose, not according to supposed natural relationships, as in a natural soil classification system.

Soils are grouped according to the kinds of problems they present for agronomic management in terms of their chemical and physical properties. FCC emphasises quantifiable topsoil parameters as well as subsoil parameters directly relevant to plant growth. Fertility capacity soil classification classes indicate the main fertility-related soil constraints, which can be interpreted in relation to specific farming systems or land utilisation types (Sanchez *et al.*, 1982).

2.4.7 LESA: A successful land classification for farmland protection

This modern land classification method is, like the previous one, a non-FAO system. The original system is presented in a document titled US Department of Agriculture, 1983a. Example applications are given by Dunford *et al.* (1983); Van Horn *et al.* (1989) and Wright *et al.* (1983). A critical examination of the first decade of LESA implementation is to be found in Steiner *et al.* (1994), with a brief overview by Coughlin *et al.* (1994).

LESA was developed by the US Soil Conservation Service to help implement the 1981 Farmland Protection Policy Act. The system's primary purpose was to provide local decision-makers with an objective and consistent numerically-based system for determining which farmland should be available for development and what should be protected for farming (Daniels, 1990). The basic idea is to identify the land that is 'the best farmland' in two respects: its inherent productive capacity and the possibility that a farm on the site can be economically and politically viable.

LESA has been applied to the purchase of development rights in critical farmland areas where limited money was spent for maximum public benefit. Other important applications are in zoning permissions for non-farm and farm-related uses, the designation of agricultural districts, transfer of development rights and property tax assessment.

2.5 USE OF COMPUTERS FOR LAND EVALUATION

The personal or microcomputer is revolutionising the field of land evaluation. The possibility exists for bringing powerful analytical techniques to bear at the project or local level. It is completely feasible to have a county-level land information system including remotely sensed data with a low hardware and software investment by sharing expensive peripherals (digitising tables, 9-track and cartridge tapes, plotters, laser and colour printers) at a central site.

At a more sophisticated level, but still within reach of national organisations and universities, is the workstation or technical computer. The trend is towards ever cheaper and more powerful hardware (machines), and ever more sophisticated software (programmes). The problem is one of knowledge and imagination and not money.

2.5.1 Special-purpose programmes for land evaluation

As in all areas of science and technology, computers are now indispensable for the practising scientist or engineer. The following kinds of computer programmes can be used to support land evaluation:

a) *Expert systems* and simple microeconomic analysis for physical and economic FAO-style land evaluation (ALES);

b) *Statistical models* for yield estimation and prediction of land qualities (MINITAB);

c) *Dynamic simulation models* for yield estimation and prediction of land qualities (GAPS, WOFOST, LEACHM, CERES, GRO, STOR, SUCROS);

d) *Geographical Information Systems* (IDRISI, ArcVIEW);

e) *Remote sensing and image processing* (IDRISI);

f) *Spreadsheets and Optimisation* under constraints (Quattro Pro, Excel, LINDO);

g) *Database managers* for natural resources databases (e.g., soils and climate) (Paradox, Microsoft Access, FoxPro, dBase);

h) *Risk analysis* (@RISK);

i) Land classification (AEZ, CDA, LECS from the FAO).

It can be concluded, after this review of the most common land evaluation approaches, that modern land evaluation has gradually developed into an interdisciplinary field of study aiming at the integration of knowledge of land resources and land use, and that computing is becoming an integral part of this development. This opens a door for the use of Geographical Information Systems (GIS) in the field of land evaluation and justifies the main objectives of this research.

CHAPTER 3: METHODOLOGY DEVELOPEMNT

The ability of Geographical Information Systems (GIS) to process a wide variety of spatial information in an integrated way creates the possibility for simplifying the selection of optimal areas in a land evaluation process. One of the aims of this study is to develop a methodology for the application of GIS in identifying alternative uses for land under forestry. Chapter Three explains the methodology followed.

3.1 PROPOSED RESEARCH FRAMEWORK

The research for the land evaluation exercise can be divided into eleven steps, as shown in Figure 3.1. These steps can contain feedbacks, i.e., the results of a step may suggest modifications that should be made to previous steps. The most important feedbacks are shown in the figure with arrows. Each of these eleven ten steps is described in the section that follows.

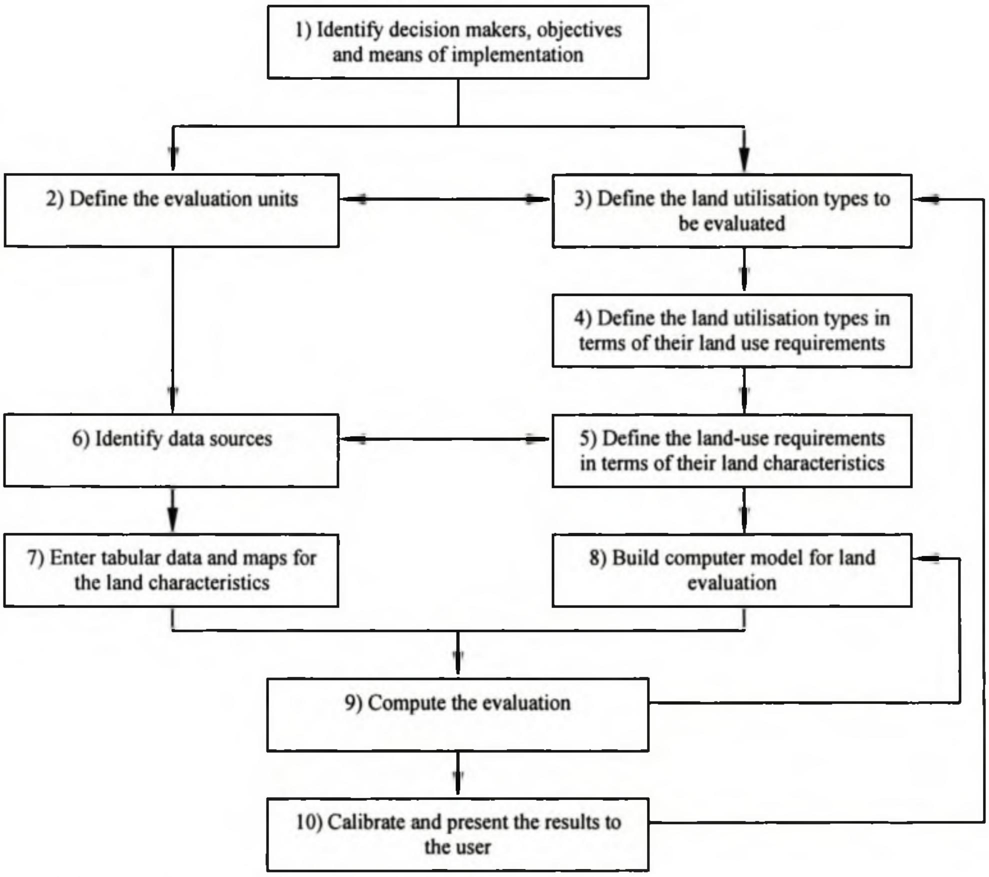

Figure 3.1: Steps in the land evaluation process.

3.1.1 Identify the decision makers, their objectives and their means of implementation (step 1)

Land evaluation cannot take place as an isolated activity. This implies that there is a recognised need to plan, and for decision-makers who are prepared to plan, so that the results of the land evaluation will be used by these decision-makers to inform their plan. Therefore, the first step in a land evaluation exercise is to determine exactly who wants to plan, what their objectives are, and what the scope is of their decision-making power to implement a plan. A series of interviews were conducted with Mr Kobus Venter and Mr Brand du Preez (SAFCOL's regional managers for the Southern Cape and Boland region, respectively), and relevant SAFCOL internal documents were provided in order to answer these questions.

After the meeting it was concluded that the primary decision-maker for this land evaluation process is the party who commissioned the study, in this case SAFCOL. Up to seven government departments are involved in the land-use planning process, but it is not yet very clear what the respective roles are.

As far as resources, methods of implementation and enforcement are concerned, SAFCOL and the seven government departments involve will have to transfer the state land to the new users and it will be up to them to make the decisions about future land use. The new land users will be able to use this report for implementation.

3.1.2 Define the evaluation units (step 2)

The reliability of a land evaluation can be no greater than the quality of the data on which it is based, and the one really important requirement is that the reliability of each data source is checked. For the purpose of this land evaluation a database from an irreproachable source was used. SAFCOL provided their digital spatial database for the La Motte plantation (see figure 3.2 for location map), consisting of the following data sets: soil survey, elevations, current land use, water bodies, roads and infrastructures, 1 km square grid, forestry compartments, contour lines and plantation boundaries. Of all the data sets contained in this database only the soil survey, elevations and contour lines provided relevant data and were used in the land evaluation process. The soil survey provides some of the data required to build and run the model, and elevations and contour lines were used to derive the aspects. The other sets do not provide any relevant data for the model.

The output of this phase is a list of evaluation units, with an indication of how they were defined, the minimum decision area, the total project area and the map scale or resolution. Because in this specific case the output of this step was dictated by SAFCOL's digital spatial database, the evaluation units defined were the same land units identified in the soil survey coverage. The attribute information or specific land characteristics provided in the polygon attribute table that was used to describe each homogeneous single piece of land can be summarised as follows:

a) Soil group;
b) Productivity class;
c) Species choice: preferred species suited to the site listed first, and relate to productivity class given for that site.

Other soil survey information provided by SAFCOL in a non-digital format was:

d) Predicted MAI20 for each species;
e) Topography: terrain position, slope shape, and slope gradient and ground strength;
h) Silviculture: site sensitivity, erosion potential, compaction, wetness, wind throw;
i) Dominant and sub-dominant soil forms and families of the SA soil taxonomic classification;
j) Soil description with horizon codes.

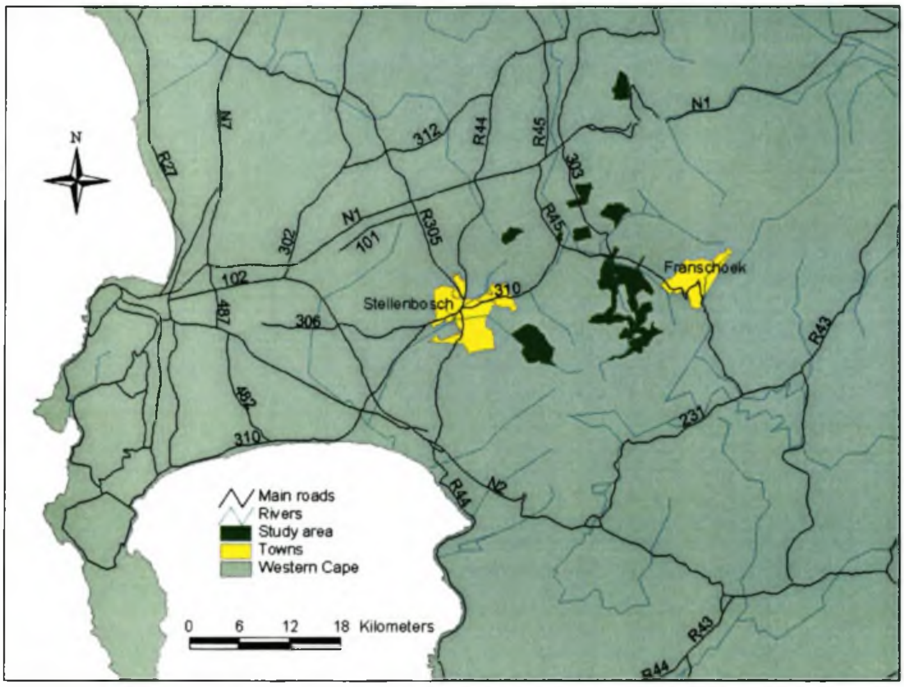

Figure 3.2: Location of study area

3.1.3 Identify data sources (step 6)

The range of data that is relevant for land evaluation is huge and collecting such data can be costly in terms both of time and money. Selecting the right data is the most difficult of these steps, because it is not easy to know in advance which kinds of data will prove essential. To focus on the right direction when selecting the data, it is important to bear in mind that the requirements of the different land uses that are to be evaluated determine the range of basic data that must be collected before evaluation can begin. Communication with decision-makers, experts and stakeholders is crucial at this stage of the land evaluation process.

Seeking out existing data is not as easy as it sounds. Valuable data are often hidden in obscure archives and can be traced only by systematic enquiry. Once located, old data were carefully compared with the present situation to establish their relevance and reliability.

Climatic information was obtained from twenty-eight weather stations in the Stellenbosch, Paarl and Franschhoek areas. The data were provided by Mike Wallace from the Depart. of Agriculture: Western Cape weather database. For each weather station the latitude, longitude, daily rainfall, daily maximum and minimum temperatures, starting and last date of collection were available.

Information on climatic, soil and terrain requirements for six deciduous fruits planted in the Western Cape region was obtained from Pretorius (2000) and the ECOCROP database. Similar information for eight vine cultivars was obtained from Suid-Afrika (1990 and 1991) and Tait (1997). This documentation was provided by Kobus Louw (ARC Infruitec-Nietvoorbij), Charles Visser (KWV), Prof. Archer and Prof. H. L Zietman (US).

Information on soil and terrain requirements for afromontane forest and fynbos for the specific study area was obtained from Masson (1990). More general information on climatic, soil and terrain requirements was obtained from Kruger (1974 & 1979) and Donald & Theron (1984) respectively. Additional documentation was provided by Dr Kobus Theron (Department of Silviculture, US).

3.1.4 Define the land utilisation types (step 3)

The output of this phase is a list of the land utilisation types proposed as alternative land uses. These are the land-use options and are specified in enough detail to support the later phases of the evaluation (see Chapter 4). The fifteen land uses identified for this land evaluation exercise are: a) Fynbos, b) Afromontane forest, c) Chardonnay, d) Sauvignon blanc, e) Merlot, f) Shiraz, g) Pinotage, h) Cabernet franc, i) Cabernet sauvignon, j) Apples, k) Pears, m) Peaches, n) Citrus, o) Olives and p) Plums.

3.1.5 Define the land utilisation types in terms of their land-use requirements (step 4)

The land utilisation types proposed in the previous step are defined in this phase by a set of more or less independent requirements, which are the general conditions of the land necessary for successful use according to the system specified by the land utilisation types. Different experts were consulted and participated at this stage (see also 3.1.6). The output of this phase is a list of land-use requirements for each land utilisation type and the number of severity levels of the corresponding land quality and their effect on suitability.

Defining the land use requirements for each land utilisation type is the heart of the ALES model. When building an ALES model, a severity-level decision tree must be built for each land utilisation type and land-use requirement combination. This decision tree will allow ALES to infer the severity level of the land quality corresponding to that particular land-use requirement from the set of land characteristics. During computation of an evaluation result, ALES will place each map unit into one of the severity levels of land quality for each of the corresponding land requirements of the land utilisation types.

In this research study a single land-use requirement named "potential of use" was defined for each of the fifteen land utilisation types. In this way only fifteen decision trees were necessary to build the entire model. Each of the fifteen "potential of use" land-use requirements were defined with four severity levels of land quality, from no limitation (Level 1) to total land-use impracticality (Level 4). Levels 2 and 3 are increasingly severe limitations. The next step needed was to define the fifteen land-use requirements in terms of their relevant diagnostic land characteristics in order to build the severity-level decision trees.

3.1.6 Define the land-use requirements in terms of their diagnostic land characteristics (step 5)

The aim of this phase is to identify the measurable diagnostic land characteristics that will be used to determine to what degree the land-use requirement "potential of use" from each land utilisation type is satisfied. Land resource and land-use expert participation was also essential in this phase.

The output of this phase is a list for each of the fifteen "potential of use" land-use requirements of the land characteristics that will be used to evaluate them, and a general description of how the land characteristics will be combined. The optimum values of the relevant land characteristics used to determine the severity levels of land qualities for the "potential of use" land-use requirement for each of the land utilisation types are to be found in Appendix D.

3.1.7 Enter tabular data and maps for the land characteristics (step 7)

A digital geographical database ready for a land evaluation exercise is the output required from this phase. As indicated earlier, SAFCOL provided the La Motte plantation digital spatial database for the purpose of this research study. This database consists of different Arc/Info coverages and each has its own polygon attribute table with relevant attribute information. The evaluation units defined in step 2 (3.1.2) were the same land units identified in the soil survey coverage, but the polygon attribute table only provided a subset of the land characteristic necessary to build the model. Soil form, depth, drainage, wetness, terrain type, aspect and climatic information was not available in the soil survey polygon attribute table. Data validation, entry and transformation were necessary in order to obtain all the relevant land characteristic values for each land unit.

As part of an integrated land evaluation system, ALES is only involved from step 7 to 11 in the proposed research framework (see Figure 3.1). ALES is not a GIS and does not by itself display maps. It can, however, analyse geographical land characteristics if map units are appropriately defined, and it can directly reclassify IDRISI or Arc/Info maps with the same mapping unit legend as the ALES database.

ALES can exchange information with other computer systems, including relational databases that read the dBase file format, GIS systems that store their attributes in dBase-format files (e.g. PC-ARC/INFO and PC-ArcView), word processors and spreadsheets. After all the relevant land characteristics were added for each land unit to the soil survey polygon attribute table, the land unit definition (ID-code) and attribute data (land characteristics) were imported directly from the SAFCOL La Motte Plantation database into ALES, not only to obviate typing the data manually but also to ensure data consistency between the two databases.

3.1.8 Build the computer model for land evaluation (step 8)

In a land evaluation exercise the land use planner matches land areas (land mapping units) with land uses (land utilisation types) to determine the relative suitability of each land area for each land use. As already indicated, land utilisation types are specified by a set of land-use requirements and land units are defined by the values of a set of land characteristics. In the FAO approach land characteristic values are combined into levels of land qualities, which are complex attributes of land which influence the suitability of land in a semi-independent manner. These land qualities are matched with the land-use requirement one by one to infer suitability. In ALES the model builder, with the help of decision trees, expresses the land utilisation type in terms of its land-use requirements and the system computes the relevant land qualities from the diagnostic land characteristics. Decision trees are then used to infer the suitability of a land unit for the land utilisation types from the land qualities, resulting in a suitability matrix.

In order to build the ALES computer model, the following steps must be followed:

a) Define the land utilisation types (step 3). Codes, description names and number of physical classes should be entered;

b) Express the land utilisation types in terms of their most important land-use requirements (step 4). Codes, descriptive name, number of severity levels and severity-levels name are entered;

c) Determine which land characteristics are available and relevant to form the basis of evaluation (step 5). Codes, names, number of classes and units of measurement are entered;

d) Construct the decision trees (step 8). Decision trees are constructed for each land utilisation type and land-use requirement combination to compute the severity levels of land qualities from the diagnostic land characteristics. An ALES decision tree is a hierarchical multi-way key in which the leaves are results such as land-quality single-factor ratings (severity levels), and the interior nodes or branch points of the tree are decision criteria such as land characteristics values;

e) Collect and enter land characteristic data into the database for each land map unit (step 7);

f) Define the maps units in ALES and import their land characteristic values (step 7). A template was created that defined and entered the same land map unit legends as in the soil survey coverage and imported its land characteristic values.

3.1.9 Compute the evaluation (step 9)

This phase has three steps:

a) Run the model for each land utilisation type and land map unit and compute an evaluation result matrix. The evaluation result matrix is a two-dimensional array with the rows being the map units evaluated and the columns being the land utilization types for which an evaluation was computed. Each cell is located at the intersection of a single row (map unit) and column (land utilisation type) and shows the predicted physical suitability subclass result for that map unit and land utilisation type.

During computation of an evaluation result matrix, ALES traversed each of the fifteen decision trees for each of the land map units using the actual land characteristic data from that map unit. A severity level of land quality was obtained for each combination of land utilisation type and land map unit. Physical suitability of the land unit for each land utilisation type was determined by the maximum limitation method and a result placed in the corresponding cell. This method was appropriate because the severity levels of each land quality represented the same degree of physical limitation to the land utilisation type. In other words, the land use requirement "potential of use" was defined with four severity levels of land quality for each of the fifteen land utilisation types, and the meanings of these severity levels are comparable with the four physical suitability subclasses presented in the FAO framework for land evaluation (FAO, 1976). In all cases severity level 4 means that the land utilisation type is physically unsuitable (N2), and level 1 means that there is no limitation (highly suitable, S1). Levels 2 and 3 are increasingly severe limitations (suitable S2; marginally suitable S3/N1).

b) Export the results for optimisation and/or geographical analysis into the soil survey coverage polygon attribute table. A physical suitability rating value was exported for each land map unit and land utilisation type combination.

c) Optimisation and geographical analysis were performed in ArcGIS. ArcGis was used to perform analysis that is beyond the scope of ALES in order to further process the results. The outputs of this step were the results of the computation in the form of tables and maps.

3.1.10 Calibration and presentation of the results (steps 10)

The internal consistency of the results for the potential land utilisation types considered must be verified and the model must be adjusted accordingly and results recalculated if inconsistencies are found. The preliminary results of this land evaluation exercise were presented to the experts previously consulted for verification with positive feedback in all cases.

The results were also presented and discussed in detail with SAFCOL and other stakeholders at the "Symposium on the conservation of plantation forestry to alternative land uses". Faculty of Forestry, University of Stellenbosch, 2 May 2003.

The theoretical foundations for the research have been laid in this chapter. A subsequent practical application of the methodology for the La Motte plantation is the next step to assess the proposed methodology, but before doing so the set of general criteria that define the parameters according to which optimal terrain is selected must be determined. Chapter Four will elaborate on that.

CHAPTER 4: DESCRIPTION OF ALTERNATIVE LAND USES

This chapter determines a set of general criteria that define the parameters according to which optimal terroir was selected in the land evaluation exercise. This is done in three steps: firstly, the different alternative land uses are identified; secondly, the diagnostic natural factors for each of the land uses are presented; and thirdly, their land-use requirements are determined in terms of their land characteristics.

4.1 AFROMONTANE FOREST

Of all the African forests, those of the southern Cape coast in the Republic of South Africa are regarded as being the most similar to temperate broad-leaved evergreen forests elsewhere; however, conifers (*Podocarpus* spp.) are common in them. Forests similar in physiognomy to these Cape forests, and with a surprising number of common species, occur on isolated mountain ranges throughout the continent, where altitude has compensated for latitude to give a temperate climate (Keay, 1959; White, 1978).

The afromontane forests of Africa stretch from the southern Cape along the eastern mountain ranges of the continent to Ethiopia, and also occur as an outlier in West Africa (White, 1978). This distribution is extremely disjointed.

In South Africa the greatest area of forest is found on the southern slopes of the coastal mountains and coastal plateau of the Southern Cape from Mossel Bay to Humansdorp. The total area of indigenous forest in the region is approximately 65 000 ha (Von Breitenbach, 1974). Remnants of these forests occur to the west in kloofs, or gorges, of the coastal mountain ranges where they have been protected against fire. The greatest area of these remnants is at Swellendam, where the Grootvadersbosch Forest covers 425 ha. Further west forest virtually disappears, apart from isolated patches on Table Mountain (Cape Town), in the protected kloofs of the Jonkershoek Mountains (Stellenbosch), Steynskloof Mountains and on the coastal mountains near Cape Hangklip (Boucher, 1978). On the east coast forest remnants are much more numerous than to the west, but nowhere do they approach the extent of the southern Cape forests. In the Southern Cape, at latitude 34°S, the forests occur from about 200 m above sea level (Donald *et al.*, 1983); with decreasing latitude up the east coast, the altitude of forest increases until it reaches about 1830 m in the Cathedral Peak area, at 29°S.

Masson (1991) determined the floristic and structural similarities and differences of the forest community types at Swartboskloof in the Jonkershoek Forest Reserve some 15 kilometres from Stellenbosch. In addition, comparisons of the species-environment relationships in the forest margin and adjacent fynbos areas were undertaken to determine whether the regeneration potential in these areas differed substantially between forest types and also what environmental variables were responsible for the differences.

Masson (1991) classified the Afromontane forest remnants at Swartboskloof into two communities: the scree forest found on rocky sandstone boulder screes and the riparian forest confined to moist river banks. This latter forest type includes the riverine and mature forests. The riverine forest is found in the lower parts of the valley and the mature forest in rockier substrate than the low-lying riverine forest. Although scree forests are noticeably different from riverine and mature forests, the latter two forest types are similar in both species composition and density composition.

4.2. FYNBOS

Fynbos is a comprehensive term for the vegetation of a well-defined and limited landscape of the Southern Cape. Taylor (1978) has identified the following as characteristics of the physiognomy of fynbos communities: (a) the restioid element, which is invariably the only constant and differential floristic element and comprises wiry aphyllous hemicryptophytes of the Restioceae and some Cyperaceae; and (b) the ericoid element, which comprises dwarf and low evergreen ericoid shrubs. A frequent, but not constant, feature is a component of taller broad-sclerophyllous shrubs (the proteiod element). Other typical taxa are the genera *Protea*, *Leucadendron*, *leucoespermum*, (Proteaceae), *Erica* and *Blaeria* (Ericaceae), *Aspalathus* (Fabaceae), *Tetraria* and *Ficinia* (Cyperaceae), *Merxmuellera*, *Pentaschistis* and *Ehrharta* (Poaceae), *Agathosma* (Rutaceae), *Cliffortia* (Rosaceae), *Brunia* and *Berzelia* (Bruniaceae), *Gnidia*, *Struthiola* and *Passerina* (Thymelaeaceae), *Metalasia*, *Helichrysum*, *Stoebe*, *Corymbium* and many others in the Asteraceae, and numerous genera in the Liliaceae, Orchidaceae, and Iridaceae (Taylor, 1978). The flora is marked by a great richness and high degree of endemism (Kruger, 1979). Numerous species exist as small populations in isolated habitats.

Fynbos is largely devoid of native tress but is replaced abruptly by evergreen forest in suitable habitats. In the south and south-west, forest is restricted to sheltered kloofs and patches of rock scree (Werger *et al.*, 1972). Taylor (1978) distinguished two categories of fynbos: coastal and mountain. Coastal fynbos is confined to the recent sands of the coastal forelands, southwards from near Redelinghuys (32°28'S, 18°32'E) to the Cape Flats, on the northern shores of False Bay, where its eastward extension is interrupted by the mountains. It re-appears west of Hermanus and continues in an almost unbroken zone to Mossel Bay. Outliers and fragments occur wherever the rocky coastline or chains of hills are broken by local accumulations of sand (as at the Fishhoek gap in the Cape Peninsula and near Betty's Bay), and these extend eastwards to near Cape St. Francis.

Mountain fynbos is confined to the ranges of the Cape Folded Belt, southward from Nieuwoudtville to the Peninsula and Cape Hangklip, and thence eastward to Port Elizabeth and Grahamstown. A northern outlier occurs on granite hills in the Kamiesberg (30°18'S, 18 °05'E), and "islands" occur on high quartzite ridges in the Little Karoo. This formation occupies a relatively small area of about 3,5 million ha. Acocks (1953) and Taylor (1978) describe the "islands" as a sub-category of mountain fynbos called arid fynbos. In the study area fynbos constitutes the dominant vegetation type. Appendix A details further the fynbos communities.

4.3. DETERMINANTS OF VEGETATION PATTERNS AND BOUNDARIES BETWEEN FOREST AND FYNBOS

The factors governing the boundary between forest and fynbos are obscure. Maps produced by Neethling (1970) show that forest occurs on soil types as shallow, highly leached and infertile as those on which fynbos occurs, so that the governing factor appears to lie in soil moisture regimes or a complex of soil physical variables. The common factor in the fynbos zone, aside from low to very low levels of soil moisture, is a seasonally severe soil moisture deficit, even on situations where the profile is periodically waterlogged. This influence is probably the one which by and large precludes the growth of native trees and its effect is reinforced by periodic fires.

In fact, Acock's (1953) representation of the forest (Veld Type 4) is to some extent hypothetical since much, if not most, of the area is covered by fynbos. Thus, though the forest zone experiences relatively low summer temperatures and is probably more humid due to favourable maritime influences than fynbos stations with the same effective precipitation indices, there is little evidence of macroclimatic differences between adjacent forest and fynbos (Kruger, 1979)

Most recently, the forest-fynbos boundary and the factors affecting its composition and dynamics have been the subject of investigation. In the southern Cape Van Daalen (1981) found forest on all soil types except those derived from granites and the Enon conglomerates. In limited areas only was soil moisture related to the forest-fynbos ecotone and the location of forest was indirectly affected by topography and aspect through their influence on soil moisture and the spread of fires. In the south-eastern Cape Meadows and Dewey (1986) found a clear difference in the characteristic of soils collected from within the forest and from the grassland-heath communities.

Although this is not directly related to the forest-fynbos boundary theme, Van Wilgen (1981) concluded from a study on the effects of fire frequency on fynbos composition and structure that sites having the same soil type, geology and fire history do not necessarily have the same vegetation composition. The appearance of tree species in certain areas of Jonkershoek suggested that forest expansion could occur, but was considered unlikely in view of the shallow soils and summer drought in the study area.

At Swartboskloof McDonald (1987) found it difficult to isolate one factor that had an overriding effect on vegetation pattern, and Masson and Moll (1987) suggested a combination of soil type, degree of rockiness and soil nutrient status were responsible for determining the location of forest and fynbos species at Orange Kloof on the Cape Peninsula.

In contrast to McDonald's (1987) finding in which the interpretation of the vegetation-environment data proved difficult, the use of Canonical Correspondence analysis by Masson (1991) provided a clear indication of which environmental factors were important in determining forest types and the forest-fynbos boundary.

Masson (1991) found that the separation between scree forest and riverine and mature forest can be related to rock cover and soil depth respectively. Rock cover is highest in the scree forest plots and declines towards the riverine and mature forest. Conversely, soil depth values were greatest in the plots located on the riverine and mature forest, declining towards the scree forest. Soil depths recorded from the scree area were approximately half of those measurements obtained from mature plots. Campbell and Moll (1977) found a similar association between vegetation type and rock cover on Table Mountain, where a *Maytenus oleoides* sub-association was commonly found in areas with shallow sandy soils and high rock cover.

Masson (1991) also indicates that the factors responsible for determining the separation among forest, margin and fynbos are soil moisture and slope. Soil moisture levels were highest in the forest plots, declining to their lowest levels in the fynbos plots. The implication that soil moisture availability controls the distribution of forest has been stated by Craib (1929), Glyphis *et al.* (1978) and Marker and Russel (1984). Van Daalen (1981) found this to be the case in the foothills of the Outeniqua Mountains, where forests were found only on the moister southern slopes. Contrary to their expectations, Meadows and Dewey (1986) found soil moisture levels were lower inside the Beggarsbush State Forest than in the surrounding grassland-fynbos. Weather conditions prior to soil sampling, higher evapo-transpiration losses and leaf canopy interception of rainfall were suggested as possible explanations for this anomaly.

Although soil moisture played an important role in determining forest types in the Transkei, the influence of slope and aspect on the floristic composition of forests was not considered to be important (Cawe and McKenzie 1989). At Swartboskloof near Stellenbosch Masson (1991) found that slope was related to differences in composition of forest and fynbos communities, but was not associated with differences in forest composition. Fynbos plots were usually found on steep slopes which become less severe to finally level out within forest stands. Similarly, aspect does not appear to be an important determinant of forest composition at Swartboskloof although aspect and geological substrate were related to fynbos community composition in the earliest study of Werger *et al.* (1972).

The importance of geological substrate on fynbos community distribution and composition was also supported by McDonald (1987). Its effect on forest community distribution was less obvious, but nevertheless was thought to be more important than soil moisture.

Owing to the lack of adequate soil data, no conclusive testing of the effects of soil nutrient status on forest distribution and composition could be made by McDonald (1987). Results from Masson's (1991) study indicate that pH levels and Na are highest within scree forests, declining to their lowest levels in mature margin and fynbos plots. The reverse trend was shown by Al levels, acidity and silt content, with lowest levels apparent in scree forests and highest in the margin and fynbos plots. Although not as important, sulphur, calcium, potassium, and magnesium values were highest within forests and lowest in fynbos plots. This supports the findings of Meadows and Dewey (1986) and Granger (1976) that levels of potassium, magnesium and calcium increased from grassland to forest.

4.4 IDENTIFICATION OF SUITABLE VINE CULTIVARS AND ASSOCIATED ENVIRONMENTAL FACTORS

According to Dr E Archer (Viticulture and Oenology, US) the following seven cultivars are the ones that are mainly planted in the study area and thrive the best: a) Chardonnay, b) Sauvignon blanc, c) Merlot, d) Shiraz, e) Pinotage, f) Cabernet franc and g) Cabernet sauvignon. These are the seven vine types considered in the research study.

The effect of climate and soil on the performance of the grapevine and quality of the grape and wine involves a complicated interaction between temperature, moisture supply, sunlight and physiological processes (Saayman, 1981). Although knowledge of this complex interaction is still relatively limited, certain aspects have been identified which influence the behaviour of the grapevine.

Environmental factors which have an influence on terroir identification are defined, with consensus among the authors consulted, as soil type and its moisture-holding capacity, slope and aspect, air and soil temperature and climate (De Blij, 1983; De Villiers, 1995; Hopkins, 1995; Marais, 1996; Schoeman & Scotney, 1987; and Seguin, 1990). Obviously not all authors put the same emphasis on the same factors, but from a thorough study it can be concluded that the environmental factors mentioned play a important role in terroir identification.

4.4.1 Soil types and water retention

Certain wine characteristics are associated with chemical soil characteristics (Renner, 1990). Some experts allege that they can identify the physical characteristics of the soil and the surrounding mother material from the distinctive character of the wine. In other cases the moisture retention of the soil is considered as of primary importance (Saayman, 1981). Renner (1990) describes the concept of terroir and also places more emphasis on the importance of soil and the underlying mother material than on the other environmental factors, climate and slope. Saayman (1973) proved that soil types have a very clear influence on the result of the vine.

The water-holding capacity of the soil is of great importance for the growing of vine cultivars, especially in a winter rainfall region such as the Western Cape. According to De Villiers *et al.* (1995) the depth, texture, structure, rockiness and presence of organic materials influence the humidity in the soil. Soil types with great holding capacity can retain up to 200 mm of water inside the root zone, collected during the great rainfall in winter, into the summer season. Saayman (1981) indicated that the presence and fluctuation of ground water tables determine the moisture-holding capacity of the soil. If the moisture fluctuation in the soil fits in with the natural moisture requirements of the vine, for example, moderate and steady moisture supply till ripening, followed by a gradual rise in moisture hindrance until the harvest time, this would lead to an increase in grape quality. High clay percentages in soil are important because clay has a high moisture-retention ability, as well as a relatively high presence of rock and gravel, which is important for better draining (Renner, 1990). De Blij (1983) agreed with Renner that the texture of the soil is a critical factor. He suggests that this is an indication of the volume of water that the soil can hold, of the effectiveness of internal circulation and feeding ability and volume of air in the soil.

Information regarding the most suitable soil forms and types for different grapevine cultivars can be obtained from South Africa (1990 and 1991). This publication indicates all the cultivars grown in the Stellenbosch, Franschhoek and Paarl areas, the soil types and forms where those cultivars are planted and the production levels per quality category (ton/hectare) for those soil forms and types.

Table 4.1 was compiled with this information. To be placed in the best-quality category (A) a cultivar must produce the highest amount of quality grapes per ton. It can be presumed that the soil type and form where a cultivar produces the highest amount of best-quality grapes is the most suitable for the growth of that specific vine in that area. Suitable soil types and forms for the cultivars considered were listed from the highest to the lowest quality categories in the table.

TABLE 4.1: Vine cultivars, associated soil forms and quality ratings.

CULTIVAR	SOIL FORMS *	QUALITY CATEGORIES **
Chardonnay	- Glenrosa	A & B
	- Cartref	A & B
	- Avalon, Bainsvlei, Constantia	A & B
	- Hutton, Clovelly, Oakleaf, Pinegrove	A & B
Sauvignon blanc	- Glenrosa	A & B
	- Cartref	A & B
	-Avalon, Bainsvlei, Constantia	A & B
	- Hutton, Clovelly, Oakleaf, Pinegrove	A & B
	- Hutton, Clovelly, Avalon	A & B
	- La motte, Longlands, Avalon, Constantia, Fernwood	B & C
	-Fernwood, Dundee, Avalon, longlands	B & C
Merlot	- Cartref	A & B
	- Avalon, Bainsvlei, Constantia, Villafontes, Tukulu	A & B
	-Hutton, Clovelly	A & B
	- Glenrosa	A, B & C
	- Hutton, Clovely, Oakleaf, Pingrove	A, B & C
Shiraz	- Kroonstad	A
	- Kroonstad	A & B
	- Hutton, Clovelly, Oakleaf	B & C
	-Fernwood, Dundee, Longlands, avalon	B & C
Pinotage	- Glenrosa	B & C
	- Cartref	B & C
	- Avalon, Bainsvlei	B & C
	- Kroonstad	B & C
Cabernet franc	- Glenrosa	A & B
	- Cartref	A & B
	- Avalon, Bainsvlei, Constantia	A & B
	- Hutton, Clovelly, Oakleaf	A, B & C
	- Kroonstad	B
Cabernet sauvignon	- Cartref	A & B
	- Avalon, Bainsvlei, Constantia	A & B
	- Glenrosa	A, B & C
	- Hutton, Clovelly, Oakleaf	A, B & C
	-Kroonstad	A, B & C
	-Ferwood, Dundee, Longlands	B & C

Source: South Africa (1990 and 1991).

* The soil forms in Table 4.1 are all found in the study area. More information about the soil forms in La Motte plantation is available in Appendices II, III and IV

** Quality categories are distinguished into A, B and C.

A: Wine made from these grapes can be sold at higher premium than wine described in category B.

B: Wine made from these grapes can be sold at rates higher than minimum good wine rates.

C: Wine made from these grapes will only reach the minimum good or standard wine rates.

4.4.2 Aspect

Aspect is a term used to indicate the direction an object is facing, with specific reference to slope direction in relation to the sun (Clark, 1987). The aspect or compass direction in which the vineyard slope is orientated influences the temperature of the slope. Therefore aspect has a noticeable effect on vegetation and cultivated land (Monkhouse & Small, 1970).

Vineyards in the Southern Hemisphere with slopes facing in the northern and north-western direction are warmer than those on the southern and south-eastern slopes. The reason is that these slopes receive more direct sunlight. This characteristic is more noticeable in higher latitudes than closer to the equator (Gladstones, 1992). On the other hand, sunlight that strikes a surface at a small angle will have a lower heating effect. This will cause the slope to be cooler than a slope that receives sunlight at a perpendicular angle. As a general rule, convex landscapes will show less day and night temperature fluctuations than concave landscapes (Saayman, 1981). Table 4.2 lists the most suitable slope direction for the cultivars considered (South Africa, 1990 and 1991).

TABLE 4.2: Vine cultivars and preferred aspects.

CULTIVAR	ASPECT
Chardonnay	South
Sauvignon blanc	South, West
Merlot	South
Shiraz	East
Pinotage A	North, West
Pinotage B	East
Cabernet franc	North
Cabernet sauvignon	North

4.4.3 Slope percentage

The effect that slopes have on agricultural crops (production and harvest) was illustrated by Whitman *et al.* (1985). In his research various agricultural crops were studied and in all cases the differences in yields were associated with the differences in slopes. The study differentiated four slope categories derived from four topographical areas, ranging from flat slopes to slopes up to 36% (this includes from the top part of the hill to the valley bottoms).

For Schoeman & Scotney (1987) different slope types are important for the identification of terroir. For them the agricultural potential, apart from daily management and methods, mostly depends on climate, soil and slope, and they especially emphasise the effect of slope. Information on the suitability of the different terrain types was also taken from South Africa (1990 and 1991).

TABLE 4.3: Vine cultivars and preferred slope types

CULTIVAR	SUITABLE TERRAIN TYPE
Chardonnay	4 & 5
Sauvignon blanc	3 & 4
Merlot	4 & 5
Shiraz	5
Pinotage	4
Cabernet franc	3 & 4
Cabernet sauvignon	3 & 4

A description of the different terrain types was obtained from the memoirs attached to the land types of the 1:250000 scale maps on the agricultural natural resources of South Africa.

1. **Crest.** This is the highest, mostly dome-shaped part of a mountain or hill with slopes which switch from 0% to 7%.
2. **Scarp**. This is the very sharp, generally perpendicular cliff from crest to the midslope and usually steeper than 90%

3/4. **Midslope (3 middle high and 4 middle low)**. A midslope is the sloping part from the bottom of a scarp or the edge of the crest to where the slope flattens to a less steep level via a knick-point. Midslopes can change from 15% to 75%, where the middle high is between 45% and 75%, and the middle low is between 15% and 45%.

5. **Footslope**. A footslope reaches from the bottom of the midslope to the valley bottom. A footslope has a slope from 1% to 15%.
6. **Valley bottom**. This is the flat or level-lying terrain on either side of the river or water streams that can flood sometimes.

4.4.4 Microclimatic factors

Climate, soil and slope are the key factors in viticulture, but according to De Blij (1983), climate is the most critical factor. Vineyards can be grown in almost any soil (although the quality of the harvest may differ), but particularly high or low temperature conditions during the growing season can lower the yield or destroy it altogether.

In studies by Kappel & Nielsen (1994) the important role played by microclimate in the development of fruit was investigated. They found that early exposure of fruit to large amounts of sunlight had a positive influence on size, development and quality. Smart *et al*. (1985) found in their study on the influence of microclimate on vine cultivars (especially Shiraz) that microclimate plays a big role in the different characters of wine.

Climate is influenced by many factors, which are not easily separated from each other (Saayman, 1981). These elements include temperature, humidity, dampness, orientation, slope, height above sea level and closeness of a water mass, like the sea (Saayman, 1981).

Temperature is an essential component of climate. The sun radiation that vine cultivars receive from the beginning of the growth cycle in early spring (budding stage), to the end of the cycle at the beginning of autumn (after harvest stage), gives the energy necessary to finish the cycle (De Blij, 1983). Without the minimum sunlight energy a grape cannot finish its full cycle or become ripe (Saayman, 1981). In the growth cycle of the grape there is a stage known as grape setting. After this stage the active cell separation stage results in fast grape size expansion. This takes from three to six weeks. Relatively high temperatures during this period have a negative effect on the cell separation process (Pienaar, 1986). According to De Villiers (1995:12) climate and "also temperature is the most important element that defines the quality and wine type in the Western Cape."

Table 4.4 indicates the temperature needs of the different grape cultivars considered. These values were provided by Dr E. Archer Viticulture and Oenology, US). The different temperature preferences listed in the table refer to the average day temperature during the growth season, and more specifically the ripening time of the cultivars. The period stretches from approximately middle January to the middle of March (South Africa, 1990 and 1991).

TABLE 4.4: Temperature needs per cultivar

CULTIVAR	AVERAGE DAY TEMPERATURE (JANUARY – MARCH)
Chardonnay	22 – 24°C
Sauvignon blanc	20°C
Merlot	22°C
Shiraz	22 – 28°C
Pinotage A	26 – 32°C
Pinotage B	22 – 24°C
Cabernet franc	26 – 32°C
Cabernet sauvignon	26 – 32°C

Air humidity and moisture availability to the grapevine are essential factors determining the harvest and the quality of the wine (Seguin, 1990). De Villiers *et al.* (1995) wrote that availability of water during the growth season greatly affects the growth of the grapevine, the size of the harvest and the quality of the wine. During the development of a grape, cell enlargement takes place after cell separation. Pienaar (1986) found that cell enlargement is negatively influenced by low moisture availability.

The effect of altitude on the quality of the grapes plays a role only at a microclimatic level. Mean temperature decreases with elevation at 0.3°C for every 100 m, and for this reason grapevines at higher elevations enjoy a cooler microenvironment (Saayman, 1981). They are also influenced during the day by the cooling effect of the wind and at night the valleys are cooler than the surrounding hills. According to Dr E Archer (Viticulture and Oenology, US), 430 m above sea level is the ideal area for wine grapevine agriculture in the Western Cape.

The preceding section referred to the needs of the wine cultivar considered regarding soil, aspect or slope direction, terrain type and temperature and a theoretical base was laid in which the terroir requirements of the cultivars were revealed .

4.5. FIELD REQUIREMENTS OF DECIDUOUS FRUITS

The main species of deciduous fruit grown in South Africa are pears, apples, Japanese and European plums, peaches, nectarines and apricots. Not just any variety of these various fruits can be exported. Only a selected number of varieties which have proven themselves suitable in all respects are allowed to be exported. When a new variety, perhaps obtained by breeding, selection or importation, appears on the scene, it must first undergo a stringent local test in which export conditions are simulated as far as possible. Should it pass this test, then experimental shipments are sent over and not until reports from overseas on the exports are favourable for at least two successive seasons does the Deciduous Fruit Board place such a variety on its export list.

4.5.1 Apples

Apple trees may tolerate temperatures of -26 to -37.5°C in the winter when fully dormant and -4° to -8°C in late spring, while fruit will be damaged by temperatures between -2° to -4°C. Generally apples require a period of winter dormancy, in general 900-1000 hours or more at less than 7°C, but low chilling varieties need only 200-300 hours below 7.5°C. Apples perform best in areas with medium to low humidity, with long daylight hours, high light intensity and relatively warm days and cool nights (Jackson, 2000; Cronje, 2002).

Apples require good drainage and grow excellently on soils of all textures provided they have adequate depth and free drainage. Fruit crops in general prefer the soil to be slightly acid with a pH of 6,0 to 6,2, which is near the optimum (Lal Kaushal & Sharma, 1995). Where pH is considerably higher, fruit trees develop deficiencies of iron and manganese, even though these elements are present in ample quantities (Barooah, 1996). The optimal and absolute climatic, terrain and soil requirements as well as the most suitable soil forms and types for apples in the study area are shown in Tables 4.5 and 4.6 at the end of this section.

4.5.2 Pears

Pears can withstand frost and their main temperature-limiting factor is their cold requirement. Pears need between 1000 and 2000 hours of chilling to set fruit. As long as this cold requirement is met, the pear trees will bear good-quality fruit in climates hotter than the optimum for apples. Pears like warm summers. The tree may tolerate -29 to -34°C in the winter when fully dormant, while the buds will be damaged by -12°C, the breaking buds by -9°C, the flowers and open buds by -3.5°C, the fruit set by -3°C, the small green fruit by -2.8°C and the mature fruit by -2°C (Kadam *et al.*, 1995).

Pears will tolerate heavier soil conditions than most fruit trees, including water logging. Best soils are deep warm loam, well drained but retaining moisture. Thin, light soils that dry out too readily in summer will have an adverse effect on the tree growth, fruit development, size and texture. The pear will tolerate moderate soil drainage impedance better than the apple. However, several varieties of pears will succeed on clay soils. Nevertheless, like all kinds of fruit, they grow with far greater health and vigour if the soil is freely drained (Barooah, 1996). The optimal and absolute climatic, terrain and soil requirements, as well as the most suitable soil forms and types for the study area, are indicated in Tables 4.5 and 4.6 at the end of this section.

4.5.3 Peaches

Peaches require a site on full sun and with good airflow, allowing both cold air to flow away in frosty months and keeping the air relatively cool in summer (Glowinski, 1999). Peaches will withstand drought. Their water requirements are somewhat less than half those of the apple. The leaves are firm in texture and do not appear to give up their moisture in the same way as do the leaves of the apple or pear trees. It thrives best in areas with medium to low relative air humidity, but the trees must have continuous soil moisture during the growing season (Barooak, 1996).

Areas that regularly have late spring frosts are not suitable for peach production because the opened flowers may be killed, although their blossoms can withstand spring frost better than plum blossoms. The trees usually require from 100 to 400 hours with temperatures less than 7°C to overcome the dormancy period; however, the tree may be killed at temperatures of about –5°C. Humid conditions during the ripening of the fruit are undesirable because this promotes the development of brown rot. Late frost may kill flowers and summer rains may lead to diseases (Joshi & Bhutani, 1995; George, 2000).

The peach will grow in almost any soil, but it undoubtedly prefers a medium to light loam and perfect drainage conditions. The optimal and absolute climatic, terrain and soil requirement as well as the most suitable soil forms and types for the study area are indicated in Tables 4.5 and 4.6.

4.5.4 Citrus

Optimal temperatures for growing citrus are between 20 and 30°C and both above and below this range, growth slows, stopping completely at 38°C and 13°C, but the trees will survive. Citrus trees will tolerate up to 50°C, but at the other end of the scale freezing point or a few degrees below seems to be the lower limit. Temperatures of -7°C to -10°C will kill the tree (Gilfillan, 1987). Du Plessis (1982) showed that the minimum and maximum temperatures and solar radiation in the pre-bloom and bloom periods are the major determining factors of the eventual fruit size. He found that the average maximum temperatures in October and November were the main determinants of fruit size in 'Valencias' in the Nelspruit area, with lower temperatures resulting in smaller fruit sizes. Temperatures of 25°C to 30°C are optimal (Spiegel-Roy and Goldschmidt, 1996).

Higher maximum temperatures during the pre-bloom period improve fruit growth as long as these temperatures are below 30°C for most varieties (Reuther, 1973). Growth declines at maximum temperatures above 30°C and there is no growth and possible heat damage at 40°C (Reuther, 1973). Excessive maximum temperatures during the fruit set period often have a depressive effect on fruit set (yield) of navel orange trees and this in turn results in a large fruit size at harvest (Gilfillan, 1987).

The bulk of the citrus orchards in South Africa are planted in soils of reddish to dark brown colour, and there is little doubt that on the whole these comprise the best and most suitable land for the purpose. As a rule these soils are deep and well drained. The most important considerations are soil depth and drainage. Soils shallower than 50 cm are not recommended for citrus. Citrus trees do not require such deep soils as some deciduous species, but their best yields will be in the deepest, richest loams (Chadler, 1958). A deep soil generally means good drainage. In any case, the question of drainage is also an important one, as it is fatal to plant citrus on a poorly drained soil. A clay subsoil may be responsible for the loss of an orchard, not so much on account of the fact that it is clay, but that through its being impervious it has held up the water and prevented its natural percolation downwards, thus causing the roots of the trees practically to stand in water. Smaller fruit are produced in heavy textured soil types (clay) than in lighter types (sand) (Du Plessis &

Smart, 1982). The optimal and absolute climatic, terrain and soil requirements as well as the most suitable soil forms and types for the study area are indicated in Tables 4.5 and 4.7.

4.5.5 Olives

There is a wide diversity of conditions under which olives are grown. Commercial production of olives is possible throughout the warm temperate and subtropical zones, between 30° and 45° latitude (Raina, 1995). It is indigenous to the Mediterranean Basin, where the climate is characterised by a mild winter, which is the rainy season, a dry and hot summer and a short autumn and spring.

Olive-growing areas have a mean annual temperature of between 15 and 20°C. The absolute maximum may rise above 40°C without doing harm. On the other hand, the minimum should not fall below –7°C; below this temperature, frost can cause serious damage. This susceptibility to frost limits the extension of the olive-growing area north and south of the specified latitudes. It is wise, in view of the serious damage that can be caused, to retain a margin of safety as regards temperature and to refrain from planting olives in areas where the temperature drops below –5°C (Du Preez 2003).

As olive trees flower late, spring frosts are not so dangerous. The tree will easily withstand high temperatures if it is well supplied with water. In spite of its susceptibility to frost, the olive needs fairly low temperatures for bud differentiation, which starts from August to October (Raina, 1995).

Provided it has sufficient (but not too much) water, the olive is not very particular with regard to the nature of the soil. Although the olive is easily satisfied as to its soil needs when its water supply is unlimited, it becomes more exacting in areas where the rainfall is low. For a tree to get though a dry summer, all water must be so deeply stored as to be fully protected from direct evaporation by the sun. For this two conditions are necessary: firstly, the soil must be very permeable to a fairly good depth, so that water is absorbed rapidly and, secondly, the soil's water-retention capacity should be very low so that the liquid can infiltrate deeply. Light, sandy soils best fulfil these requirements (Du Preez, 2003).

What soil studies should investigate principally are the factors of permeability and water-retention capacity (speed and depth of infiltration). There are two main points having a bearing on the success of olive groves (FAO, 1961). While the olive will adjust itself to any well-drained soil, it is best to choose loamy soils, fairly light on the surface, into which the roots can penetrate readily, which are not difficult to till, and where harvesting in rainy weather is easier.

Between the two extremes of arid and irrigated land, the clay content which can be tolerated in an olive-growing soil is a function of the rainfall: 10 percent clay for an annual fall of 200 mm, 20 percent for 400 mm and 30 percent for 600 mm (FAO, 1961; Raina, 1995). The presence of a hard pan at a certain depth below the surface can lead to the accumulation of water in the subsoil after heavy rains (Du Preez, 2003). Consequently, any soils showing a profile of this nature must be carefully avoided. The optimal and absolute climatic, terrain and soil requirements as well as the most suitable soil forms and types for the study area are indicated in Tables 4.5 and 4.7.

4.6.6 Plums

Keeping in mind their susceptibility to brown rot, plums require sun and good airflow. Mature fruit may tolerate temperatures as low as -2.0°C, open buds -5.0°C and the tree is quite winter hardy. Some varieties require a minimum of 700 to 1100 hours below 4°C during the dormancy period; others require a minimum of 1500 hours below 7°C to break the bud dormancy. Humid conditions during the ripening of the fruit are undesirable, because this promotes the development of brown rot (Barooah, 1996; George, 2000). The optimal and absolute climatic, terrain and soil requirements as well as the most suitable soil forms and types for the study area are indicated in Tables 4.5 and 4.7.

With regard to frost, plums are particularly susceptible, being one of the first fruits to flower. Because they require good soil, plums have been often planted in low-lying land with devastating results (Bhutani & Joshi, 1995; George, 2000). The lesson about the association between low-lying land and spring frost has been learnt. Spring frost, cold winds in spring, and drought in summer still can cause considerable fluctuation in the production and condition of the fruit.

TABLE 4.5: Most suitable soil forms and types for deciduous trees in the study area. Source: Pretorius (2000)

	BEST YIELDS ARE OBTAINED FROM	GOOD YIELDS ARE OBTAINED FROM
APPLES	A and B	C, D and E
PEARS	A	B, C and E C E
PEACHES	A, B, C and E	D
CITRUS	A, B, C and E	D
OLIVES	A, B, C and E	D
PLUMS	A and B	C and E

A) Yellow and red apedal soils, freely drained without water tables and belonging to one or more of the following soil forms: Magwa, Hutton and Clovelly

B) Pedologically young landscapes that are not predominantly rock and not predominantly alluvial or aeolian and in which the dominant soil-forming processes have been rock weathering, the formation of orthic topsoil horizons and, commonly, clay illuviation, giving rise typically to lithocutanic horizons. The soil forms which epitomise these processes are Glenrosa , Mispah and shallow and deep soils of the Oakleaf form (usually on upland sites) developed by rock weathering

C) Soils with a diagnostic ferrihumic horizon of the Lamotte and/or Houwhoek forms

D) Deep grey regic sands of Fernwood, Constantia and Vilafontes forms

E) Pedologically youthful, deep (more than 1000 mm to underlying rock) unconsolidated deposits. Common soil forms are Dundee and Oakleaf.

TABLE 4.6: Optimal and absolute climatic, terrain and soil requirement for apples, pears and peaches. SOURCE: FAO ECOCROP database

	APPLES				PEARS				PEACHES			
	Optimal		Absolute		Optimal		Absolute		Optimal		Absolute	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature	14	27	8	33	20	35	10	37	20	33	7	35
Annual rainfall	700	2500	500	3200	600	900	400	2100	900	1100	750	1600
Latitude					35	55	0	60	30	50	30	50
Altitude							0	2000			0	1000
Light intensity	very bright	clear skies	very bright	cloudy skies	very bright	very bright	very bright	clear skies	very bright	very bright	very bright	cloudy skies
	Optimal		Absolute		Optimal		Absolute		Optimal		Absolute	
Soil depth	deep (>150 cm)		medium (50-150 cm)		medium (50-150 cm)		shallow (20-50 cm)		deep (>150 cm)		medium (50-150 cm)	
Soil texture	medium, light		heavy, medium, light		heavy, medium		heavy, medium, light		medium, light		heavy, medium, light	
Soil fertility	high		moderate		moderate		moderate		high		moderate	
Soil salinity	low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)	
Soil drainage	well (dry spells)		Well (dry spells)		well (dry spells)		well (dry spells)		well (dry spells)		well (dry spells)	
Terrain	midslopes and footslopes (3,4 & 5)				midslopes and footslopes (3, 4,& 5)				midslopes (3 & 4)			

TABLE 4.7: Optimal and absolute climatic, terrain and soil requirements for citrus, olives and plums. SOURCE: FAO ECOCROP database

	CITRUS				OLIVES				PLUMS			
	Optimal		Absolute		Optimal		Absolute		Optimal		Absolute	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature	20	30	13	38	20	34	5	40	18	33	6	36
Annual rainfall	1200	2000	450	2700	400	700	200	1200	900	1500	600	1800
Latitude	0	40	0	40	30	45	25	50	35	50	10	60
Altitude			0	2100			0	1200			0	2500
Light intensity	very bright	very bright	very bright	clear skies	very bright	very bright	clear skies	very bright	very bright	very bright	very bright	clear skies
	Optimal		Absolute		Optimal		Absolute		Optimal		Absolute	
Soil depth	deep (>150 cm)		medium (50-150 cm)		deep (>150 cm)		shallow (50-150 cm)		deep (>150 cm)		medium (50-150 cm)	
Soil texture	medium, light		heavy, medium, light		medium, light		wide		heavy, medium		heavy, medium, light	
Soil fertility	moderate		low		moderate		low		high		moderate	
Soil salinity	low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)		low (<4 dS/m)	
Soil drainage	well (dry spells)		well (dry spells)		well (dry spells)		excessive (dry/moderate)		well (dry spells)		well (dry spells)	
Terrain	midslopes and footslopes (3, 4 & 5				midslopes, footslopes & valley bottoms (3, 4, 5 & 6)				midslopes and footslopes (3, 4 & 5)			

It can be concluded that many environmental factors affect vegetation and this chapter has by no means tried to enumerate all of them. The measurable diagnostic land characteristics were identified and they will be used to determine to what degree the land-use requirements of each land utilisation type are satisfied. To do so, the findings made so far need to be applied to the study area by making use of ALES as an integrated part of a Geographic Information System. Chapter Four deals with the application of the methodology.

CHAPTER 5: METHODOLOGY APPLICATION

This chapter explains the process followed to identify the most ideal land unit for the planting of the land uses considered in La Motte plantation by making use of a Geographical Information System (GIS). The process entailed the preparation of ARC/INFO coverages with the required land characteristic data and the building of an ALES model base on the land-use requirements presented by the different land uses. The optimisation and further analysis process of the ALES results are also explained and the results are presented and discussed.

5.1 DESCRIPTION OF STUDY AREA: LA MOTTE PLANTATION

La Motte Plantation is situated in the Western Cape region of SAFCOL's forest holdings. Blocks A to L of the plantation are situated in the Franschhoek valley, approximately 5 km west of the town of Franschhoek. Block M of the plantation, formerly known as the Jonkershoek Plantation, is situated approximately 9 km south-east of the town of Stellenbosch in the Jonkershoek Valley.

5.1.1 Description of the environment

The total planted area of SAFCOL's La Motte Plantation is 5894 ha. See Figure 5.1 for a detail view of blocks distribution. Its climate, topography, geology, lithology and soils are described in the following sections

5.1.1.1 Climate

La Motte plantation receives the greater amount of rainfall during the winter months. In the Franschhoek Valley winters are characterised by rain-bearing north-westerly winds and cold fronts. Summer rains come predominantly from a south-easterly direction (De Villiers *et al.* 1964). The highest rainfall (2000+ mm) occurs in the mountainous areas of Blocks B, C and D (Robertsvlei 2011 mm), while less rainfall is recorded on the floodplains in the north-western portion of the plantation (La Mote office 839 mm).

The rainfall patterns in the Jonkershoek Valley are strongly influenced by the topography, and a very conspicuous orographic effect is found. The result is a rainfall gradient from north-west to south-east with the highest rainfalls occurring in the high-lying south eastern peaks (Victoria Peak, Sneeukop and Bergriviernek), which can reach values of up to 3000 mm per annum. The long-term mean for the lower-lying north-western extremes of the valley is more in the order of 1000 mm per annum (South African Weather Bureau, 1988). Hail is generally a rare phenomenon in the valley. Snow often occurs during mid-winter or early spring. The snow cover does not last for long periods. The afforested area of the valley generally lies below the snow line.

In summer La Motte plantation falls under the influence of the Atlantic high-pressure cell. As a result, the weather is hot, cloudless and dry, and windy conditions, predominantly south easterly, are a common phenomenon (Schulze, 1974). Maximum values in temperature approaching 40°C have been measured during the month of January, while temperatures as low as –1°C have been measured during June to August.

According to the classification system of Köppen (1936), the climate is moderately humid **(Cfb)** on the basis that the temperatures of the coldest month are between 3°C and 18°C, while the warmest month is below 22°C.

5.1.1.2 Geomorphology

La Motte plantation Blocks A to L consist of very steep to steep to moderate mountain slopes and level valley basins or floodplains. The afforested area of Block M in the Jonkershoek Valley has a typical U-shape appearance. This is mainly a result of differential weathering of the softer granite of the valley bottom, while the more resistant sandstone of the higher-lying areas gave rise to very steep slopes and cliffs. The higher-lying areas of the afforested area are therefore characterised by slopes often in excess of 35%, combined with sharply incised drainage lines. The lower-lying areas in close proximity to the main drainage line are characterised by more gentle slopes, which seldom exceed 20%.

The afforested area is subdivided into two portions on opposite sides of the valley, with the biggest portion having a predominantly south-westerly aspect, and the remaining part has a north-easterly aspect. The altitude of the plantation varies from 220 to 750 m above sea level.

The geology of the mountain ranges in the Franschhoek Valley is comprised of sandstones of the Table Mountain Group (TMG) and granites of the Cape Granite Suite. Colluvial deposits often of mixed origin occur on mountain pediment slopes, whereas deep alluvial deposits occur in valley bottoms. This alluvium consists of deep sands as well as boulder beds of well-rounded quartzite material. The different soil types are strongly correlated with the underlying lithology (Shafer *et al.*, 1995).

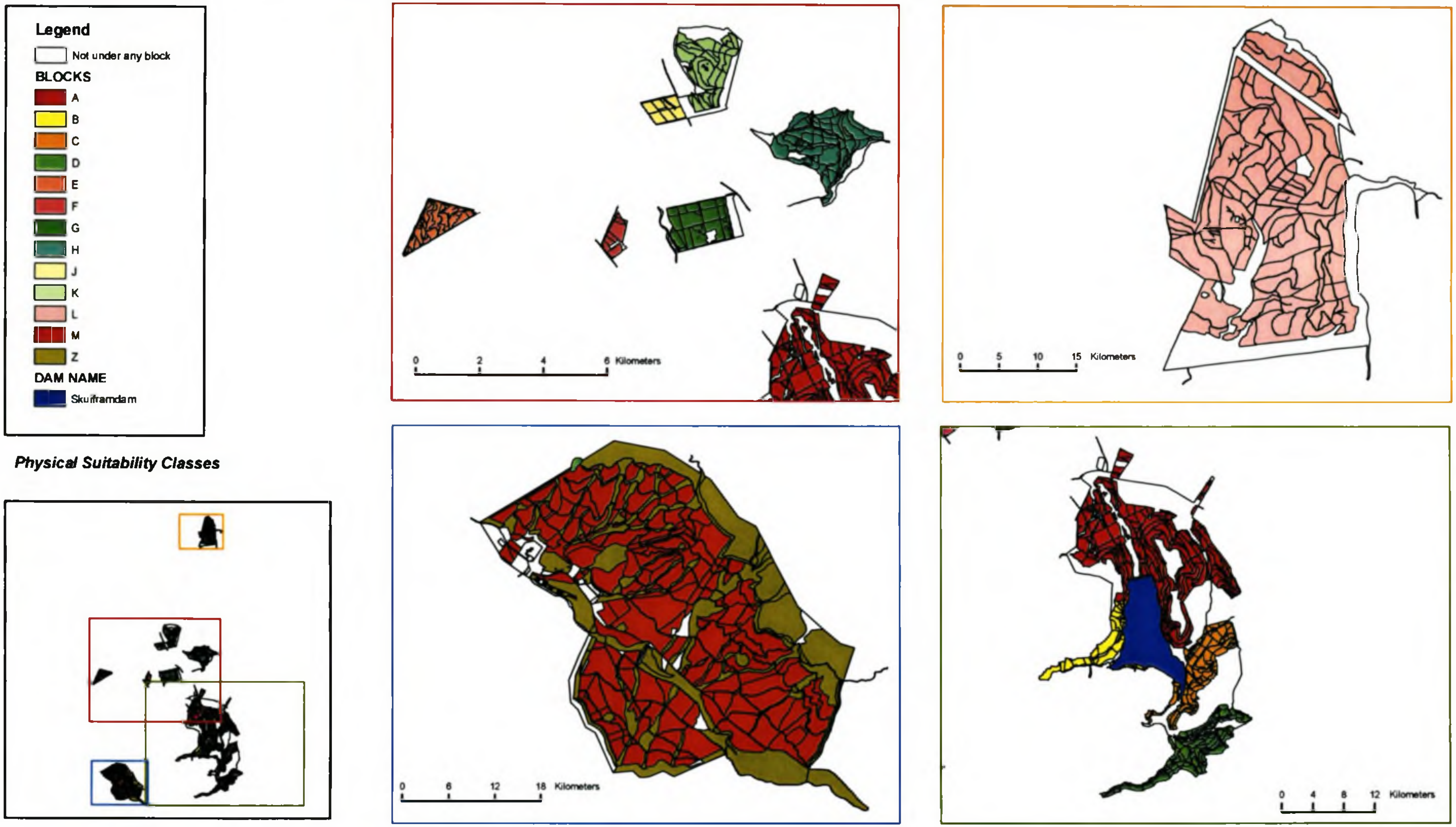

Figure 5.1: Blocks distribution and area under water

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5.1.1.3 Soils

Soils that are derived from sandstones are generally lower in organic carbon than the granite derived soils. They are usually pale coloured, coarse textured (sandy), acid and have a low cation exchange capacity (CEC) and low water-holding capacity. Soils weathered from the Nardouw formation sandstones, however, are slightly higher in clay and are predominantly red or yellow coloured due to the greater amount of iron in the parent rock. The soils derived from granite parent materials are finer textured (higher percentage of clay), have a relatively high CEC and a moderate to high water-holding capacity (Shafer *et al.*, 1995). Information about the soil groups and forms present in La Motte plantation is available in Appendices B and C.

Soils derived from Sandstones

All the sandstone derived soils in Block M are of a colluvial origin. Although these soils can be very deep, a relatively light texture and associated lower moisture-holding capacity, and often a very high stone content mean these soils have only moderate potential for forestry. The dominant soil families include Constantia 1100 and Oakleaf 2110. Weak podzolic characteristics are found in areas with very light texture; in these cases soils were classified as Constantia 1200. The Fernwood 2110 and Lamotte 1100 soil families are dominant in areas with poor drainage, and Katspruit 1000 and Westleigh 1000 soil families are found in bottomland positions with waterlogged conditions. The soils vary considerably in terms of depth criteria, texture of gravel and stone.

Soils derived from phyllite and quartzitic sandstone

In Block M fillite and quartzitic soils have a scattered appearance and are generally highly variable in terms of texture and stone contents. These soils are generally shallower than granite-derived soils. Due to a prominent southerly aspect, these soils are also characterised by strongly developed humic topsoils. Dominant soil families include Magwa 1100, Nomanci 1100 and Sweetwater 1110. Both topsoils and subsoils have a medium to heavy texture. Although the soil profiles are generally derived in situ, colluvial soils are also found and weathering products of, for example, granite are often well mixed with those of fillite and sandstone.

Fluvial deposits

Deep colluvial or alluvial sands and cobble bed deposits occur in the valley bottoms and floodplains of the Franschhoek valley. Most of these sites (suffixed w2 on the site map) occur in bottomlands and it is recommended that they should be conserved as sponge zones for the maintenance of the downstream water supply. Duplex hydromorphic soils (Cb2 and Cb5) occur to a small extent where a clay horizon at a depth of 450 to 600 mm prevents vertical water infiltration. Well developed podzols (Lamotte soil form) are found in some of the older deposits (Ga soil sub-groups).

In the Jonkershoek valley isolated areas of alluvial deposits occur in close association with the main drainage lines. These soils are generally very deep, with signs of wetness at depths varying from 60 to 140 cm. Soils are generally very darkly coloured due to an accumulation of organic matter and textures vary considerably. The dominant soil families include Tukulu 1110 and Westleigh 1000. The Tukulu soil form can be of very high potential, with the Westleigh form sometimes imposing limitations on the form of shallow fluctuating water tables. The nutritional status of these soils varies considerably, and especially the Cb and Cc soil groups have variable P deficiencies.

Soil derived from granites

Soils derived from granite include some of the highest potential forestry soils in the Western Cape Region. These soils are medium to relatively heavily textured topsoil and subsoil, and generally have well weathered profiles and favourable water-holding capacities. Sites at higher altitudes (cooler and wetter) have developed humus-rich topsoils. These soils are usually high in nitrogen, but often have marginally low phosphate levels. The underlying granite parent material is generally well weathered and affords relatively deep rooting.

Blocks E and L are almost entirely underlain by granites. These are deeply weathered, largely in situ and the soils have been enriched by organic matter accumulation to form friable neocutanic B horizons (Oakleaf form). Moderately deep lithosols (Glenrosa form) also occur to a lesser extent. All of these soils have hard-setting subsoils.

The greater part of the afforested area in the Jonkershoek Valley has a southerly aspect. The resultant cooler conditions, combined with a very high rainfall, create conditions favourable for the development of humic topsoils. These soils therefore have a high nitrogen mineralisation capacity. Phosphate levels are, however, often still moderate, although significantly higher than the sandstone-derived soils. Granite-derived soils in this area can either be formed in situ, or they can be of colluvial origin, often well mixed with weathering products of other lithologies, for example, Sandstone. The dominant soil family is Sweetwater 1110, while neocutanic 1100 soil families also occur as sub-dominant families.

5.1.2 Current land use

With the current policy of the Department of Water Affairs and Forestry to concentrate mainly on establishing *P. radiata* in the Western Cape Region, La Motte plantation presents a problem as a high percentage of compartments are planted with other pine species, or have off-site plantings. *Pinus canariensis* has not been phased out yet and *Pinus pinaster* is still covering a large area where trees should never have been established, or where there is far better potential with *P. radiata*, with or without fertiliser (De Ronde, 1992).

Many compartments on the steep slopes of Block A, B, C and D have already been abandoned or allocated to alternative land uses, as a result of the limited soil media available for tree growth. However, on the deep soils that occur on the bottom land of these blocks and make out the bulk of these plantation units, many *P. radiata* growth contrasts are recorded as a result of the fluctuating nutrient status and variation in physical soil parameters. MAI20 recorded here can range from less than 5 to more than 20 $m^3ha^{-1}year^{-1}$ within a distance of 100 metres. In Block D most good sites where *P. radiata* will grow well were planted with *P. pinaster*.

A portion of Blocks C and D was originally set aside for a dam, which is now planned to cover a much larger area of Blocks A, B and C on a new site identified for this purpose. The new dam site (544 ha) will now apparently be clear-felled and abandoned, while the old site now becomes available for plantation establishment. See Figure 5.1 for a detail view of area under water. The area considered for this land evaluation study would be the plantation area excluding the area under water.

The average MAI20 recorded in Block E is 17 m^3 ha^{-1} $year^{-1}$, producing some of the best *P. radiata* tree growth at La Motte with the exception of a portion of Block A, which produces even better growth. The tree growth rates recorded in Block L (before it burned down) are not far behind this level. Block F has an average MAI20 of 10 m^3 ha^{-1} $year^{-1}$, but is small, and difficult to manage. Fire protection and other maintenance costs are probably too high to make it profitable.

The present *P. radiata* tree growth performance in Blocks G, H, J and K is also variable, ranging from as little as 4 to 14 $m^3ha^{-1}year^{-1}$ in Block H, and from 7 to 12 $m^3ha^{-1}year^{-1}$ in Block G. In Block J all compartments (except one) are planted with *P. pinaster* and in Block K *P. radiata* tree growth does not exceed 9 $m^3ha^{-1}year^{-1}$. The main reason for the tree growth restriction in this Block can be attributed to limited effective soil depth (ESD), but some areas have also some serious nutrient deficiencies that cause most of the limited tree growth.

Most *P. radiata* compartments in the Jonkershoek valley are producing an average MAI20 of 16 – 20 $m^3ha^{-1}year^{-1}$ and no recommendations for improvement are necessary. It is only in compartments A2, 7, 8, 9 and A10 that an average MAI20 of 10 $m^3ha^{-1}year^{-1}$ was recorded, and in A34, where 11 $m^3ha^{-1}year^{-1}$ was produced. Marginal P deficiencies are probably the cause of the lower MAI20 recorded in compartments A2, 7, 8, 9 and A10. In compartment A34 restricted ESD appears to be the problem.

5.2 PREPARATION OF DATA FOR SUITABILITY ANALYSIS

An important limitation of ALES is that it does not have any georeferencing capability and does not itself produce maps, so that analysis cannot easily take into account proximity or adjacency requirements. ALES makes statements and evaluates map units, and assumes that the properties of all delineations with the same name are identical, within the precision of the map unit description. Map units used in ALES are typically natural units defined by a soil, climate, geomorphic or physiographic natural resource inventory. In this case study the land units defined in SAFCOL's La Motte plantation soil survey coverage were used. Since ALES has no map input or output, the map unit definitions (name and ID code) and their land characteristics (name and attribute values) relevant to building and running the model were imported into the ALES database. The results of the ALES analyses (evaluation result matrix) were then exported to the La Motte plantation soil survey coverage polygon attribute table for further optimisation and analysis with ArcGis.

The ALES model builder must only reason with classified data when building decision trees. The entities that are used as the basis from which the evaluation model would be built, the land characteristics, are treated as classified data. That is, data values are from a small finite set of possibilities or intervals. These can either be ordinal, with an underlying continuous scale, or nominal, with no underlying ordering. ALES also allows the model builder to define continuous land characteristics, that is, those whose data values are from an infinite set of possibilities in some range of the real numbers. ALES requires that these values be converted into analogous classified data values by defining so-called commensurate land characteristics with the same underlying scale of measurement before land qualities can be determined.

Of all the coverages contained in SAFCOL's database the soil survey provided a subset of the land characteristics needed to build the model; the rest of the data required was provided in a non-digital form by De Ronde (1992), Schafer *et al.* (1994) and Schafer *et al.* (1995). In order to prepare the data for suitability analysis, it was necessary to enter them into the polygon attribute table of the soil survey coverage and classify the existing one. Soil form, depth, drainage and wetness were entered as discrete classified land characteristics with the aid of ArcGis in two steps: a) a new field was created in the soil survey polygon attribute table for each of the four land characteristics; and b) class values were then entered for each land unit. Soil form, drainage and wetness were defined in

ALES as discrete classified land characteristics without units. Soil depth was defined as discrete classified with units. The number of classes and units were as follows:

a) Soil form: Cf, Ct, Cv, Du, Fw, Gs, Hu, Kd, Lt, Ma, No, Oa, Pg, Sr, Tu and Vf;
b) Soil depth: Shallow (20-50 cm), Medium (50-80 cm), Deep (80-150 cm);
c) Soil drainage: Good, Fair, Medium, Slight and Poor;
d) Soil wetness: None, Low, Moderate, Saturated for short to medium periods, Saturated for extended periods.

Terrain type was a land characteristic provided by De Ronde (1992) and Schafer *et al.* (1995) with low levels of precision. More detailed terrain type information can be obtained from the memoirs attached to the land types of the 1:2500000 scale maps on the agricultural natural resources of South Africa. This publication provides the terrain types in each land type as a percentage of the total land-type area. Four steps were required to obtain the most common terrain types in each land evaluation unit: a) the land-type map of the study area was first overlapped with the La Motte plantation soil survey coverage, b) with the Arc/Info POLYSTAT command the land type occupying the biggest area in each land evaluation unit was obtained, c) a new field was then created in the soil survey polygon attribute table, and d) the highest percentage terrain type in the corresponding land type was entered as a class value for each land unit. Terrain type was defined in ALES as a discrete classified land characteristic without units with the following number of classes:

e) Terrain type: Scarp with Midslope, Midslope, Midslope with Footslope, Footslope, Footslope with Valley bottom.

Aspect is a land characteristic not included in the La Motte plantation soil survey coverage. Aspect values for each map unit were obtained in five steps with the aid of the contour lines coverage. The process can be explained as follows: a) with the Arc TOPOGRID command a DEM was obtained from the contour lines coverage, b) aspects were derived from the DEM with the ArcGrid ASPECT command, c) the aspect coverage was overlapped with the soil survey coverage, d) with the Arc/Info POLYSTAT command, the aspect occupying the biggest area for each land unit was obtained, e) a new field was created in the soil survey polygon attribute table, and f) the aspect was entered as a class value for each land unit. Aspect was defined in ALES as a discrete classified land characteristic without units. The following number of classes were used:

f) Aspect: North (0° to 45° and 315° to 0°), East (45° to 135°), South (135° to 225°) and West (225° to 315°).

Climatic data were also not available in the SAFCOL database. Maximum daily temperatures for the last ten to twenty years were obtained from twenty-eight weather stations in and around the study area. To obtain the monthly maximum temperatures per land evaluation unit the following steps were followed: a) monthly maximum temperatures were obtained for each station and a surface was created in ArcGis, b) the surface was overlapped with the La Motte plantation soil survey coverage and the Arc/Info POLYSTAT command was used to obtain the maximum temperature for each land unit, c) a new field was created in the soil survey polygon attribute table and d) the maximum temperature was entered for each map unit. Maximum temperature was defined in ALES as a continuous land characteristic and was converted into discrete classified data values when imported into the ALES database by a commensurate land characteristics decision tree created for this purpose. The following number of classes were defined:

g) Maximum temperature: Low (0-14°C), Medium (15-20°C), High (21-40°C).

Seven new fields were created in the La Motte plantation soil survey coverage polygon attribute table in order to enter all the discrete data necessary to build the model; they were: a) Soil form, b) Soil depth, c) Soil drainage, d) Soil wetness, e) Terrain type, f) Terrain aspect and g) Maximum temperature. The land characteristics for each land unit were now in digital form and ready to be imported into ALES with the use of a template for suitability analysis.

5.3 APPLICATION OF CLASSIFICATION SYSTEM

The way in which the ALES model builder reasons with classified land characteristics is to build a decision tree for each land utilisation type and land-use requirement combination. These trees provide a flexible inference mechanism in which the evaluator expresses expert knowledge about the relation between some land characteristics and the land-use requirements. The ALES model in this case study was constructed with fifteen decision trees that make up a total of 1678 branches relating land characteristic to severity levels of land qualities.

During the computation of an ALES result, namely the suitability matrix, the fifteen decision trees were traversed once for each land evaluation unit using the actual land characteristic data from that land unit. A severity level of land quality was obtained for each combination of land utilisation type and land unit. A physical suitability subclass rating was then determined for each combination of land utilisation type and land unit by the maximum limitation method. This method was used because the severity levels of each land quality represented the same degree of physical limitation to the land utilisation type. In all cases level 4 means that the land use is physical unsuitable (N2) and level 1 means that it is completely suitable (S1). Levels 2 and 3 are increasingly severe limitations: suitable (S2) and marginally suitable (S3/N1).

Optimisation and geographic analysis of the evaluation results are beyond the scope of ALES and were performed with the aid of ArcGis. Figure 6.1 gives a diagrammatic layout of the process that can be described as follows. The evaluation result matrix was exported to the La Motte plantation soil survey coverage polygon attribute table for further optimisation and geographic analysis with ArcMap (ArcGIS mapping module) to enable the spatial representation of the results.

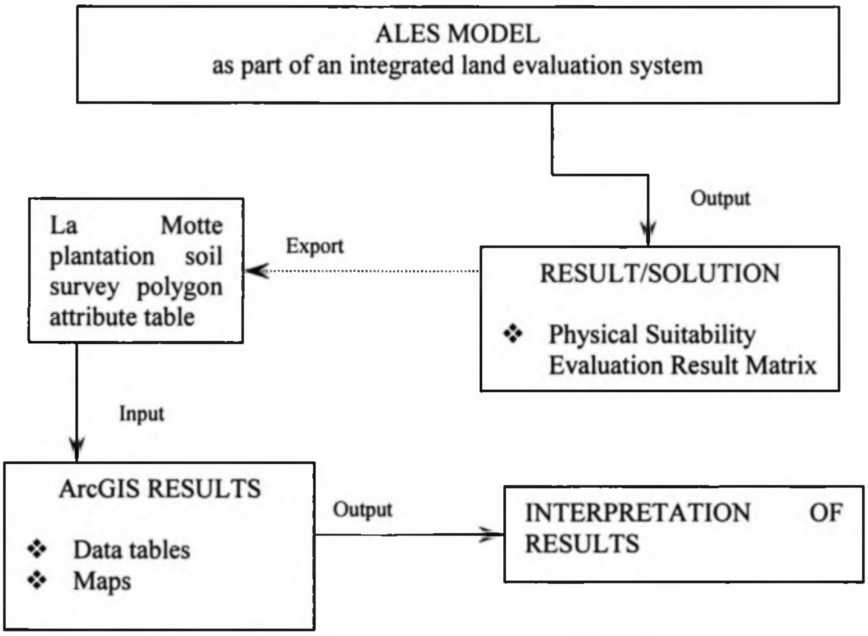

Figure 5.2: Flow chart of ALES model output results for further interpretation

The solution to the land evaluation exercise outlined in the previous chapters is presented below as a data table and maps. The different coloured areas on the maps represent the land units where all optimum land-use requirement are combined (highly suitable), most of the requirements are combined (suitable) and where the conditions become less favourable (marginally suitable) to totally impossible (physically unsuitable). The maps are interpreted in the section below. To aid the interpretation of the results the optimum land-use requirements for each land utilisation type are listed for ease of reference.

TABLE 5.1: Suitability ratings area in hectares for each of the land utilisation types considered.

	Completly Suitable (S1)	Suitable (S2)	Marginally Suitable (S3/N1)	Physically Unsuitable (N2)
Afromontane Forest	270	184	255	5171
Fynbos	3116	1864	118	781
Chardonnay	924	1844	47	3065
Sauvignon Blanc	1890	1639	633	1718
Merlot	930	1566	575	2809
Shiraz	25	131	185	5538
Pinotage	0	154	415	5311
Cabernet franc	28	1371	356	4124
Cabernet Sauvignon	25	1236	660	3958
Apples	133	154	1108	4484
Pears	3142	122	417	2200
Peaches	103	466	847	4463
Citrus	338	520	878	4144
Plums	133	275	234	5238
Olives	286	749	1719	3127

5.3.1 Afromontane forest

Most of the La Motte plantation is unsuitable for Afromontane forest due to the demanding requirements needed (high levels of soil moisture and less steep terrains). Only some areas along the rivers and streams in Blocks M and Z, a few scattered land units in Blocks A and G and Block J are rated as highly suitable, giving a total of 270 ha. 184 ha are rated as suitable in a few scattered land units in Blocks A, H, M and Z, where the determining limiting factors to fall into this class are a decrease in soil moisture, depth and pH values, together with steeper slopes (See figure 5.3).

5.3.2 Fynbos

Fynbos is the most suitable natural vegetation for La Motte plantation (see figure 5.4), with a highly suitable area of 3116 ha and a suitable area of 1864 ha, making a total of 84.7% of the study area. The entire area of Blocks L and F, most of Blocks M, Z and D, north of Block K, west of Block H, south of Blocks B and C and east of Block A fall under the highly suitable class, where all the optimum land characteristics values apply. The rest of Block A, west of Blocks B and C, north and centre of Block H and south of Block F are rated as suitable, where the determining factors to fall into this class are an increase in soil moisture, depth and pH values and levelling of terrain.

5.3.3 Chardonnay

According to map V, it can be determined that Chardonnay's best growth will be in the central areas of Block A, north of Blocks E, G and H, the whole of Blocks B, C and E and in scattered land units in Blocks M and L. There are 924 ha of highly suitable land, where all the optimum values of the

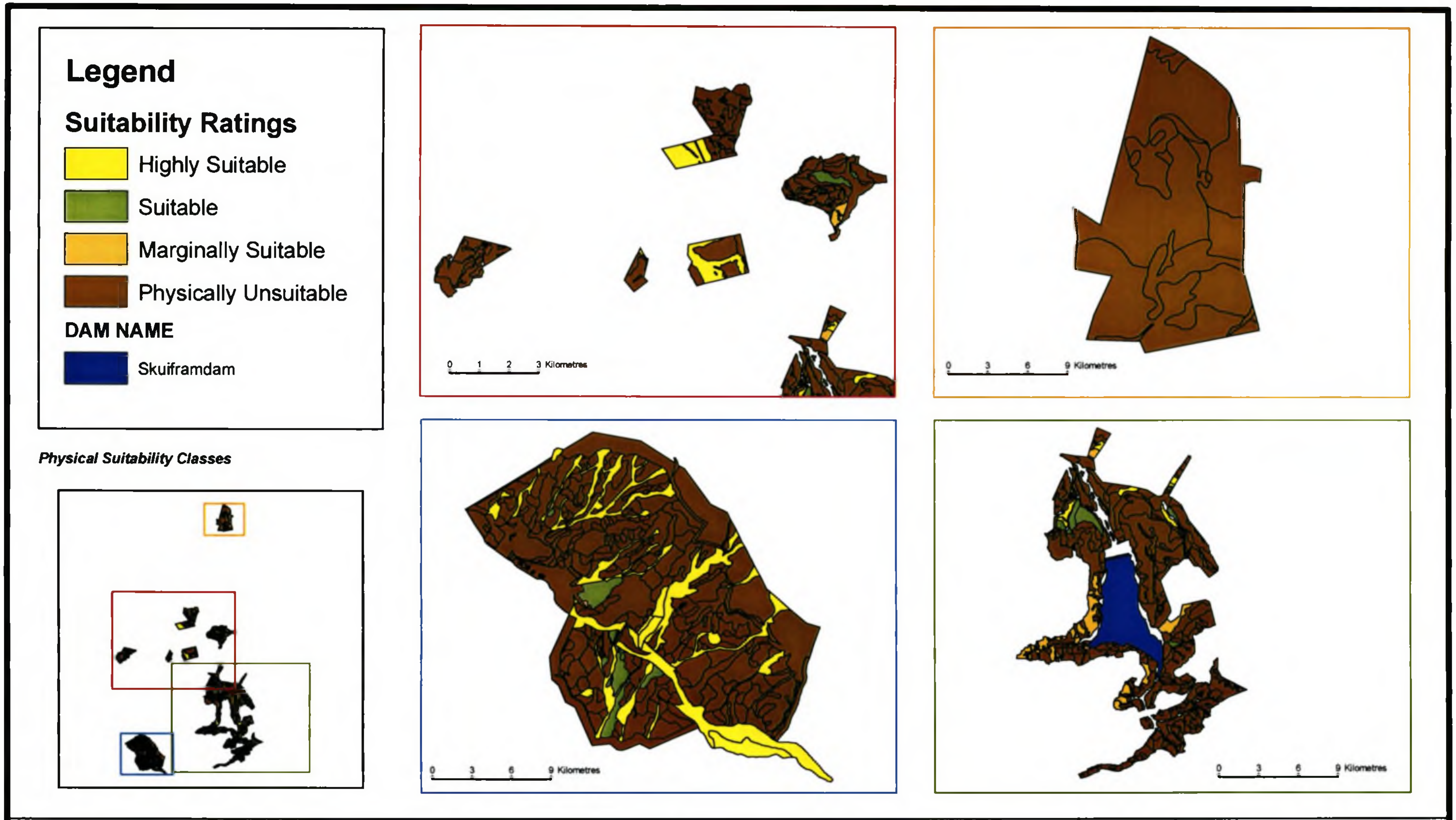

Figure 5.3: Physical suitability for Afromontane forest

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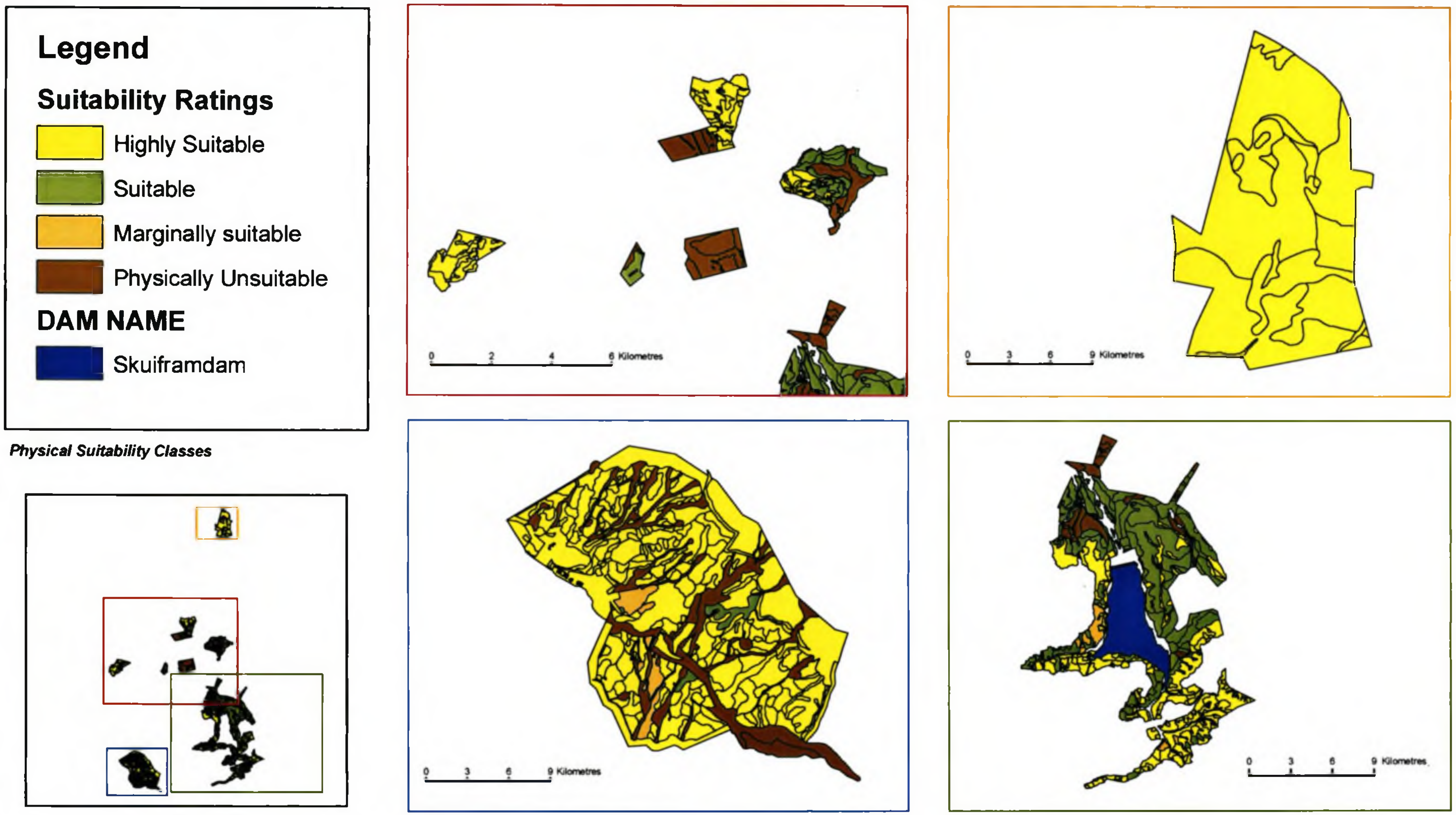

Figure 5.4: Physical suitability for fynbos

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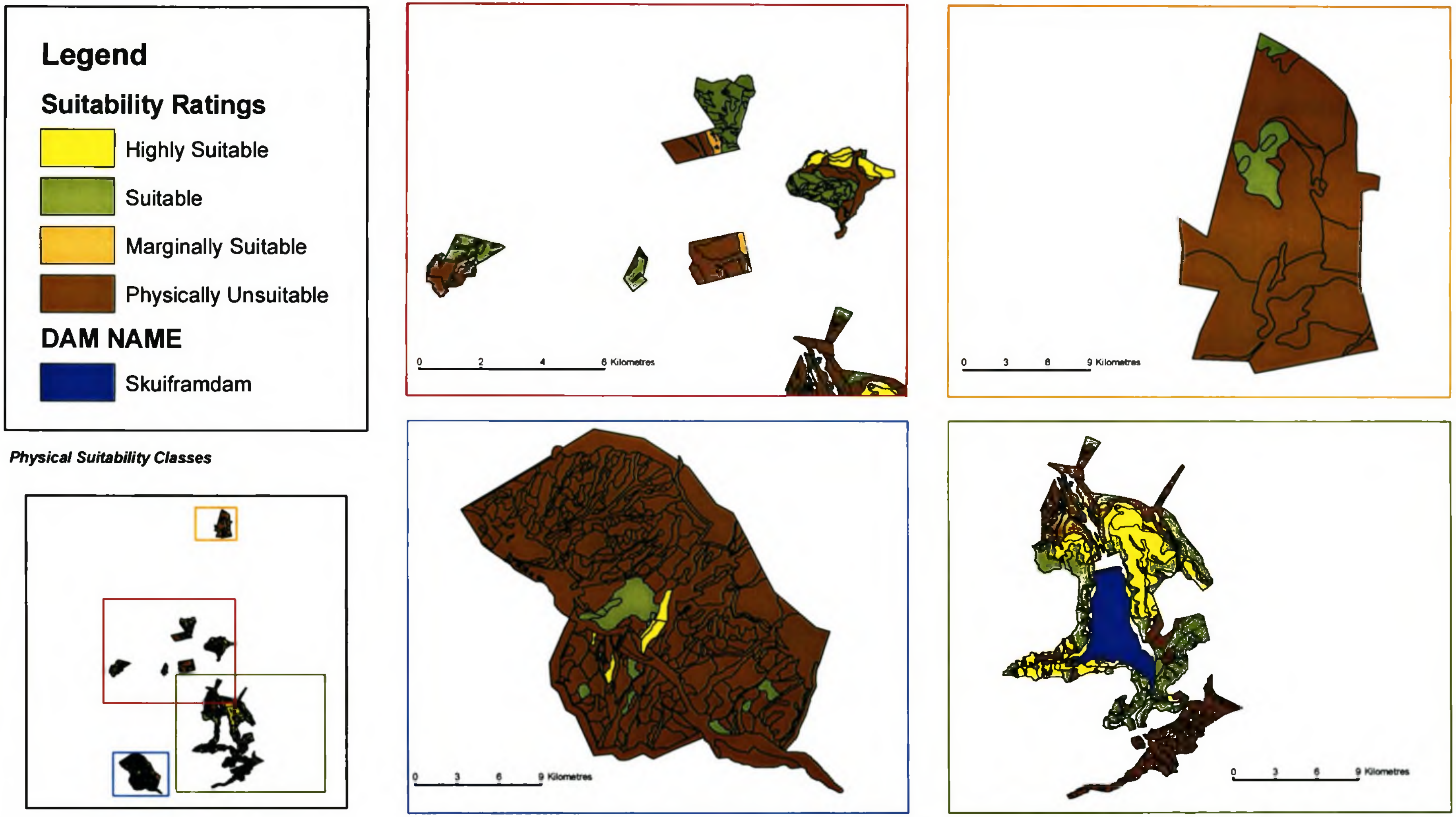

Figure 5.5: Physical suitability for Chardonnay

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relevant land characteristics apply, and 1844 ha of suitable land, where only optimum values of soil types, aspect and terrain types are found. The reasons for such a large suitable area are the high number of soil types that can produce high-category quality grapes (seven in total) and the variety of terrain types where Chardonnay can be planted (from middle-low slopes to footslopes). Many of the land units in the study area combine these soil and terrain types. Chardonnay prefers cool temperatures and the excessively high temperatures during the growing season are the constraint in the suitable land units (see figure 5.5).

5.3.4 Sauvignon Blanc

It is clear from figure 5.6 that Sauvignon Blanc is the vine that grows the best in the study area. Its suitability distribution is similar to Chardonnay's, but with more highly suitable land unit ratings. The determining factors that explain the increase in high suitability are soil type and aspect. There are more soil types that produce high-quality category grapes for Sauvignon Blanc than for Chardonnay and at the same time most of the soils in the study area belong to these soil types. On the other hand, Sauvignon Blanc (like Chardonnay) not only prefers southern aspects but also western aspects. There are 1890 ha of highly suitable land, where all optimum land characteristic values apply, and 1638 ha of suitable land, where high temperatures during the growth season are a constraint.

5.3.5 Merlot

In this case the situation is highly comparable with that for Chardonnay (see figures 5.5 and 5.7). Their land-use requirements are so similar that the suitability distribution is practically the same. Again almost half of the study area is suited and the difference between the two vines occur on the cooler southern slopes, which Merlot prefers, where a few more soil types produce high-quality category Merlot grapes. There are 930 ha of highly suitable land, where all optimum land characteristic values apply, and 1566 ha of suitable land, where high temperatures during the growth season are a constraint.

5.3.6 Shiraz

Referring to figure 5.8, it can be seen that Shiraz can only be planted in the north-western parts of Block A, where there are only 25 ha of highly suitable and 131 ha of suitable land. Two factors can explain the low suitability of the study area for this vine, namely soil type and terrain. The only soil type that produces high-quality category Shiraz grapes in the study area is Kroonstad. As far as terrain is concerned, these vines must grow only on the lower slopes (footslopes) and the

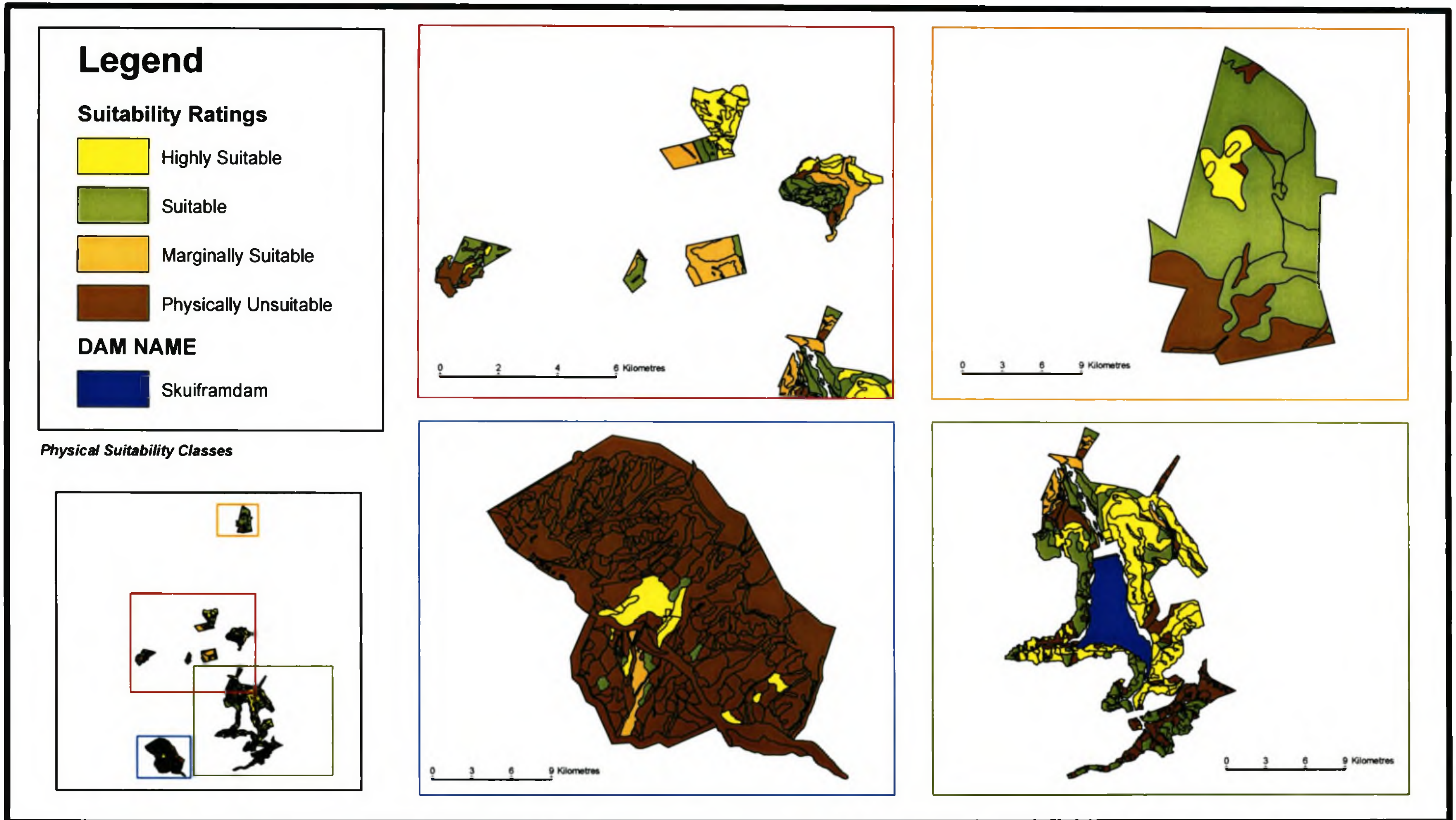

Figure 5.6: Physical suitability for Sauvignon blanc

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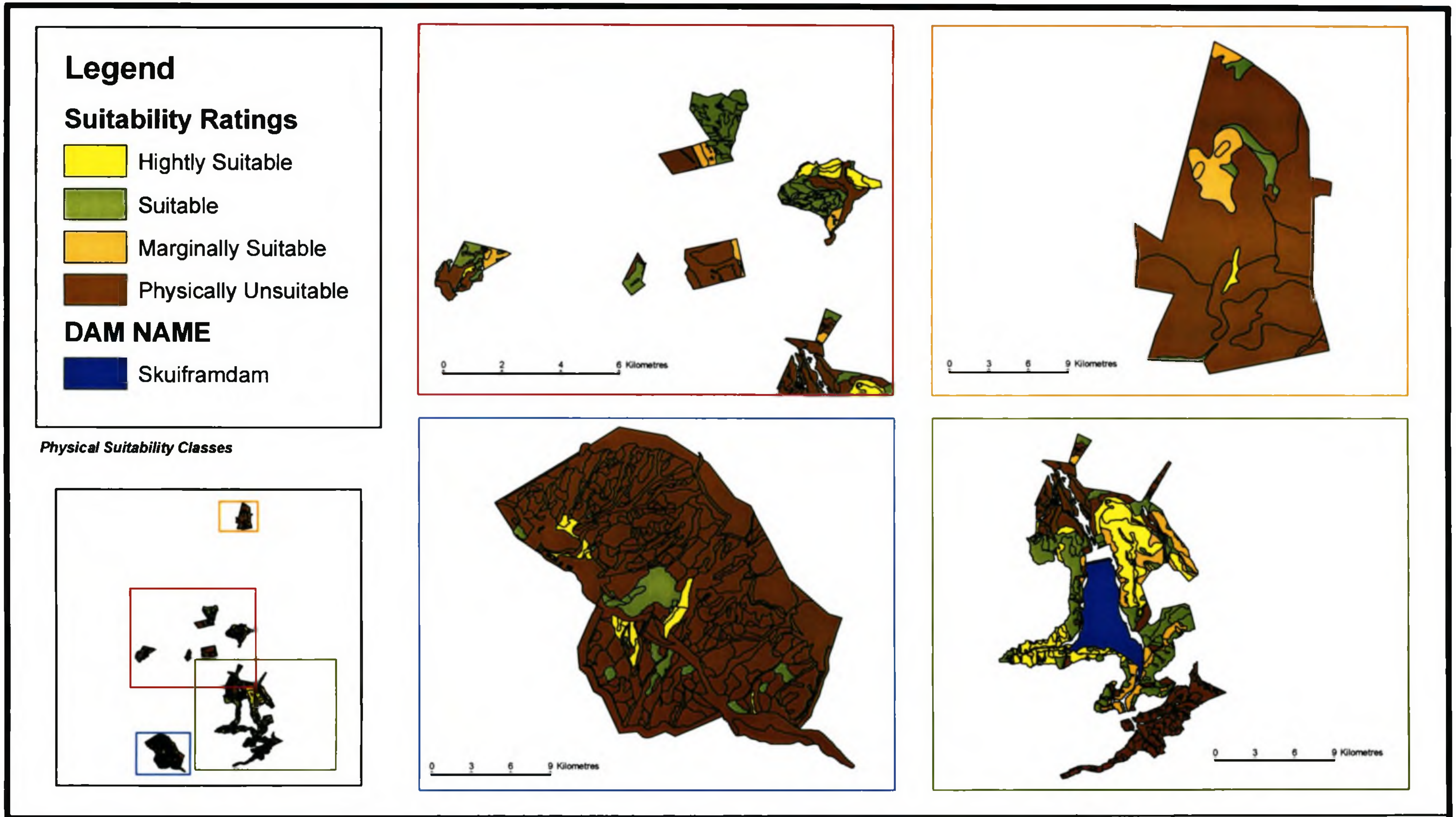

Figure 5.7: Physical suitability for Merlot

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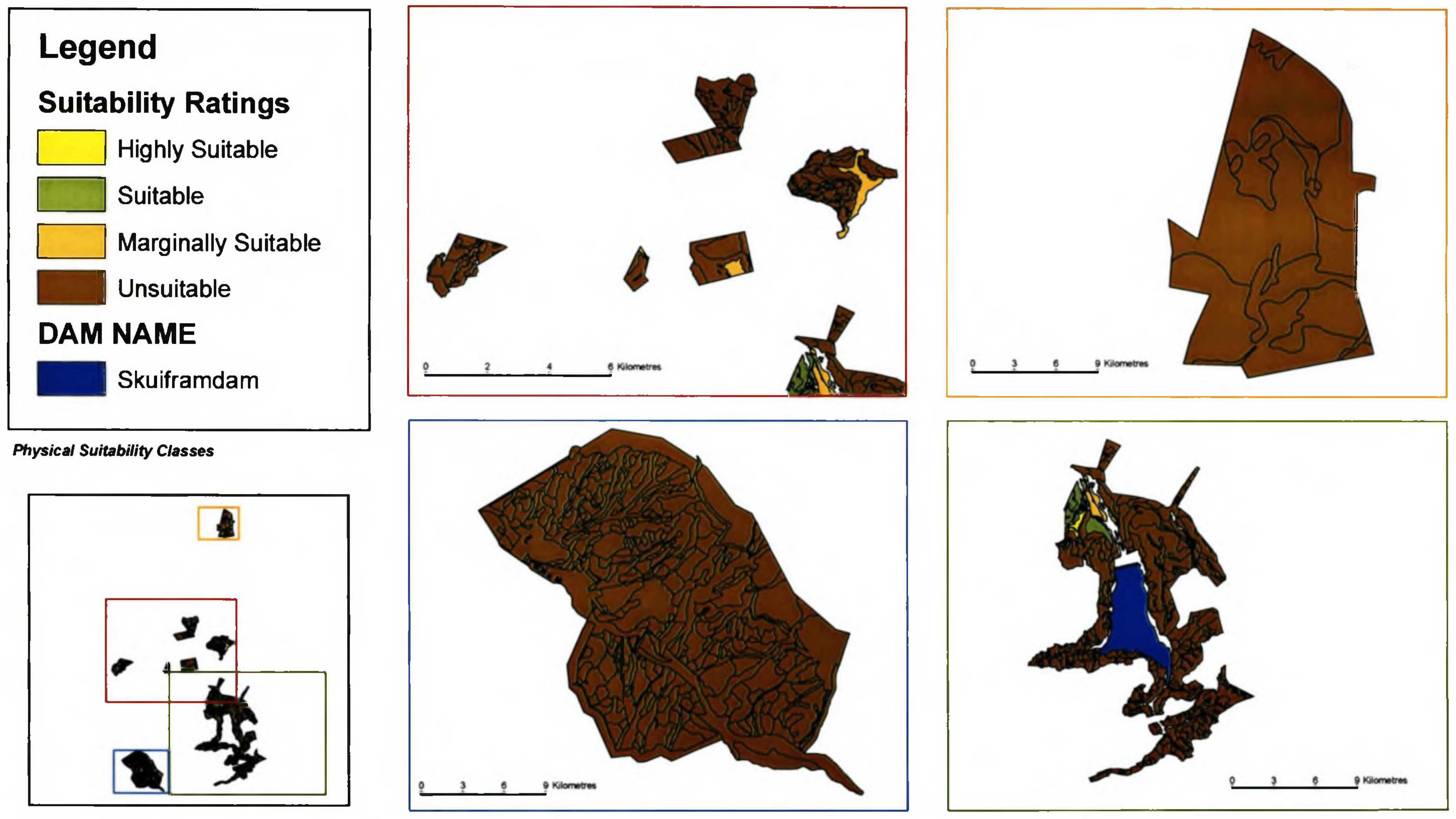

Figure 5.8: Physical suitability for Shiraz

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combination of these two factors is therefore found in a relatively small number of evaluation units. Most of the red vines are preferably planted on the lower slopes, because this plays an important role in colour formation.

5.3.7 Pinotage

There is no highly suitable land for Pinotage in the study area, which presents only 154 ha of suitable terroir in the north-western part of Block A and north of Block B (see figure 5.9). The reason that such a small area can be used for the plantation of Pinotage can be attributed to the specific vine requirements. No soil types produce high-quality category Pinotage grapes in the study area and at the same time only a few of the land units with good-quality category soil types combine northern, eastern or western aspects, middle-low slopes and high average day temperatures during the growing season.

5.3.8 Cabernet franc

figure 5.10 shows only two land units highly suitable for Cabernet franc, with a total of 28 ha in Blocks A and B. The reason for such a small highly suitable area can be attributed to the restrictive vine requirements. Unlike Chardonnay, Merlot or Sauvignon Blanc, only four soil types produce high-quality category Cabernet franc grapes. The rest of the soil requirements are also very limiting: north is the only suitable aspect; the terrain can only be a midslope and the vine requires high temperatures during the growing season. Suitable terroir is found in parts of Blocks A, B and C, south of Block F, west of Block H and north of Block K, giving a total of 137 ha. These areas have soils that produce high-quality grapes, but they are not situated on the midslopes or soils that just produce good category grapes (B).

5.3.9 Cabernet sauvignon

The situation in this case is comparable with that for Cabernet franc. Their land use requirements are so similar that Cabernet sauvignon shows more or less the same distribution (see figure 5.11). Again only a few land units (25 ha) are highly suited, but more are classified as suitable (1234 ha). The difference between the two vines lies in the soil types that produce quality category A and B grapes. Cabernet sauvignon, like Cabernet franc, shows the typical needs of a red vine, which prefers the warmer northern slopes to grow.

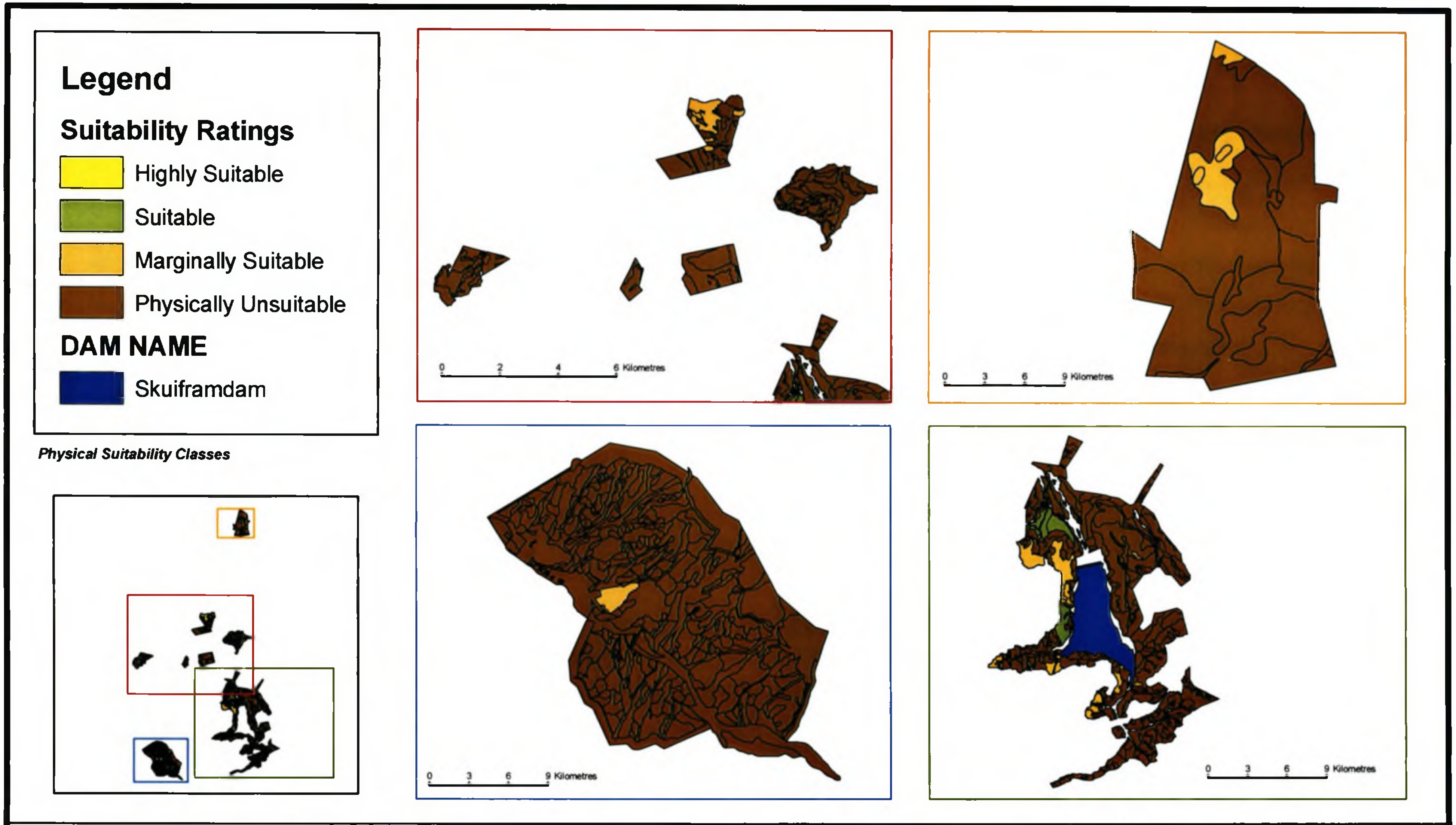

Figure 5.9: Physical suitability for Pinotage

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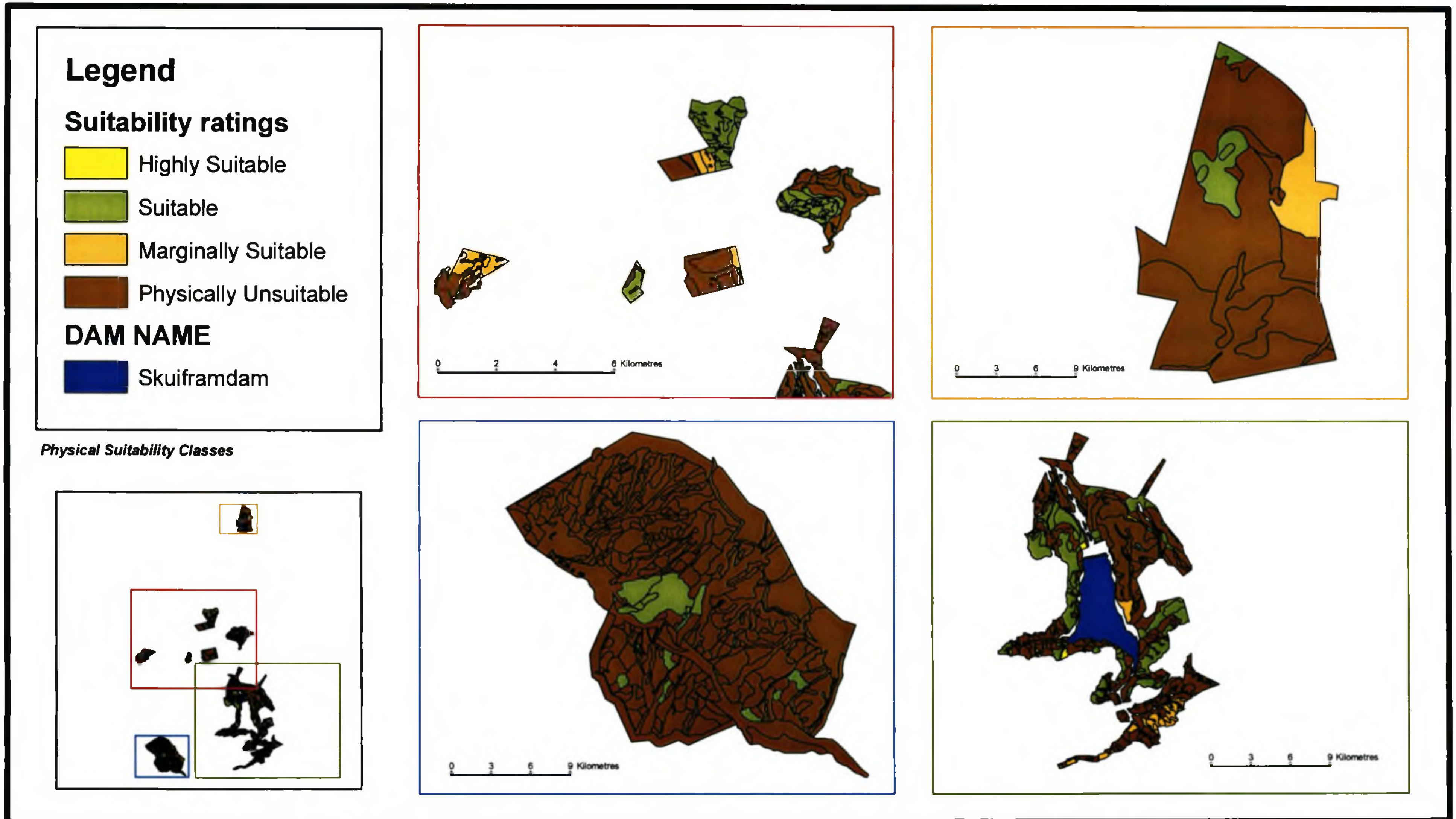

Figure 5.10: Physical Suitability for Cabernet franc

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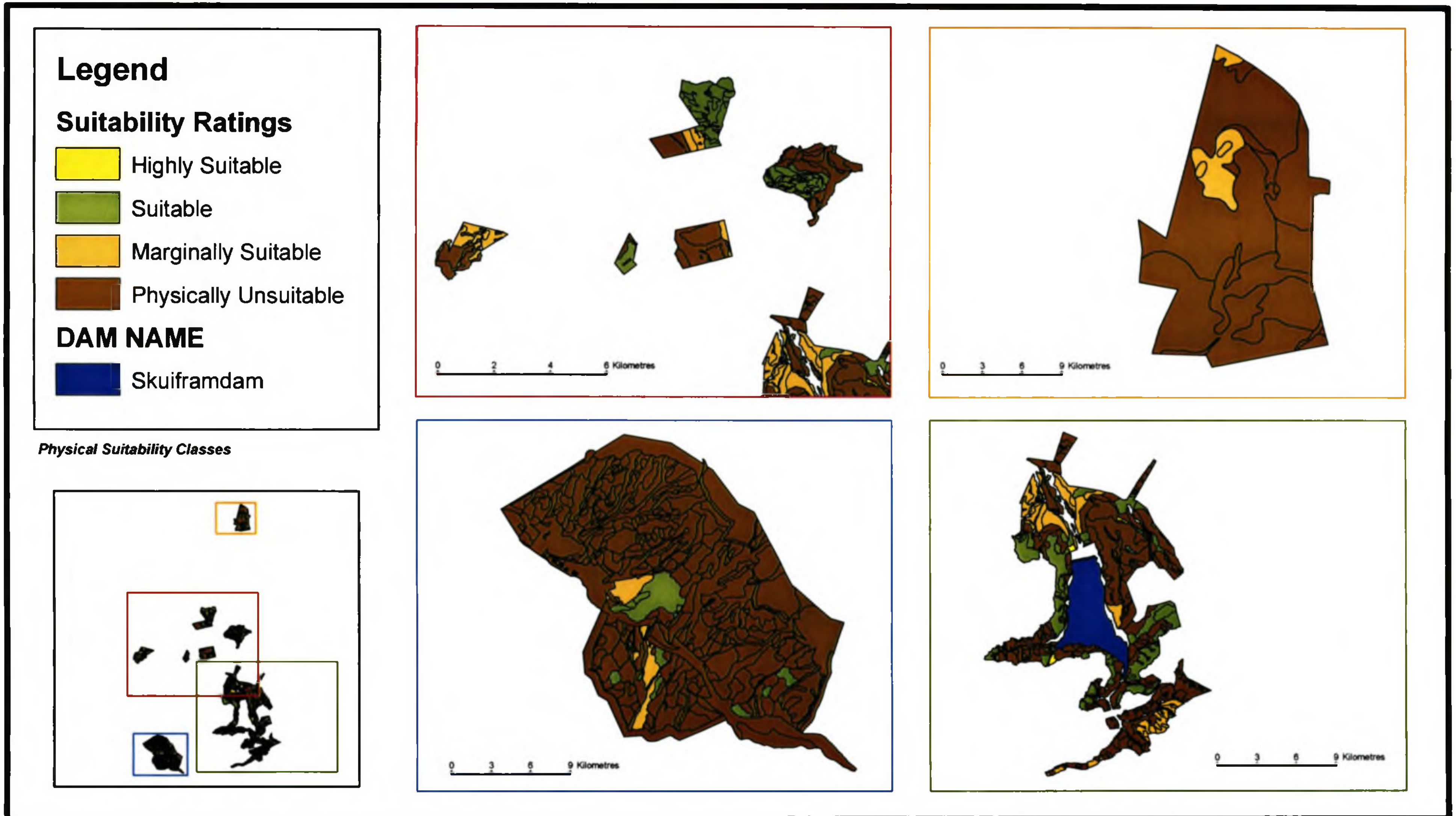

Figure 5.11: Physical suitability for Cabernet sauvignon

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5.3.10 Apples (Malus domestica)

Apples present only 133 ha of highly suitable and 154 ha of suitable terroir in scattered patches in Blocks A, B , M, Z and L and north of Block E (see figure 5.12). The reason that only such a small area can be used for the plantation of apples can be attributed to two of its land-use requirements, namely soil depth and temperature. They prefer deep soils with cool average daily temperatures during the growing season and the combination of these two factors is found only on a relatively small area.

5.3.11 Pears (Pyrus communis*)*

Pear farming is the most effective land utilisation type in that they will grow the best in the study area (see figure 5.13). The reason for such highly suitable acreage ratings is the fact than most of the study area combines Magwa, Hutton or Clovelly soils, middle or footslopes and medium or shallow deep soils. There are 3142 ha of highly suitable land, where all the optimal land characteristic values apply, and 122 ha of suitable land, where the best yield soils present middle or footslopes with shallow depths. Also the valley bottoms with medium depth soils and good yield soils combined with middle and footslopes with medium depth soils were rated as suitable.

5.3.12 Peaches (Prunus persica)

In the case of peaches the situation is comparable with that for citrus. Figure 5.14 shows that best suited areas are in north of Blocks A and E and in central areas of Blocks B, H and L. There are 103 ha of highly suitable land, where all optimum land characteristic values apply, and 466 ha of suitable land with optimum soil and terrain type or soil type and depth. The reason that only such a small area can be regarded as highly suitable can be attributed to the specific restricted requirements of the peach tree. Peaches prefer only mid-slopes with deep soils, reducing the possibility for highly suitable soils. Suitable soils were selected when high-quality category soil types presented the optimum terrain with medium soils or with flood-level terrain and deep soils or when the good-quality category soils presented optimum terrain and deep soil.

5.3.13 Citrus

Figure 5.15 shows that the best terroir for citrus will be in the north of Blocks A and E and central areas of Blocks B, H and L. There are 338 ha of highly suitable land, where all the optimum land characteristic values can be found, and 519 ha of suitable land with optimum soil type and terrain type or soil type and depth. Citrus prefers deep soil, which is not very abundant in this plantation,

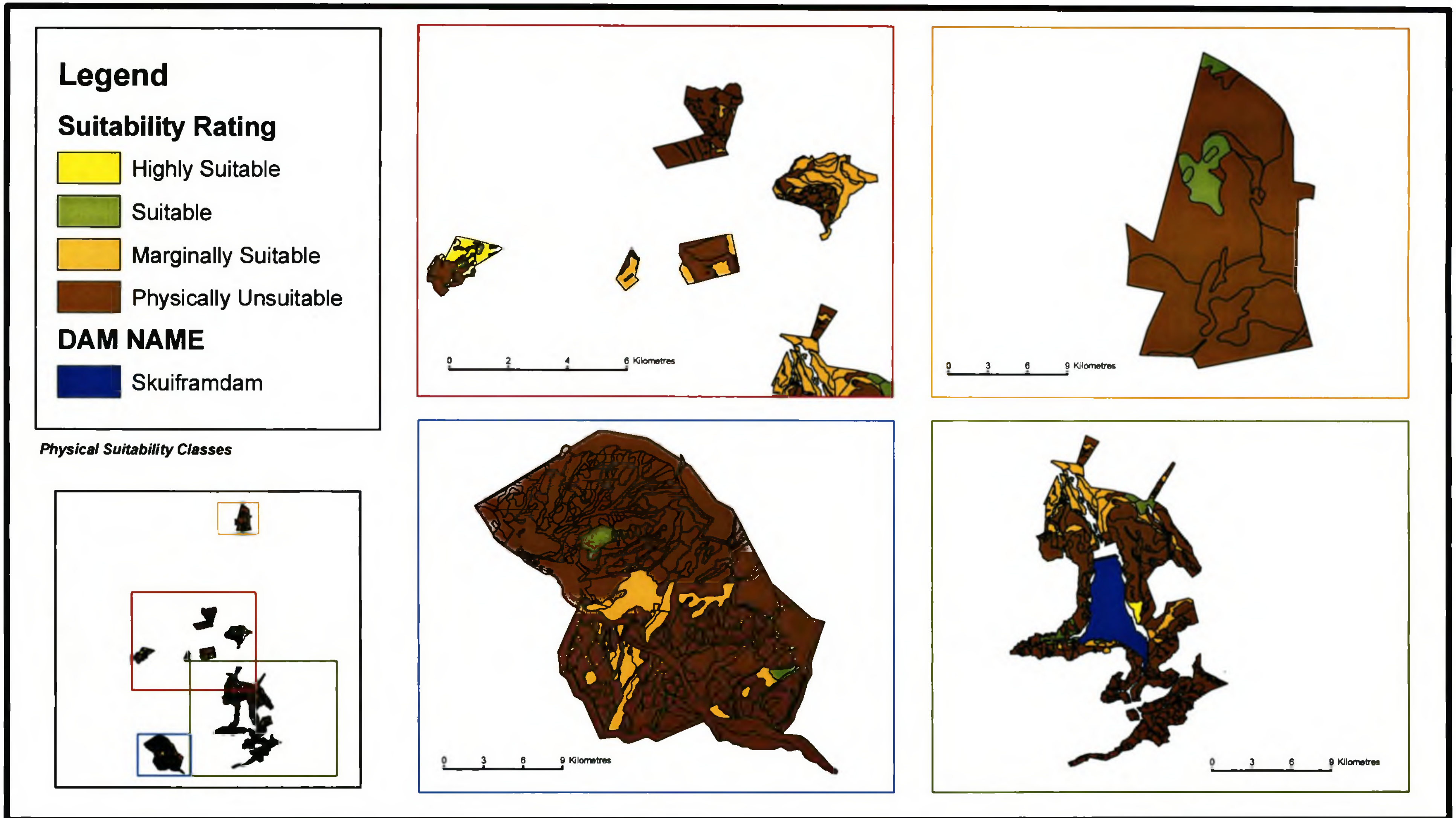

Figure 5.12: Physical suitability for Apples

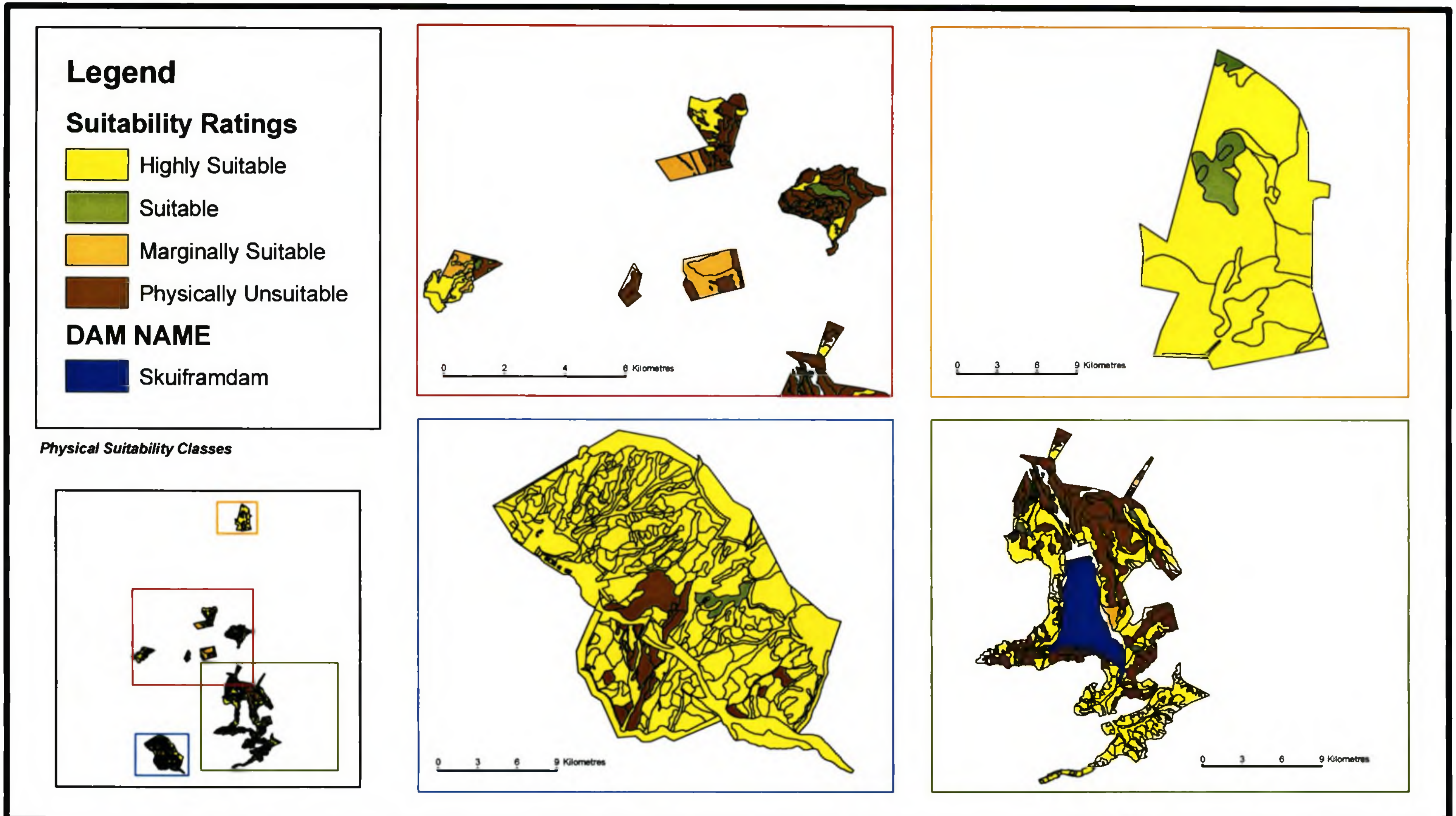

Figure 5.13: Physical suitability for Pears

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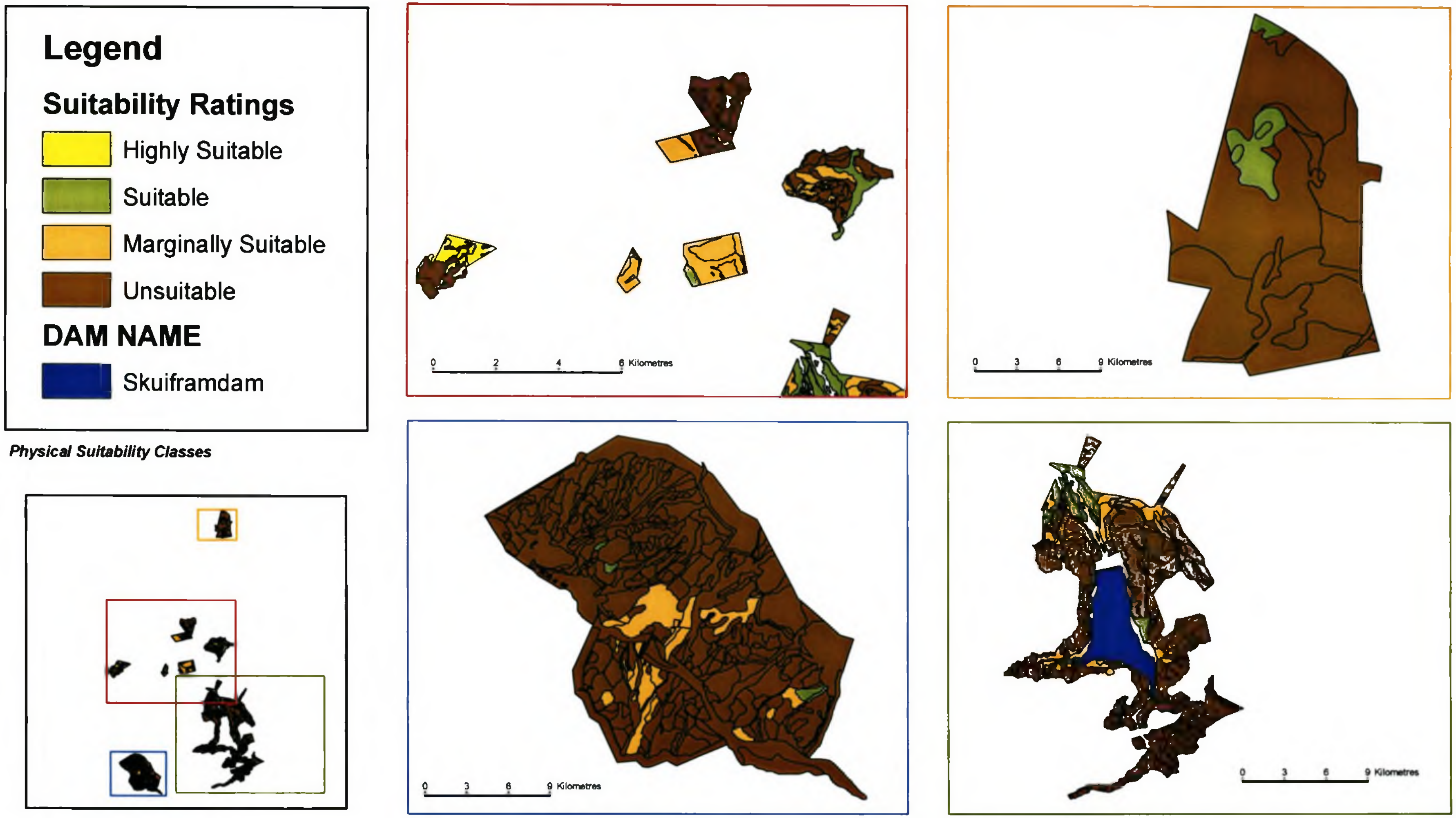

Figure 5.14: Physical suitability for Peaches

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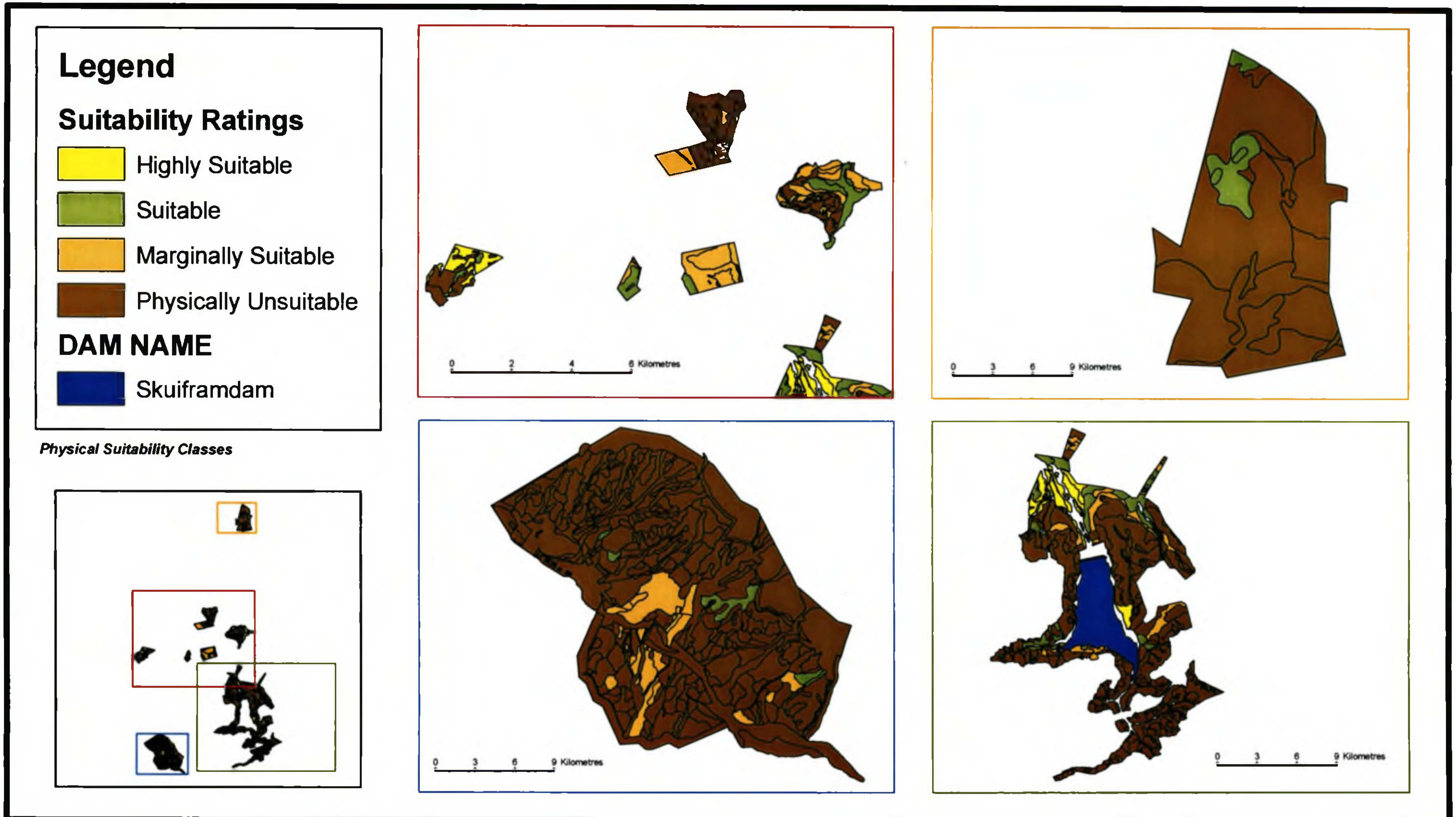

Figure 5.15: Physical suitability for Citrus

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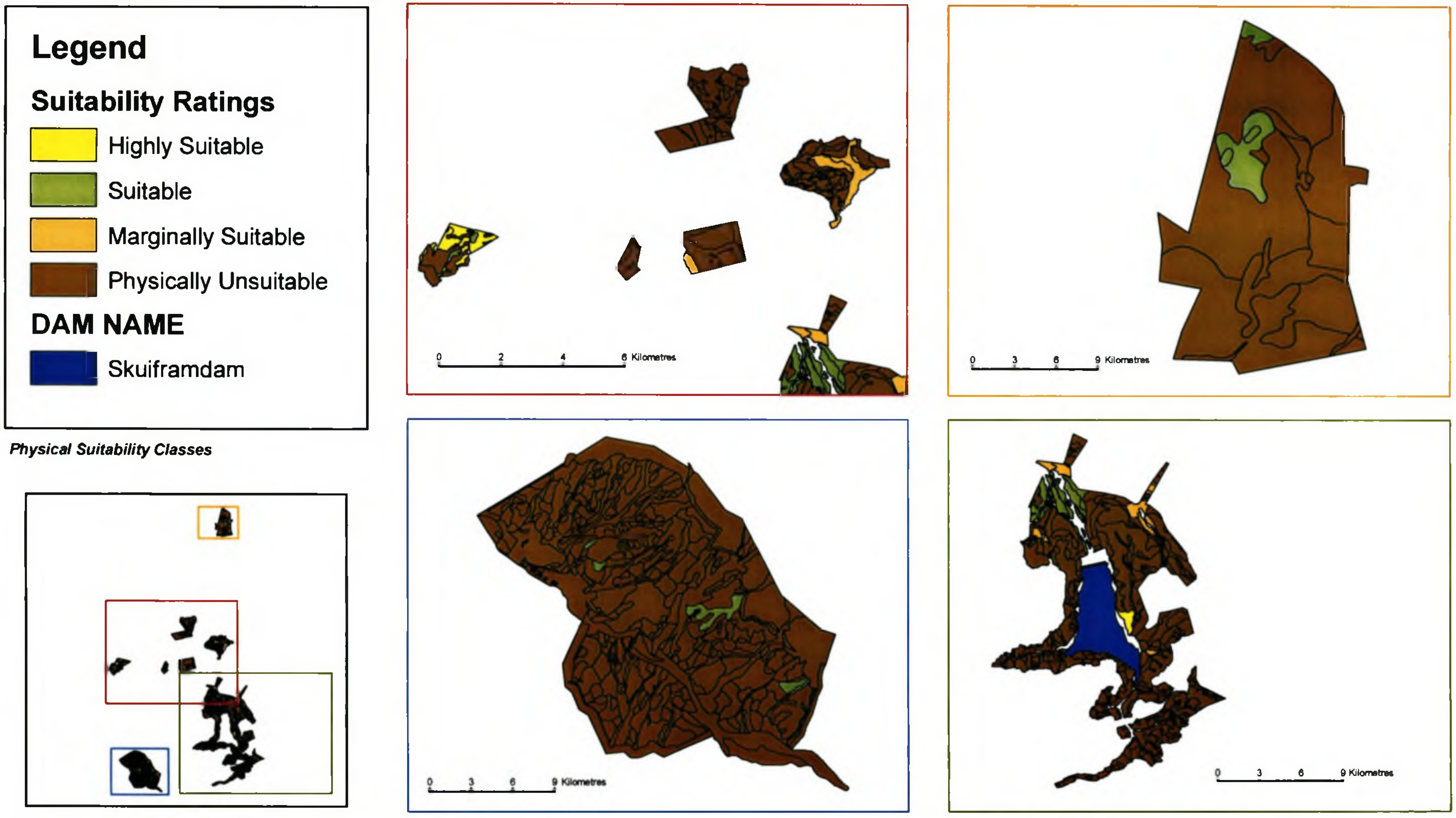

Figure 5.16: Physical suitability for Plums

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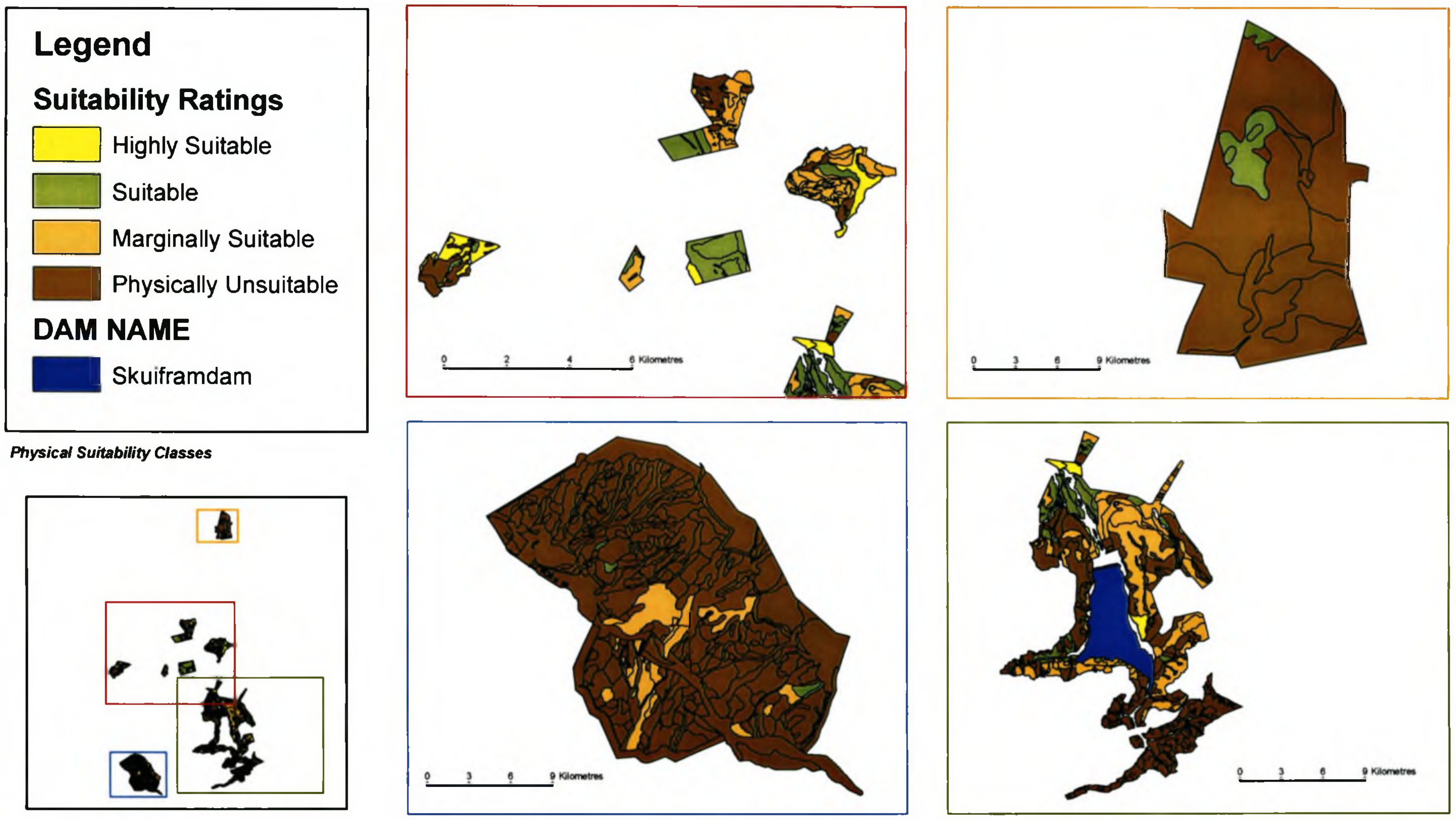

Figure 5.17: Physical suitability for Olives

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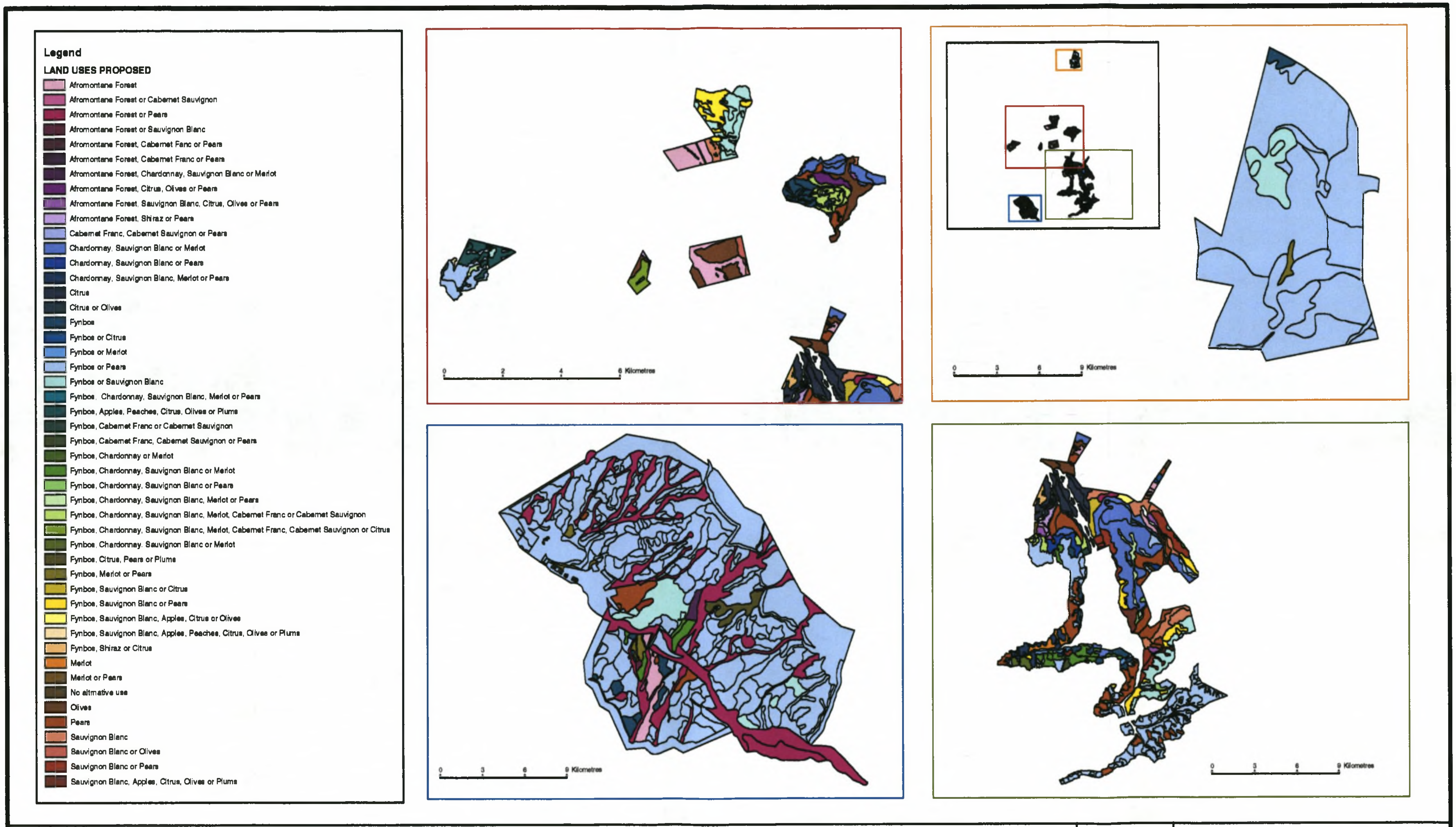

Figure 5.18: Proposed alternative land uses

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reducing the possibilities of highly suitable soils. There are other possible suitable rating combinations in the study area. Suitable soils were also selected when high-quality category soil types presented middle or footslopes with medium deep soils or with valley bottoms and deep soils. Good-quality category soils types with middle and footslopes and deep soils were also rated as suitable.

5.3.14 Plums (Prunu domesticas)

Plums can be grown on 133 ha rated as highly suitable and 275 ha rated as suitable in the north of Block E, north of Block A and scattered land units in Blocks L, M and Z (see figure 5.16). The reason for such a small suitability area can be attributed to the plums' requirement for deep soils, which are difficult to find on the required crest and middle slopes. This leaves footslopes with deep soils as the only combination of terroir that provide the best yields for a high suitability rating and middle or footslopes with medium depth for suitable land units. In the case of soil types that produce good-quality category plums, middle or footslopes with deep soils are the only combination for suitable soils.

5.3.15 Olives (Olea europea)

Olives and citrus have very similar requirements. According to figure 5.17, it can be determined that olives will thrive best in Blocks G and J, the central areas of Blocks B, H and L and north of Blocks A. There are 286 ha of highly suitable land, where all optimum land characteristic values apply, and 749 ha of suitable land with optimum soil and terrain type or soil type and depth. The reason for the small area of land with a highly suitable rating is the requirement of olives for deep soil, of which there is not much in the study area. There are more possible suitable rating combinations in La Motte plantations that explain the higher number of allocations. Suitable soils were selected when the high-quality category soil types presented the optimum terrain with shallow and medium soils or when the good-quality category soils presented optimum terrain and deep soils.

Land evaluation is only a part of the land-use planning process. The evaluation process does not in itself determine the land use changes, but provides information for the subsequent activities on the basis of which such decisions can be taken. Figure 5.18 details the proposed alternative land used for each land evaluation unit for future implementation by the new landowners.

CHAPTER 6: EVALUATION OF APPLICATION SUCCESS

The main objective of this research study was to develop a more detailed evaluation process that elaborates on the land uses previously proposed by SAFCOL and which is site-specific in terms of the type of agricultural system to be used on specific areas, or the type of indigenous vegetation to be restored in conservation areas. This section details how the objectives of this research were achieved.

6.1 TECHNIQUE DEVELOPMENT

A tendency noticed in several wine regions like Bordeaux in France, the Napa valley in California and the Rioja region in Spain is the considerable differences in climate and soil within a region and even between vineyards bordering one another. Coupled with this are the drastic differences in requirements of the vine cultivars and deciduous fruits in the different regions. These variations gave rise to the idea that there are different terriors.

For this reason the study developed a methodology whereby such terriors can be identified with a GIS for the optimal selection of alternative land uses such as deciduous fruits, wines and natural vegetation for an area currently under forestry, namely La Motte plantation. Apart from the fact that a method had to be found to reach this goal, it was also necessary to demonstrate this approach practically. The methodology encompassed two steps: the first part entailed determining a theoretical basis to work from and the second step entailed the practical implementation of the theory. The value of the study lies primarily in the fact that the findings can be applied to any SAFCOL plantation.

6.2 THEORETICAL BASIS

This process involved the identification of a set of natural factors or land-use requirements through a precise description of the agricultural systems or natural vegetation to determine the relationships between land use requirements and local land characteristics. The factors distinguished from the literature were: a) Soil type and form, b) Soil moisture, c) Slope, d) Aspect, e) Terrain type, f) pH and Na, g) Al levels, Acidity and % Silt, and h) Temperature. The environmental factors were identified because they play a role in the selection of optimal terroir for the planting of the selected land utilisation types. Chapter 4 illustrates the way each of the factors has a bearing on the land uses and was critical in the successful completion of the study. This allowed a distinction to be made between the different land uses in relation to the most suitable terroir.

In this part of the study it became clear which factors had an influence on vine cultivars, deciduous fruits and natural vegetation as well as on how the needs of the land uses differed taking into account these natural factors.

6.3 PRACTICAL APPLICATION

The Automated Land Evaluation System (ALES) was the computer software used to build the expert system to evaluate land according to the method presented in the FAO (1976) report. The ALES model built in this research study had 15 decision trees (one per land utilisation type-land use requirement conbination) that made up a total of 1678 branches relating land characteristics to severity levels of land qualities. During the computation of an evaluation, ALES attempts to place each map unit into one of the four severity levels of land qualities for each land utilisation type. Physical suitability of each land unit for each land utilisation type was determined by the maximum limitation method. ALES is not a GIS and does not itself display maps. The evaluation result matrix was exported into ArcMap for further optimisation and geographical analysis to enable the spatial representation of the results. After completion, taking into account the theoretical background, optimal land units were identified for the different land uses considered.

The development of a methodology and the improvement of the SAFCOL land evaluation studies were not the only objectives of this research. The opportunity was also used to assess whether the SAFCOL database is sufficient to meet the requirements of a detailed site-specific land evaluation process. The polygon attribute table of the soil coverage provided only a subset of the land characteristics necessary to build and run the model. Fields like soil form, depth, drainage, wetness, terrain type, aspect and climatic information had to be created, because most of the data provided were in a non-digital form. The database was not complete and needs more precise data to improve its effectiveness.

6.4 WIDER APPLICABILITY OF THE METHODOLOGY AND RECOMENDATIONS

The way in which the study was conducted and the methodology followed is important, firstly, because the techniques used here can be applied to any SAFCOL plantation. Secondly, the value of the study is that it addresses one of the big issues in the forestry sector, the phasing out of 15000 hectares of forest in the Boland region and 30000 hectares in the Southern Cape. Furthermore, according to statistics, the availability of agricultural land is too low at present. With the optimal utilisation of available agricultural land, where environmental factors such as soil types, slopes and aspects are taken into account for the cultivation of crop varieties on the best suited terroirs, every farmer and manager plays his part in protecting and preserving the natural resource base by drawing the maximum agricultural potential from the available resources.

Employing land evaluation technology generally provides answers to questions on what land is best suited for certain crop production or natural vegetation, where it is located and why it is considered to be suited. As a computerised realisation of the FAO's framework ALES has proved to be a significant advance in land evaluation. But ALES is not a GIS and does not itself display maps. The linkage of GIS and physical land evaluation methods can substantially improve the usefulness of these tools and would be very functional for future studies. It is strongly recommended that a suitable simple computerised GIS programme be developed for land evaluation / land use planning at detailed level (from regional to farm scale).

It is also recommended that SAFCOL launches a project to collate, validate, transform and enter all their existing data in a non-digital form in order to obtain a complete database for a detail site-specific land evaluation process. The search for more precise data must also be part of this project.

In conclusion, it can be said that the researcher endeavoured in this study to develop a methodology that can contribute to better land evaluation and the optimal use of scarce land previously under forestry plantations.

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APPENDIX A: ANALYTIC RECORDS FOR SELECTED FYNBOS COMMUNITIES

In each community description, the species are arranged by life-form groups. The canopy volume of each species is expressed as a percentage of the total for all species; and for each life-form group the total is indicated in bold face. Abbreviations used for leaf type and size are:

BS: broad-sclerophyll
NS: narrow-sclerophyll

Aph: aphyllous
Cup: cupressoid
Eri: ericoid

Gra: graminoid
Lep: leptophyll
Lin; Limear
Mac: macrophyll
Mes: mesophyll
Mic: microphyll

Pin: pinnae or leaflets
Nan: nanophyll
Nee: needle-like
Spi: spiny
Suc: succulent

SITE 1

Brunia nodiflora-Psoralea rotundifolia community, Jonkershoek State Forest

Latitude: 33o59'S **Longitude:** 18o57'E **Elevation:** 490 m **Nearest climate station:** Biesievlei, Jonkershoek

Geology: granite **Soil:** Clovelly form **Age:** 17 years since fire **Total canopy cover:** 95-100%

Structure: Open-scrub **Reference:** enumeration by F.J. Kruger and R.H. Whittaker, October 1975 (see also Werger *et al.*, 1972).

Table A.1: Open-scrub structural formation (mountain fynbos)

	Leaf type and size	% of total canopy volume		Leaf type and size	% of total canopy volume
Evergreen, tall shrubs (>2 m)			Evergreen, caespitose dwarf-shrubs (<25 cm)		
Cupressaceae			Asteraceae		
Widdringtonia nodiflora	(Cup)	0.1	*Helichrysum capitellatum*	BS (Lep)	trace
			H. teretifolium	NS (Lep,Eri)	trace
Proteacea			*Osteospermum tomentosum*	BS (Nan)	trace
Protea neriifolia	BS (Mic)	47.9			
			Ericaceae		
		48.0	*Erica cerinthoides*	NS (Lep, Eri)	trace
Evergreen, mid-height shrubs (1-2m)			Euphorbiaceae		
Anacardiaceae			*Clutia alaternoides*	BS (Nan)	trace
Rhus angustifolia	BS (Nan)	trace			

R. tomentosa	BS (Mic)	trace
Bruniaceae		
Berzelia lanuginosa	NS (Lep)	0.7
Brunia nodiflora	NS (Lep)	43.1
Rosaceae		
Cliffortia cuneata	BS (Nan)	trace
C. polygonifolia	BS (Nan)	trace
C. ruscifolia	BS (Lep, Spi)	0.1
Rubiaceae		
Anthospermum aethiopicum	NS (Lep)	trace
		43.9
Heterotrophic, vascular plants		
Cassythaceae		
Cassytha ciliolata (vine)	NS (Aph)	**trace**
Evergreen, low shrubs (50-100 cm)		
Asteraceae		
Helichrysum crispum	BS (Nan)	trace
Stoebe cinerea	NS (Lep, Eri)	trace
Ebenaceae		
Diospyros glabra	BS (Nan)	trace
Ericaceae		
Erica hispidula	NS (Lep, Eri)	0.5
E. plukenetii	NS (Lep, Eri)	1.2
E. sphaeroidea	NS (Lep, Eri)	trace
Fabaceae		
Podalyria racemulosa	BS (Nan)	trace
Fabaceae		
Psoralea rotundifolia	BS (Nan)	trace
		trace
Evergreen, creeping dwarf-shrubs (<25 cm)		
Rubiaceae		
Galium sp	NS (Lep)	**trace**
Evergreen, mid-height caespitose graminoid herbs (25-100 cm)		
Cyperaceae		
Ficinia grandiflora	NS (Gra)	trace
Tetraria bromoides	NS (Gra)	0.5
T. fasciata	NS (Gra)	0.6
T. fimbriolata	Ns (Gra)	0.3
Poaceae		
Ehrharta sp. E. bulbosa	NS (Gra)	trace
Merxmuellera stricta	NS (Gra)	0.3
Restionaceae		
Hypodiscus albo-aristatus	NS (Aph)	trace
Restio triticeus	NS (Aph)	2.3
		4.0
Evergreen, low caespitose graminoid herbs (<25 cm)		
Cyperaceae		
Ficinia filiformis	NS (Gra)	trace
Liliaceae		
Caesia ecklonіana	NS (Gra)	trace
Poaceae		
Anthoxantum tongo	NS (Gra)	trace

Proteaceae		
Leucadendron salignum	BS (Nan)	0.5
L. spissifolium	BS (Nan)	trace
Selaginaceae		
Agathelpis dubia	NS (Lep)	trace
		2.2
Drought-decidous, low shrubs (50-100 cm)		
LiLiaceae		
Asparagus thubergianus (spinose)	(Lep, Nee)	trace
Montiniaceae		
Montinia caryophyllacea	(Nan)	trace
		trace
Evergreen, low shrubs (25-50 cm)		
Ericaceae		
Blaeria dumosa	NS (Eri, Lep)	trace
Eremia totta	NS (Eri, Lep)	trace
Erica articularis	NS (Eri, Lep)	0.1
E. nudiflora	NS (Eri, Lep)	0.1
Rhamnaceae		
Phylica spicata	BS (Nan)	trace
Rutaceae		
Adenandra marginata	BS (Lep)	trace
Diosma hirsuta	NS (Lep)	0.2
		0.4
Decidous, mid-height geophytes (25-100 cm)		
Merxmuellera rufa	NS (Gra)	trace
Schizaeaceae		
Schizaea pectinata	NS (Aph)	trace
		trace
Deciduous rosette forbs (<25 cm)		
Droseraceae		
Drosera trinervia	(Lep)	trace
Schizaeaceae		
Mohria caffrorum	(Pin, Lep)	trace
		trace
Evergreen forbs (<25 cm)		
Hydrocotylaceae		
Centella sp	NS (Lep)	**trace**
Evergreen, mid-height geophytes (25-100 cm)		
Iridaceae		
Aristea major	BS (Mes)	0.4
Bobartia indica	NS (Gra)	trace
		0.4
Deciduous, low geophytes (<25 cm)		
Iridaceae		
Geissorhiza ovata	(Lep)	trace
Liliaceae		
Dipidax punctata	(Nan)	trace
Liliaceae spp. (3)	(Nan)	trace

Apiaceae					
Lichtensteinia lacera	(Mes-Mac)	trace	Oxalidaceae		
			Oxilis commutata	(Nan)	trace
Asteraceae			*O. eckloniana* var. *sonderi*	(Nan)	trace
Berkheya herbacea	(Mes)	trace	*O. lanata* var *rosea*	(Nan)	trace
Iridaceae			Indeterminate sp.		trace
Gladiolus sp.	(Mic)	trace			
Iridaceae sp	(Mic)	trace			**trace**
Watsonia pyramidata	(Mes)	trace	Low annuals (<25 cm)		
			Asteraceae		
Liliaceae			*Senecio cymbalariaefolius*	(Nan)	**trace**
Trachyandra hirsuta	(Mic)	trace			
Lobeliaceae					
Cyphia volubilis (twiner)	(Lep)	trace			
		trace			

SITE 2

Protea arborea-Rhus angustifolia community, Jonkershoek State Forest

Latitude: 34°00'S **Longitude:** 18°57'E **Elevation:** 285 m **Nearest climate station:** Biesievlei, Jonkershoek

Geology: quartzite colluvium over granite **Soil:** Clovelly form **Age:** 7 years since fire

Total canopy cover: 95% **Precipitation:** 1600 mm yr^{-1} **Reference:** enumeration by F.J. Kruger and R.H. Whittaker, October 1975 (see also Werger *et al.*, 1972). **Structure:** tall shrubland with heath

Table A.2: Tall shrubland with heath formation (mountain fynbos)

	Leaf type and size	% of total canopy volume		Leaf type and size	% of total canopy volume
Evergreen, tall shrubs (>2 m)			Evergreen, low shrubs (25-50 cm)		
Proteacea			Asteraceae		
Protea neriifolia	BS (Mes)	**36.8**	*Elytropappus glandulosus*	NS (Lep, Eri)	0.6
			Helichrysum capitellatum	BS (Nan	trace
Evergreen, mid-height shrubs (1-2 m)			Senecio pubigerus	NS (Lep)	trace
Asteraceae			*S.* sp.	NS (Lep)	trace
Chrysanthemoides monilifera	BS (Mic)	0.1	*Stoebe capitata*	NS (Lep, Eri)	1.6
		trace	*S. spiralis*	NS (Lep, Eri)	0.4
Anacardiaceae					
Rhus angustifolia	BS (Mic)	0.1	Campanulaceae		
R. tomentosa	BS (Mic)	0.1	*Roella ciliata*	NS (Lep)	trace
Celastraceae			Ericaceae		
Maytenus oleoides	BS (Mic)	0.2	*? Baeria ericoides*	NS (Lep, Eri)	trace
			Erica calycina var. *periplocaeflora*	NS (Lep, Eri)	trace
Ebenaceae			*E. imbricata*	NS (Lep, Eri)	trace
Diospyros glabra	BS (Nan)	1.2	*E. nudiflora*	NS (Lep. Eri)	trace
Fabaceae			Euphorbiaceae		
Aspalathus cordata	BS (Nan)	0.1	*Clutia alaternoides*	NS (Nan)	0.3
Rosaceae			Fabaceae		

Cliffortia cuneata	BS (Nan)	0.1
C. pterocarpa	NS (Lep)	0.1
Rubiaceae		
Anthospermum aethiopicum	NS (Lep)	0.2
Santalaceae		
Thesium strictum (partial root parasite)	NS (Lep)	0.2
		2.4
Evergreen, low shrubs (50-100 cm)		
Asteraceae		
Metalasia muricata	NS (Lep, Eri)	trace
Stoebe aethiopica	NS (Lep, Eri)	trace
S. plumosa	(Cup)	3.4
Ursina pinnata	NS (Lep)	2.4
Ericaceae		
Erica bicolor	NS (Lep, Eri)	trace
E. hispidula	NS (Lep, Eri)	trace
E. lucida	NS (Lep, Eri	trace
E. plukenetii	NS (Lep, Eri)	trace
E. racemosa	NS (Lep, Eri)	trace
E. sphaeroidea	NS (Lep, Eri)	0.8
Fabaceae		
Podalyria montana	BS (Nan)	trace
Psoralea obliqua	BS (Nan)	10.3
Proteaceae		
Leucadendron salignum	BS (Nan)	7.1
Aspalathus laricifolius	NS (Lep)	0.3
Podalyria racemulosa	BS (Nan)	0.5
Polygalaceae		
Muraltia heisteria	NS (Lep, Eri)	trace
Rhamnaceae		
Phylica imberbis	NS (Lep, Eri)	0.3
P. spicata	BS (Nan)	0.4
Rutaceae		
Agathosma ciliata	NS (Lep)	2.0
Diosma hirsuta	NS (Lep)	1.5
Santalaceae		
Thesium carinatum	NS (Lep)	trace
Selaginaceae		
Agathelpis dubia	NS (Lep)	0.5
Sterculiaceae		
Hermannia hyssopifolia	NS (Nan)	trace
		8.4
Drought-deciduous, low shrubs (25-50 cm)		
Anacardiaceae		
Rhus rosmarinifolia	(Nee)	**0.5**
Evergreen creeping dwarf-shubs (<25 cm)		
Fabaceae		
Psoralea decumbens	BS (Lep)	trace

		24.0
Drought-decidous, low shrubs (50-100 cm)		
LiLiaceae		
Asparagus thubergianus (spinose)	(Nee)	2.1
Montiniaceae		
Montinia caryophyllacea	(Nan)	1.0
		3.1
Evergreen, caespitose or scapose dwarf-shrubs (<25 cm)		
Asteraceae		
Helichrysum adoratissimum (suffr.)	BS (Nan)	trace
H. rutilans (suffr.)	BS (Nan)	0.3
H. zeyheri (suffr.)	NS (Lep)	trace
Metalasia cephalotes	NS (Lep, Eri)	trace
Senecio paniculatus	NS (Lep)	trace
Crassulaceae		
Crassula fascicularis	(Lep, Suc)	trace
Mesembryanthemaceae		
Lampranthus leipolditii	(Lep, Suc)	trace
Selaginaceae		
Selago spuria (suffr.)	NS (Lep)	trace
Thymelaeaceae		
Gnidia inconspicua	NS (Lep)	0.3
		0.6
Evergreen,, caespitose graminoid herbs (25-		

P. imbricata	BS (Nan)	trace
Proteaceae		
Protea acaulos	BS (Mes)	1.0
		1.0
Evergreen forbs(<25 cm)		
Asteraceae		
Leontonyx spathulatus	BS (Nan)	trace
Hydrocotylaceae		
Centella flabrata (reptant)	BS (Nan)	0.4
		0.4
Evergreen geophytes		
Asteraceae		
Corymbium glabrum	BS (Mic)	0.3
C. villosum	BS (Mic)	trace
Gerbera crocea	BS (Mic)	0.2
Iridaceae		
Aristea capitata	BS (Mes)	trace
A. spiralis	BS (Mes)	trace
		0.5
Seasonally green geophytes		
Apiaceae		
Lichtensteinia lacera	(Mic)	trace
Apiaceae sp	(Mes)	trace
Asteraceae		
Berkheya herbacea	(Mes, Spi)	trace
Haplocarpha lanata	(Mes)	trace
Droseraceae		

100 cm)			*Drosera trinervia*	(Lep)	trace
Cyperaceae					
Tetraria cuspidata	NS (Gra)	1.5	Geraniaceae		
T. ustulata	NS (Aph)	1.0	*Pelargonium pinnatum*	(Nan)	trace
Poaceae			Iridaceae		
Merxmuellera stricta	NS (Gra)	2.8	*Gladiolus carneus*	(Mic)	trace
Themeda triandra	NS (Gra)	0.8	*G.* sp.	(Mic)	trace
			Ixia sp.	(Mic)	trace
Restionaceae			*Lapeirousia corymbosa*	(Mic)	trace
Restio filiformis	NS (Aph)	trace	*Micranthus alopecuroides*	(Mic)	trace
			Romulea flava	(Mic)	trace
		6.1	*Watsonia pyramidata*	(Mes)	0.7
Evergreen, caespitose graminoid herbs (<25 cm)			Liliaceae		
Cyperaceae			*Albuca canadensis*	(Mic)	trace
Ficinia filiformis	NS (Gra)	0.3	*Baeometra uniflora*	(Mic)	trace
F. nigrescens	NS (Gra)	trace	*Dipidax punctata*	(Nan)	trace
			Lachenalia glaucina	(Mic)	trace
Liliaceae			*L.* sp	(Mic)	trace
Caesia ecklonia	NS (Gra)	trace	Liliaceae sp.	(Nan)	trace
			Trachyandra hirsuta	(Mic)	trace
Poaceae			*T. muricata*	(Mic)	0.2
Cymbopogon marginatus	NS (Gra)	2.1	*Wurmbea* sp.	(Nan)	trace
Eragrostis capensis	NS (Gra)	trace			
Pentaschistis curviflora	NS (Gra)	0.6	Lobeliaceae		
Plagiochloa uniolae	NS (Gra)	0.3	*Cyphia volubilis* (twiner)	(Lep)	trace
Restionaceae			Orchidaceae		
Restio cuspidatus	NS (Aph)	2.9	*Disa* sp	(Mic)	trace
		6.2	Oxalidaceae		
Evergreen, sparingly tufted, more or less rhizomatous graminoid herbs (25-100 cm)			*Oxalis bifida*	(Nan)	trace
			O. commutata	(Lep)	trace
Poaceae			*O. versicolor*	(lep)	trace

Ehrharta calycina	NS (Gra)	0.3
Restionaceae		
Leptocarpus distichus	NS (Gra)	trace
Restio gaudichaudianus	NS (Aph)	6.9
Thamnochortus fruticosus	NS (Gra)	0.3
Decidous forbs with erect or scrambling seasonal leaves (25-100 cm)		
Euphorbiaceae		
Euphorbia genistoides	(Lep)	trace
Geraniaceae		
Pelargonium myrrhifolium	(Pin-Lep)	trace
P. tabulare	(Mic)	trace
		trace
Seasonal rosette forbs (25-100 cm)		
Asteraceae		
Castalis nudicaulis	(Mic)	trace
Dipsacaceae		
Scabiosa columbaria	(Mic)	trace
		trace
Indeterminata spp. (2)	(Nan)	trace
		trace
Annuals		
Asteraceae		
Helichrysum indicum	(Lep)	trace
Ursinia anthemoides	(Lin)	trace
Campanulaceae sp.	(Lep)	trace
Gentianulaceae		
Sebaea exacoides	(Lep)	trace
Iridaceae		
Aristea africa	(Gra)	trace
Poaceae		
Aira cupaniana	(Gra)	trace
Helictotrichon longum	(Gra)	trace
		trace

SITE 3

Willdenowia sulcata-Erica brevifolia community, Jakkalsrivier, Grabouw

Latitude: 34°09’S	**Longitude:** 19°09’E	**Elevation:** 960 m	**Nearest climate station:** Jakkalsrivier
Precipitation: 950 mm	**Soil:** acid Glenrosa	**Age:** 19 years since fire	**Total canopy cover:** 95%
Geology: TM quartzite	**Structure:** graminoid-heath	**Reference:** enumeration by F.J. Kruger, January 1977.	

Tablw A.3: Graminoid-heathland formation (mountain fynbos)

	Leaf type and size	% of total canopy volume		Leaf type and size	% of total canopy volume
Evergreen, mid-height shrubs (1-2 m)			Santalaceae		
Bruniaceae			*Thesium ericaefolium*	NS (Lep)	trace
Berzelia abrotanoides	NS (Lep)	2.2			
					trace
Proteacea			Evergreen, mid-height caespitose graminoid herbs (25-100 cm)		
Leucadendron xanthoconus	BS (Nan)	0.2			
			Cyperaceae		
		2.4	*Chysithrix capensis*	NS (Gra)	trace
Evergreen, low shrubs (50–100 cm)			*Ficinia monticola*	NS (Gra	trace
Bruniaceae			*Tetraria cuspidata*	NS (Gra)	trace
Nebelia paleacea	NS (Lep)	trace	*T. fasciata*	NS (Gra)	0.5
			T. flexuosa	NS (Gra)	22.8
Ericaceae					
Erica brevıfolia	NS (Lep, Eri)	trace	Poaceae		
E. coccinea	NS (Lep, Eri)	0.2	*Ehrharta triscostata*	NS (Gra)	trace
E. lutea	NS (Lep, Eri)	trace	*Pentaschistis colorata*	NS (Gra)	0.6
Fabaceae			Restionaceae		
Cyclopiab falcata	BS (Lep)	trace	*Hypodiscus aristatus*	NS (Gra)	trace
			Staberoha cernua	NS (Gra)	trace
Iridaceae			*Thamnochortus similis*	NS (Gra)	trace

Klattia partita	BS (Nan)	0.3
Penaeaceae		
Penaea mucronata	BS (Lep)	0.9
Proteaceae		
Protea speciosa	BS (Mes)	0.4
P. cynaroides	BS (Mes)	trace
		8.2
Evergreen, low shrubs (25-50 cm)		
Asteraceae		
Euryops abrotanifolius	NS (Pin-Lep)	trace
Helichrysum cymosum (suffr.)	BS (Nan)	trace
Ericaceae		
Aniserica gracilis	NS (Lep, Eri)	0.7
Blaeria dumosa	NS (Lep, Eri)	trace
Erica hispidula	NS (Lep, Eri)	36.4
E. transparans	NS (Lep, Eri)	0.1
Fabaceae		
Aspalathus marginata	BS (Lep)	trace
Proteaceae		
Leucadendron spissifolium	BS (Nan)	0.3
Selaginaceae		
Agethelpis dubia (Suffr.)	NS (Lep)	trace
Rhamnaceae		
Phylica sp. cf. *P. diffusa*	NS (Lep, Eri)	0.7
		23.9
Evergreen, mid-height sparingly tufted, more or less rhizomatous graminoid herbs (25-100 cm)		
Poaceae		
Festuca scabra	NS (Gra)	trace
Restionaceae		
Chondropetalum deustum	NS (Aph)	1.2
Elegia racemosa	NS (Aph)	9.9
Leptocarpus esterhuyseniae	NS (Aph)	trace
L. membranaceous	NS (Aph)	7.5
Restio dispar	NS (Aph)	2.0
Willdenowia sulcata	NS (Aph)	trace
		20.6
Evergreen, low caespitose graminoid herbs (<25 cm)		
Cyperaceae		
Tetraria exilis	NS (Gra)	trace
Poaceae		
Ehrharta setacea	NS (Gra)	0.2
Schizaeaceae		
Schizaea pectinata	NS (Aph))	1.0
		1.2
Evergreen, low sparingly tufted more or less rhizomatous graminoid herbs (<25cm)		
Liliaceae		

		38.2
Evergreen, creeping dwarf shrubs (<25 cm)		
Ericaceae		
Erica krugeri	NS (Lep, Eri)	trace
Fabaceae		
Argyrolobium lunatis	BS (Nan)	trace
Indigofera gracilis	BS (Lep)	trace
		trace
Evergrenn, caespitose dwarf shrubs (<25 cm)		
Asteraceae		
Helichrysum felinum (suffr.)	BS (Nan)	trace
H. pinifolium (suffr.)	NS (Lep, Eri)	trace
Senecio umbellatus (suffr.)	NS (Lep)	trace
Ursinia dentata (suffr.)	NS (Pin-Lep)	trace
Euphorbiaceae		
Clutia polygonoides	NS (Lep)	trace
Myricaceae		
Myrica kraussiana	BS (Mic)	trace
Polygalaceae		
Muraltia hyssopifolia	NS (Lep)	trace
Rutaceae		
Agothosma bifida	NS (Lep)	trace
Thymelaeaceae	NS (Lep)	trace
Gnidia linearifolia		
Evergreen, mid-height geophytes (25-100		
Caesia sp.	NS (Gra)	trace
Poaceae		
Merxmuellera rufa	NS (Gra)	trace
		trace
Deciduos rosette forbs (<25 cm)		
Droseraceae		
Drosra aliceae	(Nan)	**trace**
Evergreen forbs(<25 cm)		
Asteraceae		
Osmitopsis afra	BS (Lep)	0.5
Senecio erubescens	(Mic)	trace
Campanulaceae		
Prismatocarpus nitidus	(Lep)	trace
Lobeliaceae		
Lobelia coronopifolia	BS (Lep)	trace
		0.5
Seasonally green, mid-height geophytes (<25-100 cm)		
Iridaceae		
Gladiolus brevitubus	(Mic)	trace
G. sp.	(Mic)	trace
Watsonia pyramidata	(Mes)	4.5
		4.5
Evergreen, low geophytes (<25 cm)		
Asteraceae		

cm)			*Gerbera tomentosa*	BS (Mic)	trace
Haemodoraceae			*Mairia crenata*	BS (Mic)	trace
Dilatris viscosa	(Mic)	trace			
			Hydrocotylaceae		
Iridaceae			*Hermas capitata*	BS (Nan)	trace
Aristea spiralis	(Mic)	trace	*H. ciliata*	(Mic)	trace
		trace			**trace**
Seasonally green, low geophytes (<25 cm)					
Oxalidaceae					
Oxalis sp.	(Nan)	**trace**			

SITE 4

Latitude: 34°00'S **Longitude:** 19°01'E **Elevation:** 1234 m **Nearest climate station:** Biesievlei, Jonkershoek

Precipitation: 3330 mm **Soil:** Champagne **Age:** 35 years since fire **Total canopy cover:** 95-98%

Geology: TM quartzite **Reference:** enumeration by F.J. Kruger and R.H. Whittaker, October 1975 (see also Werger *et al.*, 1972).

Structure: closed-herbland

Table A. 4: Tall closed-herbland communities. Dwarsberg, Jonkershoek (mountain fynbos)

	Leaf type and size	% of total canopy volume		Leaf type and size	% of total canopy volume
1. Chondropetalum esterhuyseniana community			**3. Epischoenus adnatus community**		
Evergreen, tall caespitose graminoid herbs (>100 cm)			Evergreen, mid-height caespitose graminoid herbs (25-100 cm)		
Restionaceae			Cyperaceae	NS (Aph)	17.8
Chondropetalum esterhuyseniana	NS (Aph)	**100.0**	*Epischoenus adnatus*		
			Poaceae		
Low, deciduous geophytes (< 25 cm)			*Ehrharta setacea*	NS (Gra)	13.4

Oxalidaceae					
Oxalis sp. Cf. *O. commutata*	(Nan)	**trace**	Restionaceae		
			Hypolaena crinalis (hummocks)	NS (Aph)	66.8
			Restio echinatus	NS (Aph)	trace
2. Elegia intermedia community					
					98.0
Evergreen, tall caespitose graminoid herbs (>100 cm)			Evergreen, mid-height rosette forbs (25-100 cm)		
Restionaceae			Asteraceae		
Elegia intermedia	NS (Mic)	**98.2**	*Senecio crispus*	(Mic)	**2.00**
Evergreen, mid-height caespitose graminoid herbs (25-100 cm)			Evergreen, low caespitose graminoid herbs (<25 cm)		
Restionaceae			Poaceae		
Hypolaena crinalis (hummocks)	NS (Aph)	**1.8**	*Pentaschistis* sp.	NS (Gra)	**trace**
Evergreen, mid-height rosette forbs (25-100 cm)					
Asteraceae					
Senecio crispus	(Mic)	trace			

APPENDIX B: SOIL GROUPS IN LA MOTTE PLANTATION

Table B.1: Soil groups and forms of the taxonomical system

SOIL GROUP	DESCRIPTION	SOIL FORMS OF THE TAXONOMICAL SYSTEM
	Red and yellow apedal soils	
Aa	Undifferentiated humic	Kp Ma Ia Lu Sr No
Ab	Red dystrophic	Hu
Ad	Yellow dystrophic	Gf Cv
Al	Yellow humic	Kp Ma
An	Humic with neocutanic subsoils	Sr
	Hydromorphic soils	
Cb	E horizon hydromorphic	Kd Lo Wa
Cc	Non-E horizon hydromorphic	Ka We
	Lithosols	
Fb	Soft lithocutanic	Cf Gs
Fc	Hard lithocutanic	Cf Cg Gs
	Youthful soils	
Hb	Undifferentiated soils with E horizons	Fw Kd Vf Ct Lo
Hc	E horizons over yellowapedal or neocutanic subsoils	Ct Vf Kk
He	Non-red neocutanics	Pr Tr Ag Tu Et Gm Ou Oa Mu Ad Pr Tr Ag Br
Hf	E horizons with high carbon topsoils	Fw
	Miscellaneous land classes	
Ia	Alluvial or colluvial deposits	Du
	Podzols	
Ga	Hydromorphic podzols	Lt Wf
Gb	Non-hydromorphic podzols	Pg Cc
Gc	Lithocutanic podzols	Hh Gk
Ge	Well dranied dry podzols	Ct

APPENDIX C: SOIL FORMS IN LA MOTTE PLANTATION

Table C.1: soil forms diagnostic horizons and materials

SOIL FORM	**DIAGNOSTIC HORIZONS AND MATERIALS**			
	TOPSOIL	**SUBSOIL**		
MAGWA	Humic	Yellow-brown apedal B	Unspecified	
SWEETWATER	Humic	Neocutanic B		
NOMANCI	Humic	Lithocutanic B		
KATSPRUIT	Orthic	G horizon		
KROONSTAD	Orthic	E horizon	G horizon	
LONGLANDS	Orthic	E horizon	Soft plinthic B	
CONSTANTIA	Orthic	E horizon	Yellow-brown apedel B	
LAMOTTE	Orthic	E horizon	Podzol B	Unconsolidated material with signs of wetness
HOUWHOEK	Orthic	E horizon	Podzol B	Saprolite
VILAFONTES	Orthic	E horizon	Neocutanic B	
CARTREF	Orthic	E horizon	Lithocutanic B	
FERNWOOD	Orthic	E horizon	Unspecified	
WESTLEIGH	Orthic	Soft plinthic B		
AVALON	Orthic	Yellow-brown apedal B	Soft plinthic B	
CLOVELLY	Orthic	Yelloe-brown apedal B	Unespecified	
BAINSVLEI	Orthic	Red apedal B	Soft plinthic B	
HUTTON	Orthic	Red apedal B	Unspecified	
PINEGROVE	Orthic	Podzol B	Unconsolidated material without signs of wetness	
GROENKOP	Orthic	Podzol B	Saprolite	
TUKULU	Orthic	Neocutanic B	Unspecified material with signs of wetness	
OAKLEAF	Orthic	Neocutanic B	Unspecified	
GLENROSA	Orthic	Lithocutanic B		
DUNDEE	Orthic	Stratified alluvium		

APPENDIX D: LAND USE REQUIREMENTS FOR THE LAND UTILIZATION TYPES CONSIDERED

Fynbos

Soil moisture: Low levels. Lower levels than forest.

Slope: fynbos usually found on steep slopes, which became less severe to finally level out within the forest

pH and Na: lower in fynbos than forest.

Al levels, acidity and % Silt: higher levels found in fynbos.

S value, Ca, K and Mg: lower in fynbos than forest.

Afromontane Forest

Soil moisture: High levels, higher levels than fynbos.

Slope: less steep terrain

pH and Na: higher within forest than fynbos.

Al levels, acidity and % Silt: tend to be lower inside forest than in fynbos.

S values, Ca, K and Mg: highest with forest.

Chardonnay

Aspect: South.

Soil type and form: best quality with Glenrosa 4, Cartref 5, Avalon 5b, Bainsvlei 5b, Constantia 5b, Hutton 6, 7 & 8, Clovelly 6, 7, & 8; Oakleaf 6, 7 & 8 and Pinegrove 6, 7, & 8.

Terrain: Middle-low slopes to footslopes (4 & 5)

Temperature: from 22 to24 °C.

Sauvignon Blanc

Aspect: South and West.

Soil type and form: best quality with Glenrosa 4, Cartref 5, Avalon 5b, Bainsvlei 5b, Constantia 5b, Hutton 6 & 7, Clovelly 6 & 7, Oakleaf 6 & 7, Pinegrove 6 & 7, Hutton 8, Clovelly 8 and Avalon 8, good quality with Dundee, Fernwood and La motte

Terrain: Midslopes (3 & 4).
Temperature: 20°C

Merlot
Aspect: South.
Soil type and form: best quality with Cartref 5, Avalon 5b, Bainsvlei 5b, Constantia 5b, Villafontes 5b, Tukulu 5b, Hutton 8 and Clovelly 8, good quality with Glenrosa 4, Hutton 6 & 7, Clovelly 6 & 7, Oakleaf 6 & 7 and Pingrove 6.
Terrain: Middle-low slopes to footslopes (4 & 5)
Temperature: 22°C

Shiraz
Aspect: East.
Soil type and form: best quality with Kroonstad 21 and Kroonstad 11.
Terrain: Footslopes (5).
Temperature: from 22 to 28°C.

Pinotage
Aspect: North East, and West.
Soil type and form: good quality with Glenrosa 4, Cartref 5, Avalon 5b, Bainsvlei 5b and Kroonstad 11.
Terrain: Middle-low slopes (4).
Temperature: from 26 to 32°C.

Cabernet Franc
Aspect: North
Soil type and form: best quality with Glenrosa 4, Cartref 5, Avalon 5b, Bainsvlei 5b and Constantia 5b, good quality with Hutton 6 & 7, Clovelly 6 & 7, Oakleaf 6 & 7 and Kroonstad 11.
Terrain: Midslopes (3 & 4).
Temperature: from 26 to 32°C

Cabernet Sauvignon

Aspect: North

Soil type and form: best quality with Cartref 5, Avalon 5b, Bainsvlei 5b and Constantia 5b, good quality with Glenrosa 4, Hutton 6&, Clovelly 6 & 7; Oakleaf 6 & 7 and Kroonstad 11.

Terrain: midslopes (3 & 4).

Temperature: from 26 to 32°C

Apples (Malus domestica)

Soil form: best yields with Glenrosa, Oakleaf, Magwa, Hutton and clovely, good yields with Fermwood, Constantia, Vilafontes, Lamotte, Houwhoek, Dundee and Oakleaf.

Terrain: midslopes and footslopes (3, 4 & 5).

Soil depth: optimal deep soils (>150 cm), absolute medium (50-150 cm).

Drainage: good (dry spells)

Temperature: from 14 to 27°C.

Pears (Pyrus communis)

Soil form: best yields with Magwa, Hutton and clovelly, good yields with Glenrosa, Lamotte, Houwhoek, Dundee and Oakleaf.

Terrain: midslopes and footslopes (3, 4 & 5).

Soil depth: optimal medium soils (50 – 150 cm), absolute shallow (20-50 cm).

Drainage: good (dry spells)

Temperature: from 20 to 35°C.

Peachess (Prunus persica)

Soil form: best yields with Magwa, Hutton, Clovely, Glenrosa, Oakleaf, Lamotte, Houwhoek, Dundeeand and Oakleaf, good yields with Fernwood, Constantia and Vilafontes.

Terrain: midslopes (3 & 4).

Soil depth: optimum deep soils (>150 cm), absolute medium (50-150 cm).

Drainage: good (dry spells).

Temperature: from 20 to 33°C.

Citrus

Soil form: best yields with Magwa, Hutton, Clovely, Glenrosa, Oakleaf, Lamotte, Houwhoek, Dundeeand and Oakleaf, good yields with Fernwood, Constantia and Vilafontes.

Terrain: midslopes and footslopes (3, 4 & 5).

Soil depth: optimal deep soils (> 150cm), absolute medium (50-150 cm).

Drainage: good (dry spells).

Aspect: North-easterly facing position.

Temperature: from 20 to 30°C.

Olives (Olea europea)

Soil form: best yields with Magwa, Hutton, Clovely, Glenrosa, Oakleaf, Lamotte, Houwhoek and Dundee, good yields with Fernwood, Constantia and Vilafontes.

Terrain: midslopes and footslopes and valley bottoms (3, 4, 5 & 6)

Soil depth: optimal deep soils (>150 cm), absolute shallow (50-150 cm).

Drainage: good (dry spells).

Temperature: from 20 to 34°C.

Plums (Prunu domesticas)

Soil form: best yields with Magwa, Hutton, Clovely, Glenrosa and Oakleaf, good yields with Lamotte, Houwhoek, Dunde and Oakleaf.

Terrain: midslopes and footslopes (3, 4 & 5)

Soil depth: Optimal deep soils (> 150cm), absolute (50-150 cm).

Drainage: good (dry spells).

Optimum Temperature: from 18 to 33°C.