Land Suitability Evaluation for Rainfed Agriculture Using GIS: The Case Study of Weenen Nature Reserve, KwaZulu-Natal, South Africa.

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Declaration

The work described in this dissertation was carried out in the Discipline of Geography, School of Applied Environmental Sciences, Faculty of Science and Agriculture, University of Natal, Pietermaritzburg, under the supervision of Dr. Fethi Ahmed.

I hereby state that this thesis is the result of my original work and has not been submitted in any form for any degree or diploma at any other university. Where use has been made of the work of others, it is acknowledge in the text.

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Abstract

Weenen Nature Reserve (WNR) has a long history of unwise land use that resulted in severe overgrazing and soil degradation. Since 1948 several soil conservation and reclamation programs have been undertaken to halt the degradation process and regain the agricultural potential of the area.

This study evaluates the current agricultural potential of the reserve under rainfed cultivation primarily based on climatic, soil, topographic and crop requirement data collected from different sources. Spatial information on each of the land resources parameters was digitally encoded in a GIS database to create thematic layers of the land resources. Crop requirement information on seven different crops that were selected as representative crops under rainfed agriculture in the area namely, maize, Sorghum, cotton, dry bean, soya bean, potato and cabbage was compared with the land resources parameters. The thematic layers of the land resources were then overlyed using a GIS to select areas that satisfy the crop requirements.

The results showed that WNR has two major limitations in relation to its use for rainfed agriculture, namely its shallow and rocky soils and its arid climate. Consequently, the resulting land suitability maps indicate that WNR has very low suitability for all of the crops considered. Dry beans are relatively well adapted to the area followed by sorghum. Maize and soya beans are preferred over cotton. Potatoes and cabbages are least adapted to the area because of the high temperatures during the growing season.

It was concluded that generally the reserve is not suitable for rainfed agriculture. However, there is a small area of land in the northern part of the reserve that can be cultivated. The rugged area in the central part of the reserve can be used for grazing with careful management. The eastern and southern parts can only be used as habitats for wildlife owing to their steep topography and inaccessibility, whereas the highly degraded areas in the western parts of the reserve should be kept under soil conservation and reclamation.

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List of Acronyms

AEC	Agro-ecological Cell
AEZ	Agro-ecological Zone
AFRA	Association for Rural Advancement (South Africa)
ASCII	American Standard Code for Information Interchange
BR	Bioresource
BRG	Bioresource Group
BRU	Bioresource Unit
CAP	Church Agricultural Project (South Africa)
CCWR	Computing Center for Water Research
CEC	Cation Exchange Capacity
CV%	Coefficient of Variability (percentage)
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
IDW	Inverse Distance Weighting
ILRI	International Land Reclamation and Improvement
KZN	KwaZulu-Natal
L0	Longitude of nought
LUT	Land Utilization Type
MAP	Mean Annual Precipitation
MCE	Multi-criteria Evaluation
NISF	National Institute for Soils and Fertilizer (Vietnam)
PMB	Pietermaritzburg
RHFA	Reasonably Homogeneous Farming Areas
RMS	Root Mean Square
RSA	Republic of South Africa
TIN	Triangulated Irregular Network
USA	United States of America
USD	AUnited States Department of Agriculture
URL	Universal Resource Locator
WNR	Weenen Nature Reserve

CHAPTER ONE

INTRODUCTION

1.1 Introduction

As the human population and their activities increase, land becomes a scarce resource and continues to be under pressure by competing land use types. Resolving the conflicting demands of different land uses for land and choosing the optimum land use asks for a decision making process that is based on a clear understanding of the opportunities and limitations presented by the relatively permanent land resources.

In response to the rapidly growing world population and the likely need for increased agricultural production and optimum use of the world's resources, the FOA developed a land evaluation methodology commonly known as the "F*ramework for Land Evaluation*" (FAO, 1976). The main principle and corner stone of this approach is that for sustained agricultural production, the edaphic and climatic conditions of an area should be matched to the requirements of a specific crop. Many countries have adapted the system to local conditions to delineate homogeneous areas of land as agro-ecological zones at different levels of detail (FAO, 1996).

In the province of KwaZulu-Natal (KZN) an agro-ecological zoning referred to as "*Bioresource Classification*" (Camp, 1999) is used as a basis for decision on land use planning through sound matching of agricultural production and other forms of land use with the natural resources. This classification has three levels of detail depending on the criteria used to delineate homogeneous areas: vegetation, climate and soil. This agro-ecological classification will be briefly discussed in section 2.4.3.

Although Weenen Nature Reserve (WNR) is classified into different agro-ecological zones (Bioresource classes) of different levels of detail in the Bioresource classification of KZN by Camp (1999), this study attempts to classify the suitability of the reserve into more detailed and specific purpose land suitability classes for rainfed agriculture by selecting representative crops. In an effort to classify the reserve into homogeneous areas of land suitability for the selected crops under rainfed agriculture, this study adapts the land evaluation methodology developed by the FAO *Framework for Land Evaluation* (FAO, 1976).

WNR was chosen as a study area to represent areas whose agricultural potential is affected by natural limitations and human impact. Historical background and present conditions in the area reveal that unwise land use in the past has deteriorated the agricultural potential of the area. The deterioration was so severe that in 1948 the Department of Agriculture of Natal Region had taken the control of the area for soil reclamation purposes until it was put under reserve in 1975. Bearing in mind that these unwise land use activities can have on the agricultural potential of the study area and the soil reclamation efforts taken to revert soil degradation in the area since 1948, this study was initiated to evaluate the current status of agricultural potential in the study area.

The study may not be directly relevant to the present land use in the area, which is game farming. However, the results may be used in assessing if agricultural land use can be considered as an alternative land use option. Secondly, the methods followed and the outcome of the study can be used as a guide in evaluating areas with similar problems and opportunities in terms of land resources. Thirdly, the fact that land evaluation is considered as a basis for any kind of land use planning makes it essential for any decision making process in land use planning. This is particularly true to marginal areas in that land evaluation not only selects lands of high agricultural potential but also prevents marginal areas from being overexploited.

1.2 Background

Historical background and present physical conditions of WNR reveal that in the past the reserve and surrounding areas had been used unwisely. Much has been said about "*labour farms*" in the area. " *Labour farming*" was a form of labour tenancy in which labourers were given the permission to live in a given area and run a stock and cultivate crops in exchange for a six-month free service they provide for another farm owned by the farm owner. A land kept for this purpose will hardly get proper care from both types of land users, the landowner and the tenant. A century ago, a district magistrate in the area described the area to be unfit for European settlers because of its poor soil, scarce water, rugged and stony topography, and thorny vegetation (Kockott, 1993). Kockott (1993) quotes a statement by the acting Chief Native Commissioner of Natal in Church Agricultural Project (CAP) Newsletter, published in August 1985, which states "If purchased by Europeans, it will only be with a view to subletting to natives in the near future".

The landowners had no care about what was happening to the lands where the tenants lived. They merely arrived at farm gates every six months to drop off one load of labour and pick up another (Kockott, 1993). Kockott (1993) points out that the labour farms were over crowded with human and animal populations and were ploughed without rest, year after year, with no conservation laws or agricultural programs. It was estimated that the population density of the area had increased from 2 people/ km^2 to 37 people/ km^2 between 1816 and 1946 (Camp, 1995b).

As the labour farming system went on, the red soils of the area wore out, as did the veld that had to sustain thousands of cattle and goats (Kockott, 1993). A survey carried out in Weenen area (WNR and surrounding areas) reflected that approximately 70% of the mapping units were seriously eroded, while 20% were completely denuded of soil by gully and sheet erosion (Camp, 1995b).

Several ecologists including Oliver West, John Acocks, and John Phillips expressed their concern about the unwise use of labour farms. However, the ecological words had been ignored for many years (Kockott, 1993). This indicates that in the past the study of land potential had received little attention and selection of lands for a given land use was only based on short-term profits without considering sustainability and land potential. A program was commenced in 1950 aimed at improving the situation (Camp, 1995b). Since then, numerous soil reclamation methods were tried to recover the potential of soils in the area for about 25 years until it was put into reserve in 1975

(KZN Nature Conservation Service 2001). Despite this step, however, very little was achieved. Camp (1995b) argues that the complex nature of the area was one of the reasons for the failure of the program. To effectively plan and manage this fragile area, Camp (1995b) suggests that knowledge of natural resources, veld condition, the forces that led to the current situation, and management techniques necessary to arrest the deterioration and to utilize the resources in a profitable and sustained manner are necessary. Land evaluation can be considered as the corner stone of all these activities. Land evaluation identifies areas of high agricultural potential preventing marginal areas from overexploitation (Scotney, 1970). Thus, evaluation of marginal areas for a specific type of land use has a twofold purpose: on the one hand, it helps in selecting high agricultural potential areas, and on the other, it prevents marginal areas from being overexploited. This objective is particularly true when evaluating an area for agricultural land use in that the primary objective common to all agricultural planning is conservation of the soil (Scotney, 1970).

1.3 Why Rainfed Agriculture?

Rainfed agriculture is a form of agricultural land use that depends on seasonal rainfall (Doolette, 1986). It is characterized by the manipulation of soil to enable plants to bear maximum moisture (Heathcote, 1983). In contrast to irrigated agriculture, this manipulation is indirect through the timing of planting to coincide with optimum soil moisture conditions, choosing plants that can tolerate the expected moisture conditions, and tillage practices which either try to conserve soil moisture prior to planting or reduce loss of moisture after planting particularly from weeds (Heathcote, 1983). The system, therefore, implies the planting of seeds in a prepared seedbed and protecting them from competitors or grazing animals until harvesting.

Rainfed agriculture varies in terms of inputs from low input where human labour and animal power are the main sources of power and with minimal land manipulation to a highly mechanized system supported by modern technology and chemical fertilization.

In arid and semi-arid areas, rainfed agriculture has been a critical subject for about 70% of the world's farmers, and a subject on which less has been accomplished in terms of achieving productivity gains in the world agriculture (Doolette, 1986).

This subject is even more relevant in Africa where the majority of the farming is affected by droughts. Changes and uncertainties of weather and climate are often responsible for this. That is, existing climatic conditions do not satisfy the *"requirements of crops"*. This term has great meaning in rainfed agriculture where climatic requirements for crops are not satisfied by artificial means as opposed to irrigated agriculture.

1.4 Aim and Objectives of the study

The aim of this study is to evaluate the suitability of WNR for rainfed agriculture and to classify it into different suitability classes based on the evaluation. To achieve this aim the following are the specific objectives of the study.

1) To set up an inventory of the necessary land resources which have influences on the production capacity of rainfed agriculture based on land resource survey.
2) To determine the land-use requirements of rainfed agriculture for soil, climate and topography and identify the limits of the requirements on which rainfed agriculture is marginal.
3) To map out the natural resources relevant to rainfed agriculture based on the land resource survey.
4) To evaluate the suitability of the study area for rainfed agriculture by comparing the land qualities with land use requirements.
5) To recommend alternative land use options and/or land management measures that can be adopted to justify sustainable use of the land resources.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

To maximize the economic and environmental benefits of land use and avoid or minimize the adverse effects, a thorough assessment of land resources in relation to their effect on the use of land is required. Assessment of these resources in relation to their potential use is referred to as land evaluation (FAO, 1983).

Land evaluation is defined as "a process of assessment of land performance when used for specified purposes" (FAO, 1983). It is a process of predicting the performance of present and alternative land use systems representing different combinations of land units with land use types taking into account the similarities and differences between land units identified during land resource studies (Beek, 1978). According to McRae and Burnham (1981) land evaluation concerns the opportunities and limitations of land resources and attempts to translate the potential information accumulated about land into a form usable by land users and decision makers.

A particular use of land is dependent not on a single parameter of natural resource attribute, but on the interaction of a number of parameters of various attributes (Stewart, 1968). Land evaluation assesses the limiting resources parameters for the specified use. For agricultural use the most limiting resources are soil, climate, topography, and socioeconomic attributes of market labour, infrastructure and land ownership. A land evaluation based the absence or presence of the observable or measurable land resources characteristics alone is not reliable for the fact that the interaction between these *land characteristics* is more limiting (Beek, 1978). The land parameter based on the interaction of the land characteristics is referred to as *land quality* and land evaluation is preferably based on this parameter. The concepts of *land quality* and *land characteristics* will be discussed in section 2.6.4.

Although there is no single universal model for evaluating land suitability or standard criteria and critical values for crop production, which will be universally applicable, there is a systematic way of evaluating land suitability as set out in the FAO's *Framework for Land Evaluation* (FAO, 1976). The FAO *Guidelines for Land Evaluation* FAO (1983) provides the sequence of activities and procedures that can be summarized by the following three phases (Sys, 1985).

Phase I: *Measurement and estimation of necessary land characteristics/qualities* having influence on the production capacity of the considered land use type. In case of agricultural land use, the characteristics used in evaluation are: climate, topography, wetness, physical soil conditions, natural fertility, salinity, and alkalinity (Sys, 1985). Each of these attributes is characterized separately. Sys (1985) points out that some of these characteristics are used as they are while others are recalculated based on weighting factor on arbitrary basis.

Phase II: *Determination of land use requirements*: In this stage, the climatic, topographic, soil, and socio-economic requirements of the land use are studied. This is done separately for each land characteristic. The data on land use requirement can be presented in different ways. In most cases of agricultural land evaluation, the requirements are prepared in tables for different crops (Sys, 1985).

Phase III: *Matching land characteristics/qualities with land use requirements*; this is the final stage of land evaluation in which land characteristics/qualities are compared with land use requirements. There are different methods used for comparisons; the most commonly used method is the one developed by FAO (1976) which expresses the suitability of land in different degrees of suitability based on limitations of land characteristics/qualities. According to this method, four levels of classification are recognized: land suitability orders, classes, sub-classes, and units (Dent and Young, 1981). This classification structure will be discussed in sub-section 2.5.2.2.

2.2 The Need for Land Evaluation

The FAO F*ramework for Land Evaluation* (FAO, 1976) states that decisions on land use have always been part of the evolution of human society. The *Framework* further argues that in the past, land use changes often came about by gradual evolutions as a result of many separate decisions taken by individuals. In the past few decades, the need for rational land use has become greater, because rapid population growth and urban expansion are putting more pressure on the use of available land and making it a scarce resource (FAO, 1983). This calls for a thorough assessment and evaluation of land resources. Beek (1978) argues that increase in population and peoples' demand of land for different purposes have put areas, which were once considered marginal, for different land uses. Use of marginal areas is, however, expensive, physically difficult and may be hazardous with regard to economic success and to the fragile environment (Purnell, 1986).

In response to the problems and situations mentioned above, scientists have been interested in the study of land resources and modifications of the methods of land evaluation (Beek, 1978). Purnell (1986) stated that land evaluation provides a systematic way of looking at various options and predicting the results of alternative courses of action. Inventorying and surveying of natural resources are essential parts of land evaluation, which help land use planners in avoiding costly mistakes and improve efficiency of investments (Camp, 1999; Young, 1998). Valid techniques of resource survey and land evaluation have helped in translating environmental data into land use potential (Young, 1998). According to the argument by Young (1998) land evaluation was developed in response to the inadequacy of soil survey to provide managers and land use planners with the information on economic and physical suitability of an area. In short, land evaluation is an essential perspective for all rational land use planning (Purnell, 1986). It forms the link between basic resource surveys and land use planning (FAO, 1983) and enables land use planners to make decisions on land use.

2.3 Land Evaluation and Land Use Planning

Beek (1978) argued that there is no sharp distinction between land evaluation and land use planning; whoever is involved in land suitability evaluation, is also involved in land use planning. Land evaluation enables land use planners to choose optimum land use for each land unit based on land resource survey. The FAO *Guidelines for Land Evaluation*

(FAO, 1983) states that land evaluation forms the link between land resource surveys and land use planning. A land use planner makes his/her decisions based on the results of land evaluation. The land evaluation procedure does not make the decision of itself, but it can provide a systematic way of analyzing various options and predicting the results of alternative courses of action. Land evaluation, therefore, is an essential perspective for rational land use planning (Purnell, 1986). It feeds important information to the subsequent stages of land use planning. Furthermore, land evaluation usually comes up with proposed changes and formulations of general and specific proposals or recommendations and decisions on which land use planning can be made. The latter stage is then land use planning that involves detailed analysis of preferred uses and their implementation and monitoring (FAO, 1976)

2.4 A Review of Land Classification Studies

There are many different approaches and methods of land classification of which the FAO *land suitability* classification and the USDA *land capability* classification are the most widely used. These two methods will be discussed in detail in section 2.5.2. In the following sub-sections emphasis is placed on the different land classification studies carried out at global, regional, and local scales.

2.4.1 The FAO Agro-Ecological Zoning (AEZ)

Stimulated by the increasing world population and the likely need for increased agricultural production and optimum use of the world's resources, the FOA in 1976 initiated a study of potential land use by agro-ecological zones to obtain a first approximation of the production potential of the world's land resources (FAO, 1978). The FAO agro-ecological zoning was based on the FAO *Framework for Land Evaluation* developed by the FAO in 1976.

According to this approach, it is recommended that crop requirements should be matched to edaphic and climatic conditions for sustained agricultural production. The methodology is based on the six basic principles. An outline of these principles is provided in section 2.5.2.2.

The overall methodology followed in classifying the world into agro-ecological zones was in accordance with the agreed land evaluation procedures developed in the FAO *Framework for Land Evaluation* (FAO, 1976), which comprises a sequence of activities. These various main activities are outlined in section 2.5.2.2.

Although the FAO agro-ecological zones project (AEZ) was a land evaluation exercise developed for continental study of land potential, the methodology employed in the assessment of land resources is the basis on which most large and small scale land classification studies depend. In fact, the FAO has been assisting developing countries in adapting the methodology to local conditions (FAO, 1996). The level of zoning can vary depending on the scale of the study. For example, an agro-ecological study in Kenya distinguishes between *agro-ecological cells* (AEC), which are smaller units of the AEZ's and basic units for land evaluation and data processing (FAO, 1996).

In its later developments the FAO has developed computerized systems of land resources appraisal such as GIS where combinations of layers of spatial data on climate, soils, landform, and other physical and socioeconomic factors can be combined and matched to crop requirements (FAO, 1993b; FAO, 1996).

2.4.2 Agro-Ecological Zones in Southern Africa

This classification was carried out partially in the Republic of South Africa (RSA) (Scotney, 1987). In this project an agro-ecological zone was defined as " a discrete area of land delineated preferably at a scale of 1: 250 000 in which the environmental conditions (such as soils, slope, landforms and climate) are sufficiently similar to permit uniform recommendations of land use and farm management practices to be made, to provide a framework in which an adaptive agricultural research program can be carried out, and to enable land use planners to make correct decisions". The following land characteristics were used as important criteria in the mapping of agro-ecological zones.

Climate

Rainfall: Including mean annual rainfall, median rainfall, length of growing period, pentades and decades analysis, mean monthly rainfall, probability of 80% rainfall and intensity of rainfall.

Temperature: Monthly means of daily maximum and minimum temperatures, mean first and last dates of frost and heat units.

Others: A-pan evaporation, frequency and intensity of hail, radiation and hours of sunshine, speed and direction of wind.

Soils: A soil association map showing dominant soil types, average profile texture, average effective depths, specific profile morphology, especially plinthite, E-horizons and gleyed horizons (MacVicar, 1977).

Vegetation: As a product of the environment, vegetation was not an important criterion but was considered an important feature of indicator significance (Camp, 1999).

In the RSA in particular, an AEZ described as Reasonably Homogeneous Farming Areas (RHFA's) have been defined in many areas of the country since 1973 (Scotney, 1987). RHFA's are units of land that have a fair degree of uniformity in respect of possible agricultural pursuits, yield horizons, and production techniques to be applied (Scotney, 1987). are delineated based on "land types", which are discussed under 2.4.3 (c) below. RHFA's may include one or more land types. In mapping RHFA's micro-climates, geology, soil pattern, adapted crops, yield potential and vulnerability to wind and water erosion were given special emphasis (Scotney, 1987).

2.4.3 Land Classification Studies in the Province of KwaZulu-Natal (KZN)

Many land classification studies have been undertaken in the Province of KwaZulu-Natal at a provincial level, which were mainly ecological and agro-ecological classifications. These include:

a) Agro-ecologiclal survey of Natal by Pentz (1945) which classified the province into three farming regions according to their homogeneity in soil, climate, vegetation and topography and indicated crop, pasture, stock and timber potential suitability of each farming region based on the requirements of each land utilization type.

b) The work by Phillips (1973) that classified the province into Bioclimatic groups based on Tugela Basin (a drainage basin of the Tugela River, which flows from the Drakensberg Mountains in KZN to the Indian Ocean). The study was regarded as invaluable in land use planning except that there was a lack of information on soil and climatic data (Camp, 1999).

c) The Land Type Classification study undertaken by the Land Type Survey Staff in 1986 is also one of the most important land classification works in the province. However, this classification is more useful as a source of information on soils, but not useful as an agro-ecological classification for the fact that there are too many Land Types and there is insufficient difference among the different land types to affect crop production, (Camp, 1999).

d) Camp (1999) has reported the methodology developed for defining agro-ecological zone for the Province of KwaZulu-Natal; the Bioresource (BR) classification, which was initiated in 1988. This methodology introduced three levels of classification based on homogeneity of the land units in terms of their natural resources which are necessary to achieve sound matching of agricultural production and other forms of land use with the existing land resources (Camp, 1999). The BR classification distinguishes between three levels of homogeneity in natural resources. The first unit is the Bioresource Unit (BRU), which was referred to as an area in which the environmental factors such as climate, soil, vegetation, and terrain show sufficient homogeneity such that land use practices can be clearly defined. Differences within the BRU were also identified which gave rise to another level of classification; the Ecotopes. An ecotope is a land class defined in terms of soils units, soil texture, soil depth, and soil surface characteristics. Bioresource Units were combined according to their homogeneity in terms of vegetation types to form a broader level of homogeneity. These broader groups are referred to as Bioresource Groups (BRG). The whole of KwaZulu-Natal is classified into a total of 23 Bioresource Groups (Camp, 1999).

The BR classification is rich in information of natural resources databases including crop production models, which make it useful in provincial, regional, specific area, and farm planning. However, it is not without limitations. While the BRU inventory gives a very good indication of overall land potential in a given area and the soils that are most likely to be found, there is no indication of the location of the particular soils in a specific area of interest.

e) A land potential classification for KwaZulu-Natal has been undertaken by Guy and Smith (1995). This classification is a combination of soil and climatic land capability classifications using the framework of the Bioresource Units (BRU). According to this land classification, the province of KwaZulu-Natal is classified into eight land potential classes.

As compared to the BR classification, this classification is broader, and hence does not provide much information on land resources databases as the BR classification. However, it makes use of the information in the BR classification to classify areas into potential capability rather than simple agro-ecological zones. The potential capability classes can be used as a guide for field workers at local scale and policy makers at regional scale (Guy and Smith, 1995).

2.5 Approaches and Methods of Land Evaluation

2.5.1 Approaches to Land Evaluation

Most land evaluation systems have been interpretative classifications which present an evaluation in different categories, each corresponding to a certain level of detail and at each level the interpretation differs in precision, objectives, requirements and assumptions (Sys, 1985).

Beek (1978) recognizes three approaches to land evaluation, according to whether the evaluation is of a general or specific purpose, physical or integral, and qualitative or quantitative. The FAO *Framework for Land Evaluation* also differentiates between current and potential land suitability evaluations (FAO, 1976).

The *general purpose* land evaluation follows a standardized procedure for all lands to evaluate their capability to support a generally defined land use. The suitability classification depends on relations between broadly defined kinds of land use and qualities of the physical environment expressed in terms of limitations or hazards (Beek, 1978). This system of land evaluation is easy to understand because it relates only physical land variables to the land use requirements, and is relatively unaffected by social, economic, and technological changes. The disadvantage of the general purpose approach is that it is only directed to the most common land uses which are of specific relevance in the socioeconomic development of developing countries without taking into consideration the technological variability between countries and the conflicting demand for land between different land uses (Beek, 1978).

A *specific purpose* land evaluation is the opposite of the *general-purpose* land evaluation for the fact that it evaluates land suitability for specific purposes based on relevant physical and socioeconomic data, which are not pre-established (Beek, 1978).

Beek (1978) also distinguishes between *physical* and *integral* types of land evaluation. *Physical* land evaluation is concerned principally with physical ecological aspects of land, and is used within a general socioeconomic context (Masahreh *et al*, 2002). This approach identifies and compares potential land use alternatives, and thus it is preceded by the recognition of the need for some change in the use of land (FAO, 1976).

Physical land evaluation begins with basic survey of soil, water, climate, and other characteristics of the biophysical resources. Frequently, *physical* land evaluation has been applied to land use on particular types of land. However, it does not provide sufficient information for establishing land use policies and guidelines (Masahreh *et al.*, 2002).

Integral land evaluation is a combination of *physical* land evaluation and socioeconomic analysis (Beek, 1978). This type of land evaluation deals with the determination of critical importance of land for specific uses in order to meet basic social goals such as economically acceptable production levels and needs of goods and services (Masareh *et al.,* 2002).

Other approaches to land evaluation are *qualitative* or *quantitative* evaluations. The former deals with evaluation of land suitability for alternative purposes expressed in qualitative terms only such as highly, moderately or marginally suitable or not suitable for a specified use (Dent and Young, 1981) without specific estimation of inputs and outputs such as costs of production yields and profits or returns (FAO, 1983). *Quantitative* land evaluation, on the other hand, is one in which the distinction between suitability classes are defined based on common numerical terms, which permit objective comparisons between classes relating to different kinds of land use (Beek, 1978). *Quantitative* land evaluation can also be categorized into physical and economic evaluations according to whether results are expressed in yields or inputs, or in economic or financial terms (FAO, 1983). The degree of quantification in which the suitability criteria are expressed will depend on the purpose and detail of land evaluation (Beek, 1978). Moreover, some criteria such as yield may be more easily expressed in quantitative terms than others.

Current (a*ctual)* and *potential* evaluation is another approach in land evaluation. *Current* land evaluation is related to the present condition of a land and is based on direct observations (Sys, 1985). A *current* land evaluation may refer to the evaluation of land as to its present suitability for the intended use, either with existing or improved management practices or for another different use without any improvement to correct its limitations (FAO, 1976). *Potential* land suitability evaluation on the other hand, reflects future situations, after the land has been changed by major land improvement practices (Sys, 1985).

2.5.2 Methods of Land Evaluation

Land can obviously be classified in a number of different ways depending on the objective of classification (Ivy, 1981). There are many different methods of land classification of which the FAO *land suitability* classification and the USDA *land* *capability* classification are the most widely used. Whatever the method is, the main objective of land evaluation is to systematically arrange and group different kinds of land, to show their intensive safe use and indicate their management requirements, and permanent hazards attached to the use of land (Manson *et al.*, 1995).

The two major methods of land evaluation that are commonly used for classification of agricultural land, the USDA system of *land capability* classification and the FAO system of *land suitability* classification, are discussed in the next two sections.

The terms *suitability* and *capability* have often been confused or even regarded as synonymous (McRae and Burnham, 1981). This thesis distinguishes between the two terms in accordance with the two methods of land classification. Suitability, as described by McRae and Burnham (1981), is concerned with a single clearly defined, reasonably homogeneous purpose or practice, whereas a capability classification is applied for a broader use such as agriculture or urban development. McRae and Burnham (1981) indicated that suitability assessment has a sharp focus, looking for sites possessing the positive features associated with successful production or use, whereas capability is vague, and is often defined in terms of negative limitations which hinder or prevent some or all the individual activities being considered.

2.5.2.1 The USDA System of Land Capability Classification

This system was developed during the 1930s in the USA. It was widespread and adopted in other places after 1960 (Davidson, 1992). The classification involves an evaluation of the degree of limitation posed by permanent and semi-permanent attributes of land to one or more land uses (Davidson, 1992). It is essentially a negative approach whereby as the degree of constraints increases, so land is allocated to a lower class. The main product of land capability classification is a map in which areas of land are put into capability classes ranging from I (best) to VIII (worst) (Dent and Young, 1981), and each class of land has the properties, or capability for use in a prescribed number of ways, or with special management techniques. Thus, class I land can be used for arable purposes without soil conservation measures whereas classes II to IV require increasingly costly conservation practices; and Classes VI-VIII should not be put to arable use at all (Dent and Young, 1981). Land which is allocated to any particular capability class has the potential for the class and for all classes below it (Dent and Young, 1981).

The USDA system of classification is based on the following principles:

1) The criteria used in assessing land units are the physical land properties made available after a soil survey.
2) The seriousness of a limitation is a function of the severity of which crop growth is inhibited.
3) The capability of a land unit for crop growth is better when a wide range of crops can be cultivated on it than on another land unit (Sys, 1985).

The classification structure provides three major categories (Sys, 1985):

1) Classes
2) Subclasses
3) Units

A land *capability class* is the broader category that has the same degree of limitation. A total of eight classes are defined labeled I to VIII (Davidson, 1992). Land *capability subclasses* are based on information on the type of limitations encountered within the classes (Davidson, 1992), such as erosion hazard, rooting restriction, or low fertility. The limitations are indicated by lower case letters following the Roman numbers. For example, land capability subclass IIe indicates an erosion hazard and IIw indicates a problem of excess water (Dent and Young, 1981).

A land *capability unit* is a subdivision of a land capability *subclass* on the basis of potential productivity (Sys, 1985). Thus, all soils within a subclass having comparable potential productivity and similar conservation, treatment and management requirement belong to the same capability unit. The yield range of crops within a unit should not be greater than 25% (Davidson, 1992). Land *Capability units* are indicated in Arabic numbers (Dent and Young, 1981). For instance, IIe-1, IIe-2.

It has been explained that land capability evaluation is a limitation method. Comment needs to be made about the nature of limitations for the fact that some limitations can easily be corrected. For example, a farmer can apply fertilizer to improve the fertility limitations of his/her land. In contrast, some land characteristics such as soil depth, soil texture, and slope are relatively permanent and more difficult to improve. The USDA land capability classification structure uses the permanent limitations as criteria for classifying the broader level of classification, that is, the land capability classes and it indicates the type of limitations in each land capability class by the use of land capability subclass. The third level of classification provides the management practices required to correct the less permanent limitations.

The land capability classification attempts to provide a single scale grading of land from the "best" to the "worst"; it assumes arable use is the most desirable; and it is strongly biased towards considerations of soil conservation; it is biased on negative land features and it only takes economics into consideration as a background (Dent and Young, 1981). These points are mentioned as limitations of the system. The system has also many advantages. Dent and Young (1981) reported that the system is versatile, simple and easy to present. Versatility lies in the fact that it can be adapted to any physical environment, and to any level of farming technology (Dent and Young, 1981).

2.5.2.2 The FAO System of Land Suitability Evaluation

The FAO Panel for Land Evaluation, in the FAO *Framework for Land Evaluation* (FAO, 1976) has differentiated between two levels of detail of land use: major land use types, and land utilization types (Beek, 1978). This concept is one of the basic principles of the FAO *Framework for Land Evaluation* and will be discussed in section 2.6.5.

The FAO *Framework for Land Evaluation* (FAO, 1976) defines land suitability evaluation as "an evaluation of fitness of a given type of land for a defined use". McRae and Burnham (1981) describe suitability evaluation as a practice of land evaluation for a single clearly defined, reasonably homogeneous purpose. In land suitability evaluation the physical and socioeconomic aspects of a given area of land are compared with the requirements of the specific land use and differences in degrees of suitability are determined by the relationships actual or anticipated between benefits and required inputs associated with the use of land in question (Sys, 1985). Sustainability, which is a process of progress that meets the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs, is the main focus of the FAO method of land evaluation. As stated by the FAO *Framework for Land Evaluation* (FAO, 1976), there might be a land use that may appear highly profitable in the short term, but may likely lead to some hazardous impacts such as soil erosion, pasture degradation, deforestation, environmental pollution resources depletion etc., in the future. These impacts usually overweigh the short term profitability and cause the land to be classified as unsuitable for the land use. It is also advised not to misunderstand the meaning of sustainable use of land as preserving the land as it is. Of course, the use of a given land is always concerned with some form of changing the state of that land, and we cannot avoid this at all. What is required is for any proposed form of land use, the probable consequences on the environment should be assessed and the results of assessment need to be taken into consideration when evaluating a land (FAO, 1976). Thus, a given land is said to be suitable for specific use if it can support the land use on sustained basis, and if it yields benefits that justify the inputs (FAO, 1993c).

The FAO land suitability evaluation methodology is based on the following six principles (FAO, 1976).

1) Land suitability is assessed and classified with respect of specified kinds of land use.
2) Evaluation requires comparison of inputs and outputs.
3) A multidisciplinary approach is required.

4) The evaluation is made with careful reference to the physical, economic, and social context of the area under investigation.
5) Suitability refers to the use on sustainable basis.
6) Different kinds of land use are compared.

The structure of suitability classification has four levels: suitability order, classes, subclasses, and units.

1) *Suitability Order* distinguishes between lands which are suitable indicated by upper case letter "S", and not suitable for the considered use, denoted by upper case letter "N".
2) *Suitability classes* indicate degrees of suitability. Within the order "suitable" there are three classes, "highly suitable" (S1), and "moderately suitable" (S2), and "marginally suitable" (S3). Within the "not suitable" order there are two classes, "N1" indicating currently not suitable and "N2" indicating permanently not suitable areas.
3) *Suitability subclasses* indicate kinds of limitations. For example, moisture limitation, erosion risk, drainage limitation and so on. Subclasses are indicated by letter symbols Such as S2d, which indicates drainage limitations.
4) *Suitability units* represent divisions of sub-classes on the basis of differences in detailed aspects of production characteristics or management requirements. For example, consider a land that has drainage limitation. This limitation can be counteracted by tile drains or by open ditches. Based on which management requirement to be practiced, the land suitability units can be either S2d-1 or S2d-2, where the letter "d" stands for drainage limitation, and numbers 1 and 2 indicate the management method to be applied.

The FAO land suitability evaluation procedure involves a sequence of activities that can be summarized as follows:

i) Initial consultations between planning authorities and the organization which will carry out the evaluation
ii) Planning the evaluation
iii) Identification of land utilization types
iv) Selection of relevant land qualities for evaluation
v) Description of land mapping units
vi) Assessment of land use requirements
vii) Comparison of land qualities with land use requirements
viii) Presentation of results

Several methods can be used within the FAO land sustainability evaluation system, what is essential is that the land characteristics/qualities need to be compared with crop requirements (Sys, 1985). Similarly, the types and number of criteria given for defining land suitability classes are not fixed and there is complete freedom in choice of the number and type of criteria (Sys, 1985). Sys (1985) has summarized the activities in the FAO land evaluation procedure into three phases. These phases have been discussed in the beginning of this chapter in section 2.1.

As opposed to the USDA land capability classification, the FAO land suitability evaluation has a sharp focus, looking for sites possessing the positive features associated with successful production, and suitability appraisal of a comprehensive list of crops with specific guidance on appropriate management practices. This has great advantages over a general capability classification, where a low rating land might conceal high suitability for a single crop with relatively unusual requirements (McRae and Burnham, 1981). For example, a water-logged area which might be considered to have low capability rating can be highly suitable for the production of padi rice, blue berries, asparagus, or coconuts. The disadvantage of the methodology is that it requires detailed description of land utilization types and their land use requirements. This makes the system complicated and usually asks multidisciplinary approach.

2.6 Basic Concepts of Land Evaluation

2.6.1 Land

As a basic source of all the natural resources, land plays the central role in the economic and social life of peoples. The struggle over the use and control of land has been part of human life (Rhind and Ray, 1980). This increases as human population increases (McRae and Burnham, 1981) and requires rational planning and state involvement to ensure proper use and distribution of land. However, this is only possible if land is properly defined. The concept of land has been a subject of constant discussion. In fact land has been defined in a wide range of ways (Davidson, 1992).

The FAO *Framework for Land Evaluation* (FAO, 1976) defines land as "an area of the earth's surface the characteristic of which embraces all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations and the results of past and present human activities, to the extent that these attributes exert a significant influence on the present and future use of land by man". This definition is unsatisfactory in a scientific sense (Davidson, 1992). However, it gives a clear guidance on how land can be interpreted taking into consideration all environmental variables that influence land use. Other interpretations take land as a consumer commodity, as location, or a form of capital (Davidson, 1992).

2.6.2 Land use

Sys (1985) defines land use as "any kind of permanent or cyclic human intervention to satisfy human needs". Land use involves the application of human control of natural ecosystems in a relatively systematic manner to derive benefits from it. Land use is a result of a continuous field of tension created between available resources and human needs and acted upon by human efforts (Sys, 1985).

The concept of land use is of great significance because, on the one hand, we all require land on which to live; on the other hand, the use of any parcel of land affects not only those who use that land but also those who live on or have use of adjacent and surrounding areas (Rhind and Ray, 1980).

We cannot always see the actual use of a parcel of land, but only the physical artifacts of the use. Some of the human activities manifest themselves on the earth's surface. An urban land use, for example, can be clearly identified from other land use categories. In contrast, in the case of forestland, there is little or no distinction between forestland used for timber production or recreational use. Due to this fact it is usually common to distinguish between land use and land cover (Campbell, 1983). In its narrowest sense, land cover refers to the features covering the surface of the earth. In a much broader sense, land cover designates the visible evidence of land use (Campbell, 1983).

2.6.3 Land Mapping Unit

A land resource survey such as soil survey attempts to delineate homogeneous units of land that behave differently or will respond differently to some specific management (Dent and Young, 1981). Delineating a given area into homogeneous units can vary depending on the purpose of the survey. In the case of rainfed agricultural land use, these units could be climatic zones, areas of growing periods, agro-climatic zones (FAO, 1983), soils and land systems (Dent and Young, 1981).

The FAO *Guidelines for Land Evaluation for Rainfed Agriculture* (FAO, 1983) proposes that two kinds of land mapping units at different stages of the evaluation for rainfed agriculture are important. In an initial stage agroclimatic zones are employed to select crops for consideration. The major part of the evaluation is then based on more detailed land units, more commonly on some combinations of soils and landform (FAO, 1983).

The following five principles are suggested in delineating land mapping units (FAO, 1983).

1) Land units should be as homogeneous as possible, but not necessarily the same.
2) The grouping should have practical value, in relation to the proposed land use.

3) It should be possible to map the units consistently.
4) The units should be defined as simple as possible and based on properties, which are readily observable in the field with use of remote sensing techniques.
5) Units should be defined according to relatively stable properties of the soil and land surface, which are unlikely to change rapidly in response to management practices.

2.6.4 Land Characteristics and Land Qualities

Physical and socioeconomic attributes of land are the main objectives of a study in land evaluation (Beek, 1978). The FAO *Framework for Land Evaluation* (FAO, 1976) distinguishes between land characteristics and land qualities.

The comparisons of land use requirements with the land attributes of land mapping units (land evaluation) are done by means of *land qualities* and *land characteristics*.

a) Land Characteristics are attributes of land that can be measured or estimated (FAO, 1976). Examples are mean annual rainfall, slope angle, soil drainage class, soil effective depth, topsoil texture, and so on. Land characteristics can either be used to estimate land qualities or directly used to assess land suitability (FAO 1984). The evaluation of land suitability using land characteristics is simpler permitting a direct comparison between the characteristics observed and suitability rating (Dent and Young, 1981; FAO, 1983). However, land characteristics are very large in number and do not take into account the interaction between different environmental factors and their effects on land use (Dent and Young, 1981; FAO, 1983).

b) Land Qualities are comprehensive attributes of land obtained by synthesizing the measurable land characteristics (Beek, 1978). The concept of land qualities was originally used in 1953 to distinguish between observable and measurable soil characteristics and the qualities interpreted from them (Beek, 1978).

The FAO *Guidelines for Land Evaluation* defines land quality as "an attribute of land which acts in distinct manner in its influence on the suitability of specific land for specified kinds of use". Examples of land quality include temperature regime, moisture availability, drainage, nutrients supply, rooting conditions, and so on. Using land qualities as a basis of land suitability evaluation has several advantages over the use of land characteristics. The following advantages are outlined by the FAO *Guidelines for Land Evaluation for Rainfed Agriculture* (FAO, 1983).

a) Land qualities are directly related to specific requirements of land use.
b) Land qualities take account of interaction between environmental factors.
c) The total number of land qualities is considerably less than the land characteristics. FAO (1976) identifies 25 land qualities used in land evaluation for rainfed agriculture which are fairly less as compared to the many hundreds of land characteristics used for the same purpose

The main disadvantage concerned with the use of land qualities is their greater complexity, in that they require intervening stages of converting characteristics into land qualities or selecting diagnostic criteria for their assessment (Dent and Young, 1981; FAO, 1983). Diagnostic criteria are land characteristics that are used for the estimation of land qualities.

2.6.5 Major Types of Land Use and Land Utilization Types

Most of rural land classifications have been based on some groupings of land characteristics according to their suitability for generalized land use types. These classification systems have a limitation in that they assess land characteristics for generalized purposes, with little attention to specific land use types (Beek, 1978).

In response to this limitation, Beek (1972) has introduced the concept of land utilization type (LUT). The FAO *Framework for Land Evaluation* (FAO, 1976) has adopted the concept to distinguish between two levels of land use; a major kind of land use and land utilization type.

A *major* kind of land use is a generalized sub-division of rural land use (FAO, 1983). Examples include: rainfed agriculture, irrigated agriculture, grazing agriculture, and forestry. Major kinds of land use are employed in evaluation studies of broad qualitative or reconnaissance nature (Dent and Young, 1981).

A *land utilization type (LUT)* is a kind of land use defined in more detail, according to a set of technical specifications in a given physical economic and social setting (FAO, 1983). According to the FAO *Guidelines for Land Evaluation* (FAO, 1983) a single crop can be regarded as a land utilization type provided a statement is made as to the socioeconomic setting in which it is cultivated, as productivity varies considerably according to the technology available to the farmer. At more detailed levels of land evaluation it is normally appropriate to regard the farming system or cropping system as definitions of land utilization types (FAO, 1983). The degree of detail at which the land utilization types are described varies according to the intensity and purpose of the evaluation. For land evaluation procedures at a reconnaissance scale, land utilization types are described in a generalized manner; in detail and semi-detail scale surveys the land utilization types are described in detail; and a further method modifying land utilization types is through the repeated process of comparison with land qualities as found by resource survey (Dent and Young, 1981).

2.6.6 Land Use Requirements

Each kind of land use requires different environmental conditions to be practiced on a sustained and economically viable basis (FAO, 1976). In agronomy the term "*Requirement*" is commonly used when speaking of specific land conditions required for the proper function of a certain crop (agricultural implement) (Beek, 1978). Examples include water requirements, nutrient requirements, soil workability requirements, topographic (slope) requirements etc. Defining crop requirements for a given crop is the most difficult and crucial aspect of land evaluation (Beek, 1978; McRae and Burnham, 1981), because information about land use requirements, especially in developing countries, is insufficient and difficult to obtain. Beek (1978) and Sys (1985) emphasize that land evaluators should resist the temptation to use land use requirement data in handbooks that refer to ideal conditions or specific agro-ecological zones (Sys, 1985) which may have little comparison to the local conditions of the study area. Crop requirement data on handbooks have to be considered only as guidelines and their relevance to the local conditions should be reviewed if they are to be adapted (Sys, 1985).

There are three major groups of crop requirements (FAO, 1983)

i) *Physiological crop requirements*: climatic and ecological requirements of a crop for its proper physiological functioning.

ii) *Management requirements*: These refer to the requirements related to the technology of management systems.

iii) *Conservation requirements*: refers to the requirements for avoidance of soil erosion and degradation.

2.7 The Role of GIS in Land Evaluation

With the rapid development of computer technology in the past three decades, an increased number of computer based systems for land resources appraisal have emerged (FAO, 1993b). One of these systems is Geographical Information System (GIS). GIS is a generic term denoting the use of computers to create and depict digital representations of the earth's surface (Longley *et al.,* 1999). GIS can be used to store, retrieve, manipulate, and display information having attributes that can be related to a position on the earth's surface (FAO, 1993b). In short,

GIS is well suited as a tool to assist land resources appraisal (FAO, 1993b). However, a GIS does not do the appraisal itself, but assists the manipulation of the data. A good example of GIS application in land evaluation is identification of parcels of lands that have a given set of properties. In doing this, GIS integrates data from a variety of sources including physical and socioeconomic land attributes of a given georeferenced land unit so as to arrive at a better decision in the evaluation.

Land use planners usually use a GIS's modeling capability to handle complex spatial problems in land evaluation. A good example of the modeling approach is Multi-Criteria Evaluation (MCE). In this technique land evaluators combine different land characteristic required for land evaluation (Burrrough, 1986; Jones, 1997). The main purpose of MCE is to assist land evaluators to distinguish sites that have a combination of characteristics required for a given land use type. In this analysis GIS uses an overlay technique, in which different characteristics of a given parcel of land are combined logically and mathematically to form a new theme of interest (FAO, 1993b). Logically, they can be intersected by the "AND" operation; merged by the use of the "OR" (UNION) operation; or excluded from the new theme by the use of the "NOT" operation. Mathematically, themes of different attributes can be added, subtracted, multiplied or divided to arrive at a required final theme. In addition to these operations, statistical operations of regression, variance, covariance, range, maximum, minimum, and mean values of themes can be carried out to summarize the attributes for integrating them with the spatial data so as to reach at a better decision.

Apart from its analytical and manipulation capabilities, GIS is also used for the presentation and display of land resources appraisal and land evaluation outputs. One good example of these is a three-dimensional viewing of a Digital Elevation Model (DEM) where the actual terrain of a given area is represented by a three-dimensional model of the topographic data. The appearance of the three-dimensional DEM map can be enhanced by applying a "shaded relief", "view shed" or other display capabilities of a GIS.

2.7.1 GIS Based Land Evaluation Case Studies

In recent years GIS has emerged as a powerful tool in the management and analysis of large amounts of data and information (FAO, 1996). As part of its activities of agro-ecological zoning, the FAO has been developing GIS for agro-ecological zoning and other issues of land at global, national, and sub-national levels and different scales (FAO, 1996).

In an agro-ecological study in Kenya (FAO, 1993a), the FAO developed an integrated software package linking databases, GIS, and models. The land resources database was obtained by combining various data layers (map and tabular data) on the physical aspects of agricultural environments such as soil, landform, and climate. The models were used to create land resources databases, calculate suitabilities and productivity and determine optimum land resources allocations (FAO, 1993a).

In principle land suitability evaluation is concerned with evaluating land resources in a give area in relation to a particular crop (land use). GIS has proved its strength in matching land characteristics of a given area with the crop requirements of a particular crop using built-in models. In a study carried out to assess the suitability of an area in west Kenya for pyrethrum cultivation (Wandahwa and Ranst, 1996), an integration of GIS (IDRISI), Automated Land Evaluation Systems (ALES), and expert knowledge was used. Land resources databases were captured and stored in the GIS. The expert knowledge was applied in ALES by defining Land Utilization Type (LUT) and crop requirements, selecting the relevant land characteristics and constructing decision trees used by the program to rate the land qualities and award them suitability classes.

In another study carried out to assess the suitability of the province of Loja in Ecuador for cherimoya (a wild fruit-tree) growth (Bydekerke *et al.*, 1998) attributes of the physical environment were mapped with the help of a GIS. Growth requirements of the plant collected from literature and local researchers and farmers were used to construct crop requirement tables. In a GIS (ArcInfo) framework a procedure was set up to attribute suitability classes to individual land units and to present the results of the classification on maps. The area was then classified into different suitability classes based on the comparison between the land resources mapped for the purpose of evaluation and the crop growth requirements following decision trees of the growth requirements.

2.8 Summary

The FAO has been expressing its concern over the continually increasing world population and the likely need for increased food production (FAO, 1976; FAO, 1978; FAO, 1983; FAO, 1993b & c; FAO, 1996). In the framework developed by the FAO in 1976 as a solution to this problem it was proposed that for sustained agricultural productivity, land potential should be correctly evaluated. The approach followed in evaluating a land may vary from one place to another even within the FAO framework. Whatever approach is followed, however, land must be matched with land use requirements. The matching process has become easier with the development of computer technology. Various customized GIS softwares that can be used for land resources appraisal have been developed. GIS has emerged as a powerful tool in management and analysis of land resource databases for the purpose of land evaluation.

CHAPTER THREE

THE STUDY AREA

3.1 Location

Weenen Nature Reserve (WNR) is situated in the midlands of the Province of KwaZulu-Natal, South Africa, between 28°49′ and 28°56′S, and 29°57′and 30°03′E. The reserve is located south of the junction of Colenso-Weenen and Estcourt-Weenen roads at an approximate distance of 10km west of Weenen village and 28km northeast of Estcourt town (see Figure 3.1). It covers an area of 4891ha fenced with 1.8m high veldspan fencing. The reserve is crossed by the main Estcourt-weenen road, which joins the Colenso-Weenen highway at the northern end of the reserve (see Figure 3.1). Most areas of the reserve, with the exception of areas south of the Bushman's River and the steep area north of the river and the eastern hills, are interlinked with a network of unpaved roads.

3.2 Historical Background

Prior to the 15th century, the reserve and surrounding areas were believed to have being highly populated by a large number of African tribes mainly Bushmen with a large number of domestic and wild animals (Camp and Richardson, 1990). During the 15th and 16th centuries, there was an increase in the population of these tribes.

During the reign of Shaka (1818-1828), the area was almost depopulated by his conquest and it is believed that the area had little grazing pressure until the arrival of Europeans.

The post-Shaka period was characterized by the arrival of Europeans, the return of African tribes to the area, and delimitation of farm boundaries. This led to an intensification of agriculture with which the so-called "labour farm" system came into practice (see section 1.2).

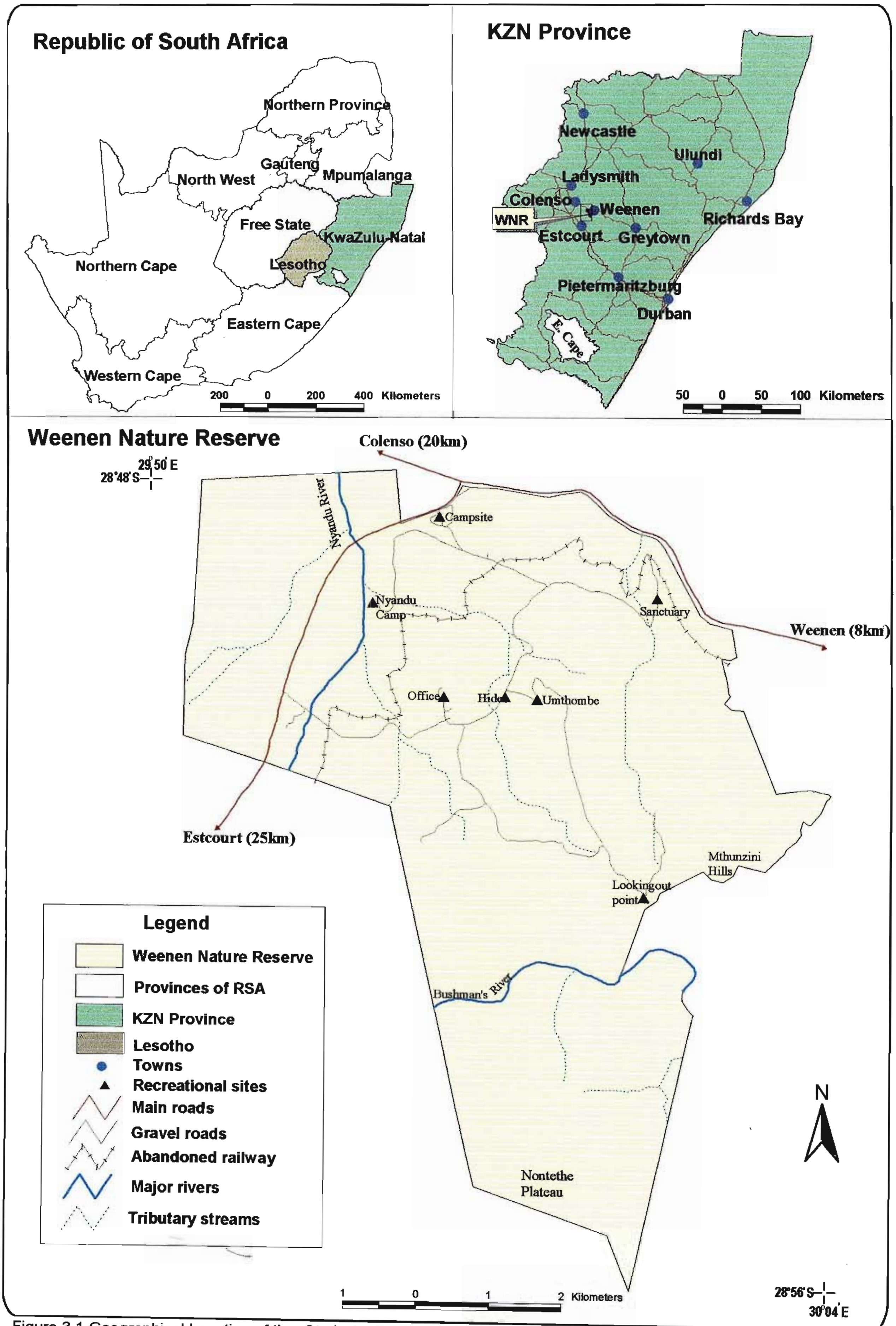


Figure 3.1 Geographical Location of the Study Area

In 1948 there was such a severe erosion problem that the land was taken over by the Department of Agriculture to research and demonstrate soil reclamation techniques.

In 1975, local farmers and Weenen town board took steps to establish a nature reserve, and the KwaZulu-Natal (KZN) Nature Conservation Service took control since then (KZN Nature Conservation Service, 2001).

3.3 Climate

WNR is characterized by having a summer rainfall, with a hot and humid rainy season and a cool to cold dry season. Rainfall in the area is highly erratic and seasonal. These are typical characteristics of dryness of the area. In the years between 1975 and 2000 the annual rainfall varied between 429mm and 1129mm (KZN Nature Conservation Service, 2001). The interpolated distribution of rainfall characteristics based on 20 or more years of data from different stations in and around the reserve (CCWR, 1989; Dent *et al.*, 1989) shows that the mean annual rainfall spatially varies from 663mm to 833mm within the reserve with mean annual precipitation (MAP) value of 710mm.

The summer months have hot temperatures with mean monthly maximum temperatures spatially ranging from 25°C to 28°C and mean monthly temperatures of 20°C to 22°C (CCWR, 1989). The maximum temperature during this season reaches up to 37°C (KZN Nature Conservation Service, 2001). The other months of the year are characterized by cool temperatures of mean monthly values of 10°C to 18°C depending on different localities of the reserve with mean monthly maximum values approaching 25°C in April and September. The mean monthly minimum temperature during these months ranges from 4°C in June and July to about 10°C in April (CCWR, 1989).

3.4 Topography and Geology

Weenen Nature Reserve is situated on the Draycott Plain, which is an extensive plain that slopes to the Tugela River (West, 1951). The reserve varies in altitude varying from approximately 925 a.m.s.l. in the north along the Nyandu River to 1278 a.m.s.l. in the Umthunzini Hills and up to 1310 a.m.s.l. in the Nontethe plateau, which are north and south of the Bushman's River respectively, dropping to about 900m along the Bushman's River and the eastern foot-slopes of the reserve (see Figure 3.1 and 5.11). The terrain of the reserve includes upland plateaus, undulating landforms, steep slopes, and bottomlands.

Geologically, the reserve is situated within the Karroo system underlain by beds of shales, mudstones, and sandstones of the Beaufort series (Hughes, 1989). Rocks of this series are quite hard when fresh, but break up into very small irregular fragments when exposed to water (West, 1951). This nature of the parent material influences soil characteristics, because it greatly accelerates the rate of erosion and it is believed to be largely responsible for the formation of deep dongas so common in the areas occupied by these beds (Hughes, 1989; West, 1951). These beds are intersected by innumerable sills and dykes of intruded dolerite whose outcrop occurs throughout the reserve (Hughes, 1989).

3.5 Vegetation

Edwards (1967) described the vegetation of the area as *Acacia karroo-Acacia nilotica* Thornveld.

The *Bioresource Classification* by Camp (1999) identifies three Bioresource Groups (BRG's) based on vegetation types of the reserve (see Figure 3.2). The northern and northwestern parts of the reserve are classified as BRG 18 (Mixed Thornveld). The plateau and undulating areas in the central part of the reserve and the plateau in the opposite side of the Bushman's River fall under BRG 13 (Dry Tall Grassveld). Whereas, the steep slopes on both sides of the Bushman's River and eastern hills of the reserve are classified as BRG 21, (Valley Bushveld).

With regard to the species composition in the area, there are three important vegetation communities; namely, semi-deciduous bush, *Euphorbia* thicket and *Acacia karroo-Acacia nilotica* thornveld (Camp, 1995b).

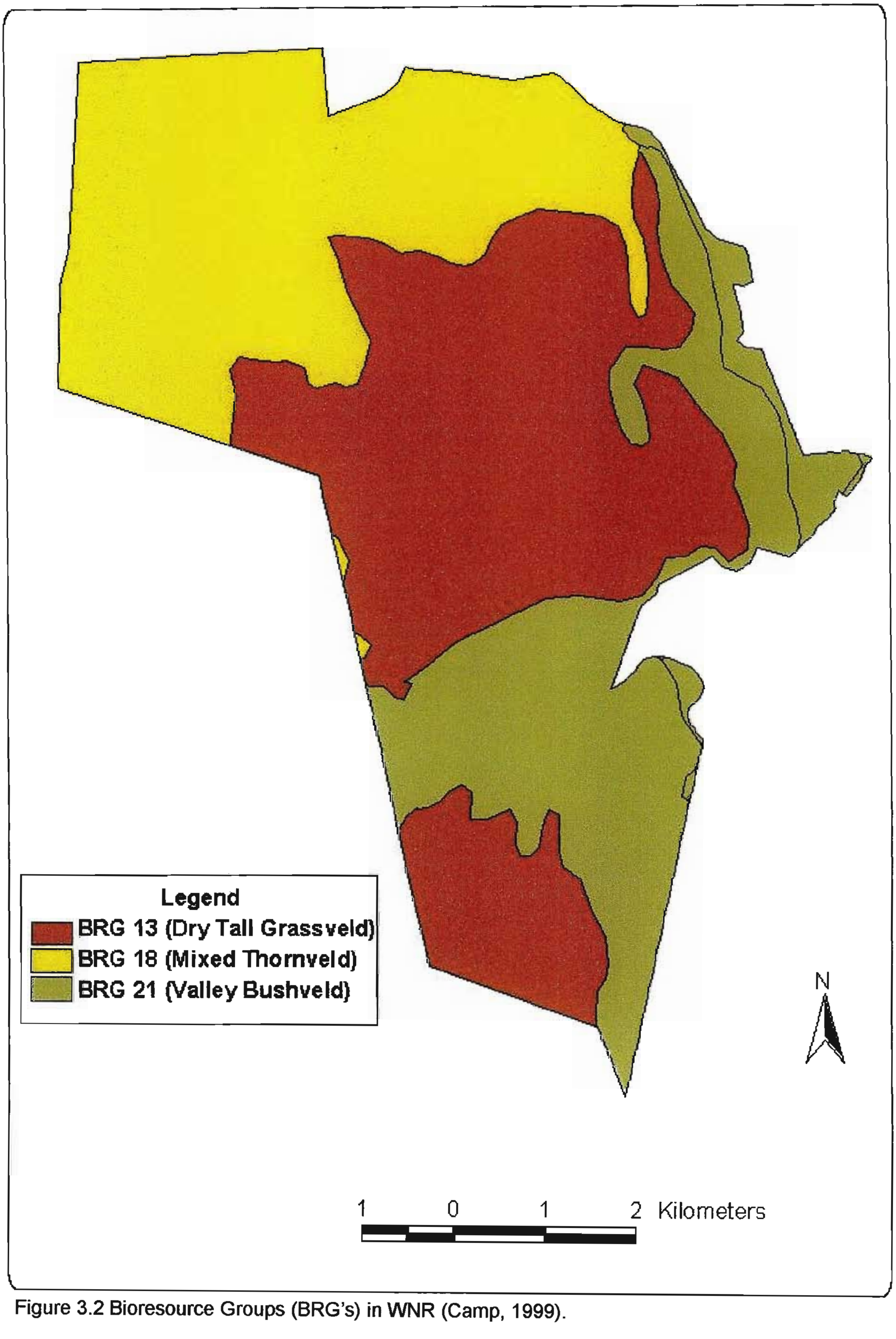


Figure 3.2 Bioresource Groups (BRG's) in WNR (Camp, 1999).

The semi-deciduous bush community consists of both deciduous and evergreen species (Camp, 1995a). This lies in the rugged areas of the dolerite and sandstone hills, sandstone and shale terraces and valley floors of highly erodible sediments (Camp, 1995b). The dominant trees, which may be regarded as indicator species, are *Olea europeasuhsp africana, Boscia albitrunca, Euclea crispa, Schotia brachypetala, and Euclea racemosa.* These are the predominantly evergreen trees.

Acacia species common to the area include: *A. karroo, A. tortolis, A. nilotica, A. cafra* and *A. steberiana* (Taolo, 1995). In many places of the reserve, the destruction and deterioration of the grass layer has led to a thickening of Acacia species mainly *A. tortolis* in the valley bottoms, and *A. nilotica* and *A. karroo* on the hillsides.

Euphorbia scrub is common in the steep and rocky areas of the reserve where forests are absent. Species common to this scrub are *Euphorbia triangularies, Euphorbia tiruculi,* and *Aloe rupes* (Camp, 1995a).

Grass cover in the area is generally poor (Camp, 1995b). Major grass species commonly found in the reserve include: *Themeda triandra*, which dominates the shallower dolerite derived soils, *Hyperrhenia hirta*, which is found in the thickets (KZN Nature Conservation Service, 2001), and *Cymbopogon validus, Bothrichola insculoa,* and *Panicium maximum* found in sparse understory in the thickets along the hillsides (Taolo, 1995).

3.6 Hydrology

Several seasonal streams flow through the reserve. The Bushman's River, which flows through a steep valley in the southern part of the reserve, is the largest of all the streams. The Nyandu River, which flows northwards in the northwestern part of the reserve, is the second largest river (Figure 3.1). All the rivers and streams in the reserve join the Tugela River, which drains into the Indian Ocean.

A number of small dams built as soil reclamation structures by the Department of Agriculture are encountered in different parts of the reserve. Presently, these dams provide drinking water for the wildlife and are a habitat for different kinds of small reptiles.

3.7 Summary

WNR has high biophysical and environmental diversity. Moving from one to another corner of the reserve, differences in terms of climatic, topographic, geologic, and vegetation aspects are evident. The diversity can be clearly observed along the Bushman's River Valley, where the topography ranges from bottomlands about 900 a.m.s.l. in elevation on the riversides to steep hills on both sides of the riverbank and to a flat plateaus on the hill tops and as high as 1310 a.m.s.l. in the southern parts of the reserve. The other environmental elements are likely to change with such variations in topography.

CHAPTER FOUR
MATERIALS AND METHODS

4.1 Data Collection

In order to achieve the aim of the research relevant datasets were required. Four data types were collected from different sources in an effort to arrive at a sound land evaluation. These included a soil map of the reserve and data on soil chemical and physical properties, climatic data, topographic data, and data on crop requirements for soil, climate, and landform.

4.1.1 Climatic data

A grided climatic data was obtained from the Computing Center for Water Research (CCWR) at the University of Natal in Pietermaritzburg. These data include different climatic parameters at a grid of 1′x1′ latitude longitude horizontal interval. Estimation of the mean annual precipitation (MAP) and other rainfall variables at each grid point was carried out in 1989 by the Department of Agricultural Engineering University of Natal, Pietermaritzburg based on recorded over 20 or more years at various station by regression analysis against several locational, physiographic and climatic attributes (CCWR, 1989; Dent *et al.*, 1989). These attributes include altitude, latitude, longitude, continentality, aspect, terrain roughness, and topographic exposure.

4.1.2 Soil Data

A soil map of WNR produced by Hughes (1989) was obtained from KZN Wildlife Service at Pietermaritzburg. The soil map showed that some areas in the reserve (steep areas in both sides of the Bushmen's River and other steep areas) were not surveyed. Although leaving steep areas unsurveyed in a soil survey for agricultural purposes is not considered a serious problem, a complementary soil survey was carried out as part of the study in an effort to classify these areas into soil units as well as to assess the nutrient status of the soil units in the reserve. For this purpose, 1: 10 000 black and white orthophotos that cover the study area referenced as (2829DD10, 2829DD15, 2830CC6, 2830CC11, and 2830CC16) were obtained from the Surveyor General at Pietermaritzburg (Office of the Surveyor General, PMB, 2002). These orthophotos were used for visual analysis of areas of the reserve to delineate homogeneous areas in terms of topography vegetation, brightness contrast, texture, tone and pattern, whose interpretation helped in defining sampling areas where soil pits were dug and auger samples were collected. A total of 15 soil pits were dug for soil profile description and sampling in different sites of the unsurveyed areas of the reserve. Soil samples from diagnostic horizons of each profile were collected for laboratory analysis. A total of 45 special auger samples were also collected from the soil units in the reserve to determine the nutrient status of the soil forms. The soil samples were analyzed in a laboratory following standard procedures of soil analysis (Allison, 1965; Bardsley *et al.*, 1965; Bremner, 1965; Chapman, 1965; Frank *et al.*, 1965; Green *et al.*, 1965; Heald, 1965; Olsen and Dean, 1965; Pratt, 1965). (Results of the soil analysis are provided in Table 5.1 in the next chapter and for location of the sampling sites see Figure 5.10)

4.1.3 Topographic data

Topographic data are vital elements of land evaluation. For this purpose, a Digital Elevation Model (DEM) data that covers the study area was obtained from the *Chief Directorate: Surveys and Mapping* at Cape Town. This dataset was obtained in ASCII (text character) format, which when imported into a GIS can be manipulated to produce different kinds of topographic maps.

4.1.4 Crop Requirement Data

In principle, land suitability evaluation is specific to specified land utilization types (FAO, 1976). Therefore, crop requirements are crop specific and even in some cases, variety specific. This means that there is no a common crop requirement for rainfed agriculture. For this reason, land suitability evaluation in this study was based on the selection of representative crops that may be grown in the area. These crops were taken as standard for land suitability evaluation for rainfed agriculture in the study area (Camp, 1999).

Information on crops that can grow in the area was obtained from the Bioclimatic Groups as it was established by (Phillips, 1973), and the Bioresource Groups (Camp, 1999). The meeting with Kelson Camp, an agro-ecologist and the author of Bioresource Classification of KZN, also helped in selecting representative crops under rainfed agriculture in the area.

Weenen Nature Reserve falls in Phillips' Bioclimatic Group 10, Sub arid Riverine and Lowland Shrub and Woodland Savanna (Phillips, 1973) and in Camp's Bioresource Groups 13, 18, and 21, which are Dry Tall Grassveld, Mixed Thornveld Valley and Bushveld, respectively (Camp, 1999) (see Figure, 3.2).

Based on the above information four different groups of crops: cereals, cash crops, legumes, and vegetables were considered for testing suitability for rainfed agriculture in the study area. Except for cash crops, where only cotton was considered, each group was represented by two individual crops that may be grown in the study area. The selected cereals were maize and sorghum; potatoes and cabbages were taken as representative vegetables; and dry beans and Soya beans represented the legumes. Information on each crop was gathered from different publications and reports of KZN Department of Agriculture, and FAO publications and reports so that they could be compared to the land qualities that were to be mapped for the purpose of suitability evaluation. The literature sources include: Anon (1972), Anon (1974), Blanks and Horne (1993), Duxbury *et al.* (1990), Manson (1993), Manson (1997), Parsons and Liebenberg (1991), Rutherfoord (1982), Smith (1993), and Smith (1997) and FAO publications which include: Doorenbos and Pruit (1977), Doorenbos and Kassam (1979), FAO (1978), and FAO (1980b). Other relevant literatures which include Hackett and Carolane (1982) and Sys (1985) were also used in obtaining reliable crop requirement information. The crop requirement data are provided in Appendix III.

4.2 Assessment of Land Resources

4.2.1 Assessment of Climatic Resources

Out of the three most important natural variables that dominate the earth's environment, that is, climatic pattern, plant distribution, and soil, climate is inevitably perceived as the principal dynamic component and obviously an independent variable shaping the other two on both meso and regional scales (Akin, 1991). Out of climatic variables, temperature, precipitation, and solar radiation are the major factors that govern the climatic adaptability and distribution (both in space and time) of crops (FAO, 1978).

4.2.1.1 Precipitation

For successful plant growth one must assure that there is enough moisture in the soil. In the case of rainfed agriculture the moisture input to the soil is only through the natural phenomenon of precipitation. The amount of precipitation can be assessed in several ways which include mean and median annual precipitation, mean and median precipitation of in the growing season, and mean and median values of monthly precipitation (Schulze, 1997).

The average amount of precipitation may not be necessarily a constraint to successfully carrying out an agricultural operation (Schulze, 1997), because it does not show the natural variability of the rainfall. Rather it is the average of rainfall totals, including abnormally high or low extreme values that are especially common to arid areas. This statistic has relatively little importance to agricultural productivity, because the distribution and variability of rainfall are required (Schulze, 1997). Median rainfall values and their coefficient of variability (CV%) as recommended by Schulze (1997) were used in this study in describing the amount and distribution of rainfall in the study area. The coefficient of variability (CV%) is a measure of variability of rainfall and is expressed as a percentage. For the Province of Kwazulu-Natal the approximate CV% of the rainfall can be calculated using Equation 4.1 (Smith and Camp, 2002). Mean annual rainfall was used for MAP.

$$CV\% = 640/\sqrt{MAP}*100 \ldots\ldots\ldots\ldots\ldots\ldots (Equation\ 4.1)$$

Where: CV% is coefficient of variability of the rainfall

MAP is mean annual precipitation in mm

Because CV% considers deviation from average, it is considered as an index of climatic risk, indicating a likelihood of fluctuations in the mean precipitation (Schulze, 1997). The higher the CV% the more erratic and unpredictable the rainfall.

Another way of assessing rainfall values is the probability of rainfall to exceed a certain value. In this case, the rainfall values are ranked in ascending order and the percentage of the rainfall values exceeding a certain rainfall value is used to assess the distribution of the rainfall in an area (Schulze, 1997). This statistic is expressed in percentile values of the rainfall data. The 80th and 20th percentiles of the rainfall data were examined in this study.

4.2.1.2 Evapotranspiration

In order to ascertain when, on average, there is enough water in the soil for sustained plant growth to take place, considering only the amount of annual precipitation is not enough, but simultaneously the precipitation must exceed a certain minimum threshold of water loss from the plant through the process of evapotranspiration (Schulze, 1997). This assures water availability to plant growth. The period in which water availability and temperature permit plant growth is referred to as growing period (FAO, 1978).

Average moisture of growing period over southern Africa can be determined by adapting a simple water budget approach of the FAO (1978), developed originally for agro-ecological zone mapping of Africa. In this approach for southern Africa it is assumed that during the period when the precipitation is at least equal to one-third of the evapotranspiration sustained plant growth can take place (Schulze, 1997). Equation 4.2 was used to determine the length of the growing season based on evapotranspiration (potential evaporation) according to the FAO water budget approach (Schulze, 1997). In this equation A-pan monthly evaporation was taken as reference potential evaporation (E_r). A-pan evaporation is a USA method of direct measurement of potential evaporation, which is commonly used by South African agricultural hydrologists (Schulze, 1997).

$$P \geq 0.3E_r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 4.2)}$$

Where: P is median monthly precipitation (mm)

E_r is monthly reference evaporation (mm)

4.2.1.3 Temperature

Temperature is a basic climatic parameter used frequently as an index of the status of the environment (Schulze, 1997). Temperature has three main effects on plant growth (FAO, 1983; Schulze, 1997). Plant growth varies with temperature; below critical temperatures, the growth stops; and very high temperatures have adverse effects. FAO (1983) suggests that the land quality temperature regime can be assessed based on individual characteristics such as mean temperatures during the growing season, temperatures of the coldest and hottest months of the growing season (absolute minimum and absolute maximum) and heat units (degree days) (see section 4.2.1.4). Schulze, (1997) also pointed out that while many activities are defined or described by mean temperatures, the so-called critical temperatures are generally of more significance to both natural plant and agricultural crop distributions.

Mean monthly maximum and minimum temperatures as well as mean monthly temperatures of the growing season were assessed as important parameters for plant growth in this study.

4.2.1.4 Heat Units

The temperature requirements of plants are more conveniently expressed in terms of heat units (degree days), (Smith, 1997). Heat units (degree days) are accumulation of mean temperatures above a certain threshold value (below which active development is considered not to take place), and below an upper limit (above which growth is considered to remain static or even decline), over a period of time (Schulze, 1997). This threshold temperature is referred to as base temperature and varies from plant to plant. Most crops such as maize, sorghum, soya beans, and dry beans stop growth when the temperature is below 10^{o}C (Smith, 1997). The base temperature is used in calculating the amount of heat units produced. Thus, if for example, the threshold temperature is

10°C and the mean temperature of a given day is 22°C, this means that 12 heat units are accumulated for that day and are added to the heat units of previous days. A heat unit is, therefore, expressed as the average of daily temperature minus the threshold temperature referred to as base temperature (Smith, 1997) and the daily heat units are calculated (summed) for the growing season. Average monthly temperatures were used as an approximation of the average daily temperatures to calculate heat units for this study for daily temperature data were not available. Two base temperatures, namely 10°C and 5°C, were used depending on the crop to be evaluated. Base temperature 5°C was used only for two of the crops considered for evaluation, namely potatoes and cabbage (Smith, 1997). The heat units were then multiplied by the number of days in each month to give the total heat units of the respective month. Finally, the heat units of each month in the growing season were summed to give the total heat units of the growing season in the study area.

4.2.2 Assessment of Soil Resources

Soil is probably the most significant determinant of agricultural potential of a particular area (Blanks and Horne, 1993). The examination and evaluation of important soil features such as effective depth, clay and mineral content, and slope are essential aspects of land use potential determination (Camp, 1995a). Dent and Young (1981) have pointed out that an assessment of soils and their response to management is required for sound decision-making in rural planning.

Assessment of soils in this study was based on the soil map of the study area produced by Hughes (1989). This map was supplemented with a complementary soil survey carried out as part of this study to classify some areas that were unclassified in the original soil map. Results of soil chemical and physical analysis from the soil survey were also used to enrich the soil map with additional soil information for the evaluation of agricultural potential of the soil units.

4.2.3 Assessment of Topographic Characteristics

Topographic information such as altitude, slope angle and length, position and aspect are important factors of land evaluation (McRae and Burnham, 1981). These land attributes may have significant effects on soil properties, soil erosion hazard or in the ease of cultivation or mechanized operations (Manson et al., 1995; McRae and Burnham, 1981). Therefore, assessment of topographic attributes is vital in land evaluation.

Topographic assessment of the study area was based on a Digital Elevation Model (DEM). From the DEM data different topographic maps that are important in evaluating the suitability of the area for agricultural land use were derived. The method used in mapping of the topographic data will be discussed in section 4.4.3.

Out of the topographic attributes, slope is agriculturally the most important parameter, because it helps in determining the area of land available for cropping and conservation practices required on the land (Blanks and Horne, 1993). The slope assessment was done based on 100m-grid cell size. Smaller grid sizes increased the steepness of the slope. This is because every locally varying slope is considered. Furthermore, smaller grid cell sizes gave small parcels of flat lands within the generally steep area, and small parcels of steep areas within the generally flat areas. Larger grid cell sizes were also disadvantageous because they over generalized the slope (Tankagi, 2002). Thus, 100m-grid cell size was taken as the appropriate mapping unit in the slope assessment, which corresponds to a one hectare land parcel.

4.3 Assessment of Crop Requirements

Obtaining reliable crop requirement data is usually the most critical aspect of land suitability evaluation. In most cases, crop requirement data in crop production guidelines and handbooks are based on local conditions and may not be applicable to other areas or under different conditions. Moreover, agronomic guidelines for crop production usually refer to the crop requirement for optimum growth. In practice, most crop production activities are undertaken under some stress from climatic and biophysical conditions. For this reason, the FAO Guidelines of *Land Evaluation for Rainfed Agriculture* identifies five levels of rating these conditions according to their suitability to crops (FAO, 1983). This suitability rating method will be described in section in section 4.5. For some of the crops considered in this study, a problem was faced in obtaining readily available crop requirement tables that rate land characteristics according to the FAO land suitability rating. To solve this problem the information on crop requirements from different literature was correlated to the FAO land suitability rating depending on various assumptions such as critical values of the land characteristics, hazardous effects to crops and yield estimates.

The soil factor table (Smith, 1997), which was applied to calculate yields of different crops according to rainfall, soil depth, and soil texture, was used in this study as an index of soil suitability for crops. Only one rainfall class (<775mm) was used in this study, because almost the entire reserve falls in this class. To convert the soil factors into qualitative indices, the soil factors were correlated to the FAO assumptions of attainable yield for different qualitative suitability ratings. It was assumed in this study that other factors being optimum the attainable yield varies according to the soil factor. Thus, the maximum yield (100% of the attainable yield) can be multiplied by the soil factor to give the percentage attainable yield adjusted according to soil conditions. For example, if the soil factor is 0.9, the attainable yield will be 100%*0.9 = 90%. According to the qualitative suitability rating of the FAO guidelines for land evaluation, this is rated as highly suitable (S1). Table 4.1 gives the correlations of the soil factors (Smith, 1997) to the qualitative suitability rating of the FAO guidelines for land evaluation (FAO, 1983) based on the above assumption.

Topographic requirements of the selected crops also were not readily available. To solve this limitation in crop requirements, the arable slope classes (see Table 4.2) developed by the KZN Department of Agriculture based on the BRG's (Camp, 1999) were used as a basis for land suitability evaluation. In the evaluation procedure, these slope classes had to be correlated to the FAO land suitability evaluation structure, which classifies land into three suitability classes, namely highly suitable (S1), moderately

Table 4.1 Correlation of the FAO suitability ratings (FAO, 1983) to soil factors of Smith (1997).

FAO suitability Rating	Attainable yield (FAO assumption)	Soil factor used to adjust yield (Smith, 1997)
S1	>80%	> 0.8
S2	40 – 80%	0.5 – 0.8
S3	20 – 40%	-
N	< 20%	-

suitable (S2), and marginally suitable (S3) which will be discussed in section 4.5. According to the land capability classification of KwaZulu-Natal, slope classes A, B, C and D are the criteria for land capability classes I, II, III and IV, respectively (Smith, 2002). Land capability class I has no slope limitations; whereas land capability class II has slight limitations that may require moderate conservation practices (Smith, 2002). These two classes may correspond to the FAO land suitability class S1, Which assumes that the impacts of the topographic slope on soil erosion hazard are slight that they do not significantly reduce productivity and do not raise inputs above an acceptable level (Dent and Young, 1981). Thus, upper slope limit for land suitability class S1 was decided to be slope class B, which has upper slope value of 7% in both BRG's 13 and 18 and 5% in BRG 21 (Table 4.2). Slope class C, which has slope values of 8 – 12% in BRG's 13 and 18 and 6 – 8 in BRG 21, is moderately steep and can impose moderate limitations on the use of land. Land suitability class S2 of the FAO land suitability classification, where the limitation is moderately severe that it can reduce productivity (Dent and Young, 1981) is appropriate class for slope class C. Slope class D is the lower limit of arable land in KZN, which can correspond to the lower suitability class in the FAO suitability classification, S3 (marginally suitable).

Table 4.2 Slope classes for arable land determination in the BRG's in WNR (Schröder, 2002).

Class	Slope %	
	BRG's 13 and 18	BRG 21
A	0 - 3	0 - 2
B	4 - 7	3 - 5
C	8 -12	6 - 8
D	13 - 20	

Tables that summarize the results of assessments of crop requirements for the relevant land resources are given in Appendix III.

4.4 Mapping of Land Resources

4.4.1 Mapping of Climatic Variables

Climatic variables such as precipitation and temperature vary over space and topographic elevation (Bryan and Adams, 1999). Understanding this spatial variability in climatic conditions is key to many agricultural and natural resource management activities. However, most common sources of climatic data are meteorological stations, which provide data only for single locations and hence, accurate estimation of climatic parameters for areas in between meteorological stations is always required.

A key issue in mapping of climatic variables is how to use point data sources of meteorological stations to produce a continuous surface map of climatic variables. This technique is referred to as interpolation. Burrough (1986) defines interpolation as "the procedure of estimating the values of properties at unsampled sites within the area covered by the existing point observations". In other words, it is a process of converting data from point observations to continuous surfaces so that the spatial pattern sampled by these measurements can be compared with the spatial entities (Burrough and McDonnel, 1998).

The climatic data used in this study were obtained from the Computing Center for Water Research (CCWR) at the University of Natal in Pietermaritzburg. It has been pointed out in section 4.1.1 that the estimate of mean annual precipitation (MAP) and other climatic statistics at each grid point was produced by regressing against factors such as altitude, latitude, longitude, continentality and aspect based on data from recording stations of 20 or more years (CCWR, 1989; Dent *et al.*, 1989). The climatic data were obtained in a 1′x1′ gridout format, which is a coarse spatial resolution for a small area such as WNR, and reference could only be made in areas of 1′x1′ latitude, longitude intervals. Thus, to create a continuous surface of finer resolution of the climatic data from the original gridout data, a GIS's mapping and interpolation capability was employed.

In recent years, alternative quantitative climatic surface interpolation has become possible using point-based climatic data within a GIS (Bryan and Adams, 1999). In fact, ArcGIS provides a number of interpolation methods (ESRI, 2000). However, none of these methods is considered as the most preferred technique for all data types and situations. Selection of a method is dependent on actual data, level of accuracy required, and time and resources available.

In this study two of the most commonly used interpolation methods, spline and Inverse Distance Weighting (IDW), were reviewed to evaluate their relative efficiency quantitatively by comparing them with the original dataset in an effort to maintain the actual measurement of climatic variables in the resulting surface.

The spline method can be thought of as fitting rubber sheet surface through the known points using a mathematical function (Anderson, 2001). This function can generate smooth curves or straight edges depending on the analyst's decision. The advantage of the spline method is that it can generate accurate surfaces from few sampled points and can retain small features. A disadvantage is that it may have different minimum and maximum values than the dataset, and it is sensitive to outliners due to inclusion of original data values at the sample points (Anderson, 2001).

Inverse Distance Weighting (IDW) is based on the assumption that nearby values contribute more to the interpolated values than distant observations. In other words, the interpolated value is weighted mean of neighboring data points and weight decreases with distance from the unknown point that is being estimated. The advantage of IDW is that it is intuitive and efficient and gives best results in evenly distributed points. Similar to the spline method, the IDW method is sensitive to outliners and unevenly distributed data clusters result in introduced errors (Anderson, 2001).

Comparison of Interpolation Techniques

Relative accuracy of the interpolation techniques was assessed by comparing them with the original data value using a GIS's map calculation technique. The differences between the interpolated and original data values of different climatic variables were calculated for both interpolation methods. The method that resulted in lower difference was considered to be relatively more accurate.

For all of the climatic variables, the IDW method resulted in lower difference between the original data values and the interpolated values than the spline method. Moreover, the comparison of the maximum and minimum values of the interpolated surfaces with the original data shows that the IWD method had relatively lower ranges. Table 4.3 shows a comparison of the maximum ranges of selected climatic variables using both interpolation methods.

The main reason for relatively lower differences between the original data and interpolated map in IDW could be attributed to the fact that the data sources used for interpolation were regularly spaced gridout point data in which IDW is believed to give better results (Burrough, 1986). Based on the results of the comparison it was decided that mapping of climatic parameters should be based on IDW interpolation to create continuous surface maps of climatic variables that cover the entire study area. In the IDW technique, it was also observed that when weighting power increases, smoothing increases, and so does the difference between the actual and interpolated data. The number of neighboring points was decided to be 12 so as to include as many data points as possible (Borrough, 1986). The weighting power of 2 resulted in better results for both smoothing and retention of the original data, because; higher powers resulted in less influence of the data points and lower powers over estimated the influence of the data points (ESRI, 1996).

Table 4.3 Comparison of differences in values between original values and interpolated values using spline and IDW interpolation methods for selected climatic statistics.

Inter-polation method	Median precipitation				Max Temp	Minimum temperatures					Solar Radiation		
	Aug	Dec	Oct	Mar	Dec	May	Sep	Jan	Nov	Jul	Jan	Apr	Oct
Spline	1.1	1.4	1.3	1.4	2.0	1.0	.3	1.7	1.3	1.7	1.3	1.4	1.6
IDW	1.0	1.1	1.1	1.1	1.0	1.0	0.7	1.1	0.5	0.6	1.0	1.0	1.0

4.4.2 Digitizing of the Soil Map

Digitizing is the process of encoding geographic features on paper in digital form as x, y coordinates in order to create spatial data from the existing hardcopy maps and documents. Digitizing in this study was performed using ArcCAD software (ESRI, 1998), which is an extension of AutoCAD.

The digitizing process was started by digitizing five control points (tic marks) of known coordinates on the 1:10 000 soil map of the reserve. The Root Mean Square (RMS) error in digitizing units between the control points was automatically calculated by the software. This helps in evaluation the accuracy of the digitizing process. For paper maps the acceptable RMS error is as high as 0.006 inches of digitizing units (ESRI, 1995). Thus, the RMS error was decided to be less than 0.005 inches, which at the

1:10 000 scale of the soil map approximates to a ground distance of 2m. The tic marks were re-entered until this acceptable error was achieved.

Once digitizing was complete, digitizing errors were cleaned. The polygons are meaningless until a relevant database is created to assign a soil type to each. This requires topology building. The Arc/Info user manual defines topology as "the mathematical procedure for explicitly defining spatial relationships" (ESRI, 1995). Topology building and cleaning were performed in ArcCAD.

Since the analysis was planned to be within the environment of ESRI's ArcView GIS software (ESRI, 1996), once the topology was constructed the ArcCAD coverage was converted to an ArcView shape file.

In the ArcView environment, all attribute data relevant for the description of soil *forms* (units) and evaluating agricultural potential of the soil units, which include soil chemical and physical properties (see Table 5.1), were entered as a simple relational database using ArcView's editing capability.

4.4.3 Topographic Mapping

The DEM data were obtained in ASCII (character text) format, which contains X, Y, and Z values at intervals of 200m horizontal distance. The X and Y values refer to the actual geographical locations of longitude and latitude, respectively and the Z values contain the elevation values at each point.

The DEM data was imported into ArcView GIS software and converted into ArcView shape file. Unfortunately, the reserve doesn't fall on one map sheet. Thus, DEM dataset of two map sheets that cover the areas of the reserve referenced as 2829DD and 2830CC were obtained. The data sets in these two map sheets were in two different map projections and asked for re-projection of the 2830CC dataset to Clark 1880 Transverse Mercator Projection with central meridian or Longitude of nought (L0) 31, because all the other datasets were in this projection. After projection, the resulting map showed an overlap of the dataset in the study area. To solve this the two datasets were aligned and edge matched into a single dataset.

For estimating elevation values between the point values so as to obtain a continuous DEM map, a GIS interpolation technique was used. The two types of interpolation techniques discussed in section 4.4.1, namely spline and Inverse Distance Weighting (IDW) were compared for the purpose of determining their accuracy in retaining the original dataset. As it was observed in the interpolation of climatic data, the comparison of the results of the two methods with the original data showed that the IDW method is relatively more accurate than the spline method. Thus, the IDW method was used in interpolating the DEM data.

4.5 Suitability Evaluation Procedure

Although there is no standard method of land evaluation, the FAO *Land evaluation Framework* (FAO, 1976) is the most widely used land evaluation method. This evaluation technique was adapted in this study with some modifications according to the aim of the study and local conditions.

In the evaluation procedure followed in this study, land qualities were compared with crop requirements in order of their significance for the crops considered in the evaluation as set out in the FAO Agro-ecological Zoning (FAO, 1996). Firstly, the climatic conditions were compared with climatic requirements of the area. Areas that do not satisfy the climatic requirements of each crop under rainfed agriculture were classified as *"Not suitable"* and excluded from any further analysis. If the climatic conditions satisfy the crop requirements, the areas were considered for further assessment.

The next step was matching of soil units present in the area to the requirements of each crop for soil resources. Appraisal of soil resources for rainfed crop production was based on soil form, soil effective depth, soil texture, surface rockiness as well as soil fertility status and other chemical and physical properties. Soil units of the reserve were rated according to their suitability for each crop under consideration. Suitability rating of the soil units was then modified according to other significant soil limitations imposed by slope, depth, texture, and fertility status.

The suitabilities of individual land qualities were then combined to give the overall suitability of the land resources for each crop.

There are different ways of combining the individual suitability ratings suggested by the FAO *Guidelines Land Evaluation for Rainfed Agriculture* (FAO, 1983):

1) *Subjective combination*: defines overall suitability based on the knowledge of the interaction between land qualities.
2) *Limiting combination*: land qualities are considered to be equally important and limitation in one land quality limits the overall suitability.
3) *Arithmetic procedures*: each suitability class is assigned a value. The overall suitability is then obtained by multiplying or adding the values.
4) *Modelling method*: this makes use of models that relate crop requirements to land qualities, whose interaction is used to predict crop yield.

The limiting method takes the least favourable resource as limiting (FAO, 1983). This method is the simplest method in that it does not consider the complicated interactions between environmental factors and their effects on land potential. However, it has several advantages in supporting this study. Firstly, this study evaluates the suitability or otherwise of the area for rainfed agriculture. Thus, care was taken not to include any risk or uncertainty imposed by climatic or edaphic factors in the suitability assessment. Consequently, any part of the reserve with one or more unfavourable land qualities was evaluated as "*unsuitable*". Moreover, land qualities evaluated in this study are major and most limiting where absence of one land quality could not be compromised by good condition of another land quality. For example, having satisfactory rainfall could not improve the suitability of soils in the area. Thus, the three important land qualities that were assessed in this study, soil, topography, and climate were rated individually and the overall suitability will be the suitability of the *least suitable* land quality.

To integrate the information from the land resources mapping and crop requirement assessment, and derive meaningful information so that they can be employed in the evaluation of land suitability, a powerful analysis technique is needed. In this project a GIS was used to identify areas that satisfy the lower limits of crop requirements for each of the land resources mapped.

The "*limiting combination*" method of suitability evaluation was applied within a GIS by employing a Boolean overlay analysis, where thematic layers of the different land resources were overlayed to select areas that satisfy the lower limits of crop requirements. The *intersection* "*AND*" operation was used to select areas where the suitabilities of all the land qualities were satisfied. Figure 4.1 shows a flow diagram of the operations followed in the suitability evaluation.

According to the land evaluation method developed in the FAO *Framework for Land Evaluation* (FAO, 1976), qualitative land suitability is expressed in descriptive terms as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently unsuitable (N1), and potentially unsuitable (N2). This classification structure was adapted in this study in order to classify the study area into different suitability classes for rainfed agriculture. However, the N1 and N2 suitability classes were not differentiated in this study, because of lack of readily available crop requirement information. Most crop requirements data obtained from literature do not provide information on the limits between crop requirement rating N1 and N2.

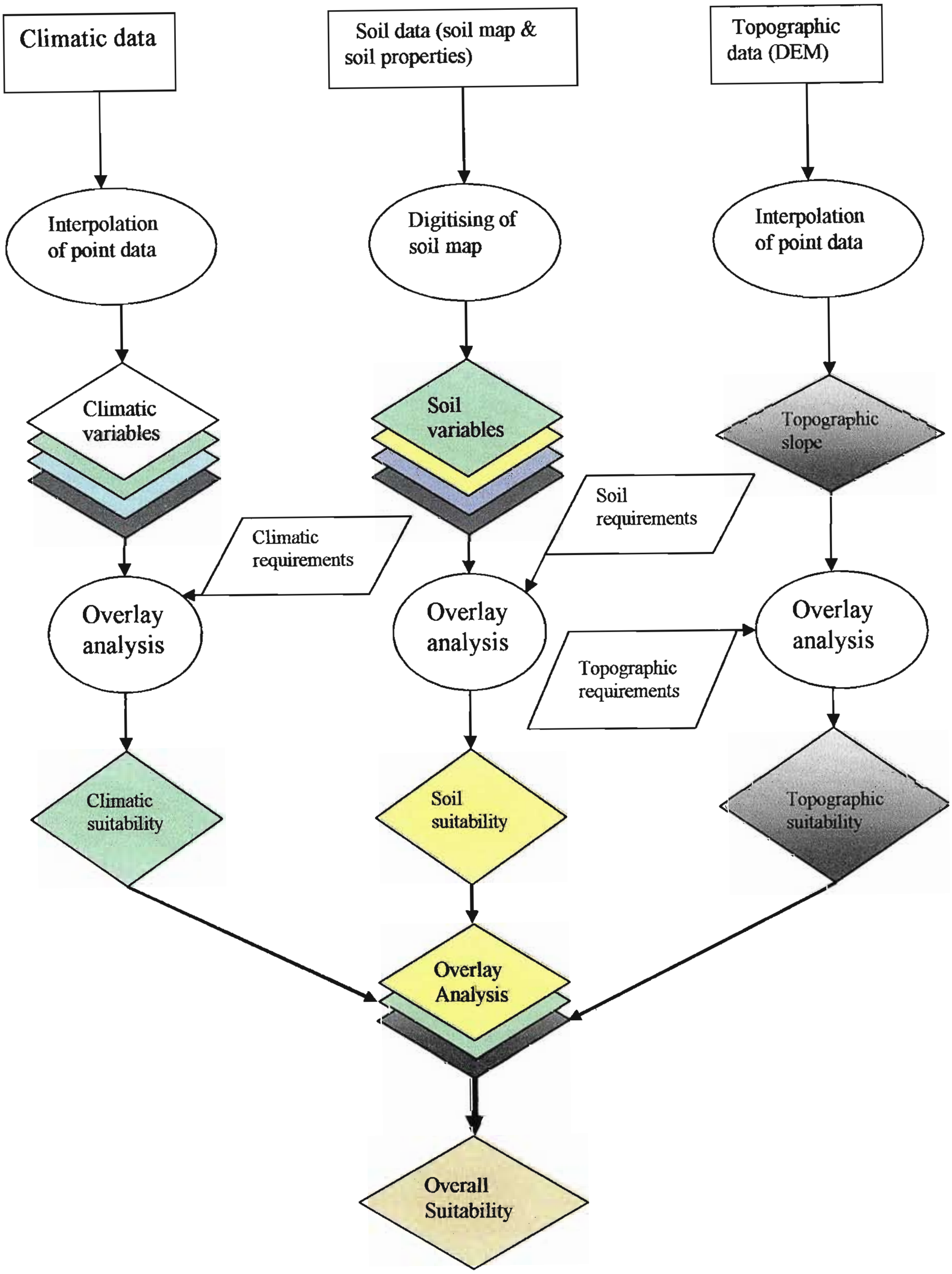


Figure 4.1 Flow diagram showing the operations followed to create the land suitability maps using the FAO land suitability evaluation procedure (FAO, 1983) in a GIS overlay analysis.

4.6 Summary

The climatic, soil, topographic, and crop requirement datasets used as a basis of land suitability evaluation in this study were obtained from different existing data sources and a field survey carried out as part of the study. These datasets were assessed in such a way that they could be employed in land suitability evaluation. The use of a GIS facilitated accurate mapping of the land resources for subsequent analyses. In the analysis stage, the two datasets, namely the land resources datasets and crop requirement information, were integrated into a GIS. The land resources were then awarded suitability ratings depending on their ability to satisfy the relevant crop requirements.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Inventory of Land Resources

5.1.1 Climatic Resources

5.1.1.1 Precipitation

Precipitation is a wide meteorological term that refers to the moisture obtained from rain, hail, mist, dew and frost. Of these, rainfall is the primary source of water for plant growth and the only form for which comprehensive records are attainable (Camp, 2002). Thus, the assessment of moisture availability in this study was based on the amount of rainfall. It has been explained in section 4.2.1.1 that mean rainfall values may not necessarily be a constraint to plant growth. For better evaluation of rainfall in an area for agricultural production one should depend on the median values of the rainfall. Figure 5.1 shows a comparison between the two rainfall statistics (mean and median) rainfall values of months of the year in the study area. The comparison shows that for most of the months the mean rainfall values are higher

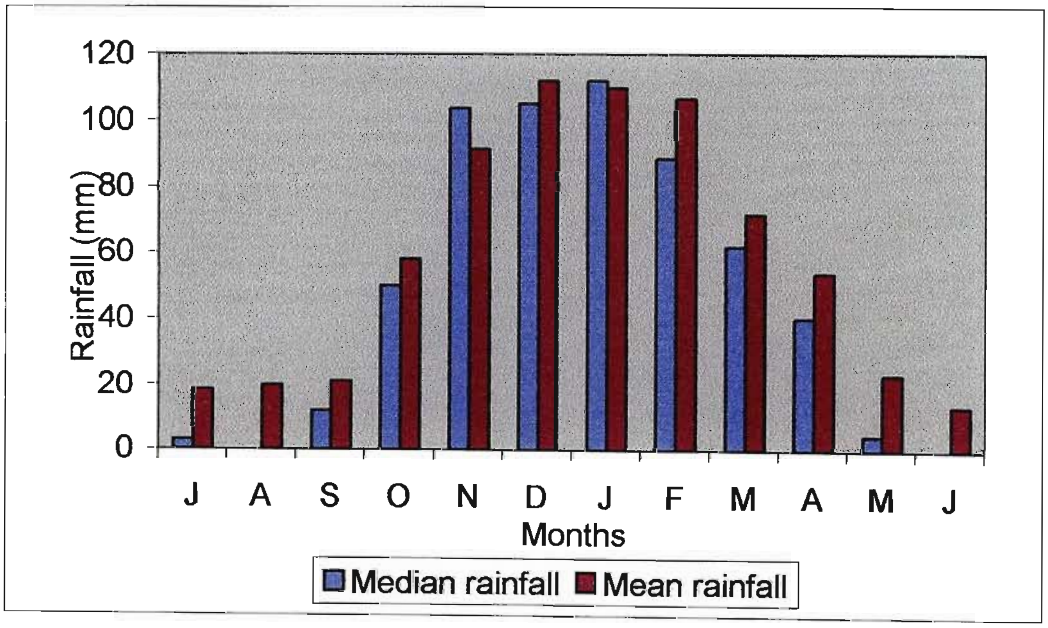


Figure 5.1 Comparison of monthly mean and monthly median rainfall statistics in WNR.

than the median rainfall values. This is especially true for drier months, where occasional high rainfall incidences raise the mean rainfall value while most days of the month are without any rainfall incidence, whereas the median value is always the middle value and there are as many days in the month with rainfall records greater than the median as there are with less than the median value.

Figure 5.2 shows the spatial distribution of mean annual rainfall over the reserve. Higher rainfall values are encountered in the eastern upland areas and hills with highest rainfall value of 883mm in the Umtunzini Mountain and in the lookout point (see Figure 5.2). Towards the west the rainfall decreases and the lowest rainfall value of 663mm is encountered in the western boarders of the reserve and along the Nyandu River banks (Figure 5.2).

The map of mean annual rainfall shows circular patterns in some areas of the reserve. These patterns are probably due to the fact that the IDW method, which was used in mapping of the spatial distribution of climatic and topographic parameters (see section 4.4.3), is susceptible to clustering of values in the original data points (Borrough, 1986; Mitas and Hitasova, 1999). This is the case for almost all of the maps produced by interpolation.

Annual rainfall values may not reflect the moisture deficit in the soil. Months of less moisture deficit (months of growing period) can be determined from equation 4.2 in subsection 4.2.1.2. Figure 5.3 shows the distribution of three climatic parameters (median rainfall, evapotranspiration, and CV%) over months of the year. The chart also shows the evapotranspiration factor ($0.3E_r$) used in the determination of months of the growing period according to equation 4.2. According to this chart a month is considered part of the growing period if its median rainfall (red bar) is greater than or equal to one-third of the potential evaporation (blue bar). This is indicated by the yellow line ($0.3E_r$). The chart shows that the growing season in WNR starts in October and ends in March, which is approximately equal to 180 days.

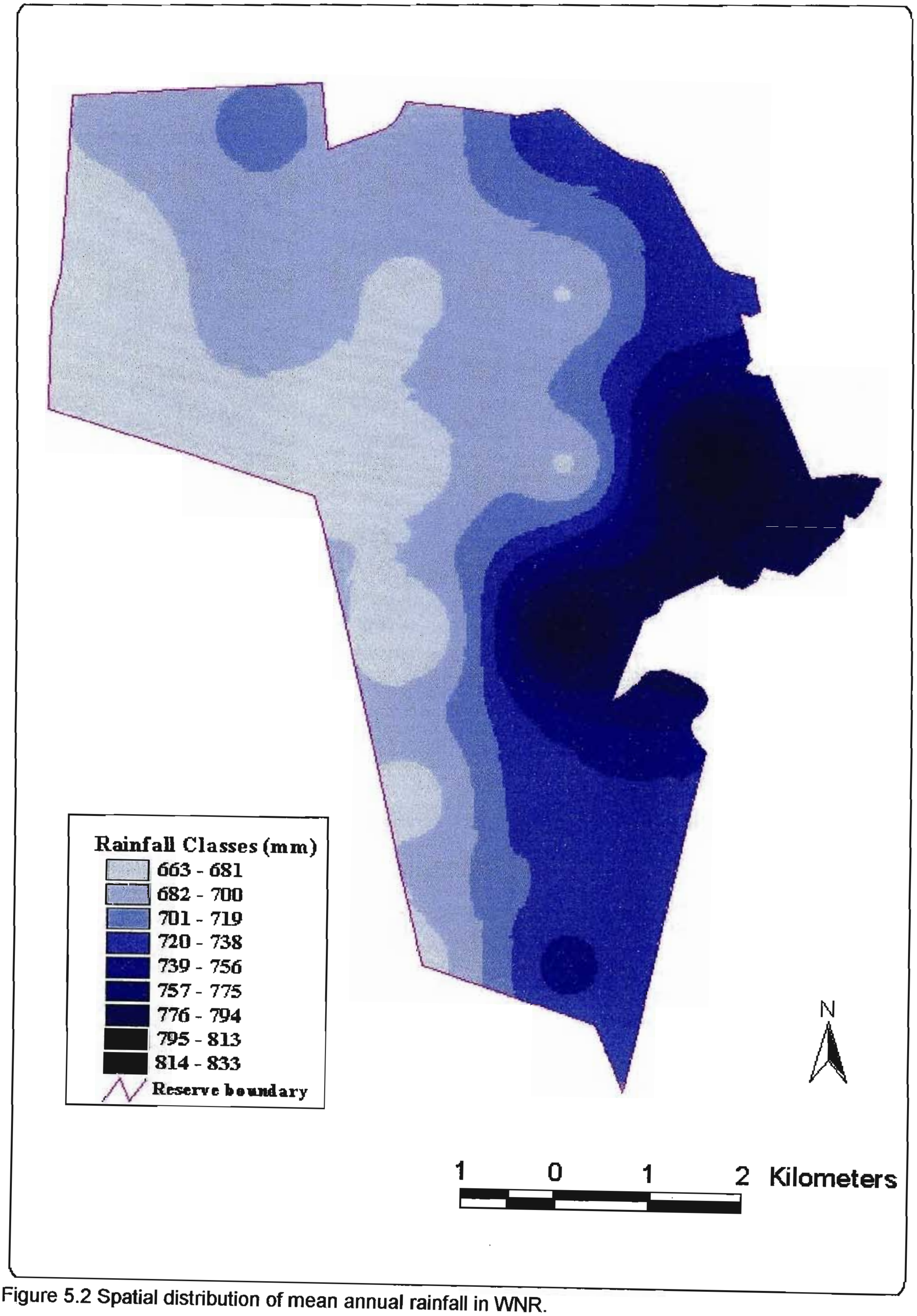


Figure 5.2 Spatial distribution of mean annual rainfall in WNR.

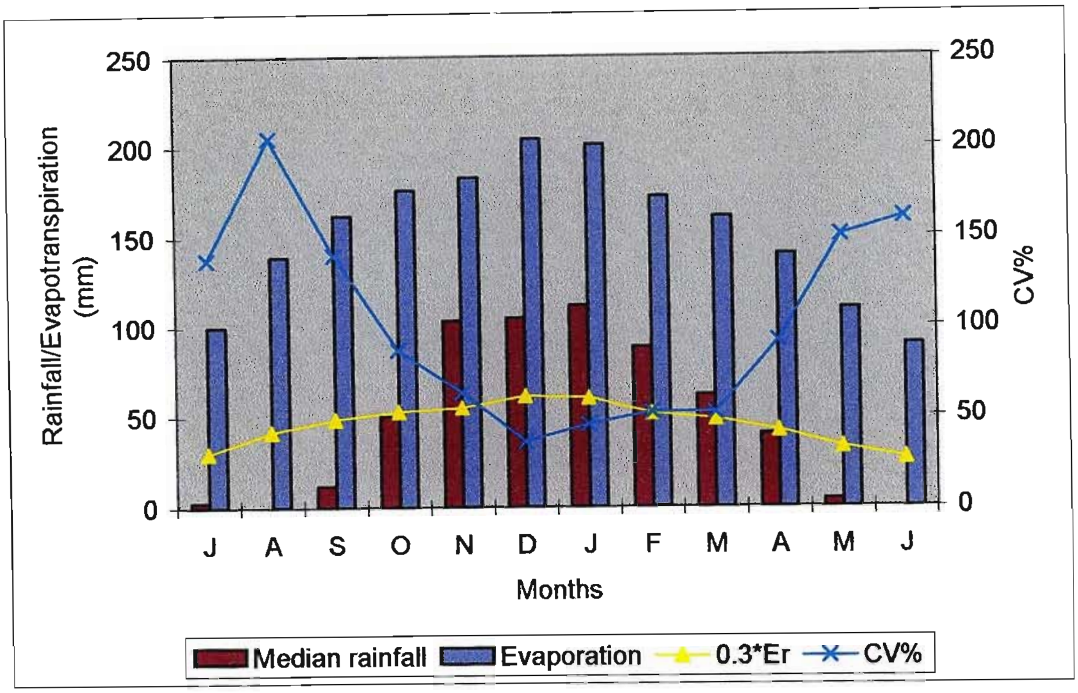


Figure 5.3 Distribution of three climatic statistics (median rainfall, evapotranspiration and CV%) over months of the year and an evapotranspiration factor for the determination of the length of growing period (0.3Er).

Figure 5.4 provides the spatial distribution of median rainfall of the growing season in the study area. This rainfall statistic has a similar spatial distribution to the mean annual rainfall with minimum and maximum values of 500mm and 625mm in the western and eastern parts of the reserve, respectively.

Rainfall in the study area is highly variable with annual coefficient of variability (CV%) of 24% calculated according to Equation 4.1 from the mean annual rainfall value of the reserve, which is 710mm. This indicates uncertainty of rainfall in the study area. This means that in two out of every three years the rainfall may fluctuate from 539mm to 880mm around the mean annual rainfall value, which is 710mm. This shows aridity of the study area that makes it worse off, because it additionally suffers from high fluctuations around its already low average rainfalls (Schulze, 1997). Monthly CV% values are much higher than annual CV% values due to the high variability in rainfall among days of a month. This is especially true for drier months (see Figure 5.3) due to the fact that during the drier months the rainfall is highly

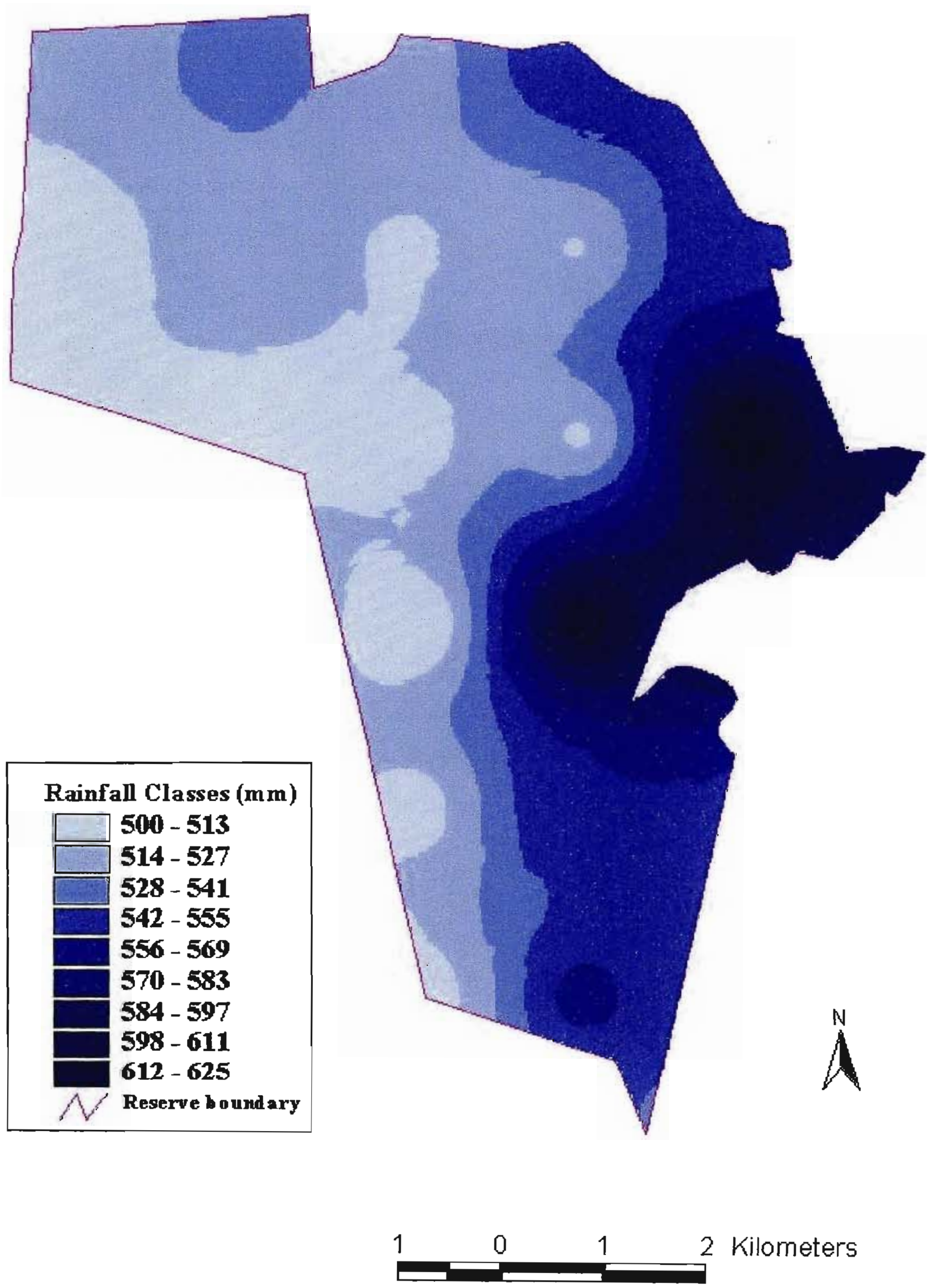


Figure 5.4 Spatial distribution of median rainfall of the growing period in WNR.

variable. This supports the above argument, that is, high mean values of drier months as compared to the median values are less predictable and unreliable. Rainfall in the study area is also characterized by high seasonality, in which 68 – 75% of the total mean annual rainfall falls in the period October to March.

The 80th and 20th percentile of rainfall, as explained in subsection 4.2.1.1, are 555mm and 806mm, respectively. These indicate that 80% of the rainfall values in the area do not exceed 555mm and the rest 20% are between 555mm and 806mm.

5.1.1.2 Evapotranspiration

In arid and semi-arid areas a high proportion of the total amount of precipitation is lost to the atmosphere in the form of evapotranspiration. This is particularly true in South Africa, where 91% of the mean annual precipitation (MAP) is lost by evaporation, which is considerably higher than the worldwide 65% of the MAP (Schulze, 1997). Thus, for optimum plant growth the precipitation in an area is required to exceed certain threshold value where moisture deficit due to evapotranspiration can be tolerated by plants. In southern Africa this threshold is considered to be one-third of the evapotranspiration (Schulze, 1997).

According to equation 4.2 in subsection 4.2.1.2 the threshold where the precipitation exceeds one-third of the evapotranspiration starts in October and ends in March as illustrated by Figure 5.3. This period is referred to as the growing period (FAO, 1978; FAO, 1983). Precipitation in this period is high enough to assure that soil moisture deficit due evapotranspiration is low that optimum plant growth can take place.

5.1.1.3 Temperature

Figure 5.5 provides three temperature statistics (mean monthly minimum, mean monthly maximum, and mean monthly temperature) of the months of the year in the study area. Summer months are hot with mean monthly maximum temperature values ranging from 25°C in October and April to 28°C in December, January, and February.

The mean monthly temperatures in summer vary from 18°C in October to 22°C in January and February. Mean monthly minimum temperature in summer ranges from 11°C in October to 16°C in January and February. The other months of the year are colder. June and July are the coldest months in the reserve with mean minimum monthly temperature of 4°C and mean monthly temperature of 12°C.

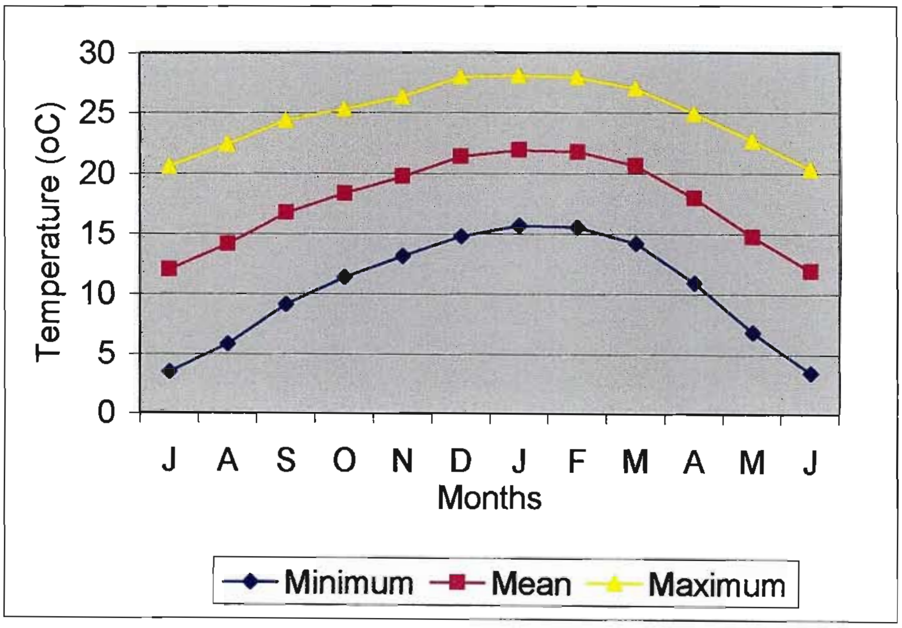


Figure 5.5 Mean monthly minimum, mean monthly, and mean monthly maximum temperatures of months of the year in WNR.

Figures 5.6, 5.7, and 5.8 show the spatial distributions of mean monthly, mean monthly maximum and mean monthly minimum temperatures of months of the growing season, respectively. Low elevation areas in the eastern and northern parts of the reserve have high temperature values for all of the three statistics. Low temperature values in the reserve are generally associated with higher topography.

5.1.1.4 Heat Units

Figure 5.9 provides the spatial distribution of values of heat units of the growing season over the reserve based on a base temperature of 10°C. The values range from 1777 to 2109. High values of heat units are associated with high temperatures. Thus, low elevation areas yield higher heat units as compared to areas of higher topography.

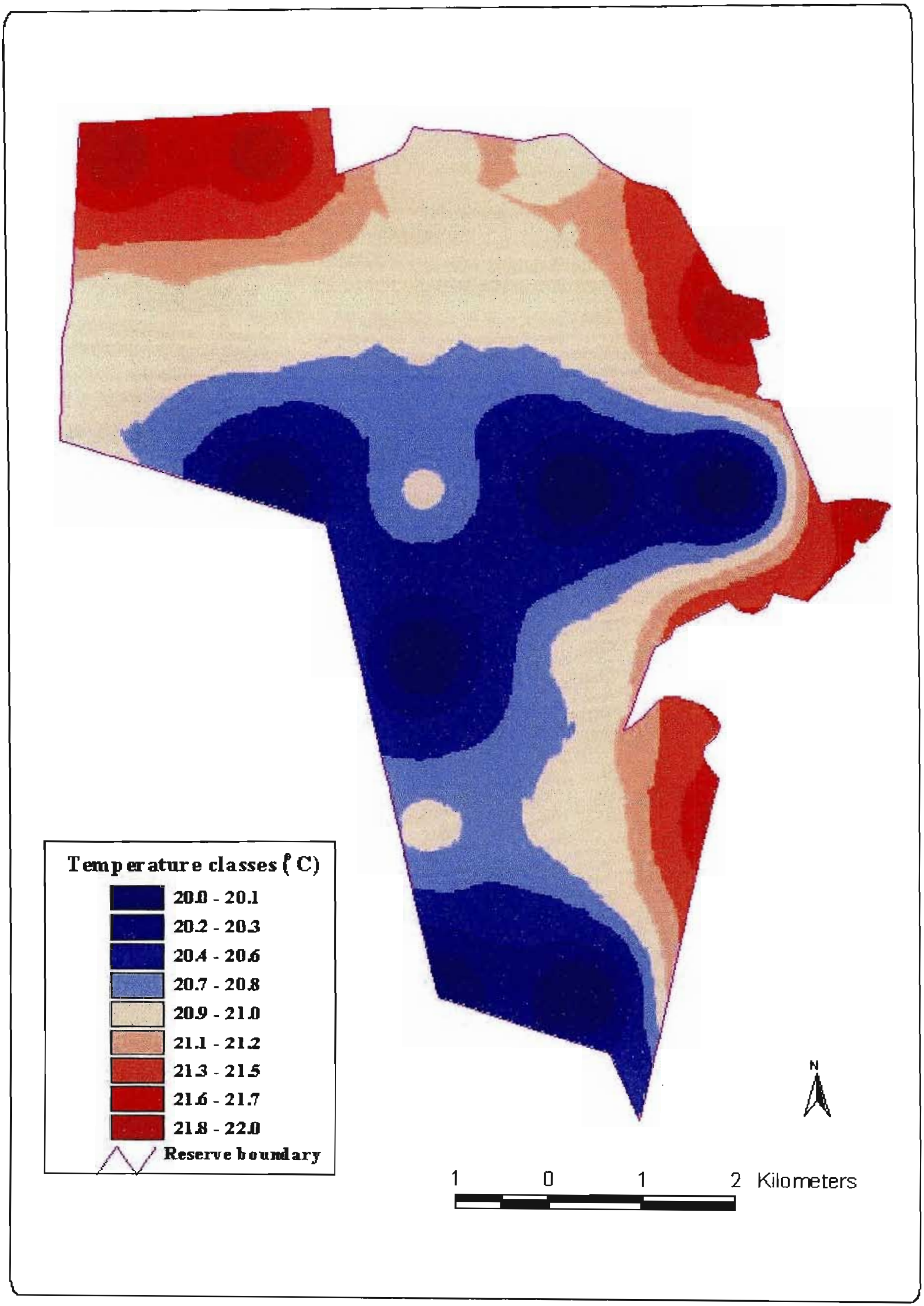


Figure 5.6 Spatial Distribution of mean monthly temperature of the growing period in WNR.

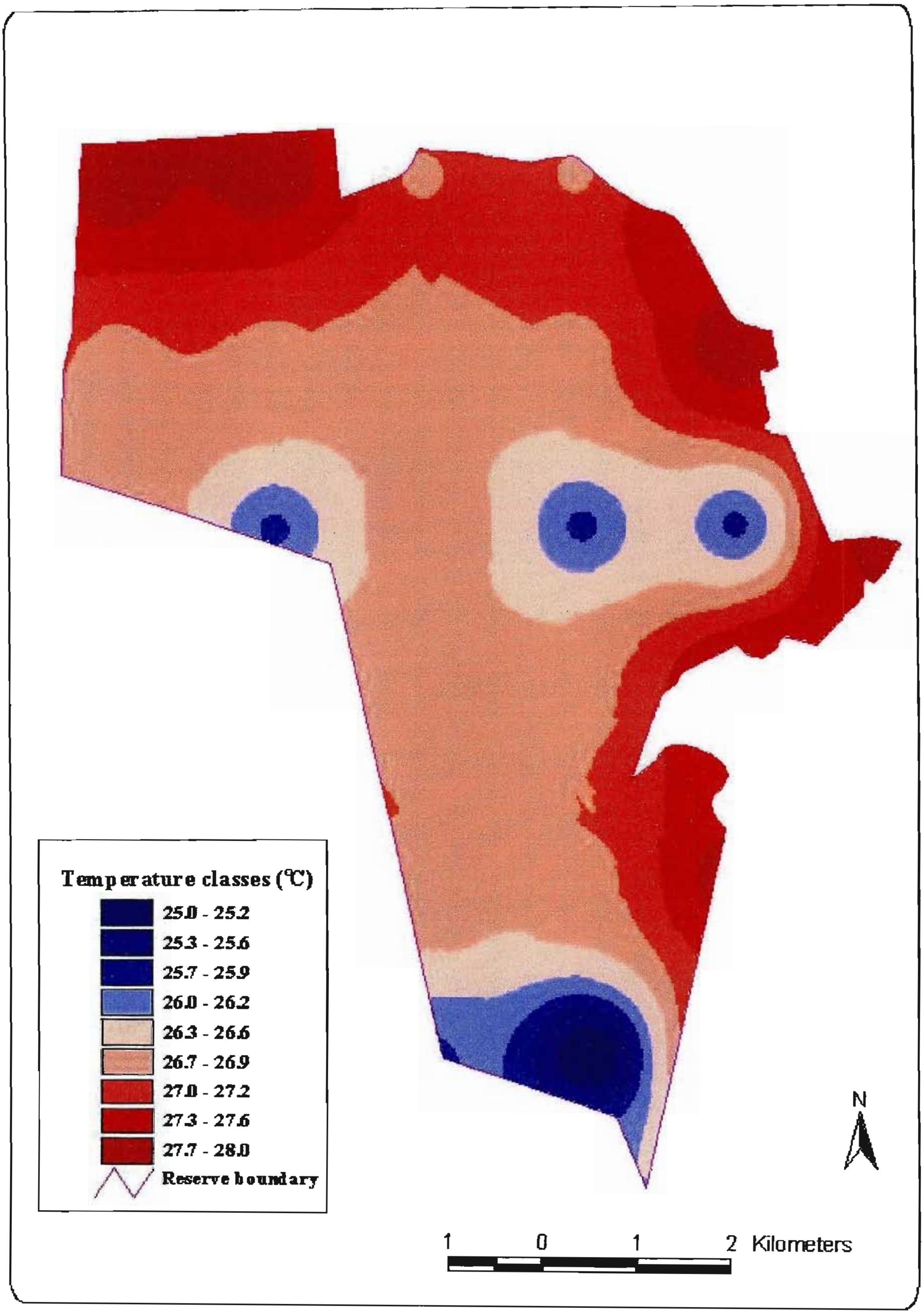


Figure 5.7 Spatial Distribution of mean monthly maximum temperature of the growing period in WNR.

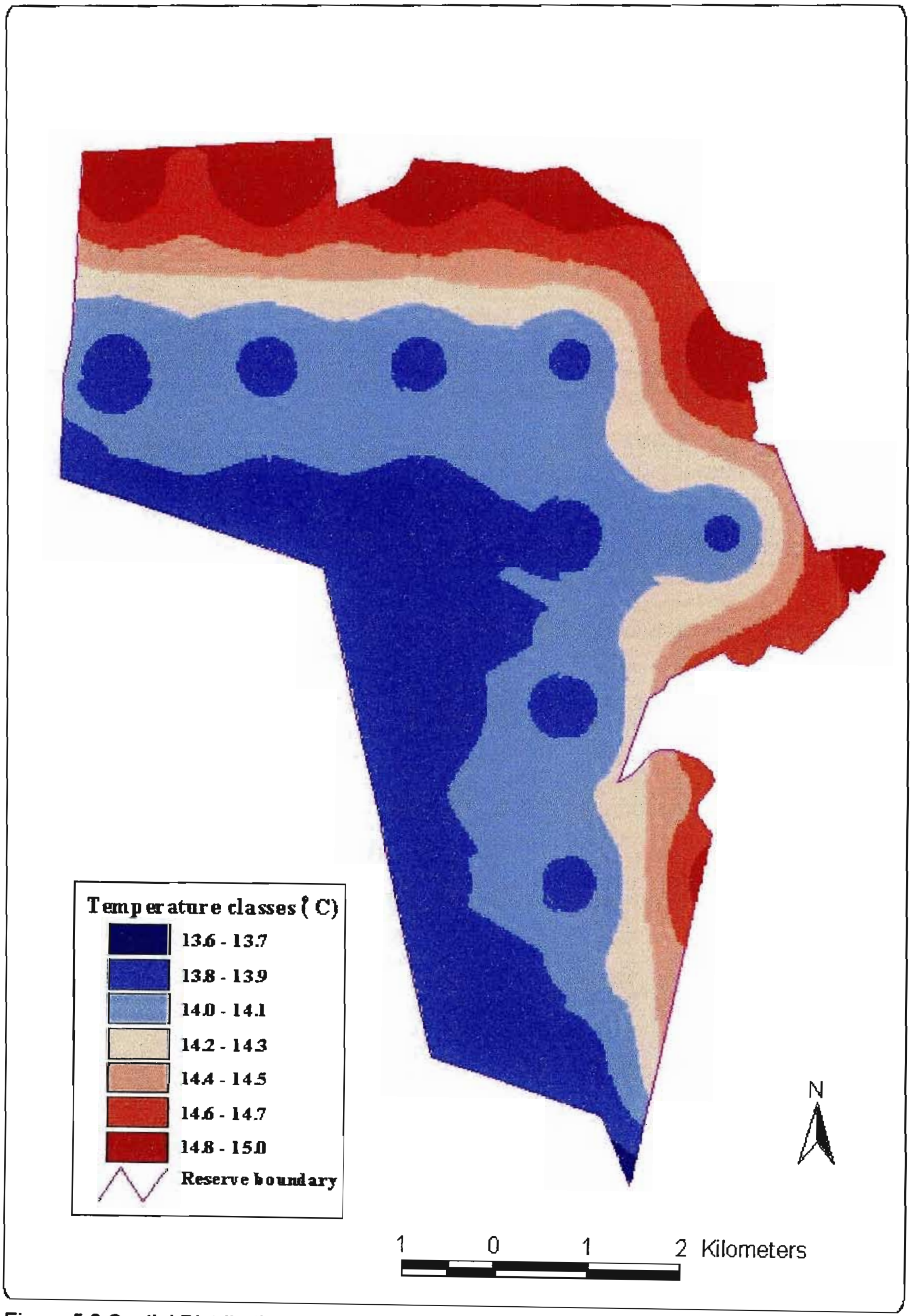


Figure 5.8 Spatial Distribution of mean monthly minimum temperature of the growing period in WNR.

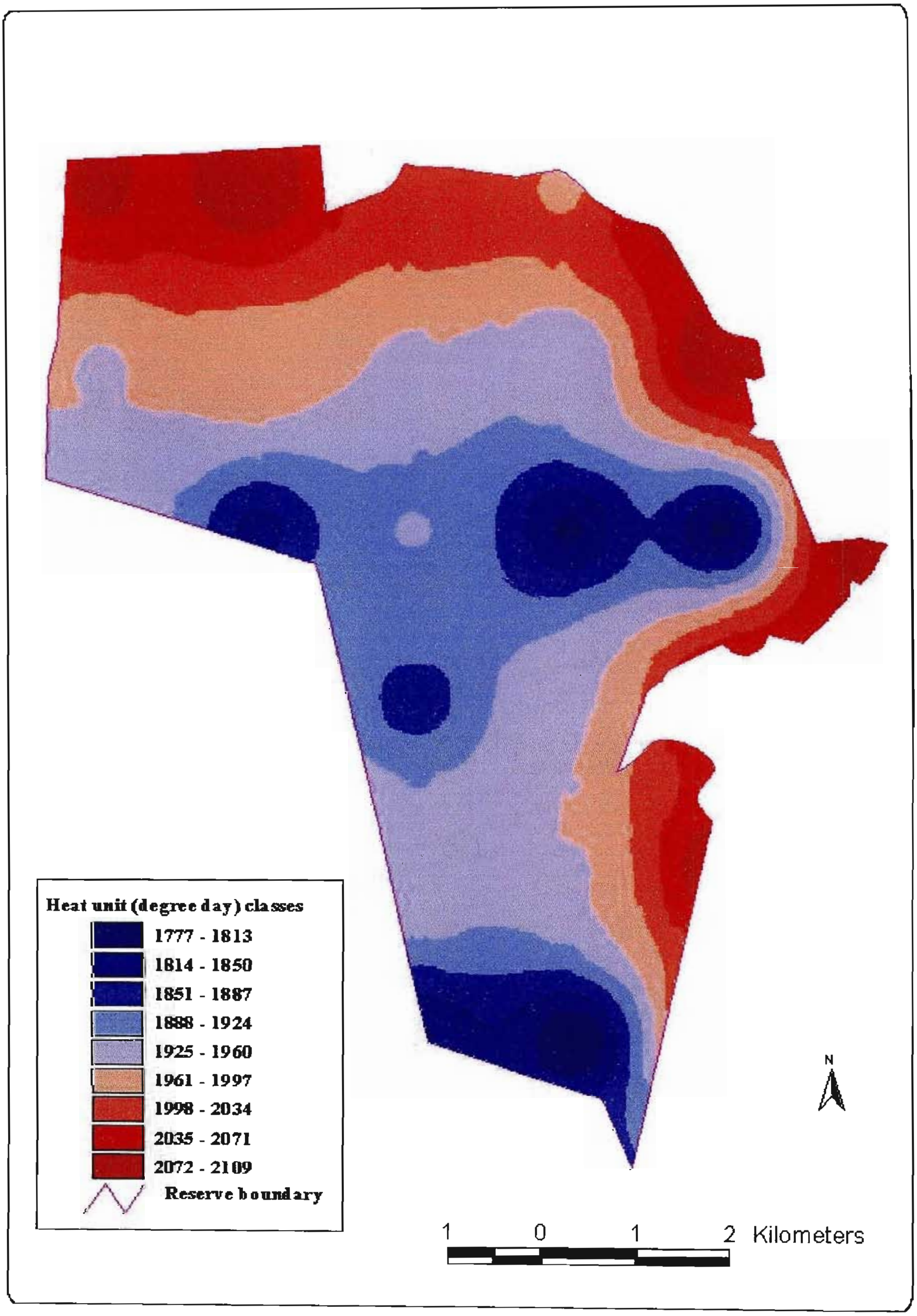


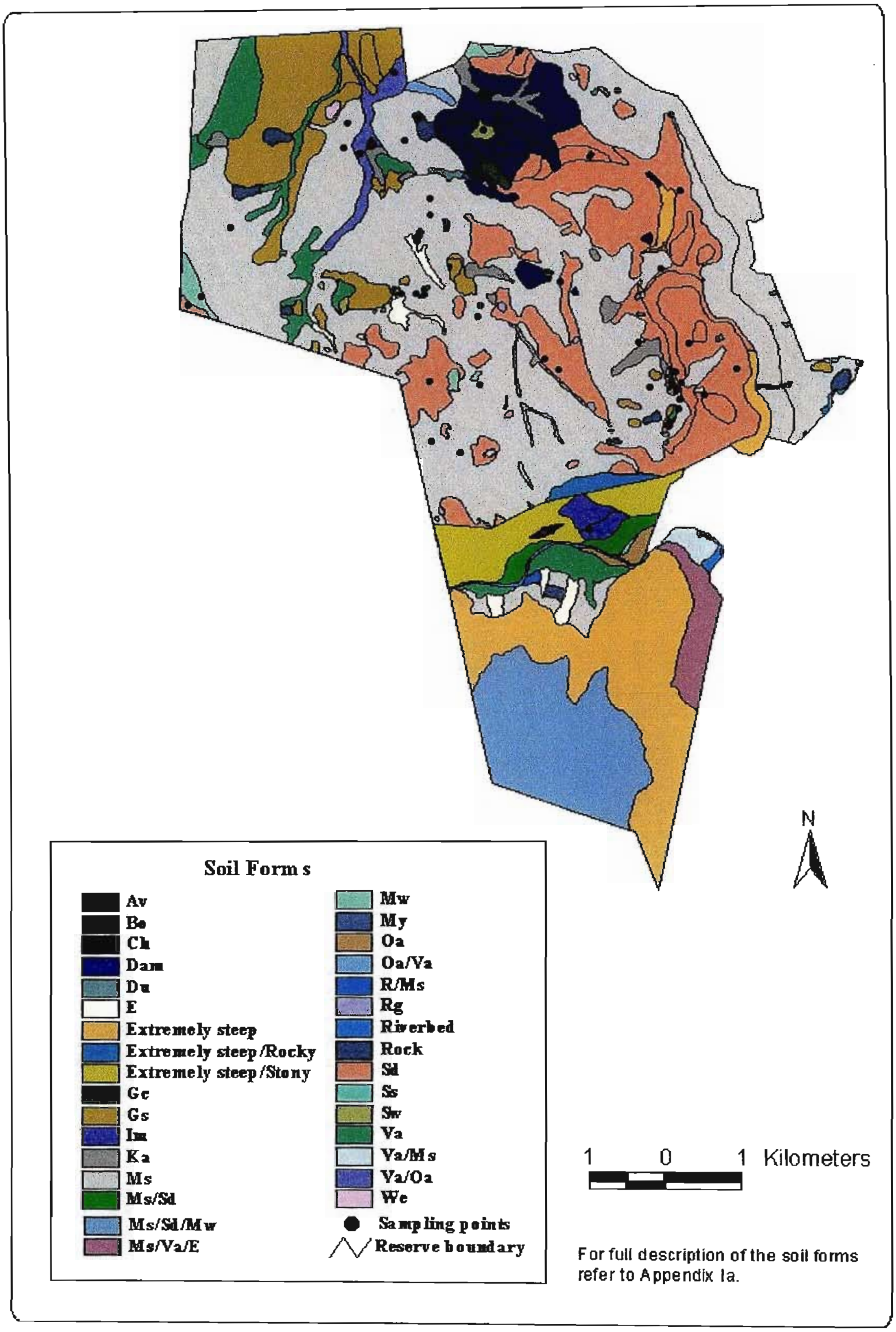
Figure 5.9 Spatial Distribution of heat units (degree days) of the growing period in WNR.

Generally speaking, the reserve is characterised by hot and wet summer season and dry and cold winter. The rainfall is low, erratic and highly seasonal. The spatial variabilies in rainfall parameters have increasing trends towards the east and with increase in altitude (see Figures 5.2 & 5.4). This may be attributed to the physiographic features of continentality and altitude, which were part of the factors used in modelling the rainfall data (CCWR, 1989; Dent *et al.*, 1989). The spatial variability in temperature conditions in WNR roughly follows the topography of the reserve; high elevation areas have relatively low temperatures, and vice versa. Seasonal variations in rainfall and temperature conditions are largely a result of the general circulation of atmospheric conditions (Camp, 2002).

5.1.2 Inventory of Soil Resources

Figure 5.10 shows the print out of a digital form of the modified soil map of the reserve, which includes results of the survey of unclassified areas in the original soil map of Hughes (1989). The soil map classifies soils of the reserve into *soil form* and depth classes based on the *Binomial Soil Classification System for South Africa* (MacVicar, 1977; MacVicar, 1991). A brief description of the *soil forms* encountered in the soil map of the reserve and their correlation to the FAO soil units are provided in Appendix Ia and Appendix Ic, respectively. The digital soil map is supplemented by additional data on soil chemical and physical properties analyzed to evaluate the potential of the soil units for rainfed agriculture in terms of soil chemical and physical properties. The *soil forms* (units) have been defined in terms of measurable and observable properties of soil. Many of the soil properties are relevant to soil use and production potential and therefore have a practical application value (FAO, 1978). Therefore, the soil units, which have been distinguished on the soil map of the reserve, have value for predicting the optimum use of soils. Results of soil analysis carried out in this study are given in Table 5.1 and their interpretation will be discussed in the following section.

Most areas of the reserve are covered with Ms and Sd soil *forms* (see Figure 5.10 and Appendix Ib), which are known for their shallow depth and surface and sub-surface



For full description of the soil forms refer to Appendix Ia.

Figure 5.10 Soil map of WNR.

Table 5.1 Chemical and physical soil properties

Sample No.	Sample Density	P	K	Ca	Mg	Exch. Acidity	Total Cations	Zn	Mn	pH (KCl)	Organic C	Acid Sat.	Total S	Total N	Clay
	Mg/L	Mg/kg	cmol(+)/kg								%				
1	0.9	2	0.440	15.11	5.292	0.080	20.900	0.006	0.022	4.98	4.16	0	0.036	0.335	69
2	0.99	1	0.225	22.365	9.564	0.050	32.150	0.002	0.011	5.17	3.76	0	0.027	0.305	68
3	0.91	14	0.309	3.620	1.926	0.090	5.190	0.003	0.015	4.98	2.11	0	0.025	0.35	60
4	1.11	1	0.394	3.905	2.486	0.740	7.520	0.002	0.022	4.04	1.16	10	0.013	0.134	38
5	1.2	17	0.611	4.600	1.440	0.750	5.890	0.003	0.011	6.1	5.16	0.75	0.02	0.122	31
6	1.07	1	0.210	4.085	3.037	0.070	7.390	0.001	0.007	5.37	1.23	1	0.012	0.131	42
7	1.05	1	0.478	20.490	4.527	0.090	25.540	0.002	0.011	5.28	2.87	0	0.02	0.241	67
8	0.93	1	0.309	5.060	3.292	0.120	7.760	0.001	0.015	5.6	1.56	1	0.04	0.155	66
9	1.13	1	0.199	3.990	2.296	0.120	6.030	0.002	0.025	6.88	0.89	2	0.008	0.2	45
10	0.98	3	0.509	2.440	1.440	0.070	3.580	0.004	0.044	5.02	1.63	2	0.011	0.0785	62
11	0.91	1	0.276	28.375	8.848	0.090	37.530	0.002	0.004	5.81	2.9	0	0.02	0.241	62
12	1.13	1	0.409	2.490	1.317	0.100	5.460	0.000	0.018	5.46	1.32	10	0.022	0.326	39
13	1.07	1	0.788	5.455	3.210	0.090	9.530	0.002	0.025	4.83	1.82	1	0.015	0.158	53
14	1.11	1	0.345	6.360	2.881	0.140	9.710	0.001	0.015	4.36	1.51	1	0.015	0.173	28
15	1.14	1	0.821	5.060	0.988	0.180	5.250	0.004	0.004	7.38	2.04	2	0.005	0.214	58
16	1.21	1	0.309	5.640	3.169	0.130	8.130	0.006	0.025	5.06	2.98	0	0.015	0.186	55
17	1.16	1	0.353	4.175	2.222	0.100	6.840	0.001	0.018	4.63	0.85	1	0.01	0.094	41
18	0.93	4	0.509	4.240	2.337	0.150	6.000	0.004	0.033	5.38	2.57	1	0.021	0.147	56
19	1.3	15	0.509	2.790	1.399	0.130	5.500	0.003	0.004	5.37	3.52	2	0.03	0.098	25
20	1.17	1	0.309	3.320	0.988	0.750	3.950	0.006	0.007	7.2	0.97	10	0.032	0.211	67
21	1.07	2	0.269	13.535	3.498	0.090	17.360	0.002	0.029	5.21	1.55	1	0.012	0.144	70
22	0.98	1	0.238	10.300	3.860	0.090	14.470	0.002	0.062	5.19	3.59	1	0.026	0.295	70

Table 5.1 continued

Sample No.	Sample Density	P	K	Ca	Mg	Exch. Acidity	Total Cations	Zn	Mn	pH (KCl)	Organic C	Acid Sat.	Total S	Total N	Clay
	Mg/L	mg/kg				cmol(+)/kg							%		
23	1.14	1	0.509	7.630	1.926	0.080	9.680	0.002	0.004	7.23	1.52	0	0.005	0.259	41
24	1.05	1	0.199	5.210	2.634	0.100	7.300	0.003	0.004	6.39	1.81	1	0.011	0.215	40
25	1.13	1	0.294	4.705	3.284	0.180	8.450	0.001	0.011	4.36	1.42	2	0.016	0.143	37
26	1.3	1	0.343	2.815	1.374	0.110	4.640	0.000	0.011	4.58	0.55	2	0.004	0.073	22
27	1.18	3	0.309	0.540	1.440	0.130	3.200	0.003	0.004	5.35	0.82	7	0.008	0.098	26
28	1.11	1	0.701	7.385	3.103	0.080	11.250	0.002	0.044	4.9	2.08	1	0.02	0.2	38
29	1.18	1	0.332	6.150	2.601	0.030	9.100	0.002	0.007	5.53	1.24	0	0.011	0.155	23
30	1.05	1	0.509	4.240	1.646	0.120	5.460	0.001	0.011	6.05	2.09	2	0.021	0.150	35
31	1.47	1	0.223	11.125	3.572	0.070	14.970	0.001	0.022	4.58	0.48	0	0.006	0.135	13
32	1.21	17	1.023	8.345	3.103	0.080	12.530	0.007	0.007	6.2	1.51	1	0.018	0.203	24
33	1.4	1	0.921	0.720	0.165	0.860	0.870	0.001	0.004	6.11	0.53	10	0.021	0.114	8
34	1.21	3	0.473	6.980	3.597	0.110	11.150	0.003	0.022	4.61	2.41	1	0.022	0.219	27
35	1.15	17	0.611	6.280	2.922	0.090	8.990	0.002	0.015	6.43	2.68	0	0.014	0.222	35
36	1.03	3	0.910	15.785	7.407	0.100	24.630	0.003	0.025	5.49	3.17	0	0.021	0.262	50
37	1.04	1	0.358	22.800	6.527	0.130	29.770	0.003	0.007	6.39	3.16	0	0.016	0.333	41
38	1.08	3	0.721	5.660	2.798	0.120	7.300	0.002	0.025	5.95	0.66	1	0.023	0.145	43
39	1	10	1.020	3.740	1.597	0.210	5.430	0.004	0.007	5.1	3.46	1	0.014	0.211	48
40	1.09	1	0.627	6.875	5.103	0.120	12.710	0.002	0.047	4.97	2.01	1	0.019	0.191	40
41	1.2	3	0.409	1.720	0.782	0.840	2.370	0.002	0.018	5.13	0.76	10	0.018	0.231	26
42	0.98	1	0.174	24.370	10.189	0.100	34.780	0.001	0.004	5.62	3.15	0	0.022	0.299	61
43	1.13	1	0.297	17.260	8.905	0.070	26.500	0.002	0.004	5.25	1.45	0	0.01	0.175	46
44	1.04	1	0.675	20.730	13.226	0.070	34.660	0.000	0.004	6.59	1.63	0	0.01	0.153	58
45	1.04	19	0.414	11.395	3.407	0.130	15.320	0.004	0.044	5.42	2.05	1	0.013	0.199	38

rockiness. These two soil *forms* together cover above 65% of the total area of the reserve (see Appendix Ib). Duplex soils, which are characterized by having high textural contrast between topsoil and subsoil, are also common in the northwestern parts of the reserve (Hughes, 1989). These soils include soil *forms* of Es (E), Va, and Sw (see Figure 5.10 and Appendix Ia, Ib). These soils are extremely susceptible to erosion by water. As a result soil erosion is still active in this area and deep and wide gullies are common. Soils in the central part of the reserve are relatively resistant to erosion. Newly formed soils and regeneration of grass in old gully floors were observed in this part of the reserve.

5.1.2.1 Physical and Chemical Soil Properties

The capacity of a soil to support plant growth is dependent on its physical and chemical properties because these properties determine the ability of a soil to supply water and nutrients for plant growth. The results of soil analysis performed in order to characterize soils in the reserve with physical and chemical soil properties are provided in Table 5.1. Although interpretation of physical and chemical soil properties is meaningful only if the crop requirements are known, some general interpretations and ratings can be made.

Soil Texture

Table 5.2 may be used as a guide to rate the analytical results of soil particle size analysis. The particle size analysis shows that most soils of the reserve have clay percentages of more than 40%, with many samples exceeding 50% (see Table 5.1). These values indicate that soils of the reserve are clayey in nature. This characteristic can aggravate the vulnerability of the soils to erosion by water through the effect of reduced infiltration due surface crusting. Heavy vertic soils are even worse due to the attraction of water by clay minerals so tightly that plant roots cannot absorb. This characteristic is critical especially in arid areas such as WNR where the climate puts more stress on plants. Heavy clay soils are also disadvantageous when using hand and animal driven tools; because their sticky nature reduces their workability. Some crops such as potatoes are not recommended in heavy soils, which cause a problem during harvesting.

Soil Nutrients

Table 5.3 provides guidelines for rating the results of soil analysis of the most common essential soil nutrients analyzed in this study. Although the fertilizer requirements depend on individual crops, the analytical results show that soils of the reserve are rich in base elements (K, Ca, Mg). More than 74% K values, 60% of the Ca values, and 94% of the Mg values of the samples have moderate to very high values according to the rating in Table 5.3.

Table 5.2 Rating of analytical results of soil clay percentage (Adapted from Hazelton and Murphy, 1992).

Clay content (%)	Rating
< 10	Very low
10-25	Low
26-40	Moderate
41-50	High
>50	Very high

Table 5.3 Guidelines for rating results of analysis of some soil nutrients (adapted from Hazelton and Murphy, 1992).

Nutrient	Unit	Very low	Low	Moderate	High	Very high
K	cmol(+)/kg	0-0.2	0.2-0.3	0.3-0.7	0.7-2	>2
Ca	"	0-2	2-5	5-10	10-20	>20
Mg	"	0-0.3	0.3-1	1-3	3-8	>8
CEC	"	<6	6-12	12-25	25-40	>40
Total N	%	<0.05	0.05-0.15	0.15-0.25	0.25-0.5	>0.5
P	mg/kg	<5	5-10	11-17	18-25	>25

Another important measure of soil fertility status is the Cation Exchange Capacity (CEC). This is the capacity of the soils to hold and exchange cations and it is a good indicator of soil fertility status, soil texture stability, and a major controlling agent of soil pH and soil reaction to fertilizers and other ameliorants (Hazelton and Murphy, 1992). According to the rating in Table 5.3 the majority of the samples have low CEC values which are in the range of 6-12 cmol (+)/kg.

Nitrogen (N) is one of the essential plant nutrients. N occurs in several forms some of which may not be directly available to plants. Total amount of nitrogen measures the total amount of nitrogen present in the soil that may be mineralized into available forms (Hazelton and Murphy, 1992).

According to the rating in Table 5.3 the soils of the reserve are rich in N in that 30% of the samples analyzed can be rated to have high N values and the rest 70% have medium N values.

The fertilizer recommendation by Cedara Fertilizer Advisory Service shows that the Zn levels in the soils of the reserve are not satisfactory (see Appendix IIa-IIc).

Phosphorus contents are extremely poor in almost all the soil samples. More than 84% of the samples in Table 5.1 have very low P contents according to the rating in Table 5.3 (<5 mg/kg in most of the samples). The fertilizer recommendation by Cedara Fertilizer Advisory Service shows that, for three of the crops on which fertilizer recommendations were made (maize, potato, and cabbage), a large amount of P fertilization is required to raise the P status of the soils to the target values (see Appendix IIa-IIc). This can highly increase the cost of agricultural production in the area. However, P levels may be increased gradually by applying P fertilizers in small quantities every growing period.

Soil pH

Table 5.4 can be used when interpreting pH values measured in water (1:5 ratio). The pH measurements in this study were done in a chloride solution. pH values measured in chloride solutions are 0.5 to 1.0 units lower than pH values measured in water solution (Hazelton and Murphy, 1992). Thus, when interpreting results of pH analysis adjustments were made to the pH values in Table 5.1 by adding 1.0 pH value to each value.

The analytical results show that soils of the reserve are generally acidic. About two-third of the samples analyzed can be rated from strongly to slightly acidic. The rest of the samples have neutral to mildly alkaline pH values.

Acid saturation of a soil is the ratio of extractable acidity ($Al^{3+} + H^{+}$) to total cations expressed as a percentage. The acid saturation values of the soils in WNR for most of the samples varies between 0% and 2%. These are considered low levels of acid saturation, and the Cedara Fertilizer Advisory Service did not recommend application

Table 5.4 General ratings of pH values measured in water (1:5 ratio) (adapted from Hazelton and Murphy, 1992).

pH	Ratings
>9.0	Very strongly alkaline
9.0-8.5	Strongly alkaline
8.4-7.9	Moderately alkaline
7.8-7.4	Mildly alkaline
7.3-6.6	Neutral
6.5-6.1	Slightly acidic
6.0-5.6	Moderately acidic
5.5-5.1	Strongly acidic
5.0-4.5	Very strongly acidic
<4.5	Extremely acidic

of lime for most of the samples except for a few samples for cabbage cultivation (see Appendix IIc).

Organic matter, which is the material in soil that is directly derived from plants and animals, is an important soil property. Through its breakdown and interaction with other soil constituents organic matter is largely responsible for much of the physical and chemical soil properties (Hazelton and Murphy, 1992).

Organic matter is usually calculated from the levels of organic carbon (%) in the soil by multiplying by 1.72 based on the assumption that the organic matter in the soil has a constant carbon composition of approximately 57% (Hazelton and Murphy, 1992). Thus, when interpreting results of organic carbon content in Table 5.1 according to the rating in Table 5.5 multiplication of organic carbon values in Table 5.1 by 1.72 is required.

The rating shows that soils of the reserve are rich in organic matter content and the majority of the samples have moderate to very high organic matter content.

Table 5.5 Guidelines for ratings of soil organic matter contents (adapted from Hazelton and Murphy, 1992).

organic matter content (%)	Rating
0.5	Extremely low
0.5-1.0	Very low
1.5-2.0	Low
2.0-3.0	Moderate
3.0-5.0	High
>5.0	Very high

Generally, soils of the reserve have two very important characteristics in common, namely their very shallow depth and their susceptibility to erosion (Hughes, 1989).

Most areas of the reserve are covered with soil *forms* of effective depths less than 30cm. Soil forms with effective depths greater than 50cm are extremely rare.

Soils of WNR have good nutrient status with regard to the essential nutrients of K, Ca, Mg, N, organic matter and soil pH. However, the soils have low CEC and Zn contents and P levels are extremely low in almost all the soils. The particle size analysis also showed that the majority of the soils are clayey.

5.1.3 Topography

Figures 5.11 and 5.12 show Triangulated Irregular Network (TIN) of the DEM data and slope map of the reserve, respectively. The TIN map was used for visual analysis of the topography of the reserve and presentation of the DEM data. The TIN map shows that the elevation of the reserve ranges from 900 meters above mean sea level (a.m.s.l) along the Bushman's River and the eastern foot slopes of the reserve to 1270 and 1295 a.m.s.l in the Umthunzini Hills and in the Nontethe plateau north and south of the Bushman's River, respectively. The TIN map has lower maximum value (1295 a.m.s.l) as compared to the topographic map of the reserve, which has a maximum elevation value of 1310 a.m.s.l as described in section 3.4. This is due to two reasons. Firstly, the DEM data originally had a maximum value of 1292 a.m.s.l . Secondly, the IDW interpolation technique as explained in section 4.4.3 always results in maximum and minimum values that are different from the actual minimum and maximum values, which can be considered as a disadvantage of the technique.

In evaluating an area for agricultural potential, the most important topographic variable is slope, because it helps to determine the area of land available for cropping and the conservation practices required on the land (Blanks and Horne, 1993). Therefore, out of the two topographic maps produced from the DEM data (TIN and slope map), slope map was directly used in the evaluation of agricultural suitability of the area.

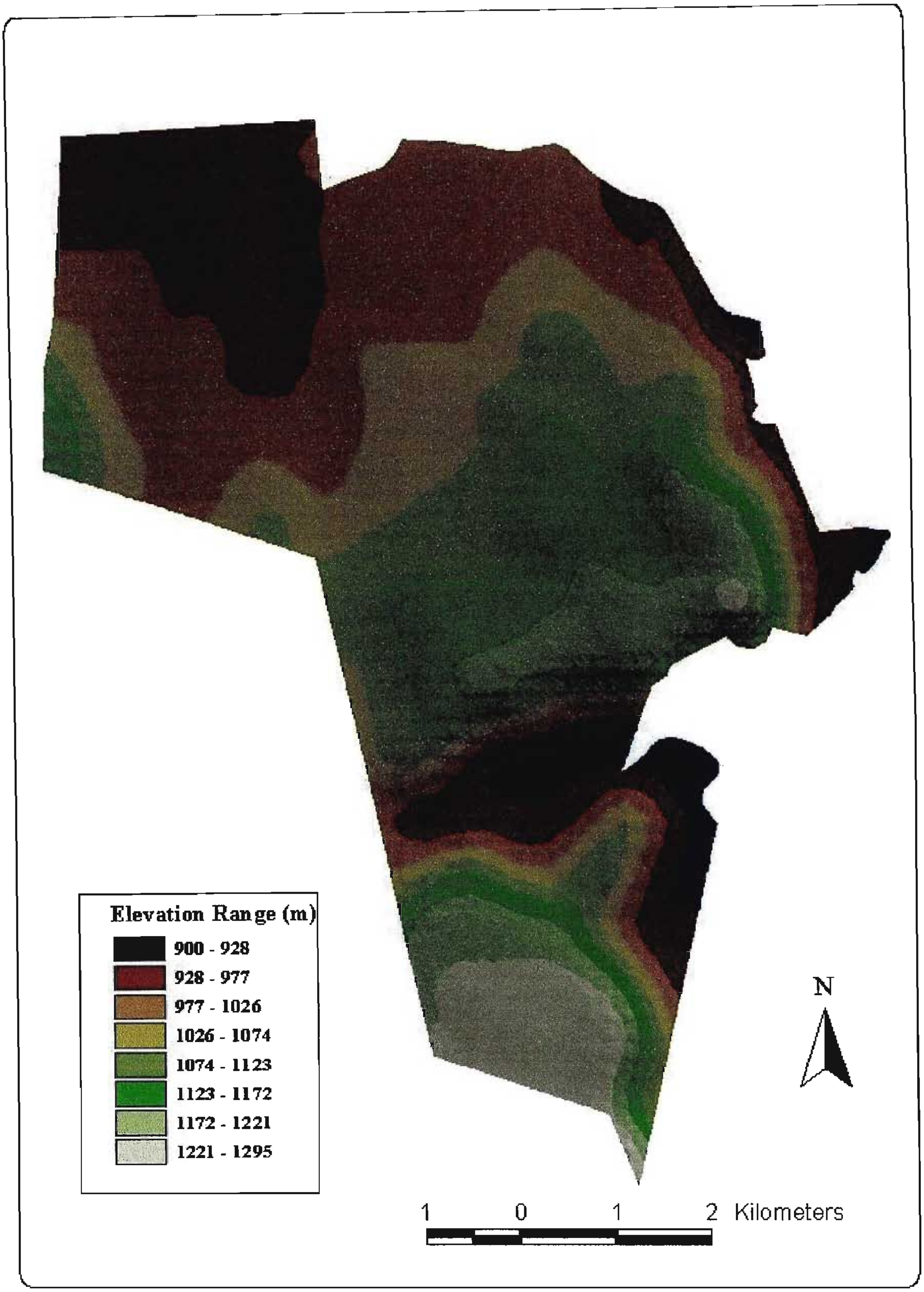


Figure 5.11 Triangulated Irregular Network (TIN) of the DEM data.

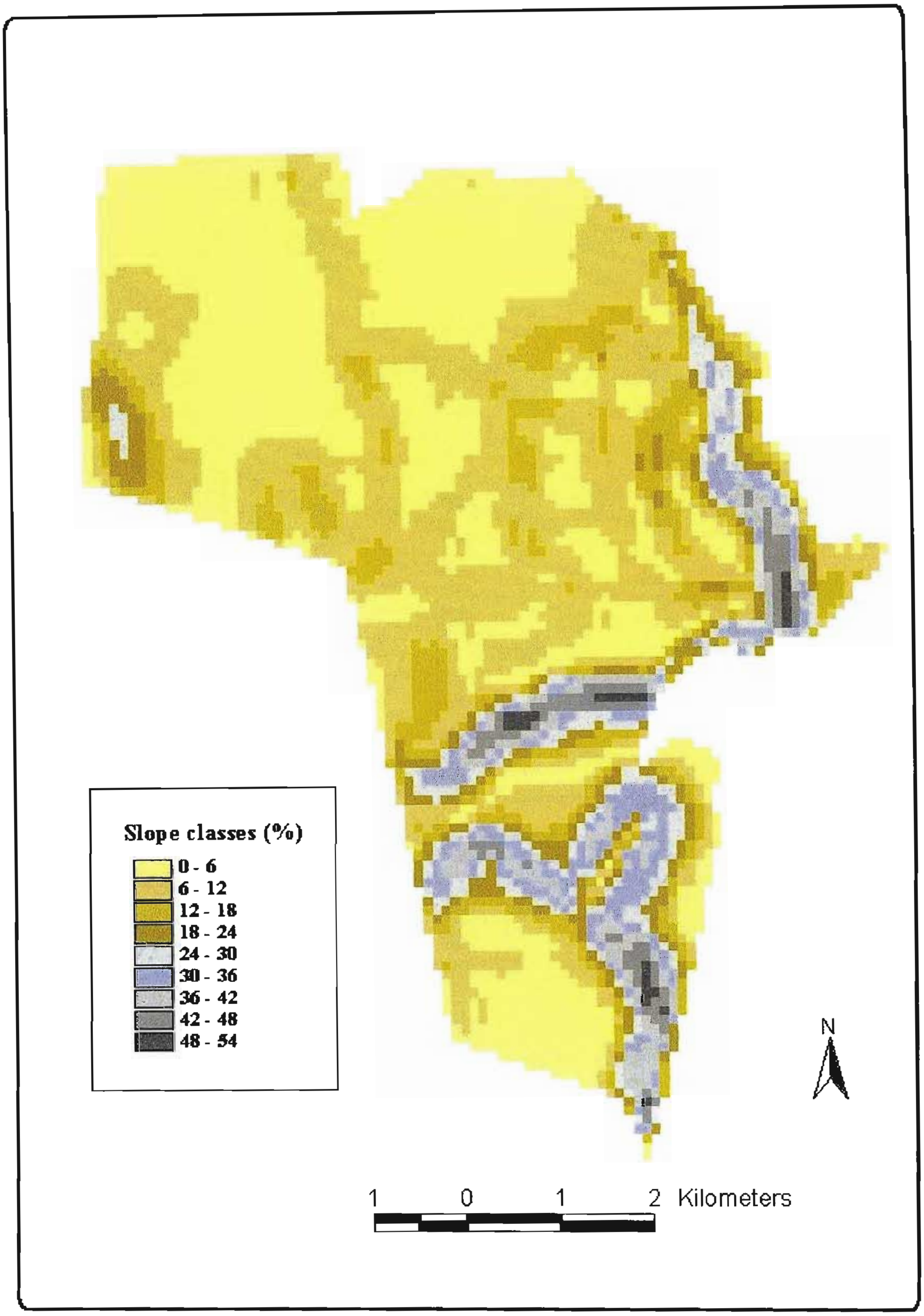


Figure 5.12 Slope map of WNR at 100mx100m grid cell size.

The slope map at 100m-by-100m grid cell size in Figure 5.12 shows that slope values in the reserve range from 0% to 54%. The northern part of the reserve and the Nontethe plateau in the south are relatively flat dominated by slope values of 0 - 6%. The central parts of the reserve are dominated by slope values of 6% - 12% although there are flat areas of slope values less than 6% and some steep areas with slope values up to 18%. About 75% of the total area of the reserve has slope values within the limits of arable slopes according the criteria set out for KZN on the basis of the BRG (Camp, 1999). The rest of the reserve is dominated by steep slopes with slope values that are outside the range of arable slope. These areas are located in both sides of the Bushman's River bank, in the eastern hills of the reserve, in the northwestern parts of the reserve (west of the Estcourt-Weenen road) (see Figure 3.1) and in some areas in the central part of the reserve.

Generally, WNR is characterized by a high diversity of topographic features, which include bottomland plains, steep hillsides, undulating landforms and upland plateaus. This variability in topographic features plays a major role in controlling other environmental features such as climate, soil and vegetation.

5.2 Crop Requirements

Information on the growth requirements of the selected crops collected from different types of literature, publications, research reports, and crop production guidelines resulted in construction of crop requirement tables for each of the crops. These tables are provided in Appendix III. Each land characteristic in the tables is rated according to its suitability for the corresponding crop so that it can be used as a basis for the land suitability evaluation. This section is essentially a summary of the tables in Appendix IIIa-IIIl, and it provides an overview of the climatic, soil, and topographic requirements of each of the crops.

5.2.1 Climatic and Soil Requirements

Maize

Maize requires warm to hot frost-free growing season. For good yields under dryland (rainfed) cutivation maize crop requires 500-700mm rainfall over the growing season (Smith, 1997).

Maize requires well-drained deep soils. Both light and heavy textured soils reduce yield (Smith, 1997). The physical properties of soil forms suitable for maize production in Kwazulu-Natal are shown in Appendix IIIb

Sorghum

In comparison to other crops, sorghum is fairly drought resistant. For example, it requires less units of water (300) than maize (400) or than sunflower (720), to produce one unit of dry material (Smith, 1997). For high production a sorghum dryland (rainfed) crop requires 450mm to 650mm of rain over the growing season (October to March) and is not recommended for areas with a mean annual rainfall below 650mm and areas with annual rainfall greater than 800mm (Smith, 1997). For optimum yields temperatures should be sufficiently high and a fairly long and frost-free growing season is required (FAO, 1980b).

Sorghum can grow successfully in a wide range of soils than maize. However, it prefers light to medium textured soils (Smith, 1997). Sorghum tolerates a pH range from 5.5 to 8.5 and some deficit of alkalinity, salinity and poor drainage (Blanks and Horne, 1993).

Cotton

Cotton requires long, warm frost-free growing season (Blanks and Horne, 1993; Smith, 1997), which is about 180 days long. Cotton responds well to temperature and long sunlight hours. Temperatures below 20°C inhibit growth (Blanks and Horne, 1993).

Cotton grows best on well-drained, fertile soils with high moisture holding capacity and of unrestricted depth (Blanks and Horne, 1993). For dryland (rainfed) crops at least 900mm deep well-drained soil is required. Sandy soils are not suitable (Smith, 1997; Blanks and Horne, 1993), and heavier soils are a problem with seedling emergence

(Blanks and Horne, 1993). High clay content soils must also be avoided owing to their water logging properties.

Dry beans

Dry beans grow well in areas that have warm frost-free conditions, and an annual rainfall of at least 700mm (Smith, 1997) and 400 – 500mm during the growing period (Blanks and Horne, 1993).

Dry beans grow well on deep well-aerated soils which have clay contents of 15 to 35%. For optimum yield, acid saturation should not exceed 5% (Smith, 1997).

Soya beans

The climatic requirements of soya beans are essentially similar to that of maize (Duxbury *et al.*, 1990; Smith, 1997). Therefore, the legume is well adapted to most cropping areas of Kwazulu-Natal where the rainfall is adequate to maize.

Soya beans can be grown on a wide range of soils except those which are very sandy or poorly drained (Smith, 1997). Soils producing satisfactory maize yields usually produce a good soya bean crop (Duxbury *et al.*, 1990).

Potatoes

For optimum production and function potatoes require cool temperatures in a range of 15-20°C and an operative range of 5-30°C. Tuber growth is sharply inhibited when temperatures are below 7°C or above 24°C (Smith, 1997). Potatoes are also susceptible to frosts and hail damage (Blanks and Horne, 1993). Under dryland (rainfed) cultivation potatoes require 500 to 700mm rainfall during the growing season of 110 to 150 days. The minimum annual rainfall requirement for potato cultivation under rainfed agriculture is 800mm (Smith, 1997).

Potatoes can successfully be grown in a variety of soils. The best results are obtained where potatoes are planted on loose, well-aerated and well-drained sandy loam soil, with clay content not more than 25% and free of undecomposed organic material (Smith, 1997). For good moisture holding capacity under dryland cultivation, potatoes require soil deeper than 600mm. Potatoes prefer soils with pH between 5 and 5.5, but they can tolerate pH levels between 4 to 8 where thereafter becomes serious yield limiting factor. Soils should preferably be fertile, with high organic matter content (Blanks and Horne, 1993).

Cabbage

Cabbage requires cool, moist climate with temperature range of 15°C to 18°C (Smith, 1997). Generally, in hot areas summer planting is not recommended (Smith, 1997). The total water demand varies from 300mm to 450mm depending on the temperature and length of the growing season, which is normally 90 to 120 days (Smith, 1997).

Cabbage does grow on a variety of soils, but prefers well-drained loam soils (Smith, 1997). Light sandy soils are less preferable than clay soils. The rooting depth is 600mm. Consequently; the requirement for soil depth is at least 750mm for optimum growth (Smith, 1997).

5.2.2 Topographic Requirements

For sustainable production of crops under rainfed agriculture landscape characteristics that limit soil erosion and degradation hazards within acceptable rates and allow management and cultivation operations with minimum cost are required. The limits of arable slopes in this study were decided to be in accordance to the arable slope classes in KwaZulu-Natal. The slope classes were originally developed as topographic criteria for land capability classification based on the framework of the BRG's (Guy and Smith, 1995). The slope classes used for determination of arable slopes in the three BRG's encountered in WNR, namely BRG's 13, 18, and 21 are shown in Table 4.2 in the previous chapter.

5.3 Land Suitability Evaluation

5.3.1 Climatic Suitability

Figure 5.13 shows pictorial representation of the climatic parameters used in the suitability evaluation and the resulting suitability maps for a sample crop (cotton). The comparison of the rainfall parameters in the study area discussed in section 5.1.1.1 with crop requirements for rainfall under rainfed production (Appendix III) revealed that rainfall in the reserve is satisfactory for three of the crops, namely Sorghum, dry beans, and cabbage, hence the whole area of the reserve can be rated as highly suitable (S1) for these crops in terms of rainfall conditions. The rainfall of the reserve has moderate limitations for rainfed potato production and is rated as moderately suitable (S2). Cotton, maize, and soya beans have relatively higher requirements for rainfall (see Appendices IIIc & IIIf). Rainfall conditions in the reserve are only marginally suitable (S3) for three of these crops with the exception of a small proportion (3.7% of the total area) of the reserve in the upland areas and hills of the eastern parts, which has moderate suitability for maize and soya beans.

The comparison of temperature parameters in the reserve (Figures 5.5 – 5.9) with the crop requirements (Appendix III) showed that all the temperature parameters are optimum for maize, soya beans, and dry beans production. Temperature conditions in the growing season, with the exception of eastern foot slopes and northern lowlands, are not hot enough for optimum Sorghum production and are too cold for cotton production. Limitation due to insufficient amount heat units during the growing period is more limiting in the case of cotton. Only the lowland areas of the eastern foot slopes and the northern parts of the reserve, which cover 24.9% of the total area have heat units more than 2000 during the growing period, which is still marginal for cotton production (see Figure 5.9).

The hot temperature conditions of the rainy season cannot support potato and cabbage growth. Thus, despite the suitability of the rainfall of the area for potatoes and cabbages, the hot climate of the study area during the growing season makes it unsuitable for rainfed production of these crops. According to the FAO land suitability assessment methodology adapted in this study, these two crops did not qualify any further suitability analysis. Therefore, the entire area is rated "*unsuitable*" for rainfed potato and cabbage production.

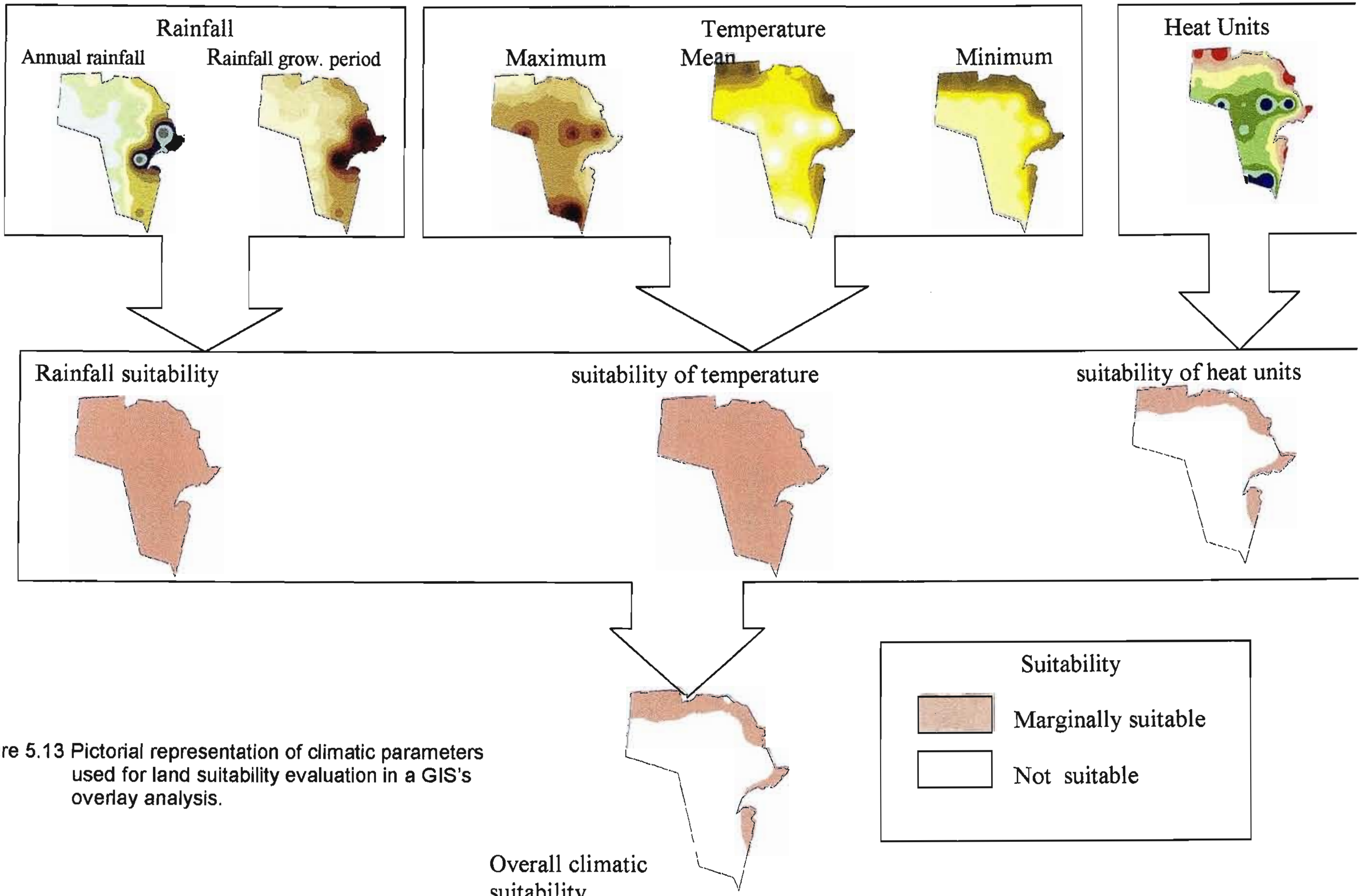


Figure 5.13 Pictorial representation of climatic parameters used for land suitability evaluation in a GIS's overlay analysis.

5.3. 2 Soil Suitability

Figure 5.14 illustrates the soil parameters used in the suitability evaluation and the resulting suitability map for a sample crop (cotton). Soft plinthic and well-drained soils in the area, which include Oa, Du, Av, Sd, and Gs soil units have the highest suitability for all of the crops (see Appendices I & III). These soils constitute 10.8% of the total area of the soil map of the reserve. Heavier textured soils in the reserve such as Mw, My, Bo, We, Rg, and Im have low suitability (marginal suitability) for most of the crops because they usually hold large quantities of water too tightly for plants to use (Manson, 1993) during moisture stress conditions and create aeration problems during excess moisture conditions. This group covers only 1.7% of the total area of the soil map of the reserve. Sorghum and cotton are relatively well adapted to these soils due to their wide range of adaptability to soil texture (Smith, 1997). There are two soil *forms* in the reserve with gleyic characteristics. These are Ch soil *form*, which is found next to the dam in the northern part of the reserve, and Ka soil *form* (Hughes, 1989), which are generally common to valley bottoms. These soil units have poor drainage and generally have low suitability for all of the crops. The Ka soil *form* can be marginally suitable for crop production if the soil depth is more than 30cm (Manson, 1993). These soils constitute 1.5% of the total area. Duplex soils such as Es (E), Ss, Va, and Sw also cover 6.2% of the total area of the soil map. These soils should not be considered for crop cultivation at all, because they are extremely susceptible to soil erosion (Hughes, 1989).

An extensive proportion of the reserve (approximately 65% of the total area) is covered by Ms and Sd soil *forms* (see Appendix Ib & Figure 5.10), which are characterized by their shallow depths and high surface and sub-surface rockiness. These soils have extremely low suitability potential for all of the crops considered in this study. These soils can have marginal suitability if the effective depth exceeds 30cm and the clay content is between 15 and 35% (Manson, 1993). Unfortunately, the soil depth is less than 30cm in most cases. Consequently, these soils are rated unsuitable for all of the crops. The rest 14.9% of the soil map is covered with extremely steep, extremely stony or rocky areas, dams and riverbeds, exposed bedrock, and unsurveyed areas. All these areas are rated unsuitable for all of the crops considered.

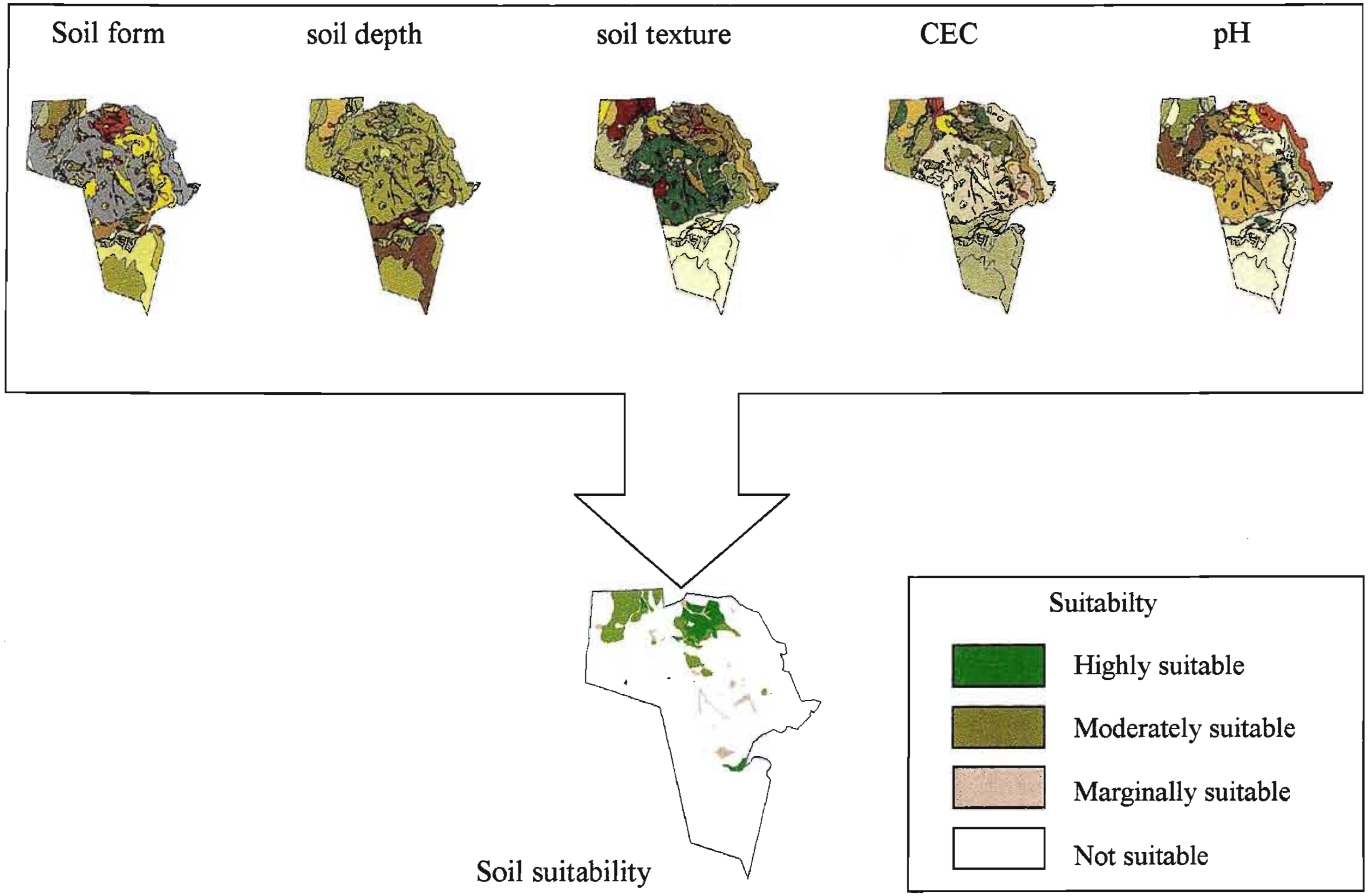


Figure 5.14 Pictorial representation of soil parameters used for land suitability evaluation in a GIS's overlay analysis.

As discussed in section 5.1.2.1 and as the recommendations by the Cedara Fertilizer Advisory Service in Appendices IIa-IIc indicate soils of the reserve are rich in essential plant nutrients of K, Ca, Mg, and N as well as in organic matter contents. The pH levels are conducive for all of the crops and the acid saturation levels are low that cultivation of crops can be carried out without any application of lime (see Appendix IIa-IIc). However, Zn and CEC levels are insufficient and P is extremely low in all of the soils. Generally, soils of the reserve have good fertility status and the low status of P and Zn are not considered as major limitations, because they can be amended by fertilizer applications.

Generally, soil depth and soil texture are most limiting soil characteristics in the reserve. Thus, soil *forms* of Oa, Du, Gs, Av, and with soil depths ≥ 75cm and with loamy texture are rated as highly suitable (S1); followed by well drained soils provided that they posses a moderate rooting depth (50-75cm). Heavy melanic and vertic soils and soils with soil depth less than 50cm are ranked next (marginally suitable). Soils with very severe limitations include soils with effective depth less than 30cm, soils of high surface and sub-surface rockiness, extremely steep areas and soils with hardpan properties as well as soils with strong gleyic characteristics. Such soils are rated as "unsuitable" (N) for crop cultivation. These soils account for 88.5% of the total area of the reserve.

5.3. 3 Slope Suitability

Slope is an important land characteristic that influences the use of a given land for agricultural purposes. Generally, steeper areas are not selected for crop cultivation due to limitation related to soil erosion hazard.

The comparison of the slope map of the reserve (Figure 5.12) with the slope classes in section 4.3 showed that about 30% of the total area is covered by slope classes A and B, which are believed to have no or slight limitations that do not significantly reduce productivity and do not raise conservation and management inputs above an acceptable level. These areas are rated as highly suitable for rainfed crop production according to the FAO suitability rating. Areas of these classes are found in the northern, northwestern, in some scattered patches in the central parts of the reserve, and south of the Bushman's River in the Nontethe plateau (see Figure 5.15). Slope class C has steeper values that have some limitations for crop cultivation owing to the soil erosion hazard. Areas of slope class C are rated as "moderately suitable" (S2). This class covers most areas in the central and northwestern parts of the reserve (see Figure 5.15) that cover about 35% of the total area. Slope class D has severe erosion hazard and is rated as "marginally suitable" (S3). Areas of this class are found scattered in the central part of the reserve and adjacent to the very steep areas in the eastern and southeastern parts of the reserve, which constitute 10% of the total area. The rest 25% of the reserve is excessively steep and highly hazardous for crop cultivation. This area of the reserve is rated as "non-arable". The slope limits for non-arable slopes are 20% for BRG's 13 and 18 and 8% for BRG 21. The non-arable slope classes were given an FAO suitability rate of "not suitable" (N). This class covers the steep areas on both sides of the Bushman's River valley and the hillsides in the eastern and southeastern parts, in the northwestern corner west of the Estcourt-Weenen road, and in scattered patches in the central parts of the reserve.

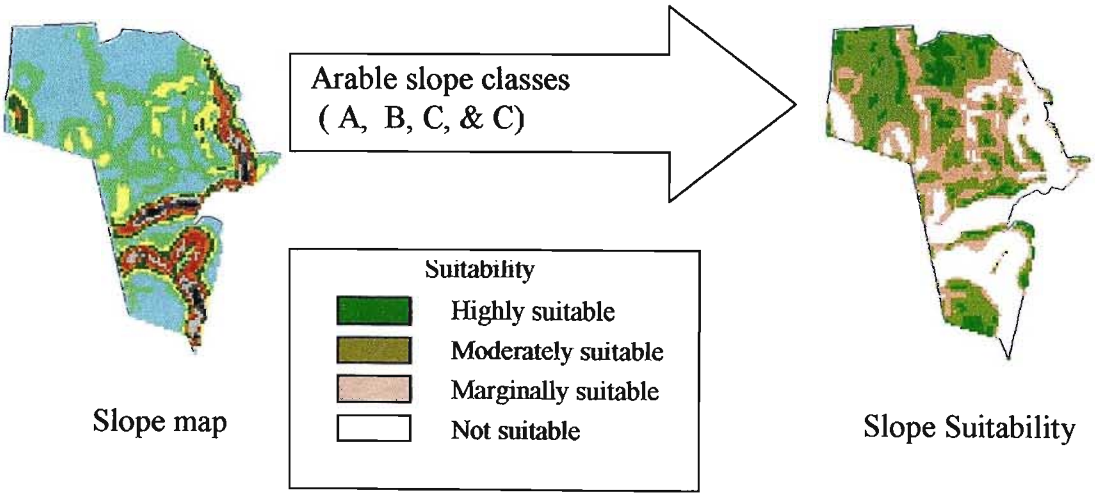


Figure 5.15 Slope suitability of WNR based on the comparison between slope map of the reserve and the arable slope classes in KZN.

5.3.4 Overall suitability

Figure 5.16 illustrates the method used in evaluation of land suitability by overlaying climatic, soil and slope suitabilities using the *limiting combination* method (FAO, 1983) discussed in section 4.5 in a GIS overlay analysis and the resulting suitability map for a sample crop (cotton). The overall suitability maps for the rest of the crops were produced following the same method; these are provided in Figures 5.17-5.20.

Table 5.6 summarizes the results of the land suitability evaluation. The overall suitability map for rainfed dry bean production has all of the four suitability classes (see Table 5.6 & Figure 5.17). The highly suitable class (S1), which accounts for 3.4% of the total area, the moderately suitable (S2) (6.2%) of the total area, marginally suitable (S3) areas, which constitutes 1.7% of the total area, and the remaining 88.7% of the area, which is unsuitable (N) for rainfed dry bean production. As discussed in subsection 5.3.2, soil depth is the major limitation of the area for cultivation of dry beans and all the other crops. The shallow soil soils of the reserve limit the suitability of the climate and topography of the reserve for dry beans to a small proportion, where there are relatively deeper soils mostly encountered in the northern parts of the reserve (see Figure 5.17). The overall suitability map for dry beans (Figure 5.17) has similar spatial distribution as the suitability maps of the other crops except that suitability map for dry

Table 5.6 Summary table of the results of land suitability evaluation.

Crop	Area coverage of suitability classes										
	S1		S2		S3		S1+S2+S3		N		Total Area
	ha	%	ha	%	ha	%	ha	%	ha	%	ha
Beans	165	3.4	304	6.2	81	1.7	550	11.3	4341	88.7	4891
Sorghum	-	-	485	9.7	81	1.7	555	11.4	4336	88.6	4891
Maize	-	-	-	-	554	11.3	554	11.3	4337	88.7	4891
Soyabeans	-	-	-	-	554	11.3	554	11.3	4337	88.7	4891
Cotton	-	-	-	-	305	6.2	305	6.2	4586	93.8	4891
Potatoes	-	-	-	-	-	-	-	-	4891	100	4891
Cabbages	-	-	-	-	-	-	-	-	4891	100	4891

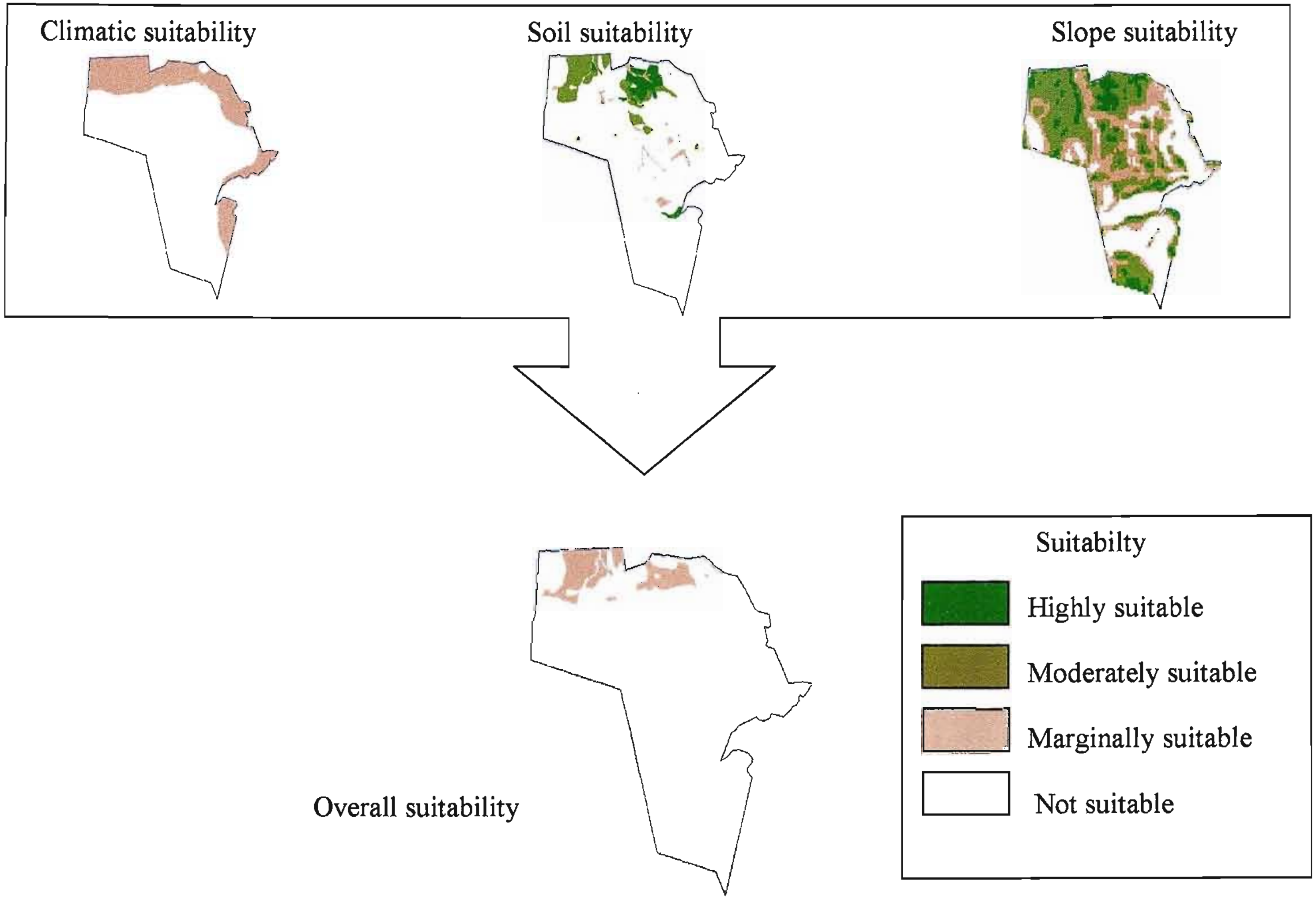


Figure 5.16 Pictorial representation of combining climatic, soil, and slope suitability maps into an overall suitability map.

bean has all the four suitability classes because of the high suitability of the climate for dry beans. Generally speaking, dry beans are better adapted to the area as compared to all other crops considered in this analysis. This is due to the fact that climatic conditions in WNR are optimum for dry bean production.

Sorghum has the highest adaptability to the rainfall of in the study area. However, the temperature conditions in the reserve are not hot enough for optimum Sorghum production. Therefore, the suitability map for rainfed Sorghum production (Figure 5.18) shows that the highest suitability for Sorghum is moderate suitability (S2), which covers 9.7% of the total area (see Table 5.6). This suitability reflects the suitability of moderate and high production potential soils. Areas of the reserve that have severe soil or slope limitations for Sorghum cultivation are awarded marginal suitability (S3) despite the fact that the whole area is rated as moderately suitable under climatic conditions. This suitability class covers only 1.7% of the total area. All in all, only 11.4% of the total area can be used for rainfed Sorghum cultivation (see Table 5.6). The rest 88.6% of the reserve is not suitable for rainfed Sorghum production primarily due to the shallow and rocky soils and steep slopes.

Maize and soya beans have similar climatic and soil requirements (Smith, 1997; Duxbury *et al.*, 1990). Thus, the resulting suitability maps for these crops are identical (see Figure 5.19). In this map the entire reserve is classified into two suitability classes, namely marginally suitable (S3), which occupies 11.3% of the total area mainly encountered in the northern parts of the reserve, and the "not suitable" (N), which accounts for the rest 88.7% of the total area of the reserve. According to the "*limiting combination*" method (FAO, 1983) followed in this study, although there are soil types that are highly or moderately suitable for maize and soya bean production, and despite the fact that a large area of the reserve (65% of the total area) is highly or moderately suitable with regard to topography of the area, the low rainfall in the area limits the suitability of the entire reserve to marginal suitability (S3) for rainfed production of maize and soya bean. The shallow and rocky soils of the reserve further limit this marginal suitability to only 11.3% of the total area. The rest 88.7% is totally unsuitable

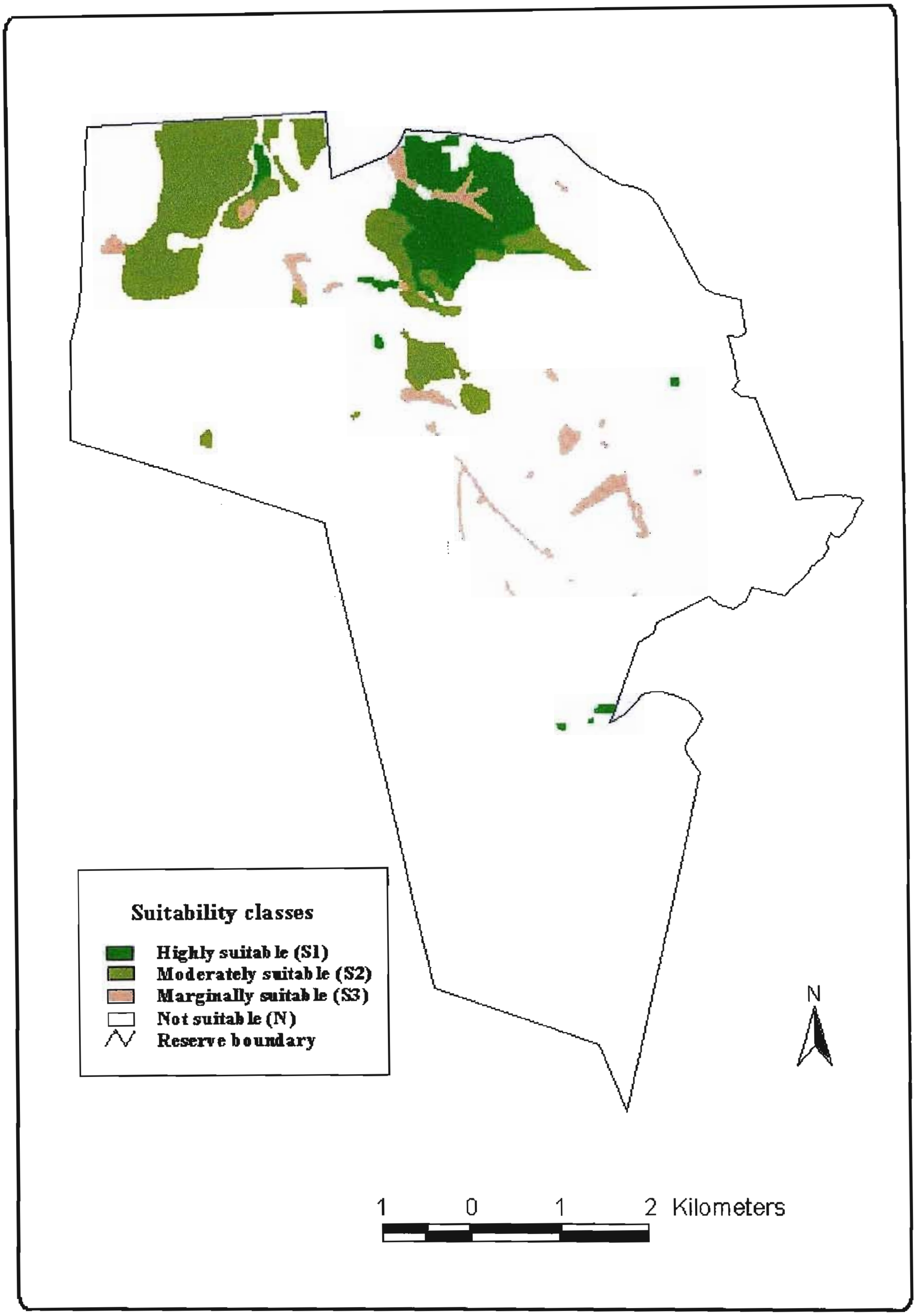


Figure 5.17 Overall suitability map for rainfed dry bean production in WNR.

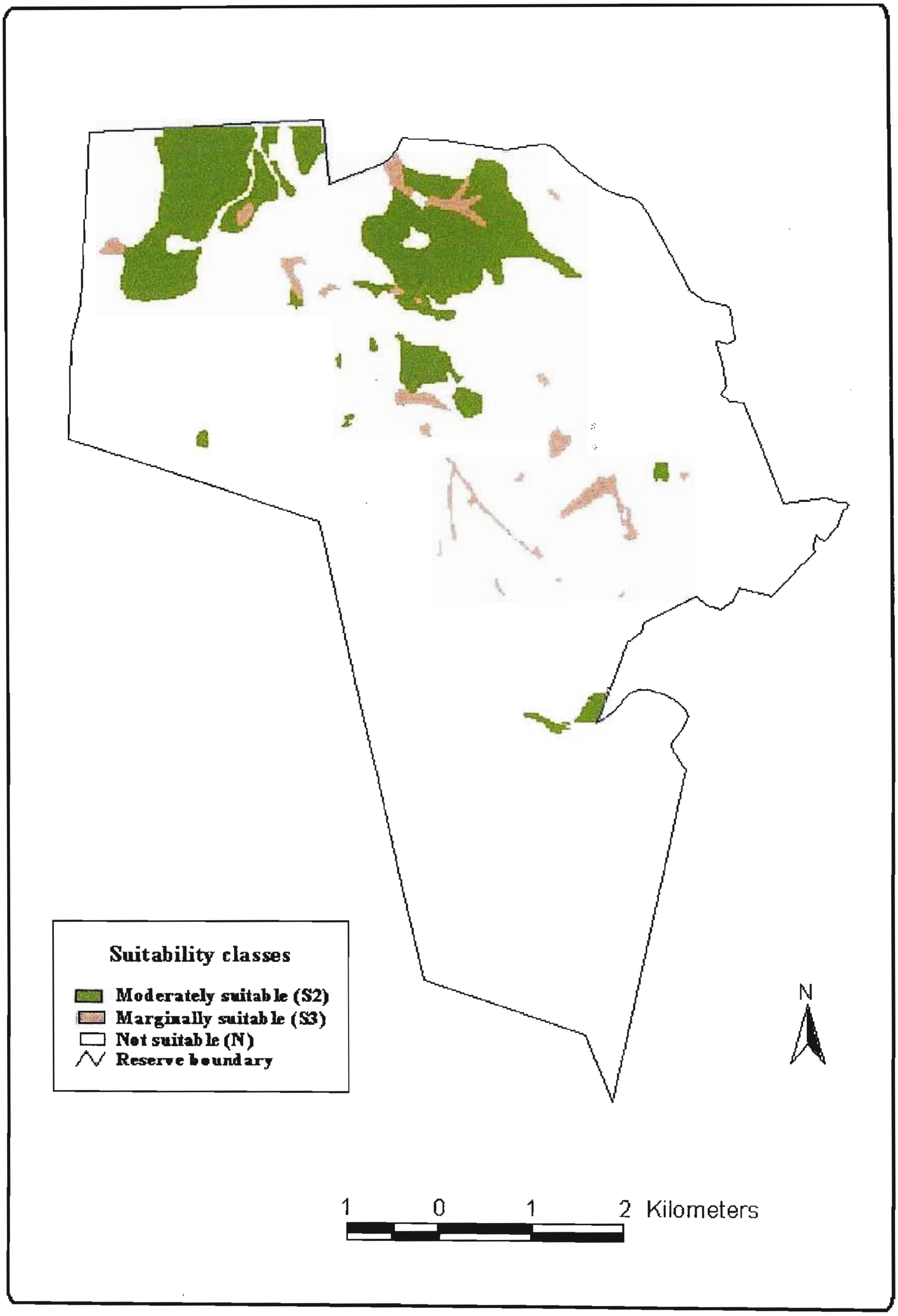


Figure 5.18 Overall suitability map for rainfed Sorghum production in WNR.

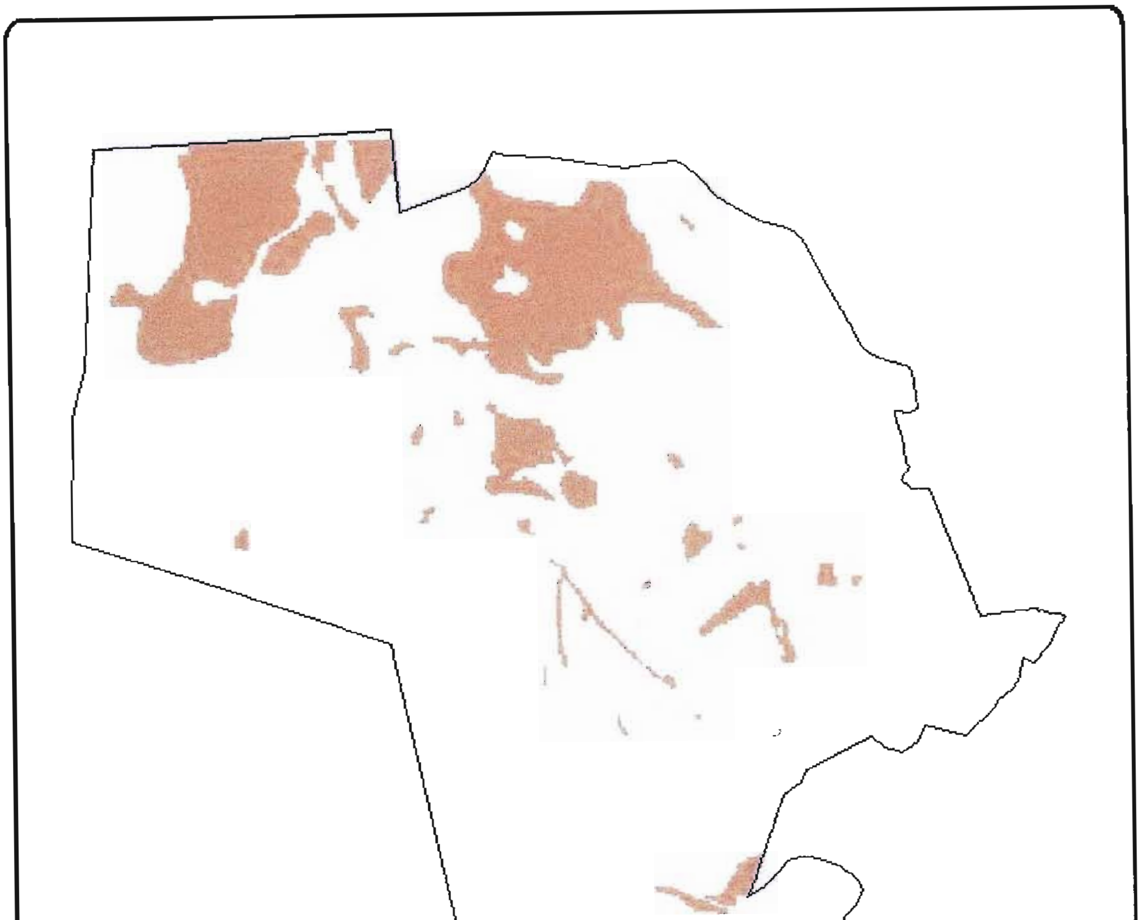


Figure 5.19 Overall suitability map for rainfed maize and soya bean production in WNR.

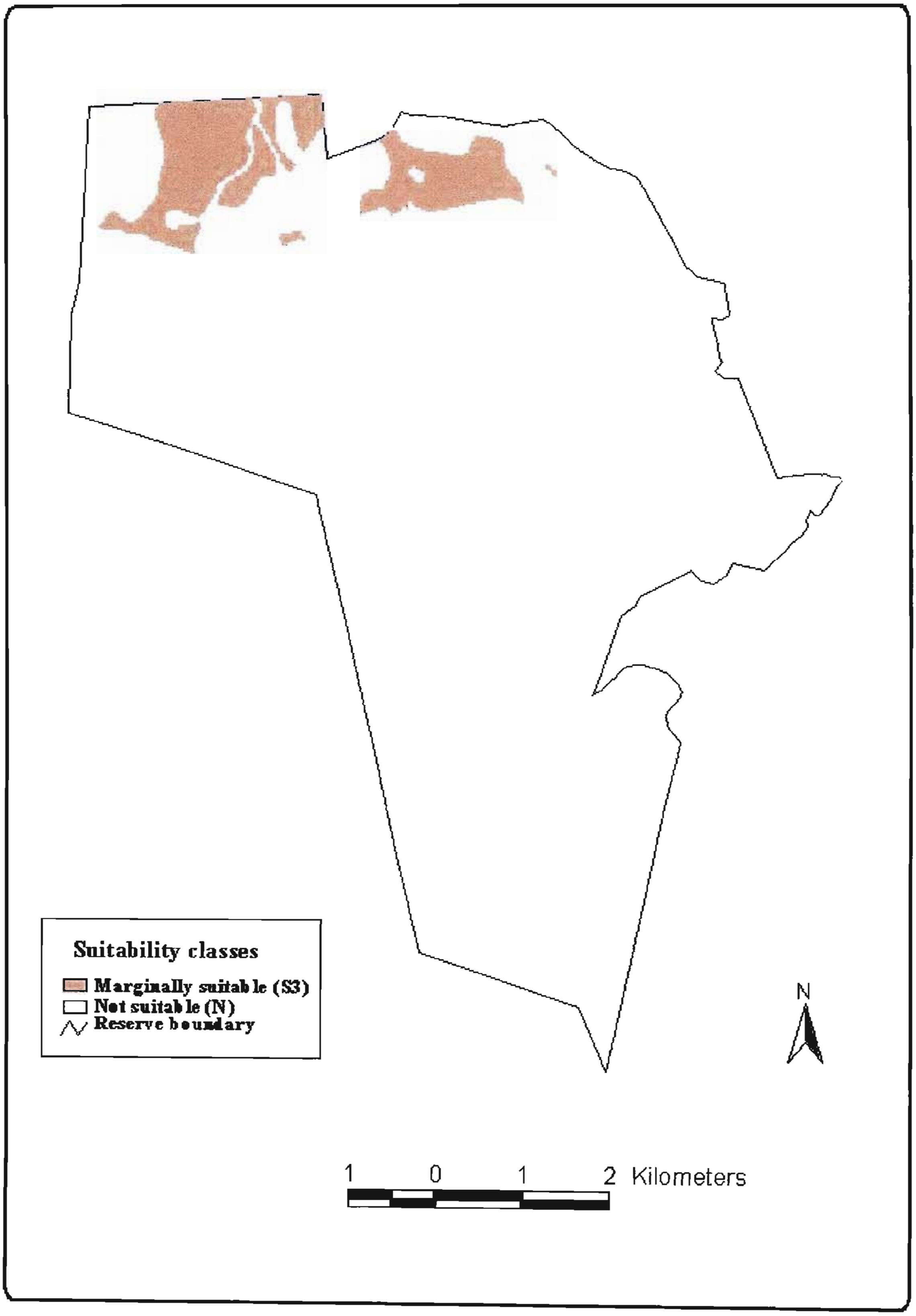


Figure 5.20 Overall suitability map for rainfed cotton production in WNR.

for the two crops because of the shallow and rocky soils and steep slopes (see Table 5.6). From Figure 5.19 it can be observed that the overall suitability is similar in spatial distribution to the suitability maps for dry beans and Sorghum in Figures 5.17 and 5.18, respectively, which follow the suitability of the soil forms except the fact that even the soil *forms* that are highly or moderately suitable are now marginally suitable because of the low rainfall in the area, which is only marginally suitable for maize and soya beans. This indicates that the two land qualities, namely soil and rainfall are the most limiting factors for rainfed production of maize and soya beans in the study area.

Similar to the other crops the shallow and rocky soils of the reserve and the low amount rainfall have severe limitations for cotton production. However, compared to other crops, cotton has specific climatic requirements. In addition to the requirements for higher rainfall, heat units (degree days) are most limiting for cotton cultivation (Smith, 1997). Heat units in the reserve during the growing period are insufficient for cotton production. Consequently, the overall suitability of WNR for rainfed cotton production is only restricted to low topography areas, where there are relatively higher heat units. This area covers 24.9% of the total area, which include flat areas in the northern, northwestern and eastern foot slopes of the reserve (see Figure 5.13 above). Out of these areas, only 6.2% of the total area can support cotton production due to soil and slope limitations (see Table 5.6 and Figure 5.20). Yet, these areas are only marginally suitable owing to their low amount of rainfall and heat units during the growing period.

5.4 Summary

The inventory of natural resources in section 5.1 revealed that WNR is characterized by hot arid climate, shallow and rocky soils, and rugged topography. The reserve can be broadly classified into four land units that have relatively similar potential primarily based on soil and topographic factors (see Figure 5.21). Spatial variation in climatic conditions in WNR are relatively less pronounced as compared to the variation in soil and topographic conditions, and wherever there are significant variations they are usually associated with variations in topographic conditions. Therefore, climatic factors were not directly used in delineating the land units in Figure 5.21.

Land Unit 1: This unit refers to the flat areas in the northern part of the reserve, and a small plot of land along the riverside of the Bushman's River (see Figure 5.21). This unit has gentle to flat topography and relatively deep soils, and hence relatively higher agricultural potential. In fact, this land unit represents the areas of WNR that have shown relatively higher agricultural potential in the land suitability assessment (see the suitability maps in Figures 5.17-5.20). This land unit covers only 8.4% of the total area of the reserve.

Land Unit 2: This unit covers 20.5% of the total area of WNR which includes the severely degraded areas in the western and northwestern parts of the reserve and some flat riverside areas along the Bushman's River that have signs of erosion (see Figure 5.21). Although this land unit has relatively flat topography and slightly deep soils in some cases, these areas are severely degraded and the agricultural potential of this area is limited due the very severe soil degradation and erosion problem in the area.

Land Unit 3: covers the rugged areas of the central parts of the reserve, the flat plateau in the southernmost part of the reserve, and the hilltop area in the western corner of the reserve, which in total cover 46.1% of WNR (see Figure 5.21). This land unit is characterized by rugged topography and shallow and rocky soils. Although soils of this unit are relatively resistant to soil erosion as compared to land unit 2, the rugged topography and shallow and rocky soils make cultivation of these areas very difficult and the agricultural potential is very low. The old railway line (see Figure 3.1) can be taken as an arbitrary dividing line between this land unit and land unit 2, which is situated to the west. In the south and east this part of land unit three ends at the hilltops and continues on the hilltops in the opposite side of the Bushman's River.

Land Unit 4: This land unit covers 25% of the total area of the reserve and includes the steep hillsides of the Bushman's River valley, the hillsides in the eastern parts of the reserve, and a small hillside area in the western corner of the reserve (see Figure 6.1).

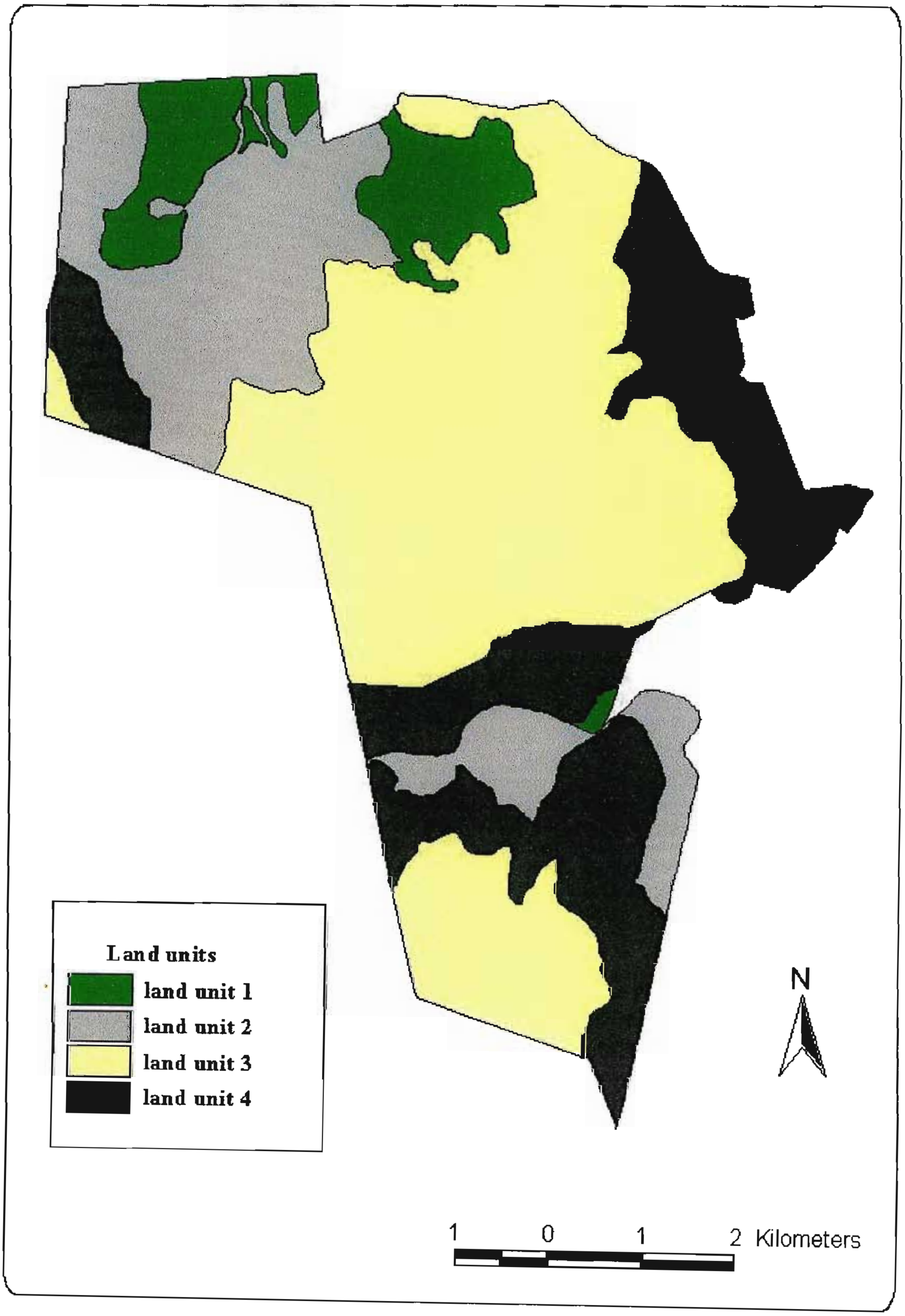


Figure 5.21 Broad land potential units in WNR primarily based on soil and topography.

These areas have very low agricultural potential due to their very steep slope and shallow and rocky soils.

Land evaluation based only on inventory of natural resources is not reliable. In fact, land that has low production potential with respect to one crop may be highly suitable to another crop with different growth requirements. Thus, although the land units indicate the overall potential of areas of the reserve, appraisal of the suitability of WNR for rainfed agriculture is based on the comparison of the land resources with the growth requirements of the seven crops selected as representative crops. Generally, the comparison showed that the study area has very low agricultural suitability for the selected crops. This is attributed to the dry and hot climate of the area and its shallow and rocky soils.

The final suitability maps revealed that compared to the other crops assessed in this study dry beans have relatively better adaptability to the area followed by Sorghum. Maize and soya beans are preferred over cotton, the adaptability of which is limited due to the relatively low heat units in addition to the limitations imposed by the dry climate and shallow and rocky soils of the area. Rainfed cultivation of potatoes and cabbages cannot be considered at all due to the unfavorable high temperatures of the rainy season.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The comparison of the land characteristics assessed for the purpose of land suitability evaluation with land use requirements of the different crops revealed that WNR has low suitability for rainfed agriculture. This is attributed to two major limitations of the land resources in the reserve in relation to crop production under rainfed agriculture namely, the dry and hot climate of the area and its shallow and rocky soils.

The dry climate of the area is only marginally suitable for most of the crops that were considered in this study. Under normal conditions, only bean is the crop that is adaptable to the climate of the area. All the other crops have one or more climatic constrains to their adaptability to the area. The dry climate of the area is further made worse by the erratic nature of the rainfall. This is indicated by the high annual CV%, which is equal to 24%. This means that the rainfall varies by 170mm above and below the mean rainfall value of 710mm in two out of every three years. Therefore, even cultivation of crops that are considered as highly drought resistant is less reliable in the area.

Some of the crops assessed in this study have special climatic requirements. For example, potatoes and cabbages require cool temperatures. This requirement is not satisfied during the rainy season of the area, which is a hot summer season. Due to this limitation, WNR is evaluated as "*unsuitable*" for rainfed cultivation of the two crops. This leads to the conclusion that rainfed cultivation of potatoes and cabbages is not a viable option.

Another special climatic requirement is that of cotton. Apart from its requirements for high rainfall and hhigh temperature, cotton also favors areas that have long sunshine hours and high amount of heat units (degree days). This limits the already low agricultural suitability of the WNR for cotton production to a small portion of the reserve where the requirement for heat units (degree days) is satisfied, namely the areas of low topography which include the flat area in the northern part of the reserve.

The second and most serious limitation of WNR for agricultural use is its soils. The assessment of soil resources indicated that soils of the reserve have major limitations for agricultural use. The most severe soil limitation is the very shallow effective depth, which is less than 30cm in most areas of the reserve.

Generally, soils in the central part of the reserve are shallow and rocky. As a result they have very low agricultural potential. The rugged topography of this part of the reserve also lowers the suitability of this area for crop cultivation. Soils in northwestern part of the reserve are affected by severe soil degradation as a result of combined effects of the susceptibility of these soils to erosion and overstocking in the past as has been described in section 1.2. Despite the efforts by the Department of Agriculture to improve the soil condition, which commenced in 1948, the soils in this part of the reserve are still in a very poor situation (Camp, 1995b; Camp, 2001). It was observed in the field survey carried out in this study in January 2002 that erosion is still active in this area. Completely exposed bedrock and deep and wide gullies are very common in this part of the reserve. This is obvious evidence that restoration of eroded soils is extremely difficult task as soil formation is a gradual process and recovering of soil to its original condition will require long time with extremely careful management. The time and cost needed to recover the devastated soils make this area of the reserve to have extremely low suitability for crop production. Thus, although the suitability maps produced by the combination of land resources show some suitable areas in this part of the reserve the soil erosion hazard in the area need to be considered in recommending sustainable land use options. Recovery of soils above the soil conservation structures and regeneration of grass even in deep and wide old gully floors was observed in many areas of the dolerite driven soils of the central parts of the reserve during the field survey. It was also observed that the grass cover in this part of the reserve is in a good condition. However, the comparison of the soils of this area with soil requirements of the crops indicates that these soils are not suitable for crop cultivation owing to their shallow depth, rocky nature and rugged topography.

The southern and eastern parts of the reserve are dominated by steep hillsides. These areas cannot be considered for cultivation primarily, due to their steep topography and secondly, due to the rocky nature of the soils. There are some flat areas in the southern end of the reserve and along the sides the Bushman's River. However, the soils are highly eroded and have very shallow effective depths in most cases, which make them unsuitable for cultivation. Furthermore, the flat plateau in the south of the Bushman' River is not accessible by any means of land transportation at the moment. This makes it unsuitable for any form of agricultural activity.

6.2 Recommendations

Sustainable use of a given land needs consideration of physical attributes of land and socioeconomic aspects such as profitability, market availability, social acceptability, land tenure system, population pressure and population dynamics, and national and regional government policies. The study of socioeconomic aspects of land was beyond the scope of this study. Thus, the land use options recommended below are only based on the physical aspects of land that have been assessed in detail in this study in relation to their potential for rainfed agriculture.

The inventory of natural resources has indicated that WNR has a very high diversity of natural resources that a single land use option may not be applicable to all areas of the reserve. In an effort to recommend sound land use or land management options, WNR has been classified into four land management units that have more or less similar potential and are believed to respond to land management and land use activities similarly based on the results of land resources inventory and land suitability evaluation. However, some areas of different land potential were also grouped together in some of the land management units owing to their size, physical proximity to other units, soil erosion hazard, and/or accessibility problems.

Land management unit 1: represents a small part of the areas in the land suitability maps (Figures 5.18-5.20) with agricultural potential that can be recommended for cultivation (see Figure 6.1). This management unit covers only 4.2% of the total area of WNR. Every single parcel of land that appears in the suitability maps cannot be recommended for cultivation, because some of the suitable areas are small parcels of land scattered in areas of generally low agricultural potential. Moreover, areas with agricultural potential in the land suitability maps (Figures 5.18-5.20) and Figure 5.21 in the northwestern part of the reserve are not recommended for cultivation because of the high erosion risk in the area.

Although their levels of adaptability differ depending on the climatic requirements, all of the crops considered in this study, except potato and cabbage, can be planted under rainfed agriculture in land management unit 1. The adaptability of these crops and other crops with similar climatic and soil requirements to this area can help in adopting different cultivation practices and crop rotation options, which are helpful in management of the soils. In addition to its relatively good soil and topographic conditions, this area is also situated within a short distance from the intersection of the Estcort-Weenen and Colenso-Weenen roads. This makes accessibility to this land management unit very easy which provides an added advantage in terms of application of any agricultural implementations and transporting agricultural equipment and products to and from this unit.

Land management unit 2: This unit covers 38.4% of the total WNR, which comprises the rugged areas of the central parts of WNR (see Figure 6.1) that were described under land unit 3 in chapter five (Figure 5.21). Areas of land unit 3 that are physically separated from the main part are excluded from this management unit. Although this management unit has a long history of overgrazing and soil deterioration, soils in this area are relatively more resistant to soil erosion. Moreover, it was observed during the field survey that this area had a good grass cover. Thus, this unit can be recommended for light and controlled grazing. However, careful grazing management and control is needed to avoid overgrazing and soil degradation. One important aspect of grazing

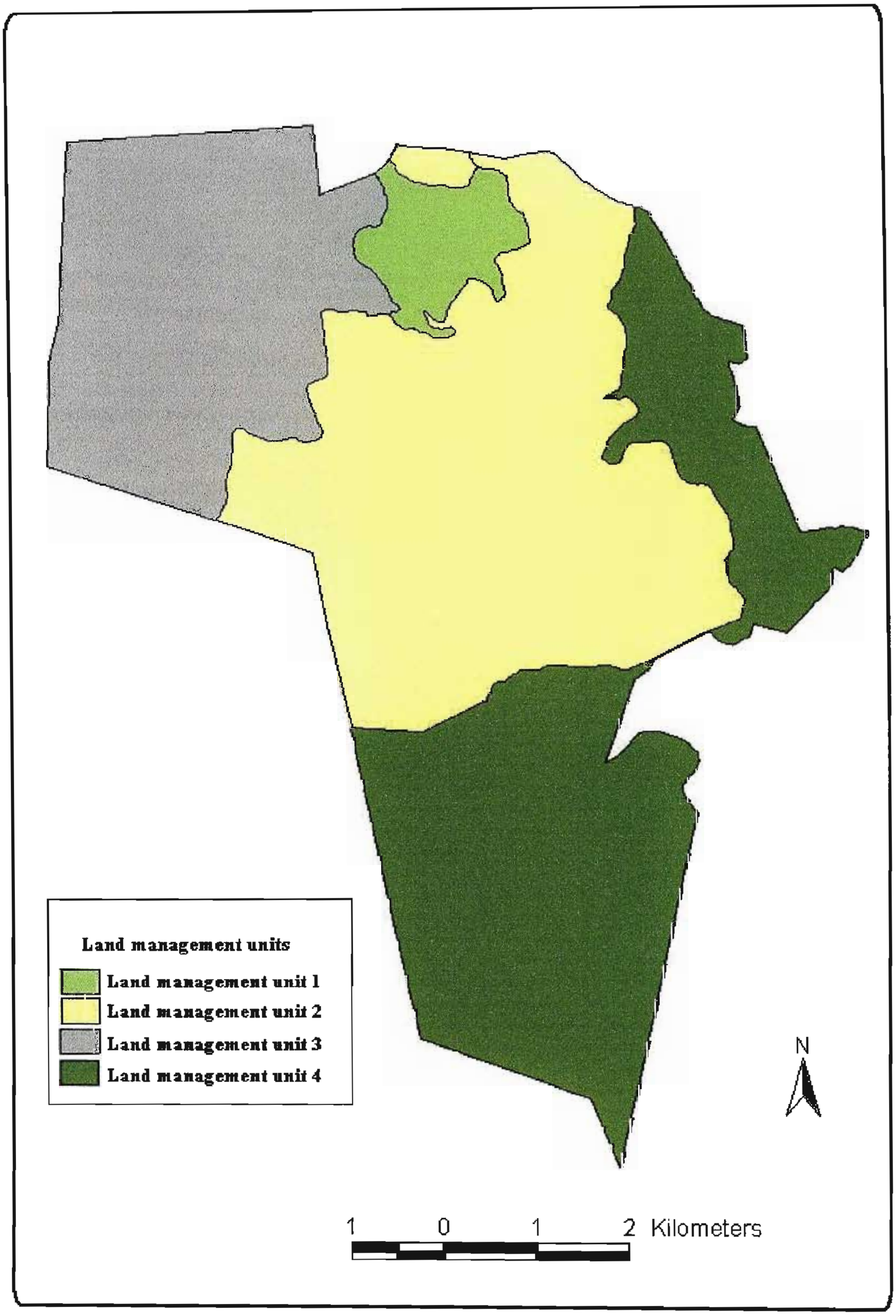


Figure 6.1 Broad land management units used as a basis in recommendation of land use options in WNR.

management that can be practiced is keeping grazing rate within the carrying capacity of the land management unit. Controlling over and under utilization of the different grass species is also important aspect of grazing management. Apart from their biological impact through grazing, animals can also have severe physical impacts on soil, especially due to trampling along footpaths. Animal footpaths to grazing and water sources can easily form erosion gullies. Therefore, when planning the use of this management unit for grazing, measures should be taken that control or minimize movements of animals. These may include keeping animals near gazing and water sources as much as possible. Unfortunately, natural water sources are poor in this area. But there are several small dams that can supply water for at least part of the year. For more reliable water sources larger dams can be constructed if financial capability of the land user allows.

Land management units 3: This unit covers 22.9% of WNR and represents the most seriously degraded part of WNR described as land unit 2 in chapter five, which can be roughly located west of the old railway line. Despite the soil conservation and reclamation efforts since 1948, this area is in poor condition and soil erosion is still active. During the field survey, which was carried out in the rainy season, some off-road vehicle routes in this area were observed to be sheet eroded. These can easily develop into erosion gullies unless necessary measures are taken. It is important that at the present land use, which is game farming, off-road movement of vehicles as well as human and animal movements be avoided or controlled. However, this alone cannot save the degraded soils of this land management unit. Soil conservation and reclamation measures, which include construction of physical soil conservation structures and management of vegetation cover of the area, should be practiced continually to stabilize the soils. There are various types of conservation structures constructed previously. Construction of new soil conservation structures and maintenance of the existing ones is essential in recovering the potential of the degraded soils of the reserve.

Land management unit 4: This management unit covers 34.5% of the total area of the WNR. It comprises of mainly areas of land unit 4 in Figure 5.21 which include the steep hillsides of the Bushman's River valley, the hillsides in the eastern parts of the reserve.

This unit also comprises the flat plateau in the south of the Bushman's River, which according to its potential should have been considered under management unit 2. However, this area is not accessible by any means of transport at the moment and is not favorable for any agricultural activity. Other areas of different potential included in this management unit are the gentle areas along the riverside of the Bushman's River. These areas are also highly eroded and should have been grouped under land management unit 3, which is a conservation area, as discussed above. However, as far as management is concerned, this area separates the two main parts of management unit 4, which makes land management unfavorable.

This land management unit is unsuitable for any form of agricultural activity due to its steep topography, shallow and rocky soils, and accessibility problems. Therefore, this unit should be reserved for wildlife. In areas of the riverside, where there is erosion hazard, soil conservation and reclamation measures need to be practiced.

6.3 Limitations of the Study

This study has attempted to evaluate the suitability of WNR for rainfed agriculture and successfully attained its objectives. The results of the inventory of land resources and land suitability evaluation may be used in land use planning for agricultural land use and other purposes. Moreover, the methodology followed in evaluating land suitability can be applied in other areas provided that the relevant information on soil, climatic and topographic resources as well as crop requirement is available. However, the study has some limitations imposed due to data unavailability and data inaccuracy.

The major limitation of the study is spatial resolution of the climatic data. The original dataset used in this study was in a one-minute by one-minute longitude-latitude grid cell size. This is too coarse for small area studies. The interpolation of the original dataset improved the data resolution. However, it could not avoid the effect of the poor data resolution of the original dataset. Furthermore, the interpolation technique has its own disadvantage in that it yields data values that are outside the range of the original dataset. Thus, although the climatic dataset gives a good indication of the overall climatic conditions in the study area, there are some inaccuracies especially in areas where there is high spatial variability in climatic conditions such as the Bushman's River valley and the upland areas in both sides of the valley.

The second limitation is the crop requirement data used as a basis for the land suitability evaluation. In the FAO methodology for land evaluation (FAO, 1983) it is recommended that crop requirement information should be based on local conditions. Although most of the crop requirement information was obtained from crop production guidelines in the publications of the KwaZulu-Natal Department of Agriculture, some of the crop requirement data were collected from FAO publications, which may not reflect the conditions in the study area. Another limitation of the crop requirement data is that crop requirement information in the local publications does not rate the land characteristics according to their degree of suitability in a similar manner as the FAO land suitability rating does. In such cases, degree of suitability was defined according to the FAO land suitability classification structure based on some assumption such as critical values of the land characteristics and their adverse effects on crops and yield estimates as explained in section 4.3. These assumptions are subjective, and hence they are not free of errors.

The area south of the Bushman's river and some steep areas in the eastern parts of the reserve were not accessible during the field survey. Thus, the results of the soil analysis do not represent these areas and little is known about the soil units in these areas in terms chemical and physical soil properties.

For more reliable results, the evaluation procedure and the results need to be further validated and quantified using more detailed land resources and crop requirement data or by the use of softwares that provide built-in expert knowledge on the crop requirements.

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APPENDIX I

Appendix Ia

Description of Soil Forms of South African Soil Classification System Encountered in WNR

Mispah (Ms)

This soil *form* has an orthic A surface horizon darkened by organic matter but lacks any characteristic of the other diagnostic horizons (MacVicar, 1991). The surface horizon directly overlies either a hard rock or a hardpan ferricrete (Dekker *et al.*, 1980). The soil depth seldom exceeds 30cm (Jeffrey and Scotney, 1979). This soil *form* is by far the most dominant and widespread soil *form* in the reserve. In most areas of the reserve this soil *form* is found in association with rock outcrops.

Glenrosa (Gs)

This soil *form* comprises an orthic A-horizon overlying a lithocutanic B-horizon which merges into underlying weathering rock (Dekker *et al.*, 1980). More than 70% of the hard lithocutanic B-horizon is parent bedrock, fresh or partly weathered (MacVicar, 1991). The presence of cutans (Clay accumulation) between the pieces of weathering rock shows that clay movement is occurring down the profile and/or that the rock is weathering to produce clay-sized material in situe (Hughes, 1989). This soil *form* is found mainly on the western part of the reserve over Beaufolt shale and is generally 30 to 60cm deep.

Black Top soils

Mayo (My)

This is a dark colored, structured soil overlying a lithocutanic B-horizon which merges underlying weathering rock (Dekker *et al.*, 1980). It has more than 35% clay in the A-horizon and no evidence of calcareousness in the lithocutanic B-horizon. This soil *form* is not very common in the reserve.

Milkwood (Mw)

This soil *form* has a dark colored usually well structured topsoil melanic A-horizon, which overlies a hard rock (MacVicar, 1991). The depth does not exceed 50cm and the agricultural productivity is lower than Mayo due to the harder and more impervious underlying rock (Dekker *et al.*, 1980). Isolated patches of this soil *form* occur across the reserve usually where dolerite is the parent rock (Hughes, 1989).

Immerpan (Im)

This soil *form* has a dark colored, well structured melanic A-horizon overlying a hard pan carbonate horizon. This soil *form* is not common in the reserve, it was only observed on the steep northern slopes of the Bushman's River valley, where dolerite boulders are abundant.

Red Topsoil

Shortlands (Sd)

This soil *form* is characterized by having a red, moderately to strongly blocky structured sub-soil (a red structured B-horizon), underlying an orthic A-horizon that is also often red in color (Hughes, 1989). This soil *form* is commonly formed on dolerite, which gives the soil its red color due to the high iron content of the parent rock that tends to be red under oxidizing conditions of well drained environment (Hughes, 1989). Shortlands soil is found throughout the reserve and is probably the second widespread soil *form* next to Mispah *form*. Almost all of the Shortlands are very shallow and dolerite outcrops are common interspersed with this soil *form*. Isolated patches of deeper Shortlands do also occur.

Soils with Plinthic Horizons

Avalon (Av)

This soil is characterized by an orthic A-horizon which overlies a yellow, macroscopically structured horizon (a yellow-brown apedal B-horizon), which overlies a soft plintic B-horizon (Hughes, 1989). The sub-soil horizon is characterized by the presence of red yellow or dark mottles set in a grey matrix which usually signifies the presence of fluctuating water table that results in oxidation and reduction conditions (Hughes, 1989). This characteristic may indicate slow drainage of the soils which is restricted by the underlying soft plinthic B-horizon. These soils are generally somewhat deeper than other soils in the reserve and are common in flatter areas in the western part of the reserve.

Westleigh (We)

This soil *form* is the same as Avalon, but without the yellow-brown apedal B-horizon. As a result they are much shallower, since the soft plinthic B-horizon is considered to be limiting for root growth due to excessive wetness in the horizon for at least part of the year (Hughes, 1989). Westleigh soils usually have shallow depth (25-50cm) (Dekker *et al.*, 1980).

Glencoe (Gc)

In places in the reserve the soft plinthite has become hardened to form a layer that cannot be cut with a spade even when wet. Above this plinthite are a yellow-brown apedal B and an orthic A-horizon (Hughes, 1989). This *form* occurs in only a few areas where the shale parent material has become impregnated with iron, presumably from the surrounding dolerite.

Duplex Soils

These are a group of soils that have somewhat light-textured topsoil underlain by heavier, strongly structured B-horizons, such that the distinction between the A and B-horizons is often abrupt (Hughes, 1989).

Estcourt (Es) and sterkspruit (Ss)

These two soil *forms* have an orthic A-horizon which in the case of sterkspruit directly overlies a prismatic B-horizon or through an E-horizon in the case of Estcourt *form*. The B-horizon is characterized by a columnar structural units (ped).

Swartland (Sw) and Valsrivier (Va)

These soils have an orthic A-horizon which overlies a strongly structured (blocky or sub-angular blocky) B-horizon that forms due to clay movement and accumulation in the form of cutans (clay skins) on the surface of individual aggregates (a pedocutanic B-horizon). In the case of Swartland soil *form* the B-horizon overlies a saprolite while in the case of Valsrivier *form* it overlies an unconsolidated material.

Soils with Black Structured Subsoil

Boheim (Bo)

The topsoil consists of a dark melanic A-horizon which overlies a black, moderately or strongly structured (a pedocutanic B) subsurface horizon. This subsoil occurs in isolated patches of locally low-lying topography on dolerite colluvium (Hughes, 1989).

Soils of Valley Sites

Rensburg (Rg)

The A-horizon is a dark black vertic A-horizon with surface cracking in dry conditions. The soil can break down into fine surface tilth on drying (self-mulching surface) and grooved, shiny pressure faces on the peds (silkensides) (Hughes, 1989). Due to almost permanent saturation, the underlying material forms a G-horizon.

Dundee (Du)

This soil *form* has an orthic A-horizon overlying a yellow alluvial deposit which has an evidence of layering (Hughes, 1989). Despite their position, the upper part of the profile is well drained due to the depth of the alluvium (Hughes, 1989).

Katspruit (Ka)

This is a soil *form* commonly found in valley bottoms. It is characterized by an orthic A-horizon overlying a wet G-horizon that has grey matrix often with blue or green tints (Hughes, 1989). The G-horizon indicates that it is saturated for almost of the whole year.

Oakleaf (Oa)

This is a soil *form* with the weakest sign of soil formation consisting of an orthic A-horizon overlying a neocutanic B-horizon. It has formed in unconsolidated material which has lost stratification that may have been originally present (Hughes, 1989), i.e, it is colluvial or alluvial in origin and thus it is found in riverbanks and on river terraces throughout the reserve. The soil can be quite deep (40-100cm deep) in many instances.

Appendix Ib. Summary of Soil *Forms* in WNR in terms of Area coverage.

Soil *form*	Area covered (ha)	Area covered (%)
Av	188.90	3.86
Bo	9.84	0.20
Ch	1.57	0.03
Dam	0.64	0.01
Du	3.73	0.08
E	40.45	0.83
Extremely steep	472.89	9.67
Extremely steep/Rocky	25.93	0.48
Extremely steep/Stony	138.74	2.84
Gs	318.06	6.50
Im	29.51	0.60
Ka	74.03	1.51
Ms	2251.63	46.04
Mw	30.54	0.62
My	0.97	0.02
Oa	18.76	0.38
Rg	8.26	0.17
Riverbed	14.22	0.29
Rock	39.31	0.80
Sd	955.60	19.54
Ss	1.40	0.03
Sw	7.51	0.15
va	254.40	5.20
We	4.13	0.08
Total Area	4891.00	100.00

Appendix Ic. Correlation of South African Soil Units (*Soil Forms*) to the FAO Soil Units (MacVicar, 1977).

South African Classification		**FAO Correlation**
Soil *form*	**Symbol**	**Soil phases**
Champagne	Ch	Histic Gleysols (Ox); Dystric (Od) & Eutric(Oe) Histisols
Kranskop	Kp	Humic Acrisols(Ah), Ferralsols(Fh) & Cambisols(Bh)
Magwa	Ma	Humic (strongly) cambisols(Ah); Humic Ferralsols(Fh); Helvic acrisols
Inanda	Ia	Humic Ferralsols (Fh); Humic cambisols (Bh)
Nomanci	No	Rankers (U) with thick A-horizon; Humic (strongly) cambisols(Ah); humic Acrisols
Rensburg	Rg	Pelvic (Vp) & (dark) chromic (Vc) Vertisols; (with Gleyic horizon)
Arcadia	Ar	Pelvic (Vp) (some dark colored) chromic (Vc) Vertisols; Vertic Cambisols (Vc)
Willowbrook	Wo	Gleyic Phaeozems (hg); humic Gleysols (Gh) (with melanic A-horizon)
Bonheim	Bo	Luvic Phaeozems (Hl), castanozems (Kl) & possibly chernozems(Cl)
Tambankulu	Tk	Plinthic castanozems,phaeozems & Chernozems
Inhoek	Ik	Haplic Phaeozems (Hh), castanozems (Kh) possibly Chermozems (Ch) all on stratified alluvium
Mayo	My	Haplic Phaeozems (Hh), castanozems (Kh) possibly Chermozems (Ch); Rendzinas
Milkwood	Mw	Haplic Phaeozems (Hh), haplic (Ch) & Calcic (Ck) henozems; haplic (kh) & Calcic (Kk) castanozems, Rendzinas
Katspruit	Ka	Gleysols (various)
Swartland	Sw	Brunic &chromic Luvisols (Lc); Luvic Xerosols (Xl) &ermosols (A-horizon usually hard and dry)
Valsrivier	Va	Brunic &chromic Luvisols (Lc); Luvic Xerosols (Xl) & ermosols (A-horizon usually hard and dry)
Sterkspruit	Ss	Ochric Solonetz
Estcourt	Es	Ochric Solonetz (with Albic horizon); Gleyic Solonetz; Solod; some Ochric Planosols.

Appendix Ic. continued

South African Classification		**FAO Correlation**
Soil *form*	**Symbol**	**Soil phases**
Kroonstad	Kd	Ochric Planosols
Constantia	Ct	Albisols, Ferric Podozols (Pf) &Rhodic, Helvic, and Humic (Ah) Acrisols
Shepstone	Sp	Albisols, Albic luvisols & Helvic, and Humic (Ah) Acrisols
Vilafontes	Vf	Albic (La) & Glossic Luvisols
Houhoek	Hh	Humoferric Podozols (Lithic) (Ph, Pf)
Lamotte	Lt	Humoferric Podozols (Lithic) (Ph, Pf)
Cartref	Cf	Not Accommodated specifically, but inter alia Gleyic Luvisols (Lg)
Wasbank	Wa	Not Accommodated specifically
Longlands	Lo	Plinthic Gleysols (Gp) (with Albic horizon)
Westleigh	We	Plinthic Acrisols (Ap) & Luvisols (Lp) (Plinthic and Argilluvic horizons coincide)
Avalon	Av	Plinthic Luvisols (Lp), Ferralsols (Fp) &Acrisols (Ap)
Glencoe	Gc	Concretionary (hardened Plinthite) phases of Ochric & eutric cambisols
Pinedene	Pn	Gleyic Luvisols (Lg); Gleyic Acrisols (Ag)
Griffin	Gf	Helvic Acrisols; Helvic Ferralsols; Eutric (Be) & Chromic (Bc Cambisols
Clovelly	Cv	Mainly Ochric, Eutric (Be), & calcic (Bk) Cambisols; Helvi & Ochric Ferralsols, but also some arenosols, rhegosols,xerosols &ermosols
Bainsvlei	Bv	Plinthic Ferralsols (Fp), Acrisols (Ap) & Luvisols (Lp)
Hutton	Hu	Mainly rhodic (Fr) & Helvic Ferralsols & arenosols, but also some Cambisols, Xertosols, and Ermosols
Shortlands	Sd	Chromic (Lc), Ferric (Lf) &Rhodic Luvisols
Oakleaf	Oa	Ochric, eutric (Be) & Calcic(Bk) Cambisols; Haplic (Xh) & Calcic (Xk) Xerosols and Ermosols; Ochric Solonchaks
Frenwood	Fw	Dystric (Rd) Eutric (Re)Regosols; Ochric and Humic (Gh) Gleysols (Coarrse textured in all cases); Arenosols
Dundee	Du	Eutric (Je), Carbonatic & possibly Dystric (Jd) and Gleyic Fluvisols

Appendix Ic. continued

Glenrosa	Gs	Ochric , Eutric (Be) & Calcic (Bk) Cambisols; Haplic Xerosols (Xh) (Lithic phases)
Mispah	Ms	Lithosols, Lithic,concretionary (Ironstone), Petrocalcic & Duripan phases of Calcic Ermosols, Calcic Xerosols (Xk), Rhegosols & Solenchaks
Immerpan	Im	-

APPENDIX II

SUMMARY OF SOIL ANALYTICAL RESULTS

Appendix IIa. Nutrient and lime recommendations for dryland (rainfed) maize production.

		Nitrogen	Phosphorus			Potassium			Lime			Zinc
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Sample Acid sat. %	PAS %	Req.lime t/ha	Fertilizer Req.
1	4	50	2	13	110	0.440	0.256	0	0	20	0	no
	5	50			110	0.440	0.256	0	0	20	0	no
	7	50			110	0.440	0.256	0	0	20	0	no
2	4	50	1	12	120	0.225	0.256	30	0	20	0	yes
	5	50			120	0.225	0.256	30	0	20	0	yes
	7	50			120	0.225	0.256	30	0	20	0	yes
3	4	50	14	13	20	0.309	0.256	0	10	20	0	yes
	5	50			20	0.309	0.256	0	10	20	0	yes
	7	50			20	0.309	0.256	0	10	20	0	yes
4	4	50	1	14	115	0.394	0.256	0	10	20	0	yes
	5	50			115	0.394	0.256	0	10	20	0	yes
	7	50			115	0.394	0.256	0	10	20	0	yes
5	4	50	17	17	20	0.611	0.256	0	0.75	20	0	yes
	5	50			20	0.611	0.256	0	0.75	20	0	yes
	7	50			20	0.611	0.256	0	0.75	20	0	yes

Appendix IIa. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. sat%	Sample PAS %	Req.lime t/ha	
6	4	50	1	15	120	0.210	0.256	45	1	20	0	yes
	5	50			120	0.210	0.256	45	1	20	0	yes
	7	50			120	0.210	0.256	45	1	20	0	yes
7	4	50	1	15	120	0.478	0.256	0	0	20	0	yes
	5	50			120	0.478	0.256	0	0	20	0	yes
	7	50			120	0.478	0.256	0	0	20	0	yes
8	4	50	1	13	95	0.309	0.256	0	1	20	0	yes
	5	50			95	0.309	0.256	0	1	20	0	yes
	7	50			95	0.309	0.256	0	1	20	0	yes
9	4	50	1	21	80	0.199	0.256	55	2	20	0	yes
	5	50			80	0.199	0.256	55	2	20	0	yes
	7	50			80	0.199	0.256	55	2	20	0	yes
10	4	50	3	12	100	0.509	0.256	0	2	20	0	yes
	5	50			100	0.509	0.256	0	2	20	0	yes
	7	50			100	0.509	0.256	0	2	20	0	yes
11	4	50	1	13	120	0.276	0.256	0	0	20	0	yes
	5	50			120	0.276	0.256	0	0	20	0	yes
	7	50			120	0.276	0.256	0	0	20	0	yes
12	4	50	1	14	115	0.409	0.256	0	10	20	0	yes
	5	50			115	0.409	0.256	0	10	20	0	yes
	7	50			155	0.409	0.256	0	10	20	0	yes

Appendix IIa. continued.

	Nitrogen		Phosphorus			Potassium			Lime			
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. Lime t/ha	Zinc Fertilizer Req.
13	4	50	1	15	120	0.788	0.256	0	1	20	0	yes
	5	50			120	0.788	0.256	0	1	20	0	yes
	7	50	1	15	120	0.788	0.256	0	1	20	0	yes
14	4	50	1	14	115	0.345	0.256	0	1	20	0	yes
	5	50			115	0.345	0.256	0	1	20	0	yes
	7	50			115	0.345	0.256	0	1	20	0	yes
15	4	50	1	14	110	0.821	0.256	0	2	20	0	yes
	5	50			110	0.821	0.256	0	2	20	0	yes
	7	50			110	0.821	0.256	0	2	20	0	yes
16	4	50	1	17	110	0.309	0.256	0	0	20	0	yes
	5	50			110	0.309	0.256	0	0	20	0	yes
	7	50			110	0.309	0.256	0	0	20	0	yes
17	4	50	1	17	120	0.353	0.256	0	1	20	0	yes
	5	50			120	0.353	0.256	0	1	20	0	yes
	7	50			120	0.353	0.256	0	1	20	0	yes
18	4	50	4	13	95	0.509	0.256	0	1	20	0	yes
	5	50			95	0.509	0.256	0	1	20	0	yes
	7	50			95	0.509	0.256	0	1	20	0	yes
19	4	50	15	18	20	0.509	0.256	0	2	20	0	yes

Appendix IIa. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
	5	50	15	18	20	0.509	0.256	0	2	20	0	yes
	7	50			20	0.509	0.256	0	2	20	0	yes
20	4	50	1	17	110	0.309	0.256	0	10	20	0	yes
	5	50			110	0.309	0.256	0	10	20	0	yes
	7	50			110	0.309	0.256	0	10	20	0	yes
21	4	50	2	15	115	0.269	0.256	0	1	20	0	yes
	5	50			115	0.269	0.256	0	1	20	0	yes
	7	50			115	0.269	0.256	0	1	20	0	yes
22	4	50	1	12	120	0.238	0.256	20	1	20	0	yes
	5	50			120	0.238	0.256	20	1	20	0	yes
	7	50			120	0.238	0.256	20	1	20	0	yes
23	4	50	1	14	110	0.509	0.256	0	0	20	0	yes
	5	50			110	0.509	0.256	0	0	20	0	yes
	7	50			110	0.509	0.256	0	0	20	0	yes
24	4	50	1	15	125	0.199	0.256	55	1	20	0	yes
	5	50			125	0.199	0.256	55	1	20	0	yes
	7	50			125	0.199	0.256	55	1	20	0	yes
25	4	50	1	14	115	0.294	0.256	0	2	20	0	yes
	5	50			115	0.294	0.256	0	2	20	0	yes
	7	50			115	0.294	0.256	0	2	20	0	yes

Appendix IIa. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
26	4	50	1	18	95	0.343	0.256	0	2	20	0	yes
	5	50			95	0.343	0.256	0	2	20	0	yes
	7	50			95	0.343	0.256	0	2	20	0	yes
27	4	50	3	17	95	0.309	0.256	0	7	20	0	yes
	5	50			95	0.309	0.256	0	7	20	0	yes
	7	50			95	0.309	0.256	0	7	20	0	yes
28	4	50	1	14	125	0.701	0.256	0	1	20	0	yes
	5	50			125	0.701	0.256	0	1	20	0	yes
	7	50			125	0.701	0.256	0	1	20	0	yes
29	4	50	1	17	110	0.332	0.256	0	0	20	0	yes
	5	50			110	0.332	0.256	0	0	20	0	yes
	7	50			110	0.332	0.256	0	0	20	0	yes
30	4	50	1	15	125	0.509	0.256	0	2	20	0	yes
	5	50			125	0.509	0.256	0	2	20	0	yes
	7	50			125	0.509	0.256	0	2	20	0	yes
31	4	50	1	22	85	0.223	0.256	35	0	20	0	yes
	5	50			85	0.223	0.256	35	0	20	0	yes
	7	50			85	0.223	0.256	35	0	20	0	yes

Appendix IIa. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
32	4	50	17	17	20	1.023	0.256	0	1	20	0	no
	5	50			20	1.023	0.256	0	1	20	0	yes
	7	50			20	1.023	0.256	0	1	20	0	yes
33	4	50	1	20	110	0.921	0.256	0	10	20	0	yes
	5	50			110	0.921	0.256	0	10	20	0	yes
	7	50			110	0.921	0.256	0	10	20	0	yes
34	4	50	3	17	100	0.473	0.256	0	1	20	0	yes
	5	50			100	0.473	0.256	0	1	20	0	yes
	7	50			100	0.473	0.256	0	1	20	0	yes
35	4	50	17	17	20	0.611	0.256	0	0	20	0	yes
	5	50			20	0.611	0.256	0	0	20	0	yes
	7	50			20	0.611	0.256	0	0	20	0	yes
36	4	50	3	16	100	0.910	0.256	0	0	20	0	yes
	5	50			100	0.910	0.256	0	0	20	0	yes
	7	50			100	0.910	0.256	0	0	20	0	yes
37	4	50	1	15	125	0.358	0.256	0	0	20	0	yes
	5	50			125	0.358	0.256	0	0	20	0	yes
	7	50			125	0.358	0.256	0	0	20	0	yes
38	4	50	3	15	100	0.721	0.256	0	1	20	0	yes
	5	50			100	0.721	0.256	0	1	20	0	yes

Appendix IIa. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
	7	50	3	15	100	0.721	0.256	0	1	20	0	yes
39	4	50	10	16	85	1.020	0.256	0	1	20	0	yes
	5	50			85	1.020	0.256	0	1	20	0	yes
	7	50			85	1.020	0.256	0	1	20	0	yes
40	4	50	1	15	115	0.627	0.256	0	1	20	0	yes
	5	50			115	0.627	0.256	0	1	20	0	yes
	7	50			115	0.627	0.256	0	1	20	0	yes
41	4	50	3	17	100	0.409	0.256	0	10	20	0	yes
	5	50			100	0.409	0.256	0	10	20	0	yes
	7	50			100	0.409	0.256	0	10	20	0	yes
42	4	50	1	12	120	0.174	0.256	80	0	20	0	yes
	5	50			120	0.174	0.256	80	0	20	0	yes
	7	50			120	0.174	0.256	80	0	20	0	yes
43	4	50	1	14	115	0.297	0.256	0	0	20	0	yes
	5	50			115	0.297	0.256	0	0	20	0	yes
	7	50			115	0.297	0.256	0	0	20	0	yes
44	4	50	1	13	125	0.675	0.256	0	0	20	0	yes
	5	50			125	0.675	0.256	0	0	20	0	yes
	7	50			125	0.675	0.256	0	0	20	0	yes
45	4	50	19	15	20	0.414	0.256	0	1	20	0	yes
	5	50			20	0.414	0.256	0	1	20	0	yes
	7	50			20	0.414	0.256	0	1	20	0	yes

Appendix IIb. Nutrient and lime recommendations for dryland (rainfed) potato production.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
1	20.00	90	2	18	150	0.440	0.409	95	0	30	0	no
	40.00	160			150	0.440	0.512	115	0	30	0	no
	60.00	200			150	0.440	0.614	170	0	30	0	no
2	20.00	90	1	16	160	0.225	0.409	180	0	30	0	yes
	40.00	160			160	0.225	0.512	280	0	30	0	yes
	60.00	200			160	0.225	0.614	380	0	30	0	yes
3	20.00	90	14	18	80	0.309	0.409	115	10	30	0	yes
	40.00	160			80	0.309	0.512	215	10	30	0	yes
	60.00	200			80	0.309	0.614	315	10	30	0	yes
4	20.00	90	1	20	160	0.394	0.409	105	10	30	0	yes
	40.00	160			160	0.394	0.512	125	10	30	0	yes
	60.00	200			160	0.394	0.614	215	10	30	0	yes
5	20.00	90	17	23	80	0.611	0.409	80	0.75	30	0	yes
	40.00	160			80	0.611	0.512	100	0.75	30	0	yes
	60.00	200			80	0.611	0.614	120	0.75	30	0	yes
6	20.00	90	1	21	165	0.210	0.409	195	1	30	0	yes
	40.00	160			165	0.210	0.512	295	1	30	0	yes
	60.00	200			165	0.210	0.614	395	1	30	0	yes

Appendix IIb. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
7	20.00	90	1	21	165	0.478	0.409	85	0	30	0	yes
	40.00	160			165	0.478	0.512	105	0	30	0	yes
	60.00	200			165	0.478	0.614	135	0	30	0	yes
8	20.00	90	1	17	180	0.309	0.409	115	1	30	0	yes
	40.00	160			180	0.309	0.512	215	1	30	0	yes
	60.00	200			180	0.309	0.614	315	1	30	0	yes
9	20.00	90	1	29	160	0.199	0.409	205	2	30	0	yes
	40.00	160			160	0.199	0.512	305	2	30	0	yes
	60.00	200			160	0.199	0.614	405	2	30	0	yes
10	20.00	90	3	16	150	0.509	0.409	75	2	30	0	yes
	40.00	160			150	0.509	0.512	95	2	30	0	yes
	60.00	200			150	0.509	0.614	125	2	30	0	yes
11	20.00	90	1	18	160	0.276	0.409	135	0	30	0	yes
	40.00	160			160	0.276	0.512	235	0	30	0	yes
	60.00	200			160	0.276	0.614	335	0	30	0	yes
12	20.00	90	1	19	160	0.409	0.409	100	10	30	0	yes
	40.00	160			160	0.409	0.512	120	10	30	0	yes
	60.00	200			160	0.409	0.614	210	10	30	0	yes
13	20.00	90	1	21	165	0.788	0.409	25	1	30	0	yes
	40.00	160			165	0.788	0.512	45	1	30	0	yes

Appendix IIb. Continued.

	Nitrogen		Phosphorus			Potassium			Lime			
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	Zinc Fertilizer Req.
	60.00	200	1	21	165	0.788	0.614	65	1	30	0	yes
14	20.00	90	1	20	160	0.345	0.409	115	1	30	0	yes
	40.00	160			160	0.345	0.512	165	1	30	0	yes
	60.00	200			160	0.345	0.614	265	1	30	0	yes
15	20.00	90	1	19	160	0.821	0.409	20	2	30	0	yes
	40.00	160			160	0.821	0.512	40	2	30	0	yes
	60.00	200			160	0.821	0.614	60	2	30	0	yes
16	20.00	90	1	22	145	0.309	0.409	115	0	30	0	yes
	40.00	160			145	0.309	0.512	215	0	30	0	yes
	60.00	200			145	0.309	0.614	315	0	30	0	yes
17	20.00	90	1	23	155	0.353	0.409	110	1	30	0	yes
	40.00	160			155	0.353	0.512	155	1	30	0	yes
	60.00	200			155	0.353	0.614	255	1	30	0	yes
18	20.00	90	4	17	150	0.509	0.409	75	1	30	0	yes
	40.00	160			150	0.509	0.512	95	1	30	0	yes
	60.00	200			150	0.509	0.614	125	1	30	0	yes
19	20.00	90	15	25	80	0.509	0.409	75	2	30	0	yes
	40.00	160			80	0.509	0.512	95	2	30	0	yes
	60.00	200			80	0.509	0.614	125	2	30	0	yes

Appendix IIb. Continued.

	Nitrogen		Phosphorus			Potassium			Lime			
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	Zinc Fertilizer Req.
20	20.00	90	1	23	155	0.309	0.409	115	10	30	0	yes
	40.00	160			155	0.309	0.512	215	10	30	0	yes
	60.00	200			155	0.309	0.614	315	10	30	0	yes
21	20.00	90	2	21	155	0.269	0.409	140	1	30	0	yes
	40.00	160			155	0.269	0.512	240	1	30	0	yes
	60.00	200			155	0.269	0.614	340	1	30	0	yes
22	20.00	90	1	16	160	0.238	0.409	170	1	30	0	yes
	40.00	160			160	0.238	0.512	270	1	30	0	yes
	60.00	200			160	0.238	0.614	370	1	30	0	yes
23	20.00	90	1	19	160	0.509	0.409	75	0	30	0	yes
	40.00	160			160	0.509	0.512	95	0	30	0	yes
	60.00	200			160	0.509	0.614	125	0	30	0	yes
24	20.00	90	1	21	165	0.199	0.409	205	1	30	0	yes
	40.00	160			165	0.199	0.512	305	1	30	0	yes
	60.00	200			165	0.199	0.614	405	1	30	0	yes
25	20.00	90	1	19	160	0.294	0.409	125	2	30	0	yes
	40.00	160			160	0.294	0.512	225	2	30	0	yes
	60.00	200			160	0.294	0.614	325	2	30	0	yes
26	20.00	90	1	25	135	0.343	0.409	115	2	30	0	yes
	40.00	160			135	0.343	0.512	135	2	30	0	yes

Appendix IIb. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
	60.00	200	1	25	135	0.343	0.614	240	2	30	0	yes
27	20.00	90	3	23	130	0.309	0.409	115	7	30	0	yes
	40.00	160			130	0.309	0.512	215	7	30	0	yes
	60.00	200			130	0.309	0.614	315	7	30	0	yes
28	20.00	90	1	20	160	0.701	0.409	45	1	30	0	yes
	40.00	160			160	0.701	0.512	65	1	30	0	yes
	60.00	200			160	0.701	0.614	85	1	30	0	yes
29	20.00	90	1	23	155	0.332	0.409	120	0	30	0	yes
	40.00	160			155	0.332	0.512	175	0	30	0	yes
	60.00	200			155	0.332	0.614	275	0	30	0	yes
30	20.00	90	1	21	165	0.509	0.409	75	2	30	0	yes
	40.00	160			165	0.509	0.512	95	2	30	0	yes
	60.00	200			165	0.509	0.614	125	2	30	0	yes
31	20.00	90	1	30	120	0.223	0.409	185	0	30	0	yes
	40.00	160			120	0.223	0.512	285	0	30	0	yes
	60.00	200			120	0.223	0.614	385	0	30	0	yes
32	20.00	90	17	22	80	1.023	0.409	0	1	30	0	no
	40.00	160			80	1.023	0.512	0	1	30	0	yes
	60.00	200			80	1.023	0.614	20	1	30	0	yes

Appendix IIb. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
33	20.00	90	1	27	150	0.921	0.409	0	10	30	0	yes
	40.00	160			150	0.921	0.512	0	10	30	0	yes
	60.00	200			150	0.921	0.614	25	10	30	0	yes
34	20.00	90	3	22	140	0.473	0.409	90	1	30	0	yes
	40.00	160			140	0.473	0.512	110	1	30	0	yes
	60.00	200			140	0.473	0.614	140	1	30	0	yes
35	20.00	90	17	23	80	0.611	0.409	80	0	30	0	yes
	40.00	160			80	0.611	0.512	100	0	30	0	yes
	60.00	200			80	0.611	0.614	120	0	30	0	yes
36	20.00	90	3	21	150	0.910	0.409	0	0	30	0	yes
	40.00	160			150	0.910	0.512	0	0	30	0	yes
	60.00	200			150	0.910	0.614	25	0	30	0	yes
37	20.00	90	1	21	165	0.358	0.409	80	0	30	0	yes
	40.00	160			165	0.358	0.512	100	0	30	0	yes
	60.00	200			165	0.358	0.614	120	0	30	0	yes
38	20.00	90	3	20	140	0.721	0.409	40	1	30	0	yes
	40.00	160			140	0.721	0.512	60	1	30	0	yes
	60.00	200			140	0.721	0.614	80	1	30	0	yes

Appendix IIb. continued.

	Nitrogen		Phosphorus			Potassium			Lime			
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req. kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	Zinc Fertilizer Req.
39	20.00	90	10	22	80	1.020	0.409	0	1	30	0	Yes
	40.00	160			80	1.020	0.512	0	1	30	0	Yes
	60.00	200			80	1.020	0.614	20	1	30	0	Yes
40	20.00	90	1	20	165	0.627	0.409	60	1	30	0	Yes
	40.00	160			165	0.627	0.512	80	1	30	0	Yes
	60.00	200			165	0.627	0.614	100	1	30	0	Yes
41	20.00	90	3	18	140	0.409	0.409	100	10	30	0	Yes
	40.00	160			140	0.409	0.512	120	10	30	0	Yes
	60.00	200			140	0.409	0.614	210	10	30	0	Yes
42	20.00	90	1	16	165	0.174	0.409	230	0	30	0	yes
	40.00	160			165	0.174	0.512	330	0	30	0	yes
	60.00	200			165	0.174	0.614	430	0	30	0	yes
43	20.00	90	1	19	160	0.297	0.409	120	0	30	0	yes
	40.00	160			160	0.297	0.512	210	0	30	0	yes
	60.00	200			160	0.297	0.614	310	0	30	0	yes
44	20.00	90	1	21	165	0.675	0.409	40	0	30	0	yes
	40.00	160			165	0.675	0.512	60	0	30	0	yes
	60.00	200			165	0.675	0.614	80	0	30	0	yes
45	20.00	90	19	21	80	0.414	0.409	100	1	30	0	yes
	40.00	160			80	0.414	0.512	120	1	30	0	yes
	60.00	200			80	0.414	0.614	210	1	30	0	yes

Appendix IIc. Nutrient and lime recommendations for dryland (rainfed) cabbage production.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
1	100	200	2	30	270	0.440	0.512	70	0	1	0	no
2	100	200	1	27	280	0.225	0.512	280	0	1	0	yes
3	100	200	4	30	120	0.309	0.512	197.5	0	1	0	yes
4	100	200	1	32	275	0.394	0.512	115	10	1	0	yes
5	100	200	17	38	100	0.611	0.512	0	0.75	1	0	yes
6	100	200	1	34	280	0.210	0.512	295	1	1	0	yes
7	100	200	1	34	290	0.478	0.512	35	0	1	0	yes
8	100	200	1	29	265	0.309	0.512	197.5	1	1	0	yes
9	100	200	1	49	275	0.199	0.512	305	2	1	1.0dol/cal	yes
10	100	200	3	28	260	0.509	0.512	20	2	1	1.0dol/cal	yes
11	100	200	1	30	280	0.276	0.512	230	0	1	0	yes
12	100	200	1	32	275	0.409	0.512	100	10	1	3.5dol/cal	yes
13	100	200	1	34	280	0.788	0.512	0	1	1	0	yes
14	100	200	1	32	275	0.345	0.512	162.5	1	1	0	yes

Appendix IIc. Continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
15	100	200	1	32	270	0.821	0.512	0	2	1	1.0dol/cal	yes
16	100	200	1	37	260	0.309	0.512	197.5	0	1	0	yes
17	100	200	1	39	270	0.353	0.512	155	1	1	0	yes
18	100	200	4	29	255	0.509	0.512	20	1	1	0	yes
19	100	200	15	42	100	0.509	0.512	20	2	1	1.0dol/cal	yes
20	100	200	1	38	270	0.309	0.512	197.5	10	1	3.5dol/cal	yes
21	100	200	2	34	270	0.269	0.512	237.5	1	1	0	yes
22	100	200	1	28	280	0.238	0.512	267.5	1	1	0	yes
23	100	200	1	32	275	0.509	0.512	20	0	1	0	yes
24	100	200	1	34	290	0.199	0.512	305	1	1	0	yes
25	100	200	1	32	275	0.294	0.512	212.5	2	1	1.0dol/cal	yes
26	100	200	1	42	225	0.343	0.512	165	2	1	1.0dol/cal	yes
27	100	200	3	38	255	0.309	0.512	197.5	7	1	3.0dol/cal	yes

Appendix IIc. continued.

	Nitrogen		Phosphorus			Potassium			Lime			
Sample No.	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	Zinc Fertilizer Req.
28	100	200	1	32	275	0.701	0.512	0	0	1	0	yes
29	100	200	1	38	265	0.332	0.512	175	0	1	0	yes
30	100	200	1	34	290	0.509	0.512	20	1	1	0	yes
31	100	200	1	50	200	0.223	0.512	282.5	1	1	0	yes
32	100	200	17	37	145	1.023	0.512	0	1	1	0	no
33	100	200	1	46	260	0.921	0.512	0	10	1	3.5dol/cal	yes
34	100	200	3	37	255	0.473	0.512	37.5	1	1	0	yes
35	100	200	17	39	100	0.611	0.512	0	0	1	0	yes
36	100	200	3	35	265	0.910	0.512	0	0	1	0	yes
37	100	200	1	35	285	0.358	0.512	150	0	1	0	yes
38	100	200	3	33	260	0.721	0.512	0	1	1	0	yes
39	100	200	10	36	125	1.020	0.512	0	1	1	0	yes
40	100	200	1	33	280	0.627	0.512	0	1	1	0	yes

Appendix IIc. continued.

Sample No.	Nitrogen		Phosphorus			Potassium			Lime			Zinc Fertilizer Req.
	Target yield t/ha	Req. N kg/ha	Sample soil test mg/kg	Target soil test mg/kg	Req. P kg/ha	Sample soil test cmol(+)/kg	Target soil test cmol(+)/kg	Req.K kg/ha	Acid. Sat %	Sample PAS %	Req. lime t/ha	
41	100	200	3	30	260	0.409	0.512	100	10	1	3.5dol/cal	yes
42	100	200	1	28	285	0.174	0.512	330	0	1	0	yes
43	100	200	1	32	275	0.297	0.512	210	0	1	0	yes
44	100	200	1	35	285	0.675	0.512	0	0	1	0	yes
45	100	200	19	35	125	0.414	0.512	95	1	1	0	yes

APPENDIX III

CROP REQUIREMENTS

Appendix IIIa. Soil properties for maize production in KZN (Milborrow, 1989).

Land Characteristics	Landscape classes				
	S1	S2	S3	N1	N2
Soil texture	C-60s-SCL	C+60V-LS	C+60V-fS	C+60V-fS	Cm-cS
Soil depth (mm)	900	500-900	250-500	-	<250
Acid saturation	<20	-	-	>20	-
Organic matter (%C 0-15cm)	>1.2	0.8-1.2	<0.8	-	-
Phosphorus (mg/kg)	>15	10-15	-	<5	-
Potassium (mg/kg)	>3.1	-	-	<3.1	-

Soils that give good yields of maize can also give good yields of soya beans (Birch *et al.*, 1990). Therefore, this table can be used to evaluate suitability of soils of the study area for soya bean production.

Appendix IIIb. The potential for maize production of soil *forms* commonly found in WNR (adapted from Smith, 1993).

Soil Forms	Texture (Clay %)	Effective Depth (mm)	Available water storage (mm)	Potential	
				Dryland	Irrigated
Shortlands (Sd)	0 – 15	300 – 750	30 – 60	2	4
		>750	60 – 130	3	5
	15 – 35	300 – 750	50 – 100	3	4
		>750	100 – 160	4	5
	>35	300 – 750	60 –120	3	4
		>750	120 – 160	4	5
Oakleaf (Oa) and Dundee (Du	0 – 15	300 – 750	30 – 60	2	
		>750	60 – 130	3	4
	15 – 35	300 – 750	50 – 100	3	5
		>750	100 – 160	4	4
	>35	300 – 750	60 –120	3	5
		>750	120 – 160	4	4
					5

Appendix IIIb. continued.

Soil Forms	Texture (Clay %)	Effective Depth (mm)	Available water storage (mm)	Potential	
				Dryland	Irrigated
Avalon (Av) and Glencoe (Gc)	0 – 15	300 – 750	30 – 60	3	3
		>750	60 – 130	4	4
	15 – 35	300 – 750	50 – 100	3	3
		>750	100 – 160	4	4
	>35	300 – 750	60 –120	3	3
		>750	120 – 160	4	4
Westleigh (We)	0 – 15	0 –300	15 –30	1	1
		300 – 500	30 – 50	2	2
	15 – 45	0 – 300	20 – 35	2	2
		300 – 500	30 – 60	3	3
Estcourt (Es), Sterkspruit (Ss)	0 – 15	0 –300	15 –30		1
		300 – 500	30 – 50	1	1
	15 – 45	0 – 300	20 – 35	1	1
		300 – 500	30 – 60	1	1
Valsvleir (Va) Swartland (Sw)	0 – 15	0 –300	15 –30	1	1
		300 –750	30 – 60	1	2 – 3
	15 – 35	0 – 300	20 – 35	1	1
		300 – 750	30 – 90	1	2 – 3
	35 – 80	0 – 300	25 – 50	1	1
		300 – 750	40 – 100	1	2 – 3

Note: Scale of potential 1 = low 5= high

Appendix IIIc. Climatic requirements for maize production in KZN (Parsons, 1993).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	750 - 1500	600 - 750	500 -600	<500	-
Length of growing Season (days)	130 - 270	110 - 130	90 - 110	-	< 90
Rainfall grow. season (mm)	700 – 1500	600 – 700	500 –600	-	-
Mean temp. grow. season (^{o}C)	18 – 32	16 – 18	14-16	-	<14
Mean min. temp. of grow. Season (^{o}C)	12 - 24	9 - 12	7-9	-	< 7

This table is also used to evaluate the suitability of the climate of the study area for soya bean production because soya bean has similar climatic requirements as maize (Smith, 1997; Birch *et al.*, 1990).

Appendix IIId. Soil factor to be applied to calculate yields of Sorghum according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting depth (mm)	Well drained soils			Soft plinthic soils			Vertic & Melanic
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay	Sand <15% clay	Loam 15-35% clay	Clay >35% clay	
1000	0.9	1.1	0.9	1.0	1.1	1.0	0.8
750	0.8	1.0	0.8	0.9	1.0	0.9	0.7
500	0.6	0.9	0.7	0.8	0.9	0.8	0.6

The soil factor was used as an index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that;

Soil factor ≥ 0.8........................... S1 80 - 100% attainable yield

Soil factor 0.6 – 0.8........................S2 60 - 80% attainable yield

Soil factor 0.5 – 0.6....................... S3 40 - 60% attainable yield

Appendix IIIe. Climatic requirements for rainfed Sorghum production (Sys, 1985).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	600 - 1200	400 - 1400	350 - 1500	-	any
Length of growing Season (days)	120 - 240	90 - 270	75 - 300	-	any
Mean max. temp. of grow. Season (°C)	24 - 34	> 22	>20	-	any
Mean temp. grow. season (°C)	21 – 32	> 18	>15	-	any
Mean min. temp. of grow. Season (°C)	>15	>12	>8	-	any

Appendix IIIf. Climatic requirements for rainfed cotton production (adapted from Sys, 1985).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Length of growing Season (days)	135-250	125-280	115-330	-	any
Rainfall of growing season	750-1400	625-1600	>500	-	any
Mean max. temp. of grow. Season (°C)	>28	>26	>24	-	any
Mean temp. grow. season (°C)	>24	>22	>20	-	any

Appendix IIIg. Soil factor to be applied to calculate yields of dry beans according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting depth (mm)	Well drained soils			Soft plinthic soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
1000	0.8	1.0	0.8	1.0	1.1	1.0
750	0.7	0.8	0.7	0.9	1.0	0.9
500	0.5	0.7	0.6	0.8	0.9	0.8

The soil factor was used as an index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that;

Soil factor ≥ 0.8........................... S1 80 - 100% attainable yield

Soil factor 0.06 – 0.08....................S2 60 - 80% attainable yield

Soil factor 0.5 – 0.6....................... S3 40- 60% attainable yield

Appendix IIIh. Climatic requirements for dry bean production in KZN compiled from the information in Smith (1997).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	> 700	-	-	-	-
Rainfall grow. season (mm)	400 - 500	-	-	-	-
Length of growing Season (days)	90 - 120	-	-	-	-
Mean max. temp. of grow. Season (°C)	<24	24-27	27-30	>30	any
Mean temp. grow. season (°C)	18-24	15 - 18 24 - 25	10 - 15 25 - 27	< 10 > 27	Any
Mean min. temp. of grow. Season (°C)	>15	12-15	10-12	<10	Any

Appendix IIIi. Soil factor to be applied to calculate yields of potato according to soil depth and texture under rainfed cultivation (soil factors adapted from Smith, 1997).

Rooting depth (mm)	Well drained soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
100	0.90	1.0	0.95
750	0.85	0.95	0.90
500	0.80	0.90	0.85

The soil factor was used as an index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that;

Soil factor ≥ 0.8............................ S1 80 - 100% attainable yield
Soil factor 0.06 – 0.08....................S2 60 - 80% attainable yield
Soil factor 0.5 – 0.6.......................S3 40 - 60% attainable yield

Appendix IIIj. Climatic requirements for rainfed potato production (Sys, 1985).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Monthly rainfall (mm)					
1st month	> 45	> 30	> 20	-	any
2nd month	> 80	> 65	> 50	-	any
3rd month	> 80	> 65	> 50	-	any
4th month	> 20	any	-	-	-
Mean temperature growing season (°C)	13 - 24	10 - 27	8 – 30	-	any
Average absolute minimum temperature in the 1st month (°C)	> 0	> -1	> -2	-	any
Average absolute minimum temperature of other months (°C)	> -1	> -2	> -3	-	any

Appendix IIIk. Soil factor to be applied to calculate yields of cabbage according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting depth (mm)	Well drained soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
750	0.90	1.0	0.95
500	0.85	0.95	0.90

The soil factor was used as an index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that;

Soil factor ≥ 0.8........................... S1 80 - 100% attainable yield
Soil factor 0.06 – 0.08.....................S2 60 - 80% attainable yield
Soil factor 0.5 – 0.6........................S3 40 - 60% attainable yield

Appendix IIIl. Climatic requirements for cabbage production in KZN compiled from the information in Smith (1997) and Doorenbos and Kassam, 1979).

Climatic characteristics	Climatic classes				
	S1	S2	S3	N1	N2
Rainfall grow. season (mm)	300 - 450	-	-	-	-
Length of growing Season (days)	90 - 120	-	-	-	-
Mean temp. grow. season (°C)	15 -18 -	11 - 15 18 - 22	10 -11 22 - 24	< 10 > 24	-
Mean min. temp. of grow. Season (°C)	> 5	-	-	< -3	-
Mean max. temp. grow. season (°C)	< 24	-	-	> 25	-